APPLICATION AND ANALYSIS OF BOREHOLE DATA FOR THE EDWARDS AQUIFER IN THE SAN ANTONIO AREA, TEXAS

LP-139

Cooperators: TEXAS DEPARTMENT OF WATER RESOURCES
U.S. GEOLOGICAL SURVEY
CITY WATER BOARD OF SAN ANTONIO

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CONTENTS

ILLUSTRATIONS

TABLES

METRIC CONVERSIONS

The "inch-pound" units used in this report may be converted to metric units by the following factors:

From		Multiply	To obtain	
Unit	Abbreviation		Unit	Abbreviation
cubic foot	ft^3	0.02832	cubic meter	m^3
cubic foot per minute	ft^3/min	0.02832	cubic meter per minute	m^3/min
foot	ft	0.3048	meter	m
foot per day	ft/d	0.3048	meter per day	m/d
foot per hour	ft/hr	0.3048	meter per hour	m/hr
foot per mile	ft/mi	0.189	meter per kilometer	m/km
foot per second	ft/s	0.3048	meter per second	m/s
gallon	gal	3.785	liter	L
gallon per minute	gal/min	0.06309	liter per second	L/s
gallon per minute per foot	(gal/min)/ft	0.207	liter per second per meter	(L/s)/m
inch	in	25.4	millimeter	mm
mile	mi	1.609	kilometer	km

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ABSTRACT

A program to make geophysical logs of all available holes that penetrate the Edwards aquifer in the San Antonio area was conducted during 1970-78. The logging program was designed to provide data for definition of aquifer characteristics, including the boundary conditions and the hydrogeology of a highly faulted and stratigraphically complex aquifer. Approximately 400 holes were logged by using electrical, neutron, gamma-gamma, natural-gamma, sonic, caliper, fluid-conductivity, and fluid-temperature probes.

The specific objectives of the logging program were to identify the top and base of the Edwards aquifer, to identify and correlate lithologic subunits within the aquifer, to determine porosity distribution, to characterize porosity into total and secondary porosities, to estimate the mineralogic composition of the aquifer, to determine vertical changes in water quality and temperature, and to identify zones where water enters or leaves the boreholes.

Cross plots of geophysical measurements were used to estimate mineralogy, secondary porosity, and to determine the occurrence of fractures. Tracer studies, using Rhodamine WT dye as a tracer, were used to investigate hydrogeologic characteristics. These techniques included tracer-dilution, single-well pulse, and transit-time tests. Salt-dilution tests were conducted to investigate vertical flow within a borehole and to identify zones of water movement.

INTRODUCTION

The San Antonio area, as defined in this report, includes parts of Kinney, Uvalde, Medina, Bexar, Comal, and Hays Counties in the vicinity of the Balcones Fault Zone (fig. 1). The area includes that part of the Edwards aquifer that supplies water to the city of San Antonio, for irrigation, and to the major springs in Uvalde, Bexar, Comal, and Hays Counties.

The freshwater part of the aquifer, which varies in width from 5 to 40 miles, is bounded by ground-water divides in Kinney County on the west and Hays County on the east, by the faulted outcrop of the Edwards Group of Rose (1972) on the north, and by the interface between fresh and saline water (the "bad-water" line) on the south (fig. 1). In the saline zone, the water contains 1,000 mg/L (milligrams per liter) or more of dissolved solids.

Purpose and Scope of This Report

The purpose of this report is to document the availability of geophysical, packer, and tracer data and to explain the methods used in the collection and interpretation of these data.

A program to geophysically log all available holes that penetrate the Edwards aquifer in the San Antonio area was conducted during 1970-78 by the U.S. Geological Survey in cooperation with the City Water Board of San Antonio and the Texas Department of Water Resources. The logging program was designed to provide data for definition of the hydrogeologic characteristics of the aquifer and to define the boundary conditions. Approximately 400 holes, most of which were water wells that partly penetrated the Edwards aquifer, were logged during the study. The suite of logs obtained at individual wells varied according to the availability of logging tools and to conditions at the well sites.

The specific objectives of the logging program were to provide data:

1. To identify the top and base of the Edwards aquifer and to identify and correlate lithologic subunits within the aquifer;
2. To determine porosities of the subunits and to determine the overall vertical distribution of porosity within the aquifer;
3. To characterize porosity into total and secondary porosities;
4. To determine the location and thickness of cavernous zones within the aquifer;
5. To estimate the mineralogic composition of the subunits;
6. To determine vertical changes in water quality and temperature; and
7. To identify zones where water enters or leaves the borehole (whether a zone is producing or losing water).

The geophysical logging tools used to investigate the aquifer included electrical, neutron, gamma-gamma, natural-gamma, sonic, caliper, fluid conductivity, and fluid temperature. Sonic and focused-electric devices were not available on the U.S. Geological Survey logging truck that was routinely available during the logging program. These logs were made either by private companies or by the borehole geophysical unit from the Denver, Colo., office of the U.S. Geological Survey.

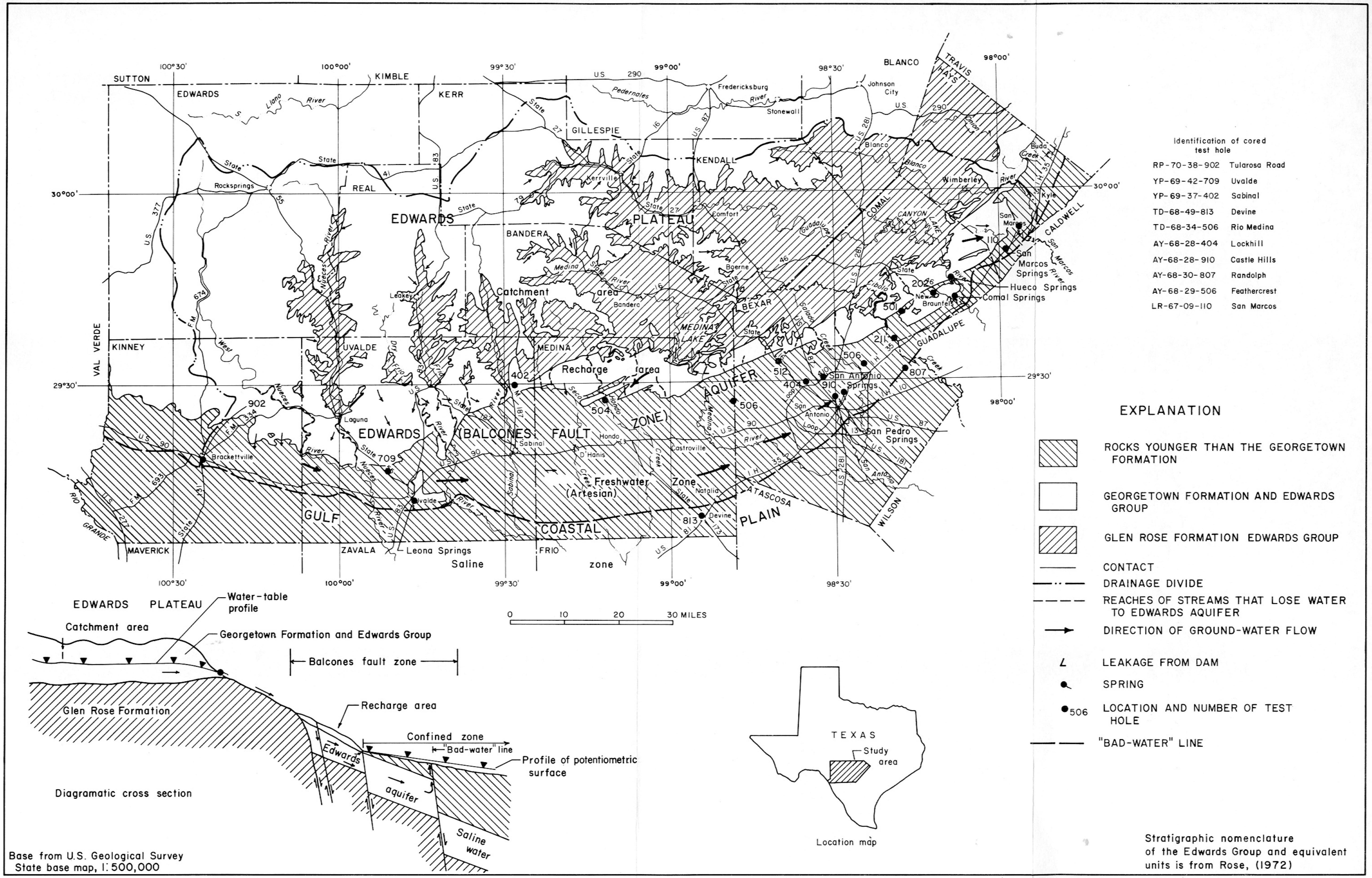


FIGURE 1.-Location and hydrologic features of the San Antonio area

A-6

Availability of Geophysical Logs and Description of Well-Numbering System

The locations of wells or test holes for which geophysical logs are available in the files of the U.S. Geological Survey in San Antonio, Tex., are shown in figure 2. The wells and test holes are identified by the standard well-numbering system used by the Texas Department of Water Resources.

The well-numbering system in Texas was developed by the Texas Department of Water Resources for use throughout the State. Under this system, each 1-degree quadrangle is given a number consisting of two digits. These are the first two digits in the well number. Each 1-degree quadrangle is divided into 7-1/2-minute quadrangles which are given two-digit numbers from 01 to 64. These are the third and fourth digits of the well number. Each 7-1/2-minute quadrangle is divided into 2-1/2-minute quadrangles which are given a single-digit number from 1 to 9. This is the fifth digit of the well number. Finally, each well within a 2-1/2-minute quadrangle is given a two-digit number in the order in which it was inventoried, starting with 01. These are the last two digits of the well number. Only the last three digits of the well number are shown at each well site; the first four digits are shown in the northwest corner of each 7-1/2-minute quadrangle.

In addition to the seven-digit well number, a two-letter prefix is used to identify the county. The prefix for counties where wells were sampled are as follows: AY, Bexar; DX, Comal; KX, Guadalupe; LR, Hays; RP, Kinney; TD, Medina; and YP, Uvalde.

The types of logs available for wells and test holes are tabulated in table 1. This tabulation includes a listing of all logs that were assembled through 1978.

APPLICATION OF GEOPHYSICAL LOGS

The types of logs and their application to hydrogeologic studies of the Edwards aquifer are as follows:

Type of log	Application
Electrical	Stratigraphic correlation, lithology, porosity
Neutron	Stratigraphic correlation, porosity
Gamma gamma	Stratigraphic correlation, bulk density, porosity, mineralogy
Gamma	Lithology
Sonic	Correlation, porosity
Caliper	Borehole diameter
Fluid conductivity	Formation-fluid conductivity
Fluid temperature	Formation-fluid temperature

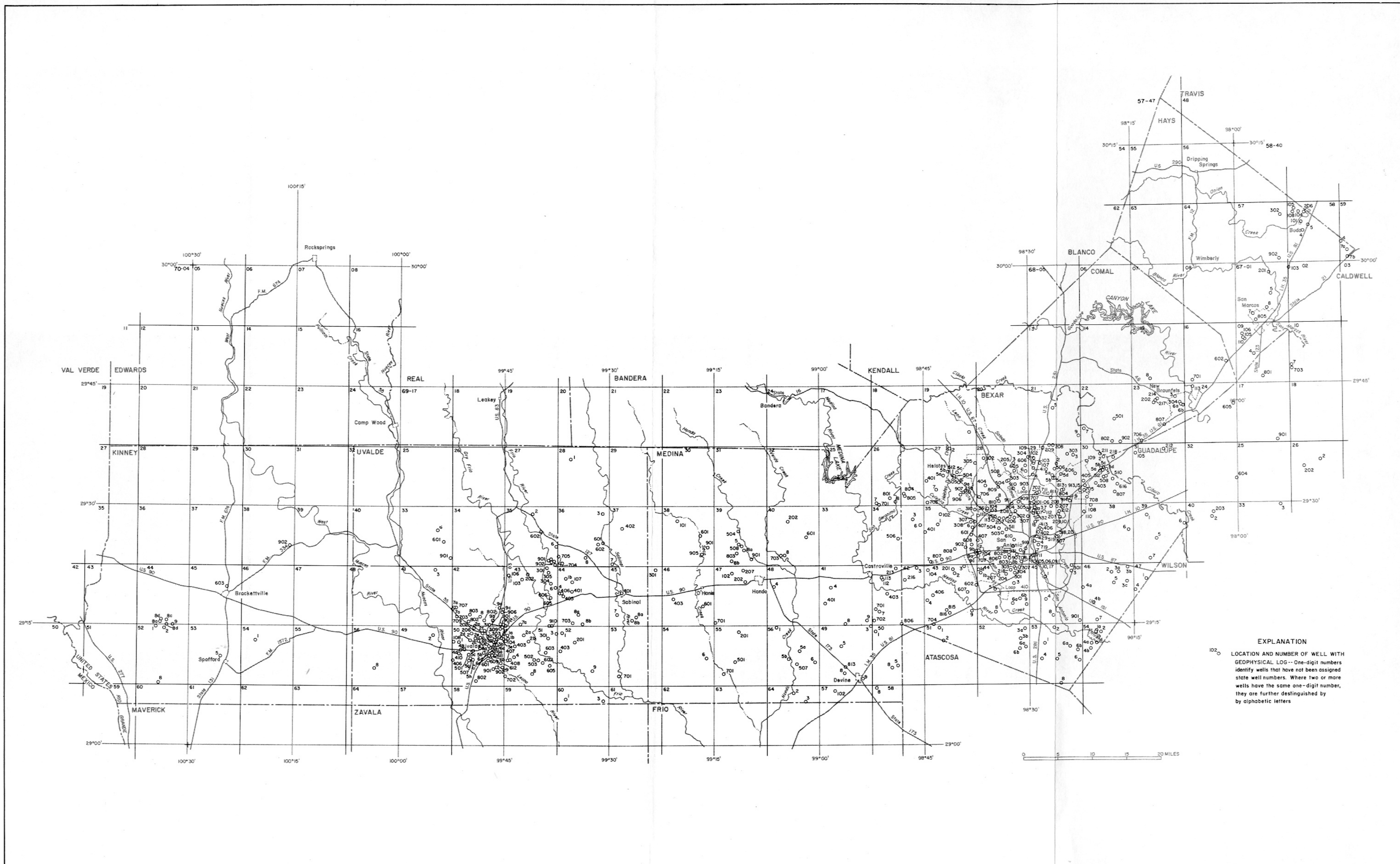


FIGURE 2.-Locations of wells and test holes for which geophysical logs are available

Stratigraphic Correlation

Stratigraphic correlation, which is the process of demonstrating that aquifer units in two or more separated areas are hydrogeologic equivalents, is the most important application of geophysical logs to the study of the Edwards aquifer. Correlation from one well to another involves matching for overall similarity in the trace of a geophysical record or for a characteristic geophysical response to a lithologic marker.

Geophysical logs were made in cored test holes in which stratigraphic subdivisions were first identified by examination of the cores. The sequence of stratigraphic units within the aquifer was identified and correlated with units previously identified by Rose (1972) in areas adjacent to the San Antonio area. The lateral continuity of these units and therefore a framework for understanding the hydrogeology of the Cretaceous Edwards Group and its subdivisions as used by Rose (1972) was established for the area of investigation.

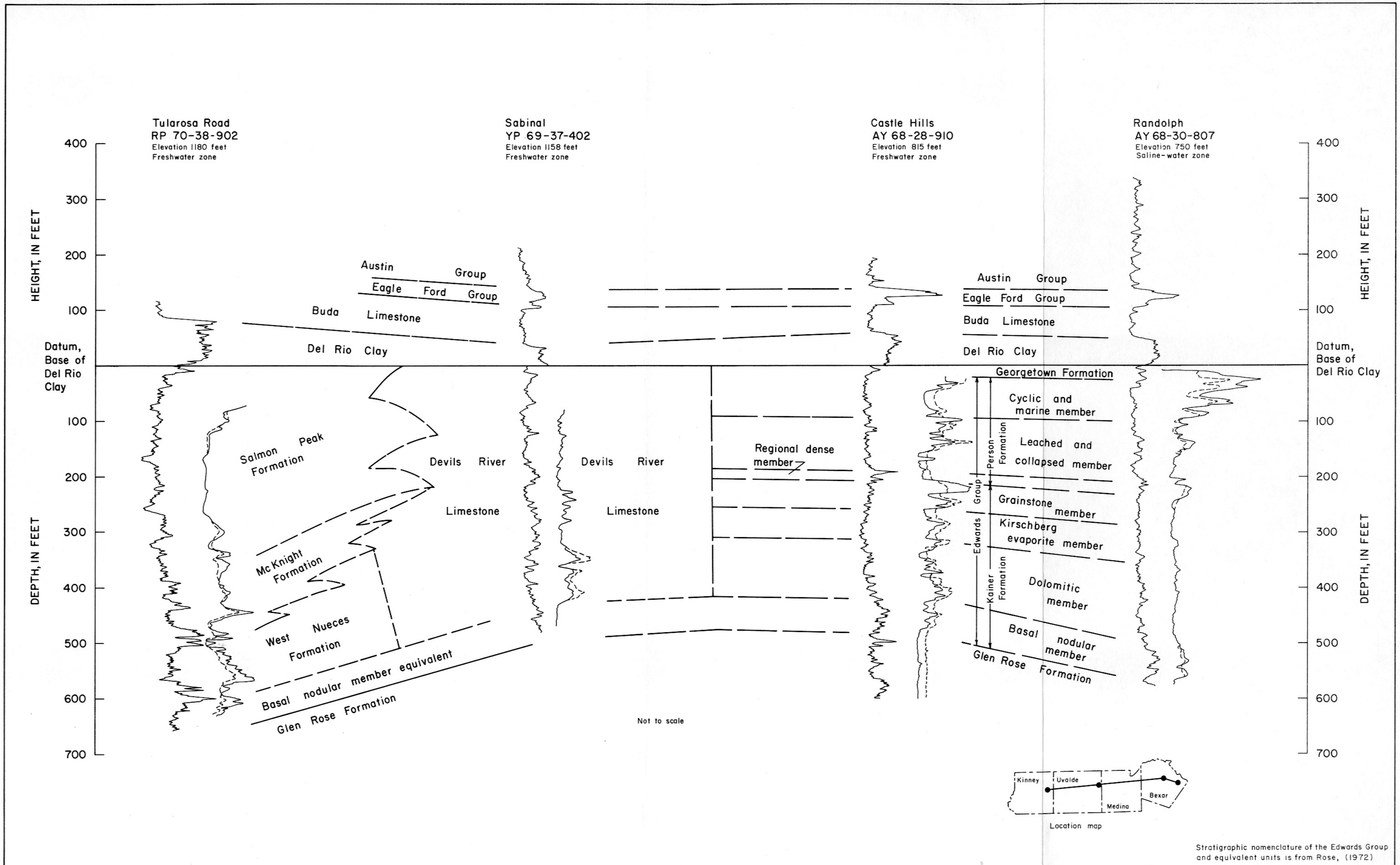
Representative logs used for correlation are shown in figure 3. The gamma-ray log was used to determine the base of the upper confining bed of the Edwards aquifer and to identify subunits within the aquifer. Other geophysical logs that are useful for correlation are the electrical, neutron, gamma-gamma, and sonic logs. The sonic log, which reflects changes in lithology accurately, is an excellent log for correlation.

Examples of the techniques of using these logs for correlation include: (1) Identification of Rose's regional dense member of his Person Formation by the high density and low porosity of the rocks and the relatively small diameter of the hole, as measured by the gamma-gamma, neutron, and caliper logs, respectively; (2) identification of Rose's leached and collapsed member of his Person Formation and his Kirschberg member of his Kainer Formation by the cycle skips shown on the sonic log, the extended diameter of the hole as measured by the caliper log, and the highly porous zones as indicated by the neutron log; and (3) identification of Rose's basal nodular member of his Kainer Formation by the higher density, increased natural-gamma radiation of the rocks, and the relatively low borehole rugosity.

Bulk Density

Gamma-gamma logs are used to obtain information on bulk density, which is the weight of the rock per unit volume of the rock. The logging equipment includes a sidewall sonde (emplaced against the borehole wall) that contains a collimated source of gamma radiation and a gamma-ray detector to measure the amount of radiation reflected by the rock formation. The measurements of reflected radiation are a function of the strength of the gamma-ray source, instrument sensitivity, bulk density of the formation, mud density, and borehole diameter and rugosity.

Bulk density may be read directly from gamma-gamma logs that are calibrated to accurately known densities and automatically compensated for borehole diameter. The errors in bulk density obtained from such logs (Keys and MacCary, 1971, p. 70) are on the order of ± 0.03 - 0.04 g/cm^3 (grams per cubic centimeter).



P12-14

FIGURE 3.-Representative logs showing correlation of units within the Edwards aquifer

Bulk density cannot be read directly from the gamma-gamma logs obtained by use of the U.S. Geological Survey logging equipment. The logs must be calibrated by comparing the log response to the measured density of a test-hole core to determine the relationship between the counts per second, as recorded by the logging equipment, and the bulk density. The relationship between the count rate (logarithmic scale) and bulk density (arithmetic scale) is exponential.

The logs were calibrated also by comparing them to gamma-gamma logs that directly record bulk density. Gamma-gamma logs made by both commercial and U.S. Geological Survey equipment were available for the San Marcos (LR-67-09-110), Randolph (AY-68-30-807), Lockhill (AY-68-28-404), Devine (TD-68-49-813), and Sabinal (YP-69-37-402) test holes. The logs were adjusted for depth correlation, and the readings of each log were recorded for selected depths. The hole diameter was noted from the caliper log for each sample reading. The data were then cross plotted to obtain a curve to which an equation, which relates counts per second to bulk density, was mathematically fitted. For example, the calibration equation for the San Marcos test hole is:

$$\text{Bulk density} = -0.0016\ (\text{CPS}) + \text{Fx} \qquad (1)$$

where CPS = counts per second, and
Fx = function of hole diameter, in inches;

$$\text{Fx} = 1.89 + 0.38\ \text{foot} - 0.0125\text{H}^2$$

where H = hole diameter, in inches.

Only noncalibrated gamma-gamma logs were available for some wells, but an apparent calibration can be made on the basis of the bulk density of rocks within regionally extensive stratigraphic units. The larger bulk densities tend to be about 2.65 to 2.70 g/cm^3 and the smaller bulk densities tend to be about 2.1 g/cm^3. The count rate of the gamma-gamma log is read for the depth where bulk density is estimated, and an exponential curve is fitted to the data. If the calibration equation is significantly in error, the computed values of porosity and mineralogy as indicated by the cross plotting procedure appear to be spurious.

The bulk density of the rocks in the Edwards aquifer, as measured by commercial density logs, ranges from about 2.10 $\pm$ 0.04 g/cm^3 to about 2.70 $\pm$ 0.04 g/cm^3. Laboratory measurements of the bulk density of 71 rock samples collected from the San Marcos, Randolph, Lockhill, and Castle Hills test holes ranged from 2.05 to 2.69 g/cm^3. Therefore, the data indicate that the bulk density is, in general, correctly measured by the density log.

Porosity

Neutron, gamma-gamma, electrical, and sonic logs were used to estimate the porosity of the Edwards aquifer. The most reliable index of relative porosity is the neutron log, which relates porosity to the hydrogen concentration within the materials forming the aquifer, including the fluids. Because the Edwards aquifer contains few hydrous minerals (clay and gypsum), and because the porosity is independent of the carbonate mineralogy of the aquifer, the neutron log is indicative of total porosity.

The neutron log is very sensitive to borehole size, and the most accurate logs are obtained in boreholes with diameters less than 16 inches (Pirson, 1963, p. 200). Neutron logs made in holes larger than 16 inches in diameter are not reliable. If the sonde is decentralized (pushed up against the wall of the borehole by a mechanical device), the effect of borehole diameter is reduced. The commercial neutron logs available for the San Antonio area are either electronically compensated for borehole effect or decentralized; the neutron sonde of the U.S. Geological Survey logger is decentralized. The caliper log needs to be used in conjunction with quantitative interpretations of neutron data to obtain accurate values of porosity.

The gamma-gamma log can be used to determine total porosity by the equation (Keys and MacCary, 1971):

$$\text{porosity} = \frac{\text{grain density - bulk density}}{\text{grain density - fluid density}} . \qquad (2)$$

The relationship between bulk density, porosity, and mineralogy is shown in figure 4.

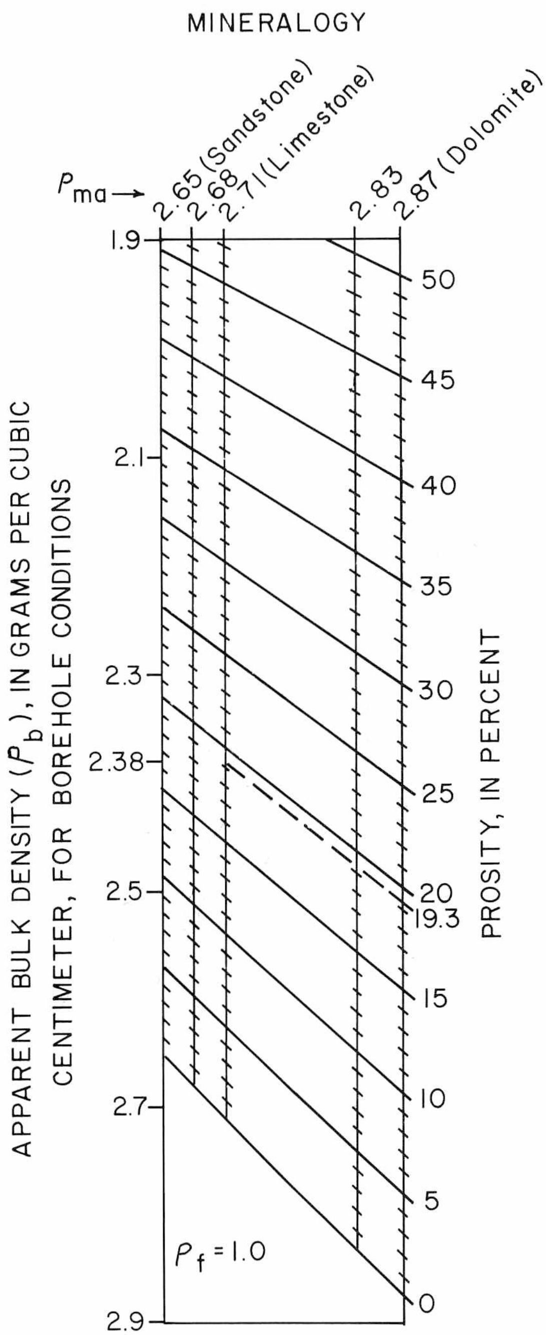
An accurate determination of porosity requires an accurate measurement of bulk density and knowledge of the grain density (mineralogy). Porosity estimates can be incorrectly estimated by more than 25 percent if an inaccurate value of grain density is used. For example, if the bulk density and fluid density are 2.38 and 1.0 g/cm^3, respectively, a porosity of 19.3 percent is calculated by using a grain density of 2.71, which is representative of limestone. A porosity of 25.5 percent is calculated by using the same bulk density and fluid density but a grain density of 2.87, which is representative of dolomite. The bulk density can be estimated within 0.04 g/cm^3 if the corrections for borehole diameter are made (Keys and MacCary, 1971).

Within the freshwater zone, the mineral composition of most of the Edwards aquifer is limestone (calcite), but zones of dolomite and dolomitic limestone occur throughout the aquifer and especially in the lower part. Therefore, reliable estimates of total porosity cannot be made from a gamma-gamma log without information on the mineral composition of the particular zones within the aquifer. Cross plots of neutron-determined porosity versus bulk density can be used to obtain reliable porosity values. This method will be described later in this report.

Sonic logs were used to estimate primary or matrix porosity. An index of secondary porosity is computed as the difference in porosity as determined by a log that measures total porosity, such as the neutron log, and the primary porosity as measured by the sonic log. Porosity is calculated from sonic logs by using the following equation (Keys and MacCary, 1971):

$$\text{porosity} = \frac{\Delta t_{log} - \Delta t_{matrix}}{\Delta t_{fluid} - \Delta t_{matrix}} \qquad (3)$$

where Δt = transit time, in microseconds per foot.
The relationship between sonic travel time and porosity for different apparent matrix velocities is shown in figure 5.



EXAMPLE

ρ_b (Bulk density) = 2.38 gm/cm^3

ρ_{ma} (Grain density, limestone) = 2.71 gm/cm^3

ρ_f (Fluid density, freshwater) = 1.0 gm/cm^3

ϕ_n (Porosity) = 19.3

Adapted from Schlumberger (1974)

FIGURE 4.-Relation between bulk density, porosity, and mineralogy

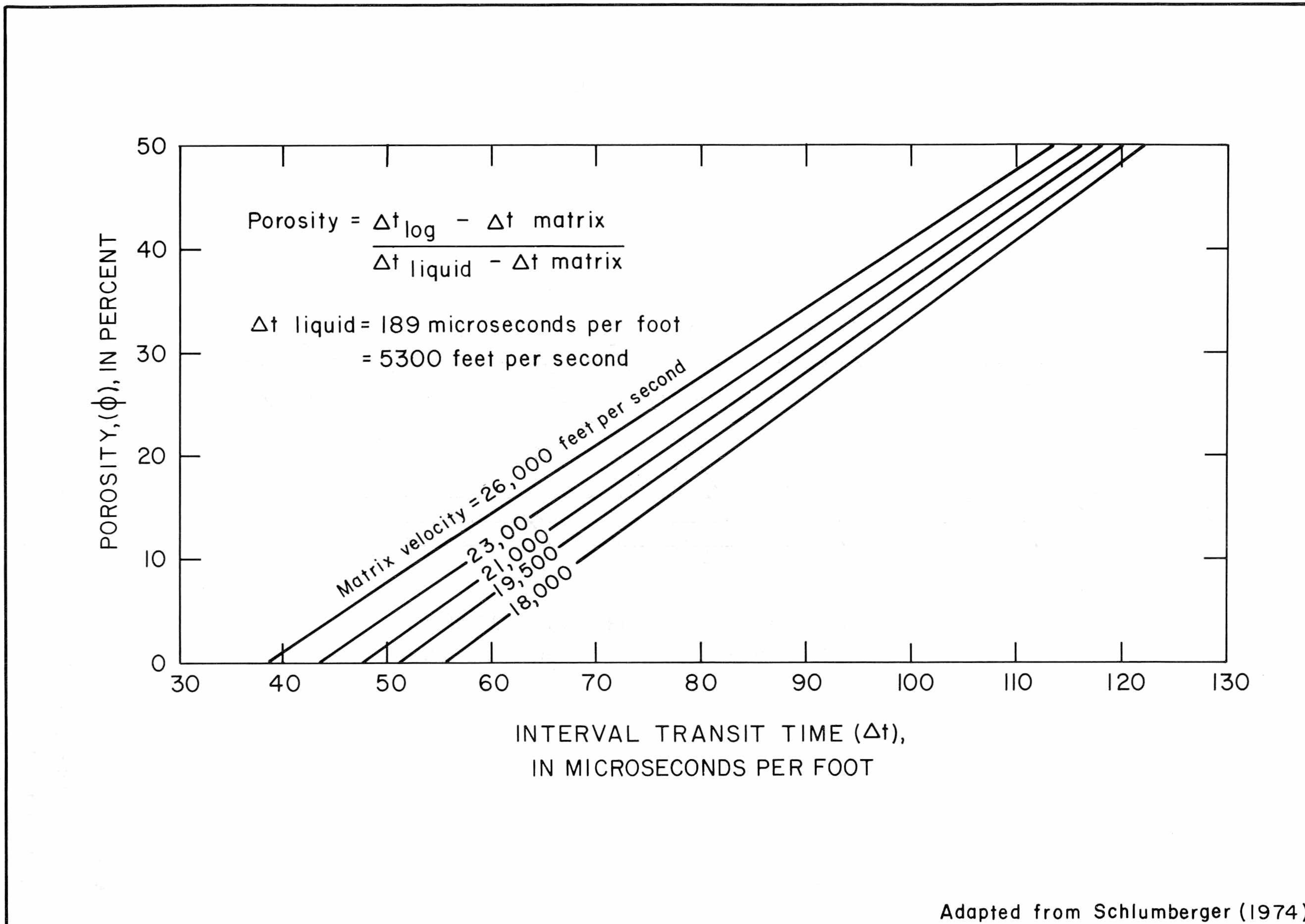


FIGURE 5.-Relation between sonic velocity and porosity for materials of different matrix velocities

The velocity of a sound wave in water is about 5,300 ft/s or about 189 μs/ft (microseconds per foot). The velocity of a sound wave in limestone ranges from 21,000 to 23,000 ft/s or 47.6 to 43.5 μs/ft; and the velocity of a sound wave in dolomite is about 23,000 ft/s or 43.5 μs/ft. The relationship between apparent bulk density and sonic velocity is shown in figure 6. In non-vuggy sections of the aquifer, the porosity can be estimated from a sonic log to within 10 percent of its true value.

Electrical logs were reliably used to estimate total porosity in the saline zone of the aquifer. In the freshwater zone, the reliability of the porosity estimate is questionable.

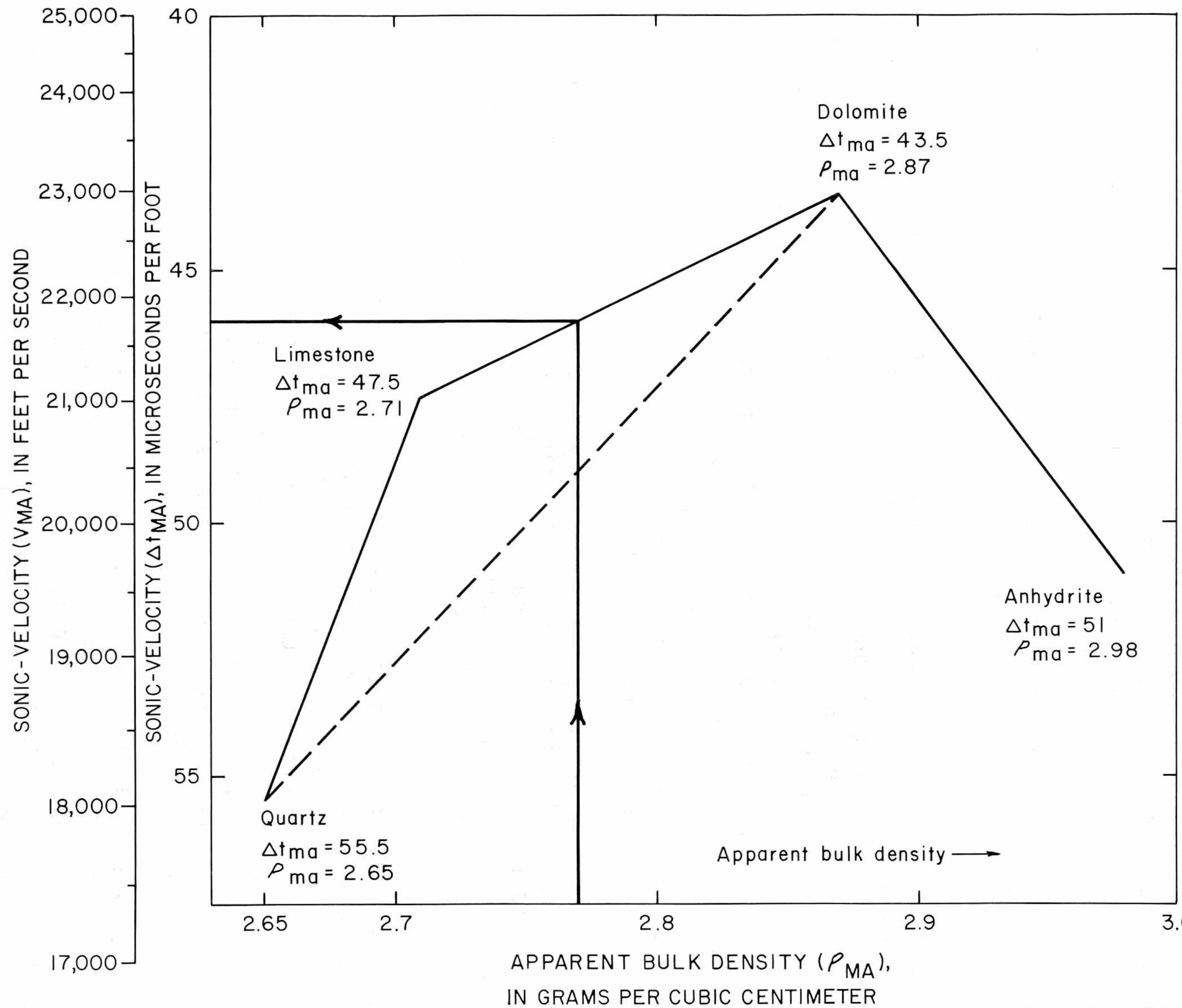
Logs that record accurate measurements of the electrical resistivity within a small vertical zone may be used to obtain quantitative estimates of porosity if the cementation and formation factors are known. An empirical relationship exists between the formation factor and porosity. The formation factor equals the porosity raised to the power of negative m (cementation factor), which is determined from laboratory measurements of saturated rock samples or is calculated from electrical logs if the electrical resistance of the formation water is known. This relationship is not completely valid for rocks saturated with freshwater having an electrical resistance significantly greater than 20 ohmmeters. The relationship between formation factor and porosity for a range in cementation factors is shown in figure 7.

In the freshwater zone, the resistivity measurement of the short-normal electrical log (a 16-inch spacing of measuring electrodes) is usually greater than that measured by the long-normal log (a 64-inch spacing of the electrodes). However, reversals of this pattern are common. The apparent resistivity recorded by each device is affected by the resistivity, geometry, and volume of the materials.

Determination of the factors causing the greater resistance indicated by the short-normal curve requires investigation of the resistivity of the borehole fluid. Fresher water (water with greater electrical resistance) may be moving from a very permeable zone, through the borehole, and flowing from the borehole at other permeable zones. This flow (invasion) could result in flushing of the low-resistance drilling mud immediately adjacent to the borehole, thereby increasing the electrical resistance of the formation as "seen" by the short-normal sonde.

The thickness of the beds of differing electrical resistance also affect the shape of the normal curves. This effect results from the relatively large vertical dimension in relation to the horizontal dimension of the volume of rock logged by nonfocused electrical logging tools. Therefore, it is important to know the bed thickness in relation to the electrode spacing in interpreting the apparent resistivity (Schlumberger Limited, 1972a, p. 15).

Use of the normal curves for quantitative determination of porosity requires that log-recorded resistivity values also be corrected for borehole effects. The borehole effects are related to the diameter of the hole and the electrical resistance of the mud or liquid filtrate within the invaded zone. Charts are available for correcting the field measurements of resistivity for the effects of both borehole diameter and bed thickness (Schlumberger Limited, 1972b).



Adapted from Schlumberger (1974)

FIGURE 6.-Relation between apparent bulk density and sonic velocity

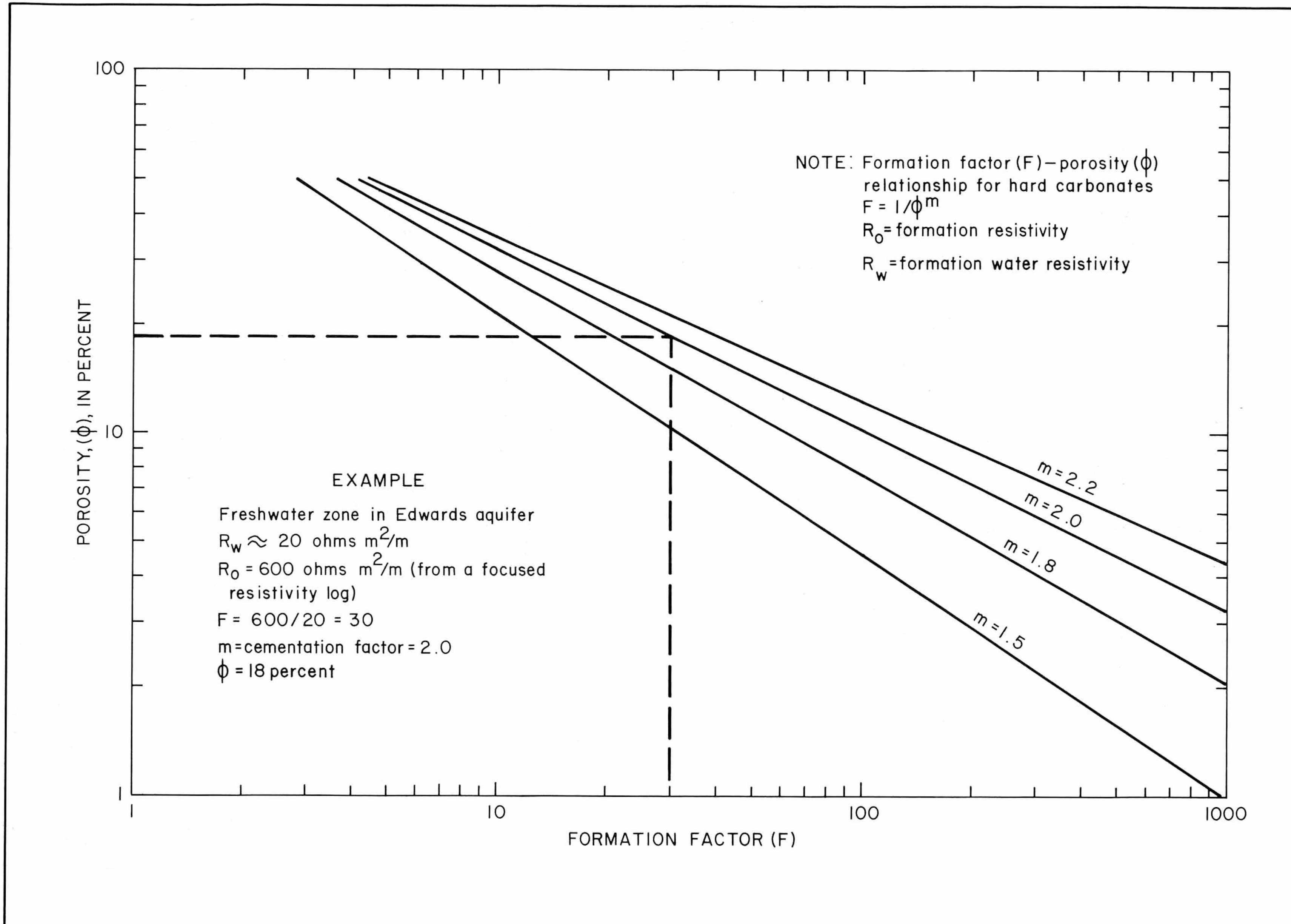


FIGURE 7.-Relation between formation factor and porosity for different cementation factors

Resistivity values obtained from focused logs, after corrections for invasion, indicate the true resistivity of thin beds and provide an accurate measurement of formation resistivity when the ratio of R_o (resistivity of the formation) to R_m (resistivity of the drilling fluid) is 50 or greater. Focused tools were not available on the U.S. Geological Survey logger at the time of this investigation; therefore, only commercial focused logs are available for analysis.

Permeability

Permeability cannot be measured directly from geophysical logs; however, knowledge of the regional stratigraphy together with geophysical data provides information for making interpretations of the relative permeabilities of vertical zones within the aquifer.

Geologic sections showing stratigraphic units as identified from geophysical logs provide the best information for investigating the relative permeabilities, either at a particular well site or for a geographical area. The less permeable units of the Edwards aquifer, which consist of rocks of high bulk density, generally high electrical resistivity, and low neutron-measured porosity, are most readily recognized. In the eastern part of the San Antonio area, rocks having these characteristics are represented by aquifer subdivisions 1, 4, and 8 (Maclay and Small, 1976).

The permeable units are generally indicated by low electrical resistivity; high neutron-measured porosity; wide excursions of the caliper log, which indicate cavernous porosity; and cycle-skips on sonic logs. Cycle-skips are described by Keys and MacCary (1971, p. 90). Other geophysical logs that can be used to interpret permeability include temperature and temperature-differential logs, which are used to determine zones where inflow and outflow of water occurs in the borehole.

Precise estimates of the transmissivity of the Edwards aquifer cannot be made from geophysical logs. Other methods, including aquifer tests and flow-net analyses, give estimates of transmissivity.

CROSS-PLOTTING PROCEDURES

Cross plotting is a graphical procedure of plotting one type of geophysical measurement versus another type on a coordinate axis. Cross plots are used to estimate mineralogy, corrected porosity, secondary porosity, and to determine the occurrence of fractures. Cross plots can be used also to identify logs that are incorrectly calibrated.

The types of cross plots used in this study and their application to the geohydrology of the Edwards aquifer are as follows:

Type of cross plot	Application
Neutron-density	Mineralogy, porosity
Sonic-neutron	Mineralogy, porosity
Sonic-resistivity	Fractures
Neutron-sonic-gamma gamma (M-N plots)	Lithology, mineralogy, porosity

Neutron-Density Cross Plot

Neutron logs and density logs respond differently and independently to the different mineralogical compositions of the aquifer. Used in combination, these logs can provide more information about the geologic environment than can the sum of information obtained from independent analyses of several logs (fig. 8).

The neutron-density cross plot consists of representative curves, each beginning at the point of zero porosity of a mineralogically pure rock (quartz sandstone, limestone, or dolomite), and extending to a point of 100-percent porosity or fluid point. However, the plots actually used rarely extend past 45 or 50 percent because higher porosities are not representative of actual saturation in the rocks. The porosity values on the cross plot were obtained from a sidewall neutron porosity (SNP) log.

A neutron-density cross plot of values measured at various zones in the San Marcos test hole is shown in figure 9. The values are listed in table 2. The pattern of the plotting positions indicates that the rocks consist mostly of dolomitic limestone, which is in agreement with observations made of the mineralogy of the core samples. The relative proportion of limestone and dolomite can be interpolated from the appropriate curves and the plotting position of each zone. For example, zone 21 is composed of about 50-percent limestone and 50-percent dolomite.

To correct the porosity values for a mixture of two known minerals, lines are drawn to connect the corresponding porosity values shown on each curve for a pure mineralogical composition. Then the plotting position is referenced to these lines of constant porosity within a field of varying porosity.

Sonic-Neutron Cross Plots

A sonic-neutron cross plot of measurements from the same zones (as in fig. 9) in the San Marcos test hole is shown in figure 10. The pattern of the plotting position indicates very similar mineralogical proportions to that shown in figure 9 except for zones 7, 8, 28, and 29. Clay and marl occur in zones 8, 28, and 29 as can be seen on the gamma-ray log in figure 8. Because of the slow velocity (increased Δt) of the sonic wave in clay, the plotting position is displaced upward and beyond the limiting curve for limestone.

Sonic-Resistivity Cross Plots

A method developed by Aguilera (1974) for identifying fractured carbonate rocks from a cross plot of sonic and electrical-resistivity data was tested in the Edwards aquifer. A theoretical model indicates that for fractured systems, the porosity exponent "m" (commonly referred to as the cementation factor) should range between -1.1 and -1.3.

The relationship between sonic velocity and resistivity is developed from the empirical relationships ($F = R_t/R_w$, $F = \emptyset^{-m}$, $\Delta t = \Delta t_m + m_{sv\emptyset}\emptyset$) where F is the formation factor, R_t is the true electrical resistivity, R_w is the

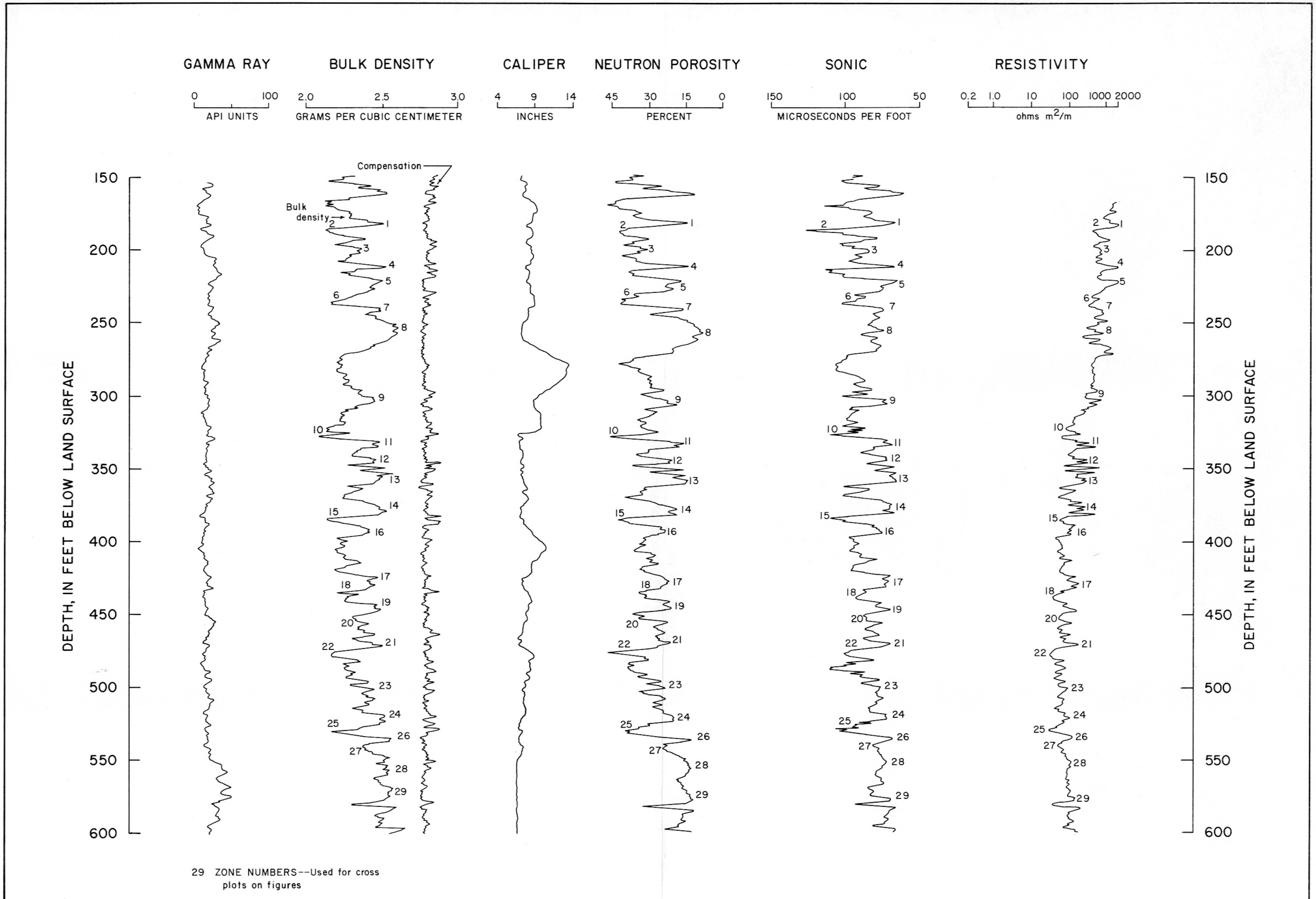


FIGURE 8.-Geophysical logs of the San Marcos test hole (LR-67-09-110)

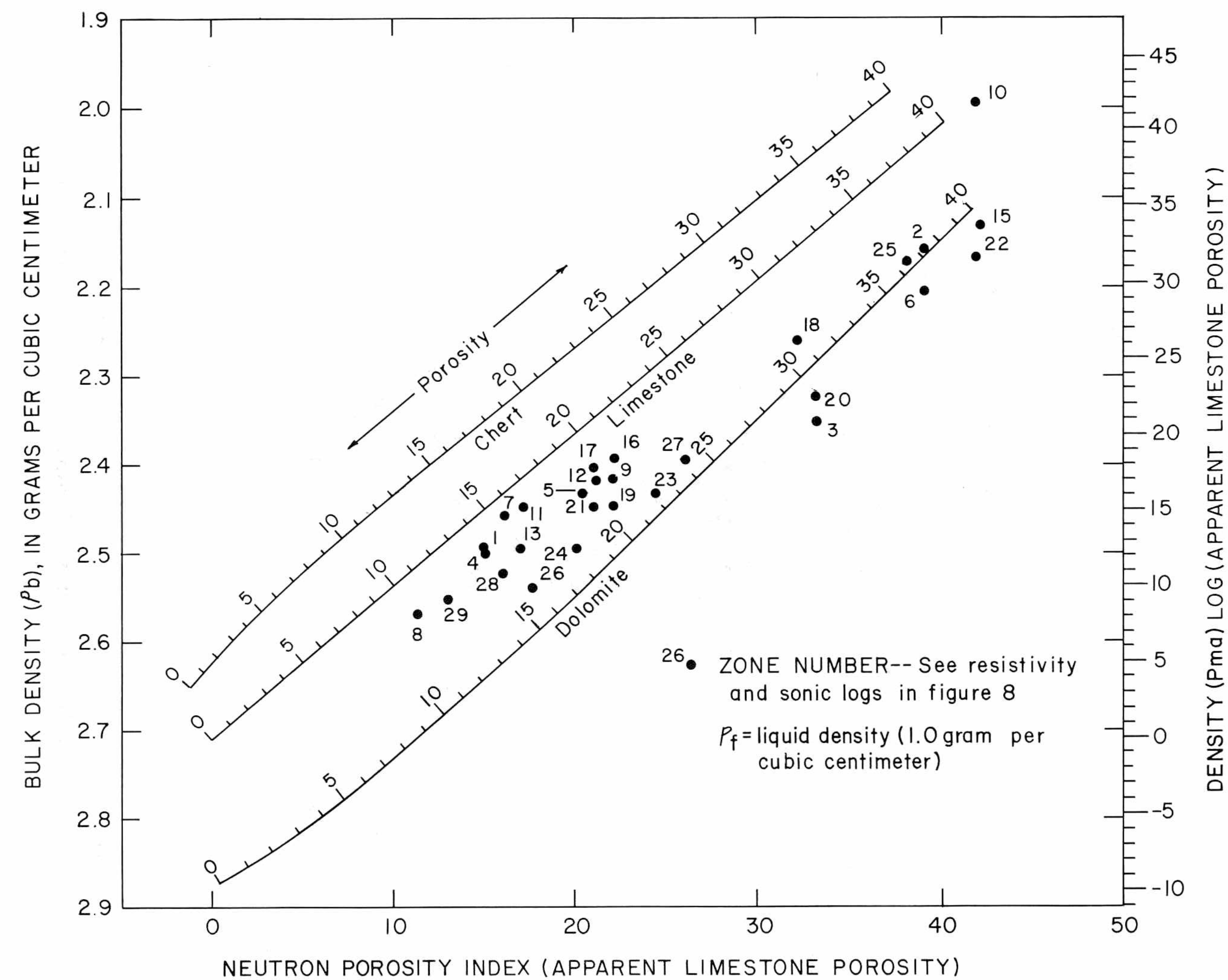


FIGURE 9.-Neutron-density cross plot of distributed zones in the San Marcos test hole (LR-67-09-110)

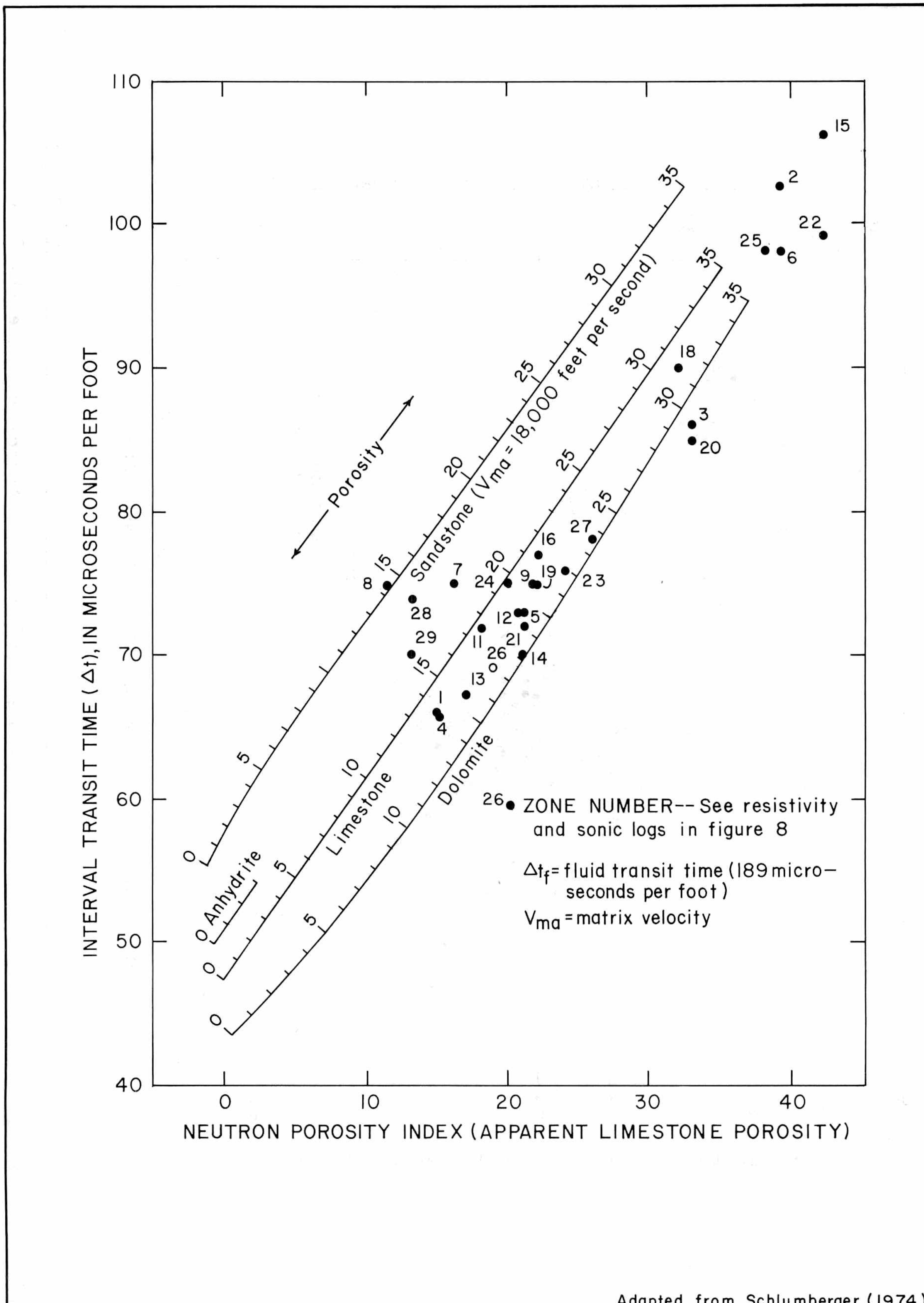


FIGURE 10.-Neutron-sonic cross plot of distributed zones in the San Marcos test hole (LR-67-09-110)

electrical resistivity of the natural fluid in the formation, $\emptyset$ is the porosity, m is the cementation factor, Δt is the response time from the sonic log, Δt_m is the response time in the matrix, and $m_{sv\emptyset}$ is the slope of the linear relationship between sonic velocity and porosity.

Manipulation of these relations gives the following relationship: $\log R_t = m \log (\Delta t - \Delta t_m) + m \log m_{sv\emptyset} + \log R_w$. This equation indicates that a plot of $\log R_t$ versus $\log (\Delta t - \Delta t_m)$ should result in a straight line with a slope of -m if R_w is constant. For fractured reservoirs, the resulting slope, based on an idealized reservoir formed by nonporous rock cubes separated by vertical and horizontal fractures of constant width, m, should be between -1.1 and -1.3.

The method was applied to geophysical data from the San Marcos test hole (LR-67-09-110), which is located near a major fault. The cross plot is shown in figure 11, and an average of measured values for the various zones is listed in table 2. The resistivity values were read from a laterolog 3, which is a focused log of good vertical resolution. The plotted zones were located at well-distributed points at depths below 300 feet, where the fluid resistivity is less than 1 ohmmeter. The slope of the graphically fitted curve is about -3.0. The derived slope indicates that the rock is not fractured, but samples of the test-hole cores showed fractures at scattered intervals.

A second test of the method was made by using geophysical data from the Sabinal test hole (YP-69-37-402). The geophysical logs are shown in figure 12, and the cross plot in figure 13. The values of average measurements of resistivity and sonic velocity for distributed areas are given in table 3. The resistivity values were obtained from a laterolog 8, which is a focused log that gives sharp vertical detail, but which is affected by borehole conditions, particularly by invasion and by enlargement of borehole diameter.

The plotting positions show some scatter; howver, the slope of a line indicating the relationship is about -1.0. This plot indicates that the rock is fractured. Observations of the core show that the limestone is extensively fractured in zones 1-7. The scatter of the plotting positions may result partly from varying velocity constants due to changing mineralogy. The lower part of the test hole penetrates shaly limestone that is less fractured.

Neutron-Sonic-Gamma Gamma (M-N) Cross Plots

Lithologic interpretations based on neutron, sonic, and gamma-gamma (density) logs are derived from M-N cross plots (Burke and others, 1969). The cross plots combine the data from all three porosity logs to provide the lithology-dependent quantities, M and N. These quantities are virtually independent of primary porosity because each quantity is a ratio of two porosity-dependent variables. (The porosity-dependent variable in the denominator cancels the porosity dependent variable in the numerator, resulting in a ratio that is dimensionless in terms of primary porosity.) A cross plot of these two quantities will therefore indicate lithology and secondary porosity.

Quantity M is obtained by dividing the porosity component of the sonic log $(\Delta t_f - \Delta t)$ by the porosity component of the density log $(\rho_b - \rho_f)$, and multiplying the resulting ratio by a scaling factor of 0.01. Quantity N is

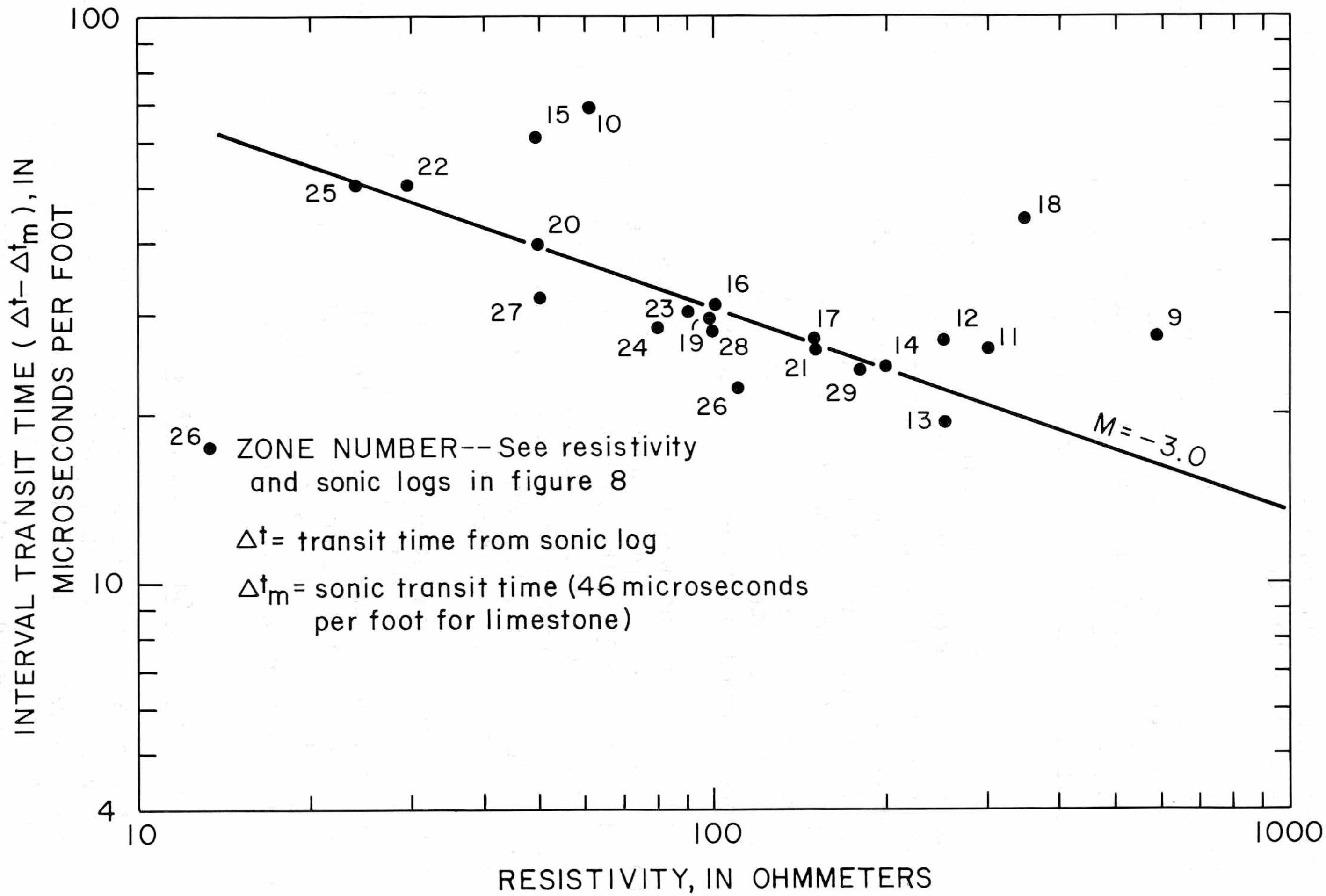


FIGURE 11.-Sonic-resistivity cross plot of distributed zones in the San Marcos test hole (LR-67-09-110)

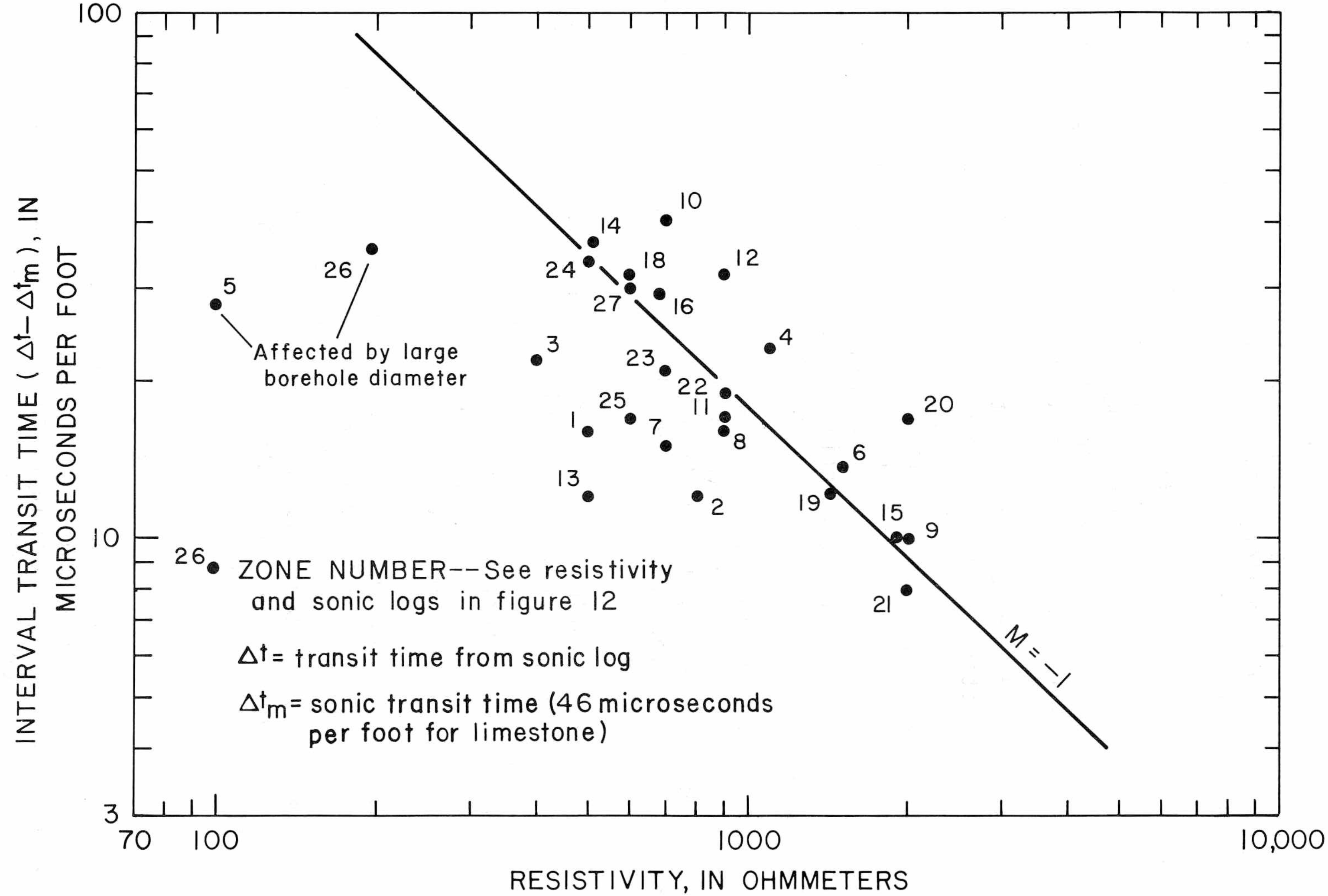


FIGURE 13.-Sonic-resistivity cross plot of distributed zones in the Sabinal test hole (YP-69-37-402)

obtained by dividing the porosity component of the neutron log ($\emptyset_{nf}$ - $\emptyset_n$) by the porosity component of the density log. For fresh muds, which are used to drill wells in the Edwards aquifer, Δt_f is 189 µs/ft, ρ_f is 1 g/cm^3, and $\emptyset_{nf}$ is 1.0. Neutron porosity, $\emptyset_n$, is calibrated for pure limestone.

The M and N values for distributed zones from the San Marcos (LR-67-09-110) and Sabinal (YP-69-37-402) test holes are given table 4. The values are plotted on M-N cross plots that show the end points for dolomite, limestone, and sandstone; the plotting area for shales of varying mineralogical composition; and the plotting area for secondary porosity.

An M-N cross plot of various zones in the San Marcos test hole is shown in figure 14. The plotting positions show considerable scatter, but most points plot near the line connecting the end points for dolomite and limestone, which indicate that the rocks are a mixture of limestone and dolomite. The points above the line connecting the end points for limestone and dolomite indicate that secondary porosity occurs within these zones. The plotting position of zones below the line connecting the end points for limestone and dolomite indicate that shale or clay may occur within these zones.

Most of the zones that plot in the shale region of the graph are from the lower part of the Edwards. The points (2, 3, 6, 10, 15, and 22) all have very high porosities as measured by the neutron log, but the sensitivity of the neutron sonde is very low for values greater than 30 percent; therefore, these porosity values may be in error.

An M-N cross plot of various zones in the Sabinal test hole is shown in figure 15. The plotting positions show a wide scatter; however, most positions are within the field of secondary porosity. The porosities for the points on the graph were determined from a compensated neutron log, which is highly sensitive to borehole diameter. Compensations for borehole diameter in zones of high porosity are not very accurate.

Points 3, 4, and 21 plot in the area of the graph indicating the occurrence of clay or shale. The positive deflection of the gamma-gamma log indicates the occurrence of clay at these points. Clay partings are evident in core samples taken at depths below 650 feet. The M-N and the sonic-resistivity cross plots previously described indicate that the carbonate rocks in the Sabinal test hole are highly fractured.

Overlays

Porosity values measured by neutron and gamma-gamma logs may be plotted on the same log track and calibrated in limestone-porosity units. This type of log presentation is called an overlay. Overlays provide information similar to that obtainable from cross plots, but the information is shown in a form that permits quick visual interpretation. An overlay on porosity logs calculated from the response of a neutron log and a gamma-gamma log for the Sabinal test hole is shown in figure 16. Interpretation of the overlay is based on information given in Schlumberger Limited (1969; 1974, table 5).

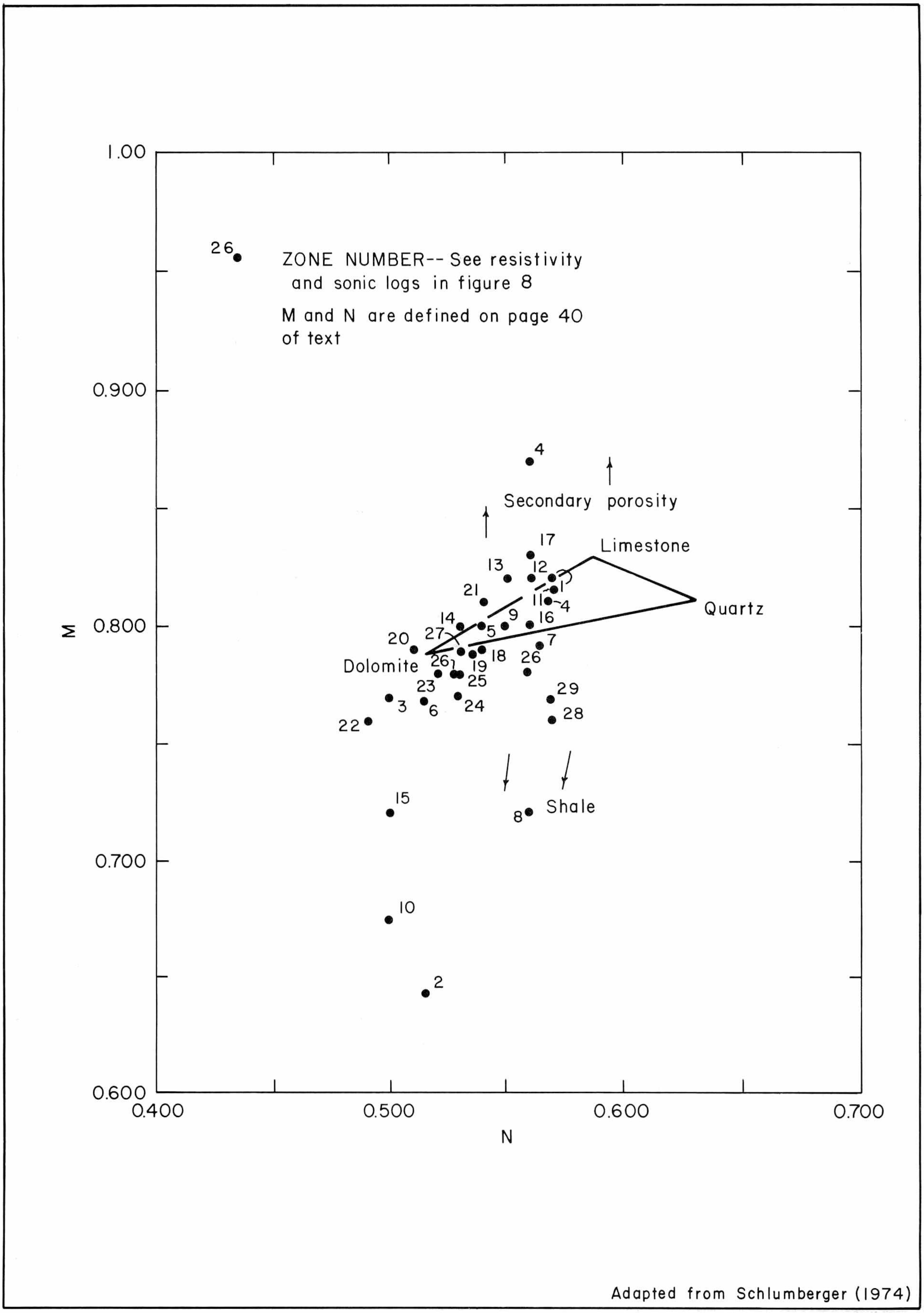


FIGURE 14.-M-N cross plot of distributed zones in the San Marcos test hole (LR-67-09-110)

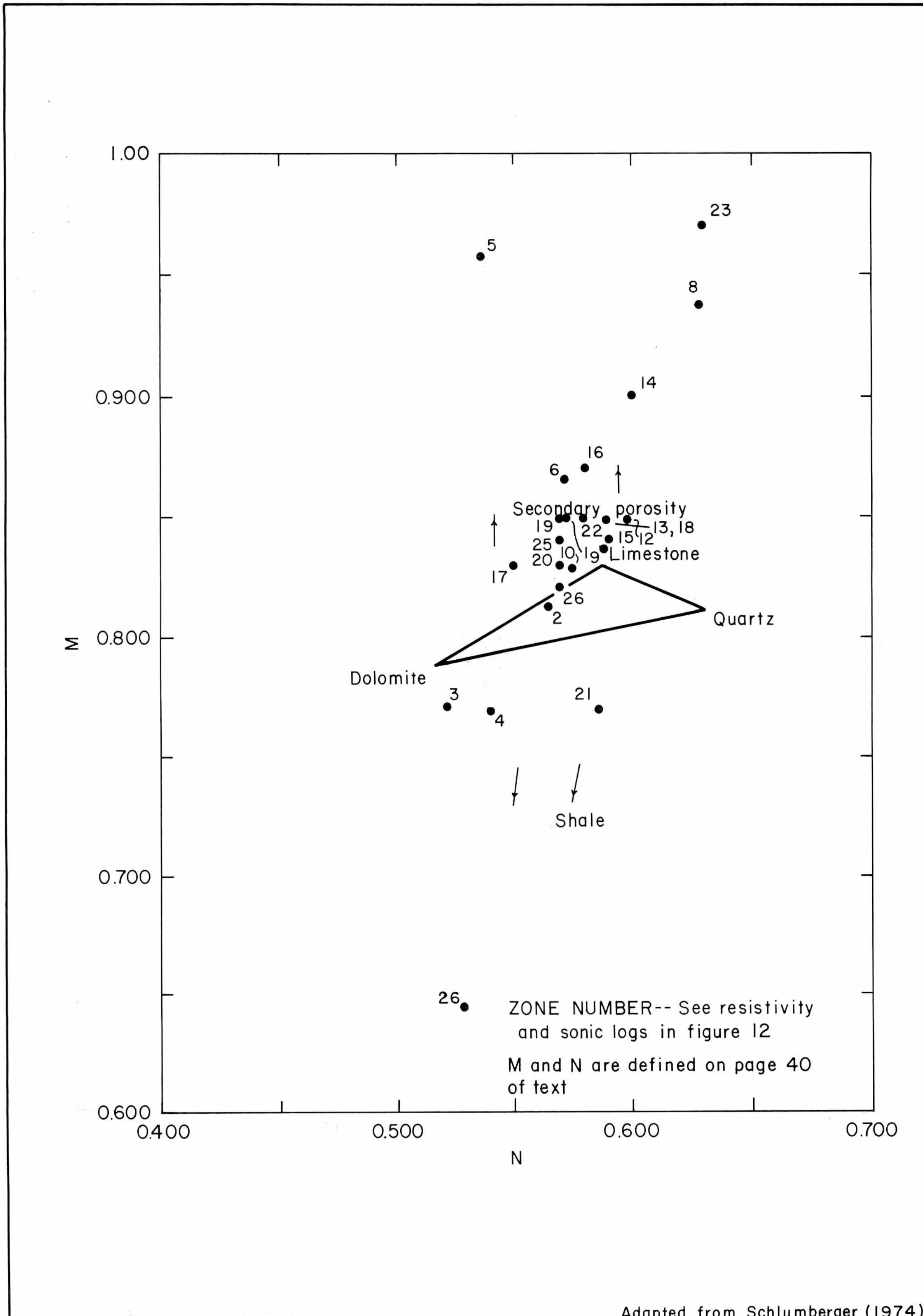


FIGURE 15.-M-N cross plot of distributed zones in the Sabinal test hole (YP-69-37-402)

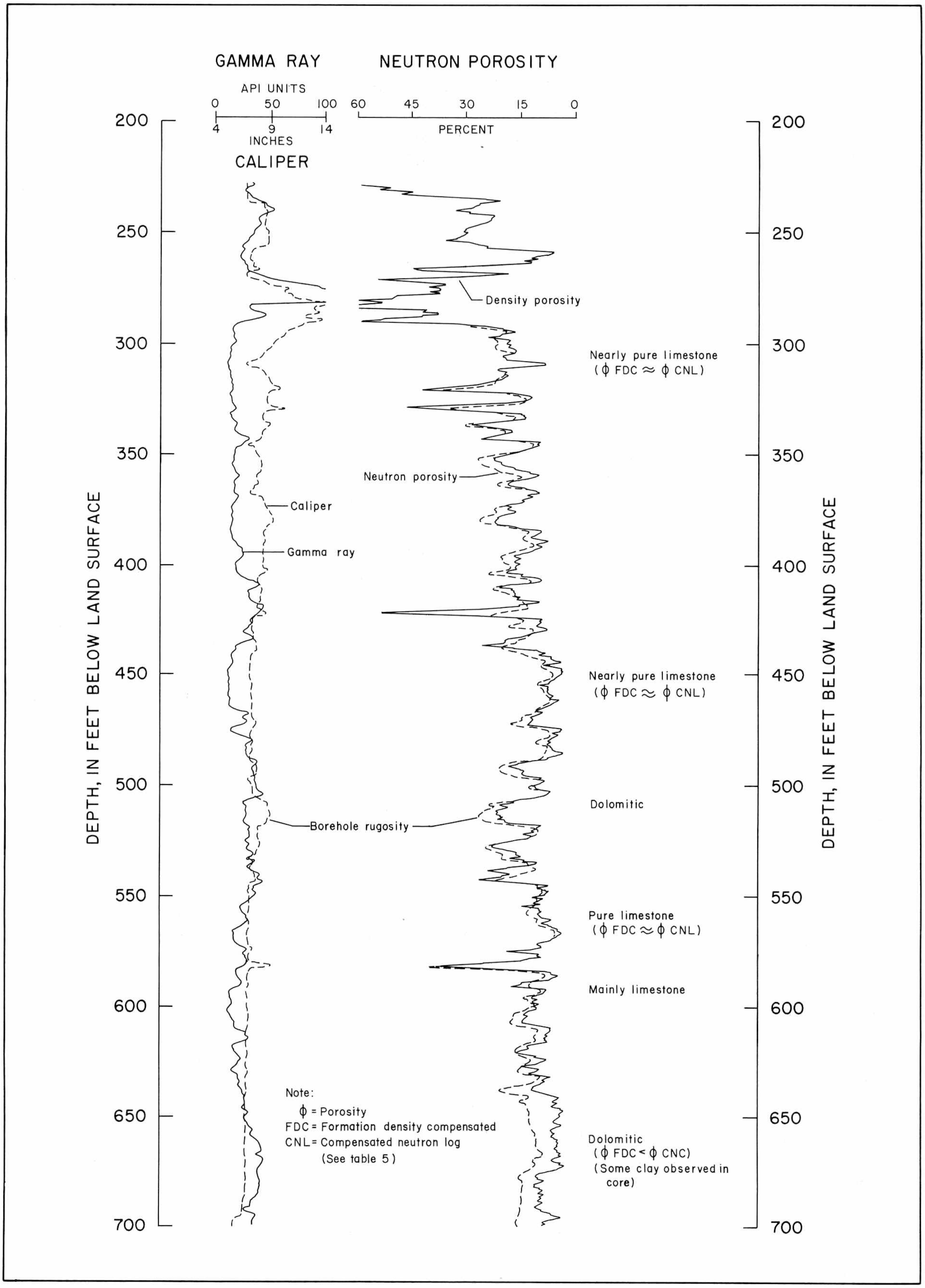


FIGURE 16.-Overlay of porosity logs calculated from density and neutron measurements in the Sabinal test hole (YP-69-37-402)

The porosity values determined from compensated neutron logs are slightly higher (0 to 3 limestone-porosity units) than those derived from density logs throughout most of the hole, which indicates that the rock is predominantly calcitic with only subordinate amounts of dolomite. This interpretation agrees well with information obtained from the cores.

The porosity values derived from density logs do not exceed the porosity values derived from neutron logs, which indicate that no chert beds of significant thickness were penetrated by the Sabinal test. The rocks below a depth of 636 feet are probably dolomitic and may contain some clay, as indicated by an increase in natural-gamma radiation.

COMPUTER-PROCESSED INTERPRETATIONS

Complex computer programs are available to produce quantitative interpretations of lithologic and porosity characteristics for every 0.5 foot of logged depth. These programs are based on a set of simultaneous equations that provide data on the mineralogic composition of the aquifer, total porosity, secondary porosity, and water quality. The computer programs that pertain to carbonate rocks were examined for general application to the Edwards aquifer.

The three-porosity method (Pirson, 1970) is used to determine lithology from the sonic, density, and neutron logs by the use of a computer. Each type of log has a unique response to a physical characteristic of the carbonate rock; therefore, rock composition can be determined by solving a set of simultaneous equations involving the log response.

An important preliminary step in the application of a computer interpretation is the editing and merging of log data. The suite of logs for a hole first needs to be adjusted so that the depths of all logs are referred to a common elevation. Then, the logs need to be edited to exclude intervals of spurious data, such as neutron responses in washout zones. The geophysical data is then digitized by machine, usually at 0.5-foot intervals, and calibrated into environmental units. After the logs have been edited and digitized, they are merged into a format that presents all calibrated geophysical readings. The set of simultaneous equations are solved by the computer by using the digitized data. The basic algorithm for solution used by the U.S. Geological Survey is described by Merkel and others (1976).

The computer program of the U.S. Geological Survey performed the following operations to estimate mineralogy and secondary porosity. First, the neutron and density logs were cross plotted to determine the relative percentages of dolomite, limestone, and sandstone or chert. Second, the mineralogic compositions were used to obtain a corrected porosity. Third, the matrix density of the rock saturated with freshwater was calculated by:

$$\rho_{ma} = (\rho_b - \emptyset)/(1-\emptyset) \tag{4}$$

(symbols have been previously defined). Fourth, this value of matrix density, ρ_{ma}, was used to obtain a value of matrix velocity from standard curves relating matrix density to matrix velocity (Schlumberger Limited, 1972, p. 16). Fifth, knowing the matrix velocity, porosity is estimated by $\Delta t_{log} = \emptyset\Delta t_{fluid} + (1-\emptyset)\Delta t_{matrix}$. Sixth, the secondary porosity is calculated as the difference between the mineralogically corrected porosity and the sonic-measured porosity. These calculations are adversely affected in zones where the rock is highly cavernous or where fractures are predominantly horizontal.

A computer-processed interpretation of an interval in the Randolph test hole (AY-68-30-807) is shown in figure 17. The computation indicates that the rock is predominantly dolomite from a depth of 800 to 807 feet and a limy dolomite from 826 to 840 feet. This interpretation agrees well with observations of the core samples. The computation indicates predominantly limestone with minor amounts of dolomite and sandstone or chert in the interval from 807 to 826 feet. The core samples indicate a predominantly clayey, dolomitic limestone of very low porosity. The application of the computer solution assumed the absence of clay, which resulted in an indication of the same porosity and a greater percentage of limestone than was observed. The interpretation of secondary porosity in the intervals above 807 feet and below 827 feet are in agreement with observations of the cores.

The CORIBAND method was applied to geophysical data from the Sabinal test hole. CORIBAND is a trade name used by Schlumberger to indicate a computer-derived solution of complex lithologies. The method takes into account the shaliness of the formation. The well logs used are the primary logs including neutron, density (gamma-gamma), sonic and supplemental logs including natural-gamma logs for evaluating clay content and caliper logs for determining the rugosity of the borehole.

An example of the use of the CORIBAND method in the Sabinal test hole is shown in figure 18. The solution indicates that the rock is limestone, with a minor amount of clay fairly well distributed throughout the section. The core samples indicated that the rock was predominantly limestone with chert throughout much of the section except in the lower part where the rocks are shaly and dolomitic. The occurrence of secondary porosity also was observed in the core samples.

A graphical presentation of the lithology and porosity as determined by computer methods for the San Marcos test hole is shown in figure 19. This display shows that the aquifer consists of dolomite, limestone, chert, and shale. The porosity is predominantly primary, but vuggy porosity occurs at scattered depths from 220-230, 330-345, and 382-386 feet, which agrees well with observations of the cores. The distribution and relative percentage of limestone and dolomite agree in general with observations of the cores, but the display overestimates the amount of shale or clay. The graphical display of the 20-foot zone from 250-270 feet indicates a nonporous, cherty, limy clay. The core from this zone is a dense, clayey limestone without chert. The discrepancy results from inaccurate calibration of the natural-gamma log in terms of clay content.

These examples of computer-processed interpretation indicated a need for prior geologic knowledge of the area to determine the lithology accurately by computation; however, they also indicate that much quantitative data may be derived from this type of analysis.

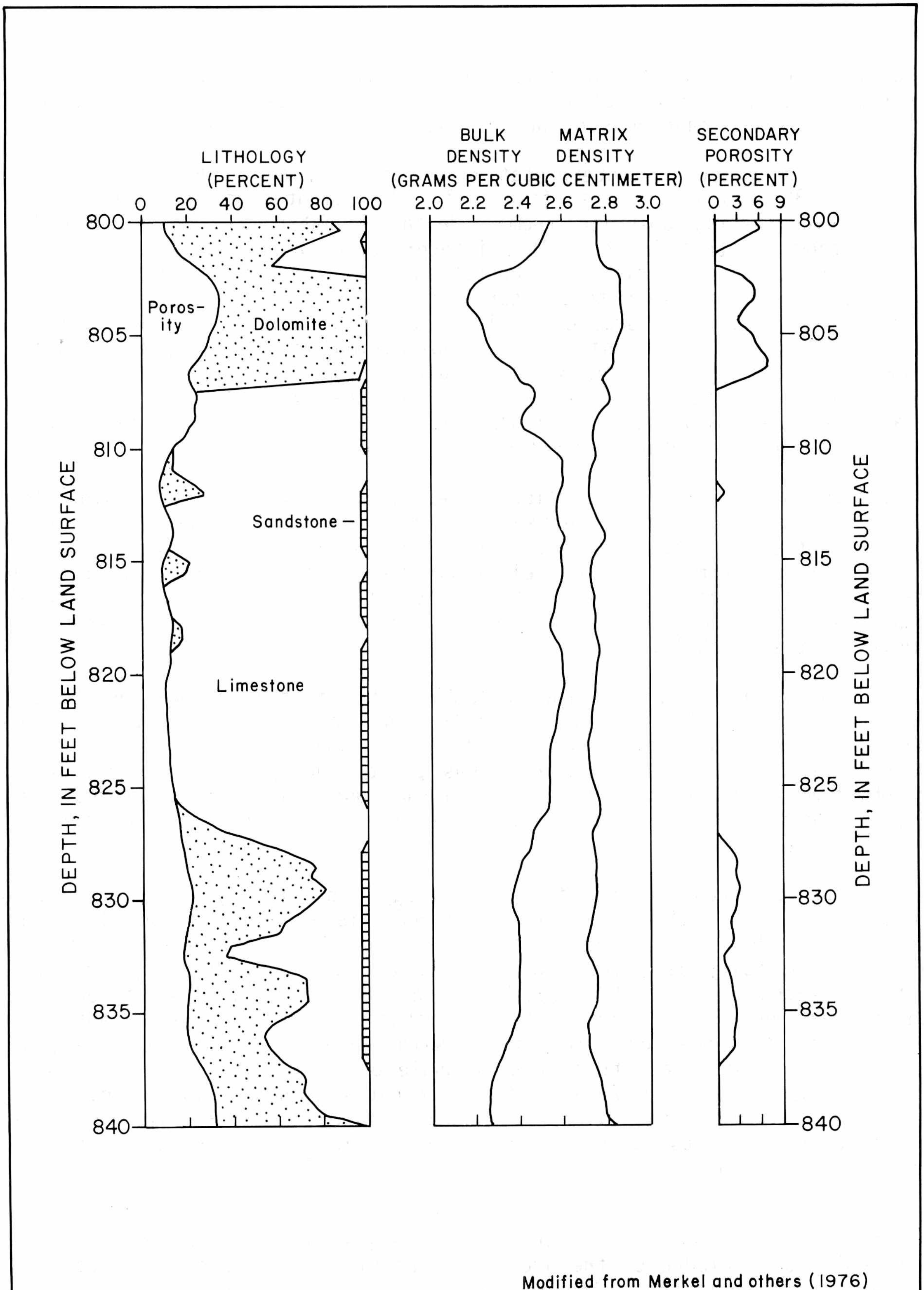


FIGURE 17.-Computer-processed interpretation of an interval in the Randolph test hole (AY-68-30-807)

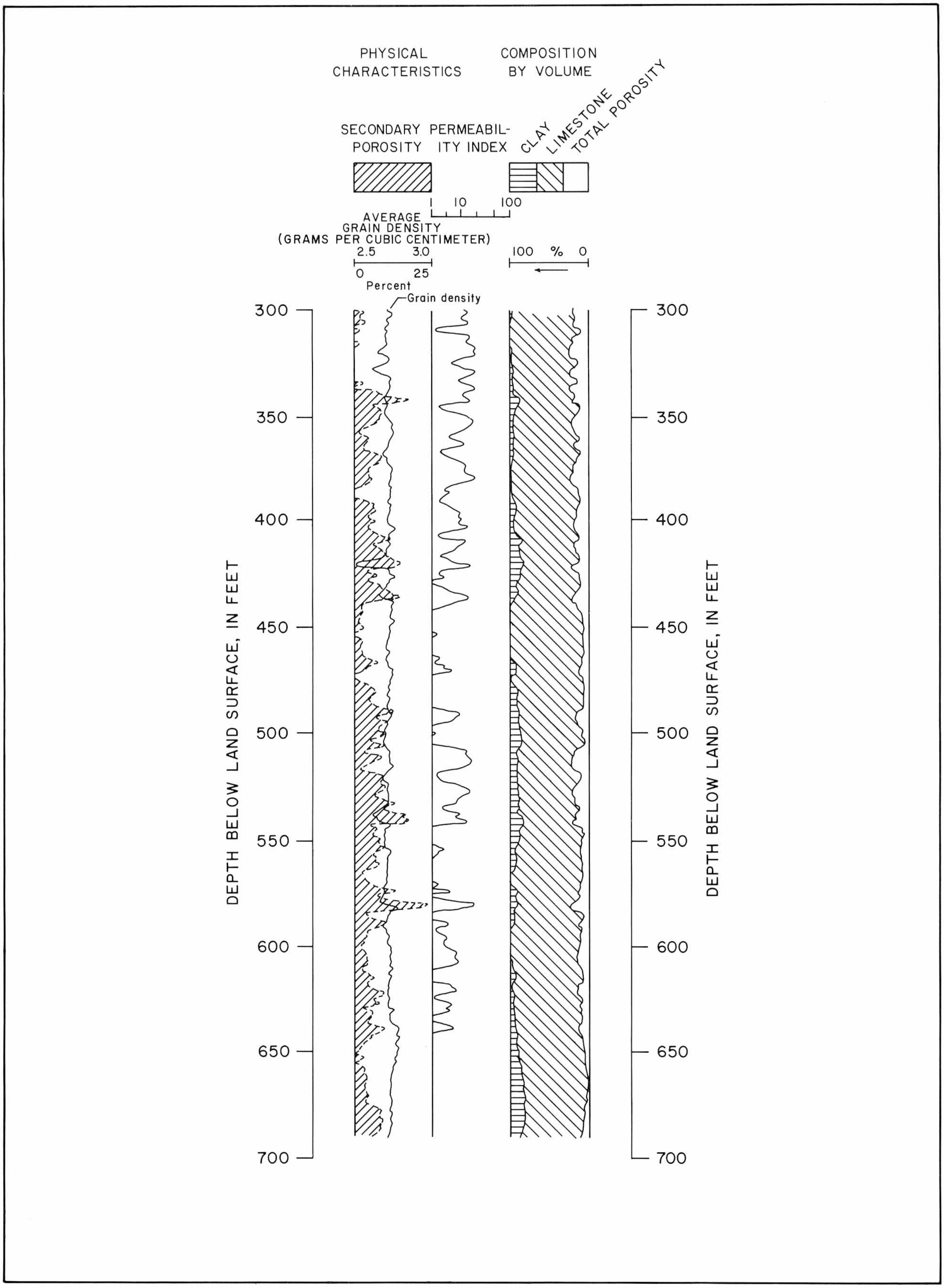


FIGURE 18.-Calculated total porosity, secondary porosity, grain density, and mineralogy for the Sabinal test hole (YP-69-37-402)

P42-44

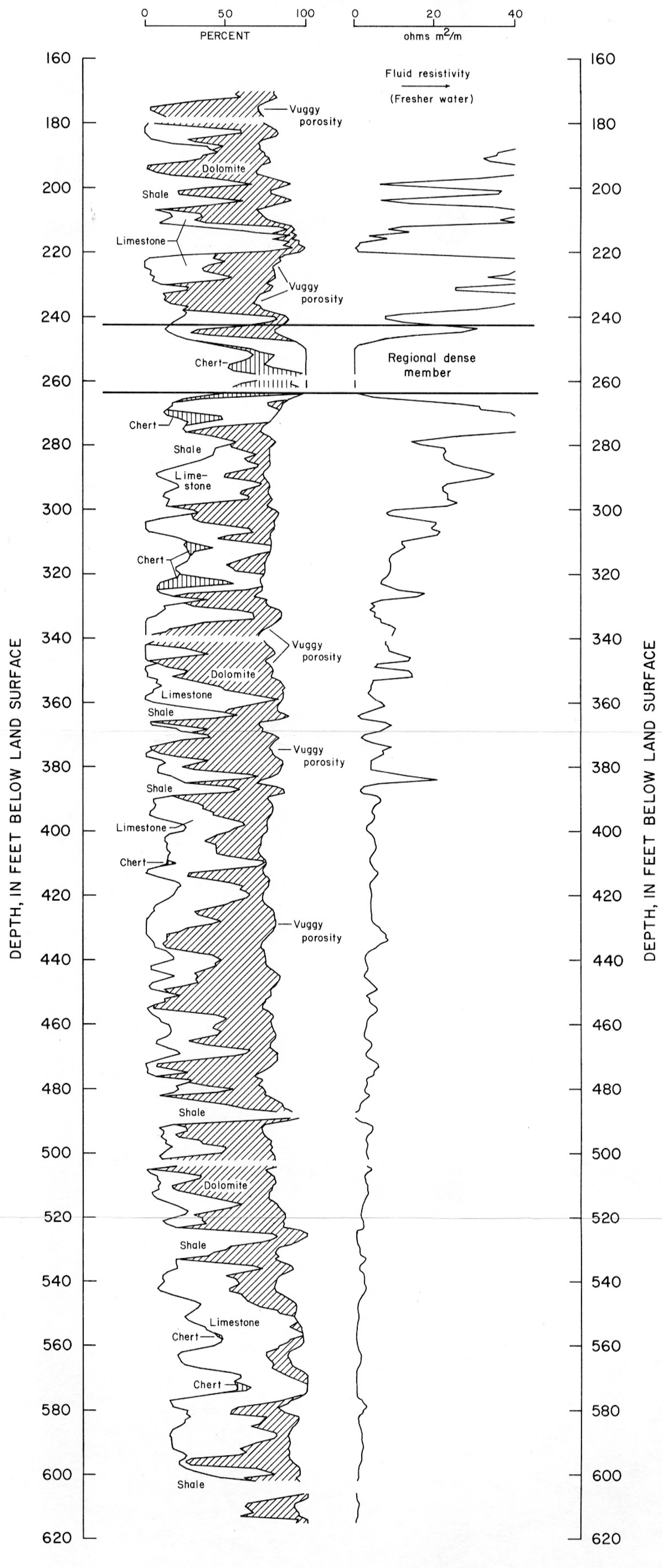


FIGURE 19.-Calculated primary and vuggy porosity, mineralogy, and apparent water resistivity for the San Marcos test hole (LR-67-09-110)

TRACER STUDIES

Tracer studies, utilizing Rhodamine WT dye as a tracer, were used to investigate the hydrogeologic characteristics of the aquifer by use of the tracer-dilution, single-well pulse, and transit-time methods. These tests are summarized in table 6, and other miscellaneous tests are summarized in table 7.

Tracer-Dilution Tests

The tracer-dilution method was used for borehole investigations in which aquifer tests could not be performed easily. In this method, a tracer is introduced into a well so that water moving horizontally through the penetrated section diminishes the concentration of the tracer with time. If all tracer-dilution is caused by water flowing through the well cross section, the apparent ground-water velocity (filtration or Darcian velocity) can be calculated from measurements of tracer-concentrations at various times after injection. The filtration velocity is defined as the relation between ground-water flow and the cross section of the aquifer (Drost and others, 1968; Lewis and others, 1966). Interstitial velocity is the velocity of a particle of the tracer that moves through the interconnected voids in the rock.

The apparent ground-water velocity and filtration velocity, is expressed by:

$$V = Q/A \qquad (5)$$

where V = apparent ground-water velocity,
Q = ground-water velocity, and
A = gross area of the cross section of flow.

The dilution equation for a circular borehole (Lewis and others, 1966) is:

$$V = [(\pi\ (1/2)\ d)/4t]\ \ln Co/C \qquad (6)$$

where V = apparent ground-water velocity,
Co = initial tracer concentration at time t,
C = tracer concentration at time t, and
d = borehole diameter.

Three conditions must exist before the tracer-dilution equations can be applied to calculate reliable estimates of apparent ground-water velocity. They are: Steady-state conditions; uniform ground-water flow and tracer distribution; and tracer-concentration diminution with time resulting from horizontal ground-water flow. Three sources of error are possible in the tracer-dilution method. First, if vertical movement is present in a well, the increased rate of dilution would give too high a value for the apparent ground-water velocity. Second, any mixing of water from within the well with formation water in the aquifer during sampling of the well causes increased rates of tracer dilution. Third, if the effective well diameter is greater than the borehole diameter, the calculated apparent velocity will be less than the actual ground-water flow.

The advantages of the borehole method are: (1) The filtration ground-water velocity can be determined without knowing the effective pore volume; (2) if Darcy's law is assumed to be valid for field conditions, the hydraulic conductivity can be calculated by using the hydraulic gradient

$$K = V_f/(dh/dl) \qquad (7)$$

where K = hydraulic conductivity,
V_f = filtration velocity, and
dh/dl = hydraulic gradient;

(3) dilution measurements are made in a single borehole; (4) the apparent ground-water velocity for any stratum in the vertical profile of the aquifer can be determined; and (5) apparent velocities ranging from a fraction of an inch per day to several hundred feet per day can be determined by the tracer-dilution method.

Rhodamine WT dye was used as the tracer for determining the ground-water velocity in the Edwards aquifer. The dye was injected by using compressed air to force the solution through a tube while the end of the tube was moved through the well. The well was sampled by moving a sampler (a 1-foot long, 0.75-inch diameter pipe sealed at both ends, but having two small ports on the side) through the well bore at a nearly uniform rate.

Tracer-dilution tests were made in five wells completed in the unconfined part of the aquifer. The test in the well at Topperwein Store (AY-68-27-505) was conducted on March 3, 1971. The well was injected with 60 milliliters of Rhodamine WT dye at 20-percent concentration placed uniformly in the well from the static water level at 259 feet below land surface to a depth of 400 feet at 0900 hours. Sampling was begun 4.5 hours later when a concentration of 6,580 μg/L (micrograms per liter) was determined by fluorometer measurements. The concentration decreased exponentially with time, and at 121 hours after injection the reading was 42 μg/L.

The plot of the logarithm of dye concentration versus time is shown in figure 20. A well located 91 feet from the dyed well was pumped at 8.5 gal/min from 0900 until 2000 hours on March 3, 1971. The results of the test indicated that the steady-state assumption was not significantly violated to affect the flow near the dye-injected well. A filtration velocity of 0.0048 foot per hour or 0.235 foot per day was calculated. Using the relationship $V_f = K/I$ and assuming a value of 10 feet per mile for the hydraulic gradient I, the hydraulic conductivity K is calculated to be approximately 150 feet per day, or in terms of the field coefficient of permeability, approximately 0.764 (gal/min)/ft.

The test at C. B. Peters (AY-68-28-102) was made in a 7-inch-diameter well 440 feet deep that penetrated 400 feet of the Edwards aquifer. The tested zone extended from the water table at 206 feet below land surface to a depth of 246 feet, where an obstruction occurs in the well. The zone is in the middle part of the Edwards. The test was started at 1100 hours on November 14, 1970, when about 10 milliliters of Rhodamine WT dye at 20-percent concentration was injected into the 40-foot section. To mix the dye in the borehole, carbon dioxide gas was injected for 15 minutes. Sampling was begun at 1145

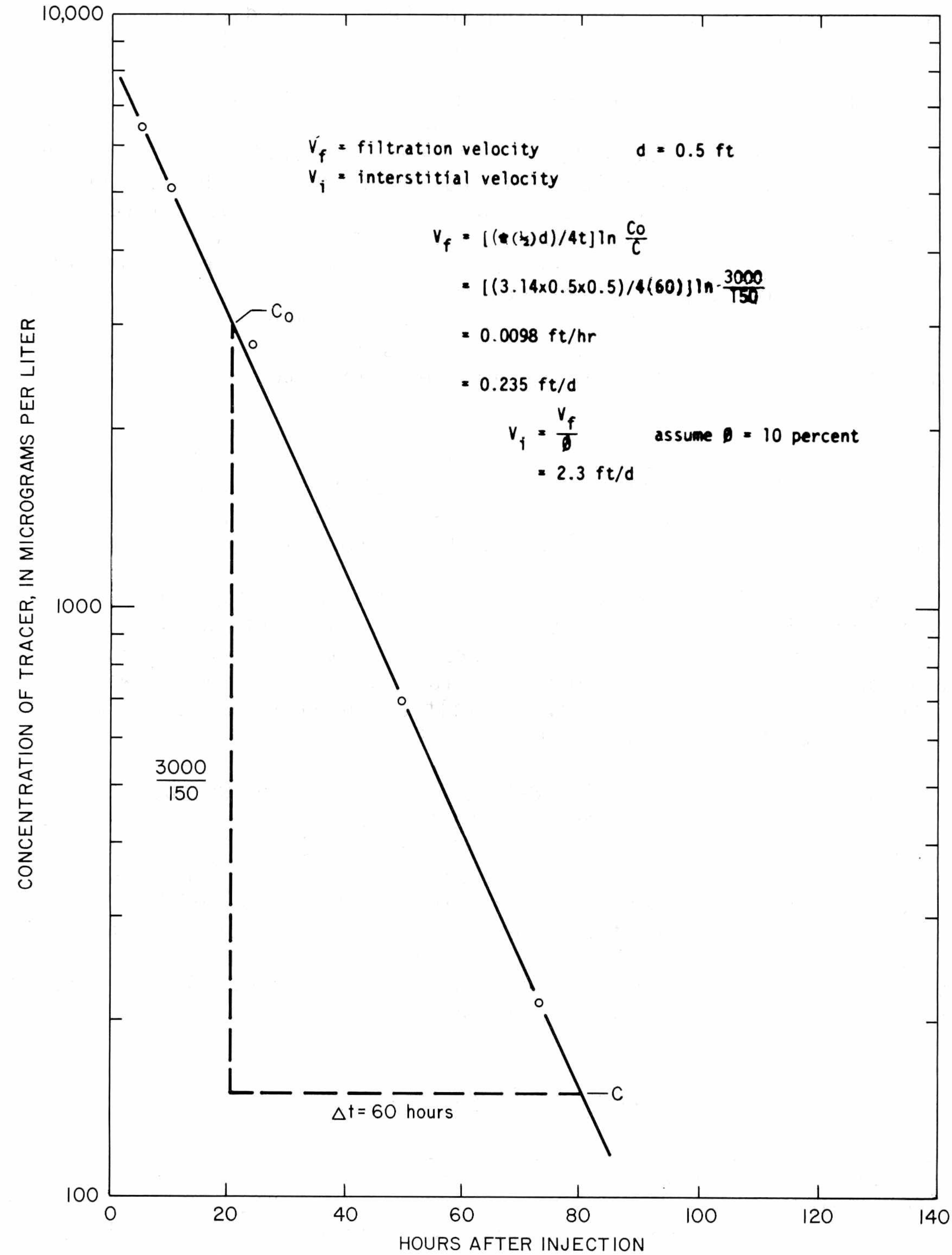


FIGURE 20.-Tracer-dilution test in well AY-68-27-505

hours and terminated at 1515 hours on November 16, 1970. No pumping of nearby wells is known to have occurred during the test. The data plot is shown in figure 21; the filtration velocity is calculated to be 0.196 foot per day.

The tests at Lockhill Cemetery in well AY-68-28-801 were made by both the tracer-dilution and single-well pulse methods. The single-well pulse test will be discussed later. The well is 5 inches in diameter and 397 feet deep. The depth of water on November 12, 1970, was about 302 feet below land surface. The upper part of the Edwards aquifer was tested at the pump intake at about 370 feet below surface. The well was injected with 5 milliliters of 20-percent solution of Rhodamine WT dye at 2445 hours, and samples were collected during about 70 hours. The samples were obtained by pumping the well for 1 minute because it was not possible to obtain a sample by lowering a sampler into the well. The data plotted as a straight line on semilog paper for about 25 hours and then flattened (fig. 22), which could be interpreted as decay of the background concentration.

The assumption of steady-state conditions and no vertical movement of water was violated by pumping the well to obtain the sample; however, the duration of pumping was short in comparison to the sampling-interval time. The filtration velocity was calculated at 0.37 foot per day.

The test at well AY-68-27-5 was made in a 6-inch-diameter well having a total depth of 352 feet. The water level was 206 feet below land surface. The well was injected with 10 milliliters of Rhodamine WT dye at 20-percent concentration at 1130 hours on December 10, 1970, and samples were obtained intermittently for about 40 hours. A filtration velocity of 0.58 foot per day was determined by using the early data (fig. 23).

The test at Hill Country (AY-68-29-103) was made on October 26, 1970, in a well 7.9 inches in diameter and 547 feet deep. The Edwards Group of Rose (1972) crops out at the surface, and its lower boundary is 400 feet below land surface at the well site. The well was injected with 95 milliliters of Rhodamine WT dye at 20-percent concentration in the interval 267-320$\pm$ feet below land surface. The water in the interval was stirred for 30 minutes before sampling was begun, and samples were obtained intermittently for 165 hours. The data plotted as a straight line on semilog paper (fig. 24), and the calculated filtration velocity was 0.17 foot per day.

Single-Well Pulse Tests

The single-well pulse technique also can be applied in a single well to determine natural ground-water velocity if the porosity and aquifer thickness are known. Briefly, the method is as follows: (1) Placing a tracer in the borehole; (2) injecting the traced water with additional water placed in the borehole--this additional water forces the dyed water into the formation; (3) allowing an interval of time, T, for the dye to move away from the well before pumping; and (4) pumping the well at a known rate and sampling the pumped water for dye concentration. Suppose that the dyed water is injected into a well bore and that this water is then removed from the borehole by ground-water flow. If there were no dispersions of the tracer, it would be found after time, T, at a distance, r, from the borehole. On starting to

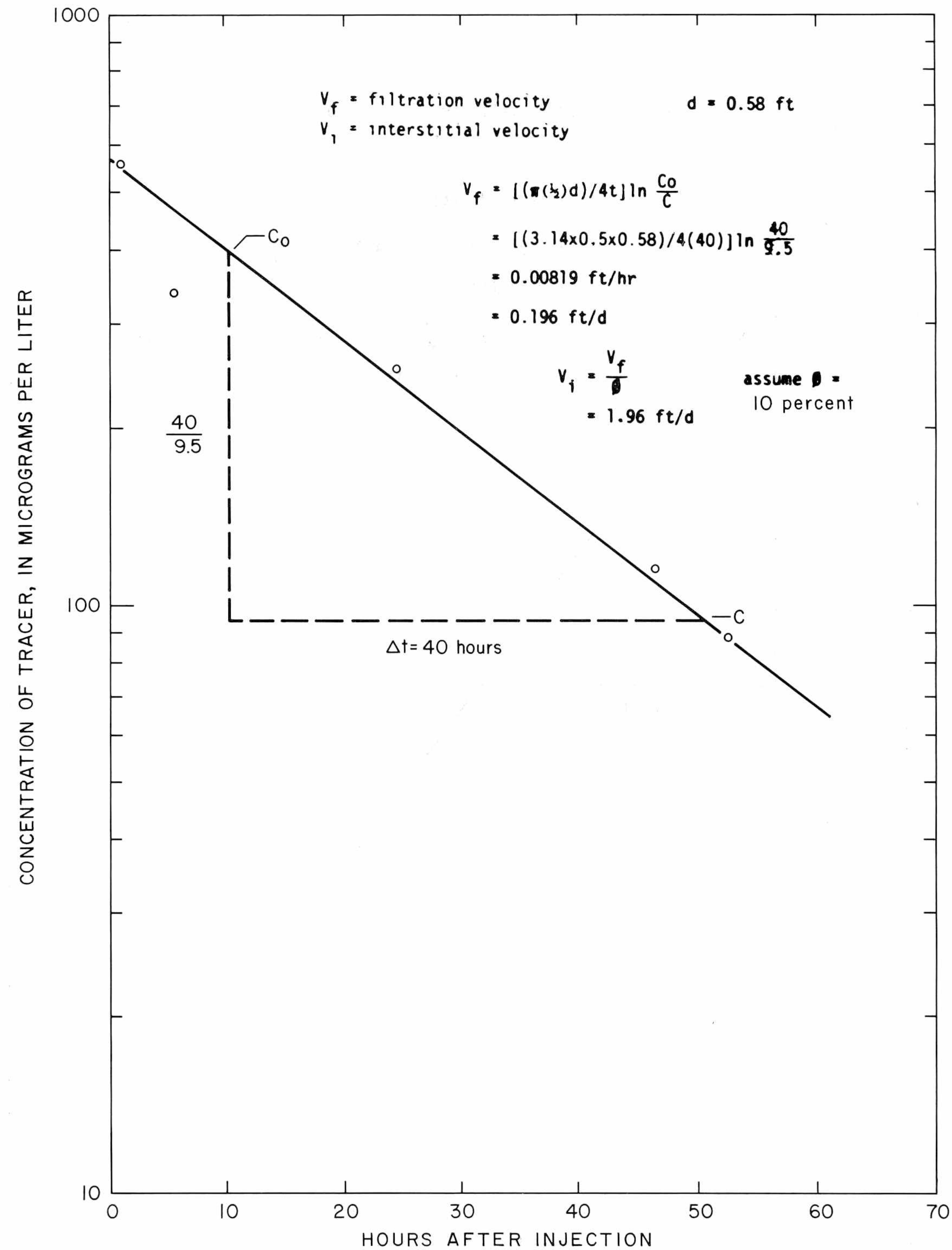


FIGURE 21.-Tracer-dilution test in well AY-68-28-102

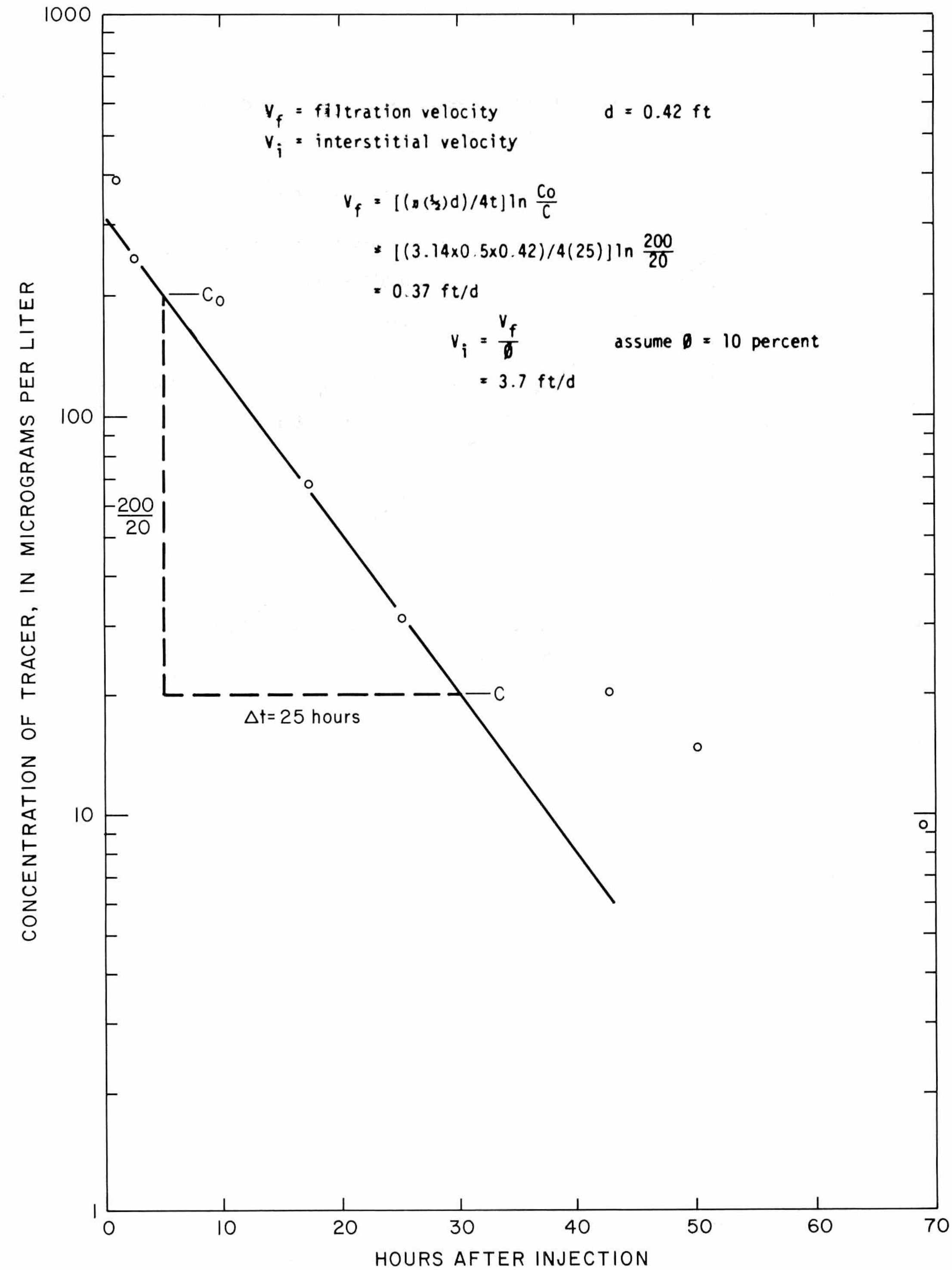


FIGURE 22.-Tracer-dilution test in well AY-68-28-801

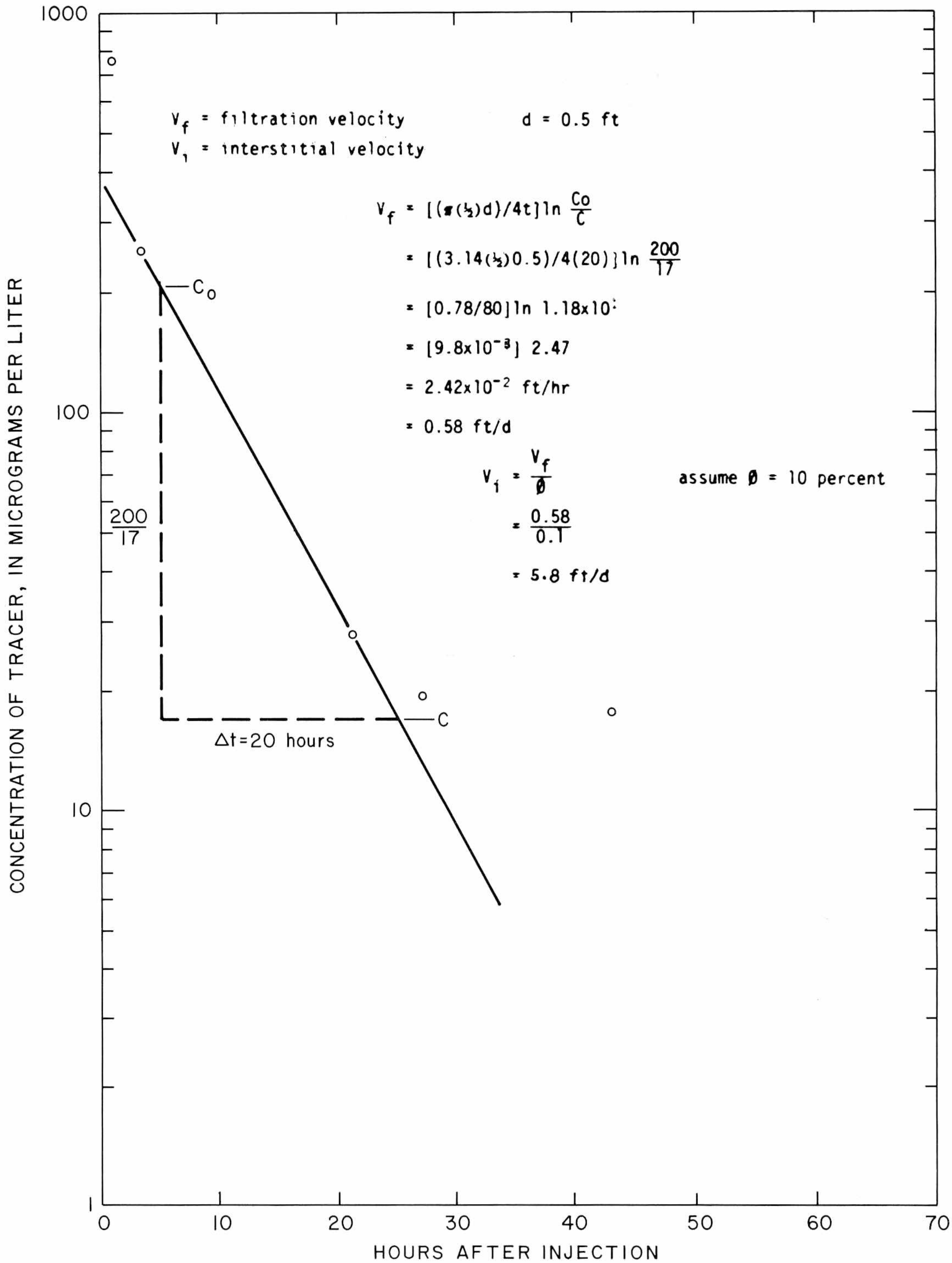


FIGURE 23.-Tracer-dilution test in well AY-68-27-5

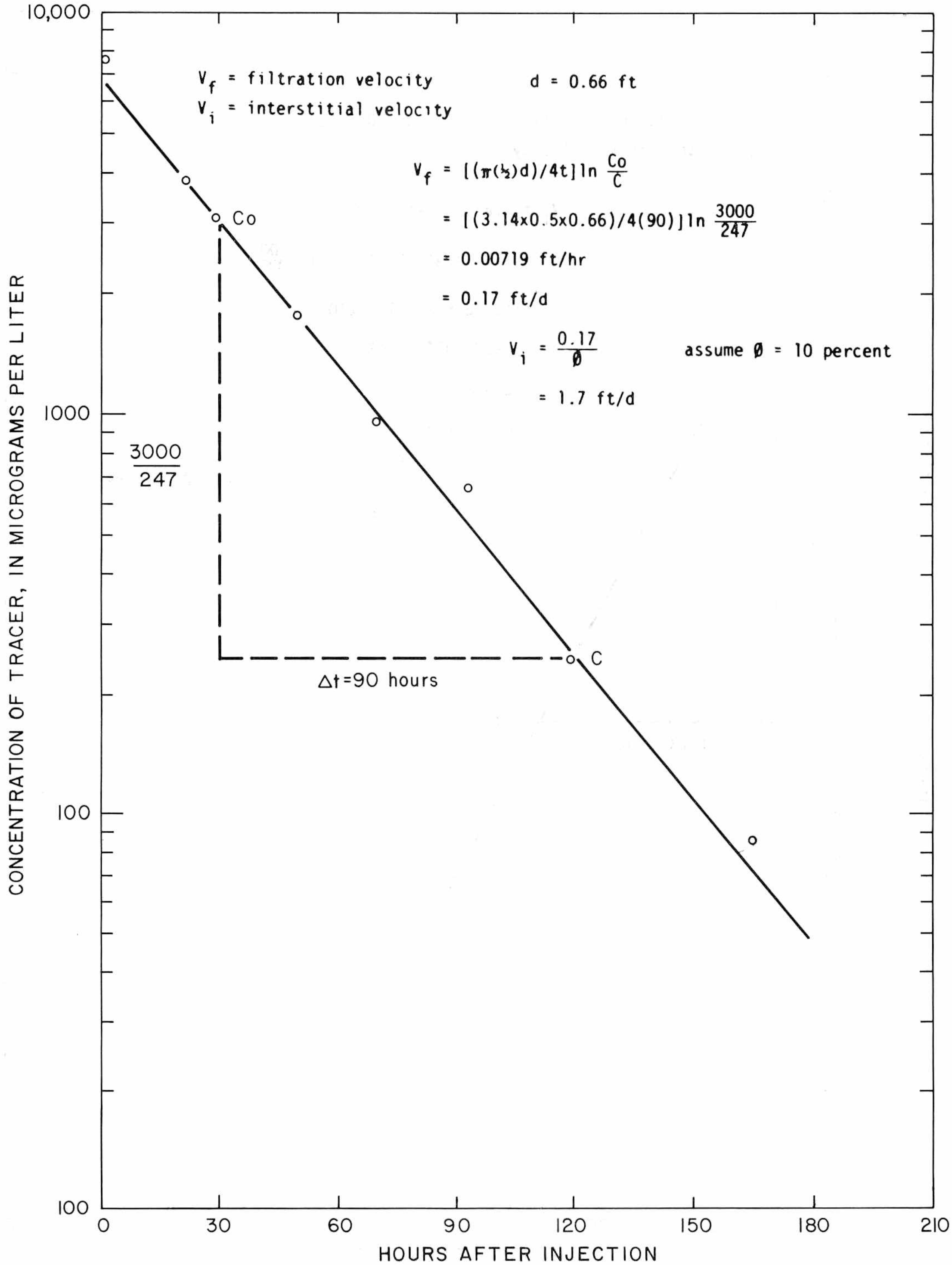


FIGURE 24.-Tracer-dilution test in well AY-68-29-103

pump the injection well at time, T, it is possible to find r from the following relation, which is valid for cylindrical symmetry of pumping and a fully penetrating borehole (Borowczyk and others, 1967):

$$Qt = \pi r^2 h \emptyset \tag{8}$$

where Q = constant pumping rate,
t = arrival time of the tracer at the injection well,
r = distance that dye cloud has traveled during the pause time, T,
h = thickness of the aquifer, and
$\emptyset$ = effective porosity.

For a partly penetrating borehole, the following conditions must be fulfilled:

$$r \ll h.$$

The velocity of ground-water flow can be found from

$$V_i = r/t$$

where V_i = ground-water velocity.

A problem in the interpretation is concerned with the estimation of the transit time (t) of the tracer by which (r) can be calculated. Because of the dispersion of the tracer and the radial symmetry of pumping, the peak of the tracer concentration in pumped water does not represent the actual transit time. The determination of the transit time from 50 percent of recovery of the recovered amount of injected tracer is used for interpretations (Borowczyk and others, 1967) provided that the diameter of the injected body is considerably less than the distance traveled by the injected body during the pause time, T. This method is described in detail by Borowczyk and others (1967).

The method, as described, assumes a one-layer aquifer of uniform hydraulic conductivity. If more than one layer occurs and each has a different hydraulic conductivity, problems in interpretations result. By waiting different pause times, T, it is possible in some instances to obtain estimates in the separate layers (Borowczyk and others, 1967).

A test on Wurzbach well no. 1 (AY-68-36-102) yielded data that could be analyzed to estimate ground-water velocity (fig. 25). The test on November 18, 1970, consisted of injecting 40 milliliters of 20-percent Rhodamine WT followed by water injected into the well at 110 gal/min for several hours. The pause time before pump back was 5 hours. Total amount of dye recovered was 0.85 milliliter. The distance the dye center, at 50-percent concentration of the recovered amount, moved during the pause time of 5 hours was 6.6 feet when the aquifer thickness was assumed to be 500 feet and the porosity 10 percent, respectively. The ground-water velocity was calculated to be 1.3 feet per hour. The data plot (fig. 25) of this test shows considerable variation in early reading, which is interpreted as a result of residual dye in the vicinity of the well bore. The condition of r<<h was satisfied since 6.6<<500.

The pulse test on November 19, 1970, at Lockhill Cemetery (AY-68-28-801) was made in a 5-inch-diameter well 397 feet deep in which the water level was 302 feet below the land surface (fig. 26). The full thickness of the Edwards

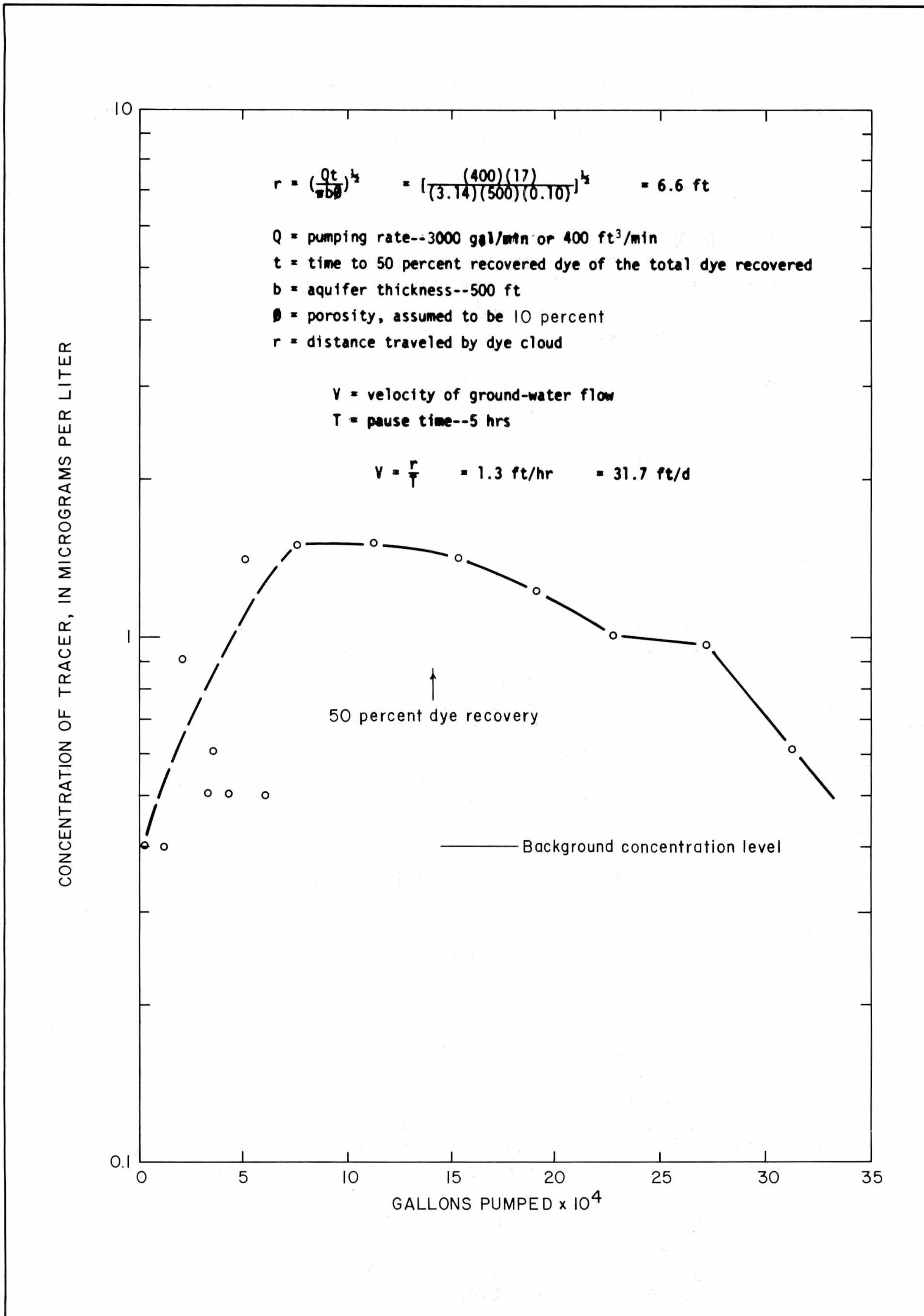


FIGURE 25.-Single-well pulse test in well AY-68-36-102

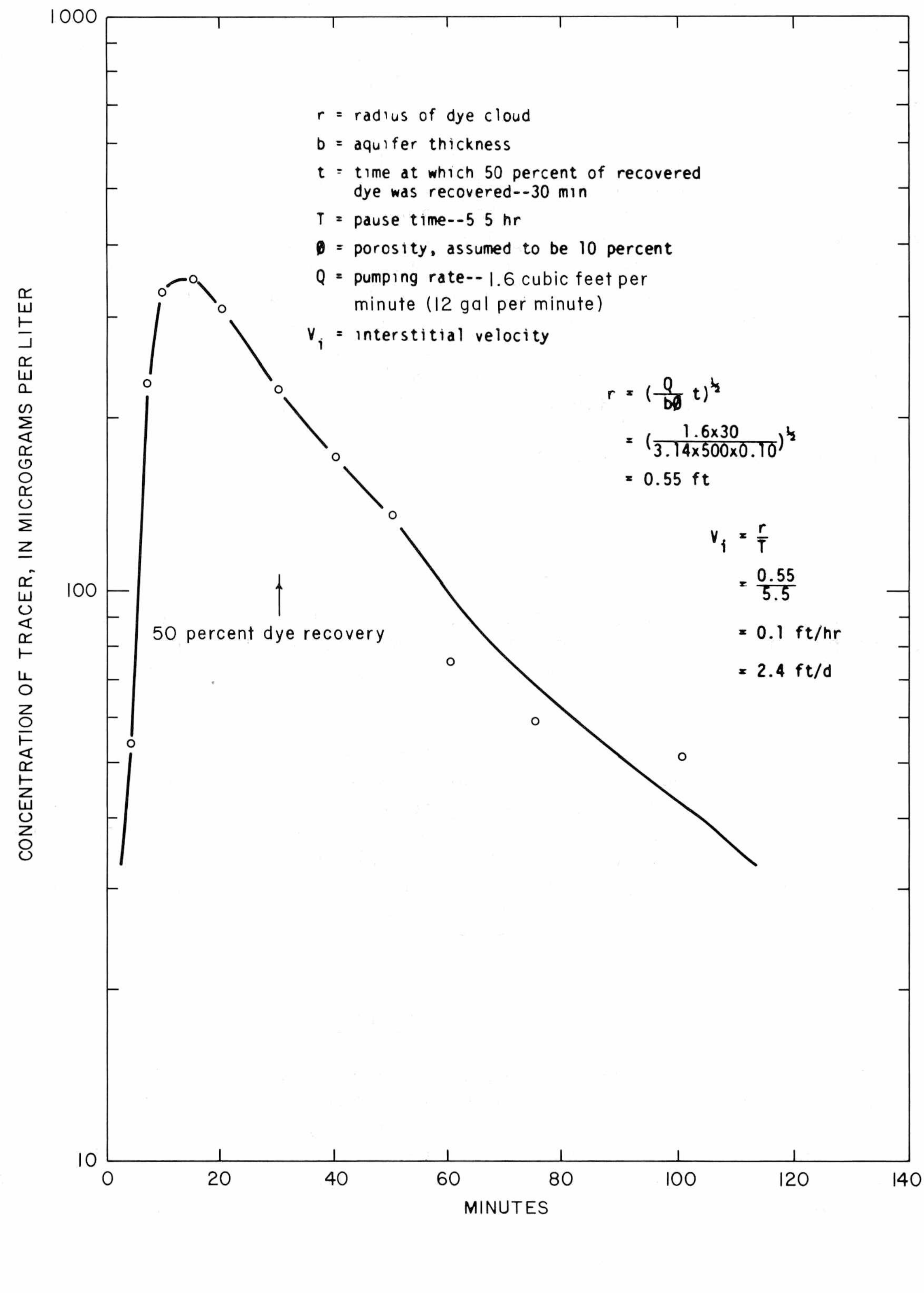


FIGURE 26.-Single-well pulse test in well AY-68-28-801

aquifer was not penetrated. The condition of partial penetration is not believed to negate the results of the test because r<<h, where h is the thickness of the aquifer (Borowczyk and others, 1967). Assuming a porosity of 10 percent and aquifer thickness of 500 feet, the interstitial ground-water velocity is 2.4 feet per day.

The pulse test during February 1971 at the farm of Elmer Pape (AY-68-30-107) was originally planned as a two-well test (fig. 27). However, the dye was never detected in a well 2,600 feet away before pumping was started in the injected well for irrigation. A pulse-test analysis was then used to utilize the information that had been collected. The 12-inch-diameter well was recently drilled to a depth of 591 feet. The top of the Edwards was at 465 feet. One thousand milliliters of 20-percent Rhodamine WT dye was injected at 480 feet below land surface. About 2,400 gallons of water were then poured into the well after injection. The pause time was 13 days before pumping began. The well was pumped 13 hours each day at a rate of 1,730 gal/min or an average daily rate of approximately 900 gal/min. Assuming a 10-percent porosity and an aquifer thickness of 500 feet, the interstitial velocity was 4.6 feet per day.

Transit-Time Tests

The transit-time method, which requires the use of two wells, can be used to determine the effective porosity of the aquifer within the influence of the well. The principle upon which the method is based is described by Halevy and Nir (1962).

In the test at Wurzbach station (AY-68-36-102), the injection well was 790 feet from the pumped well. The concentration plotted against accumulated discharge for the test is shown in figure 28. The centroid of the curve of pumpage versus concentration was calculated within 46 hours after injection. The interstitial velocity was calculated at 141 feet per day within the influence of well no. 1 pumping at an average rate of 3,300 gal/min. The percentage of the injected dye recovered at the well was about 10 percent. The porosity determined from this test was less than 1 percent.

Salt-Dilution Tests

Salt-dilution tests are conducted to investigate vertical flow within a borehole and to identify zones of water movement. The procedure is as follows: First, a bag of salt (sodium chloride) is quickly lowered through a saturated section of the borehole; second, a fluid-resistivity log is made immediately after the injection of the salt; and third, fluid-resistivity logs are made at several time intervals to measure the decrease in the concentration of salt.

The results of selected salt-dilution tests are shown in figure 29. These tests indicate that vertical movement occurs within some boreholes and that the aquifer contains zones of water movement that are related to the geology.

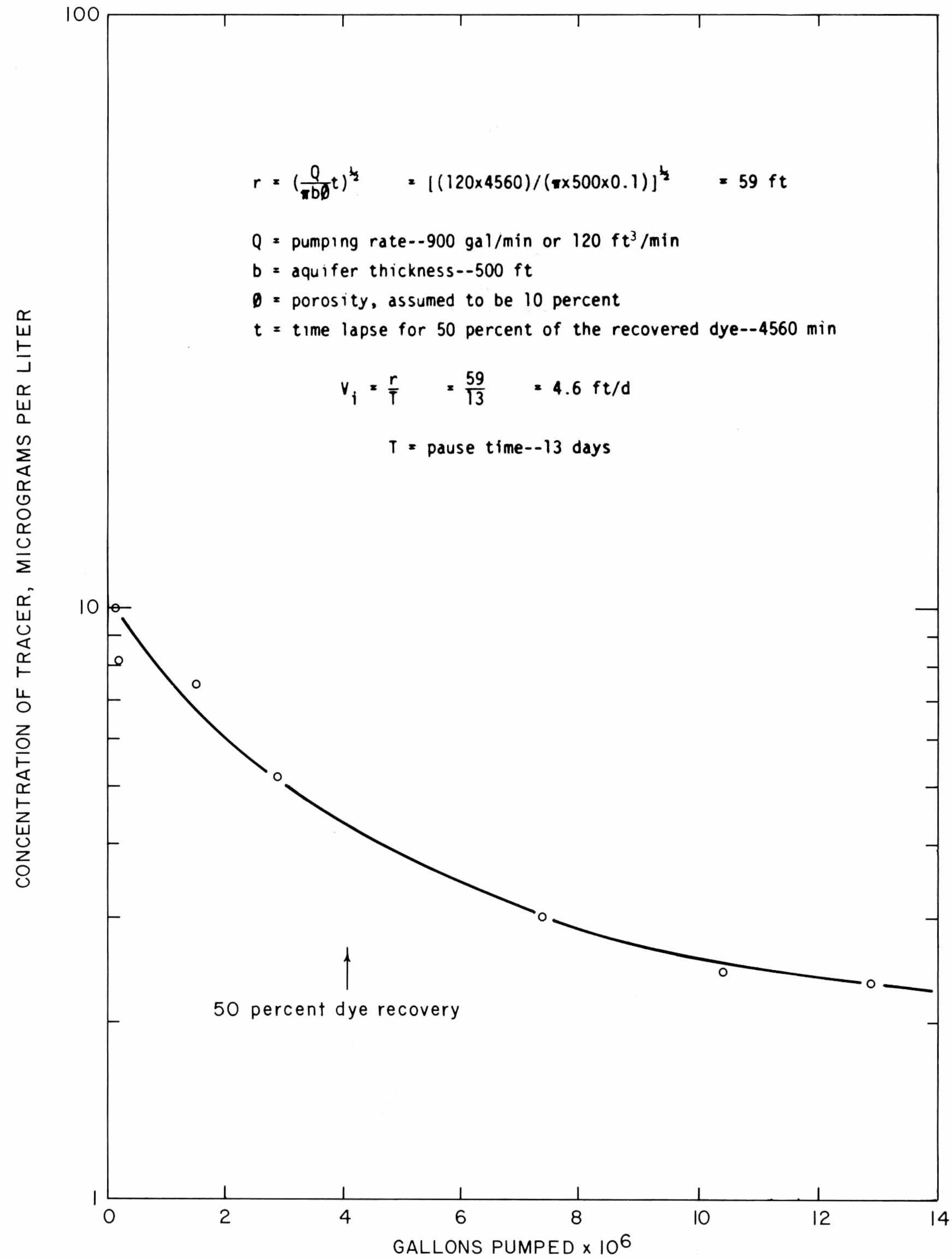


FIGURE 27.-Single-well pulse test in well AY-68-30-107

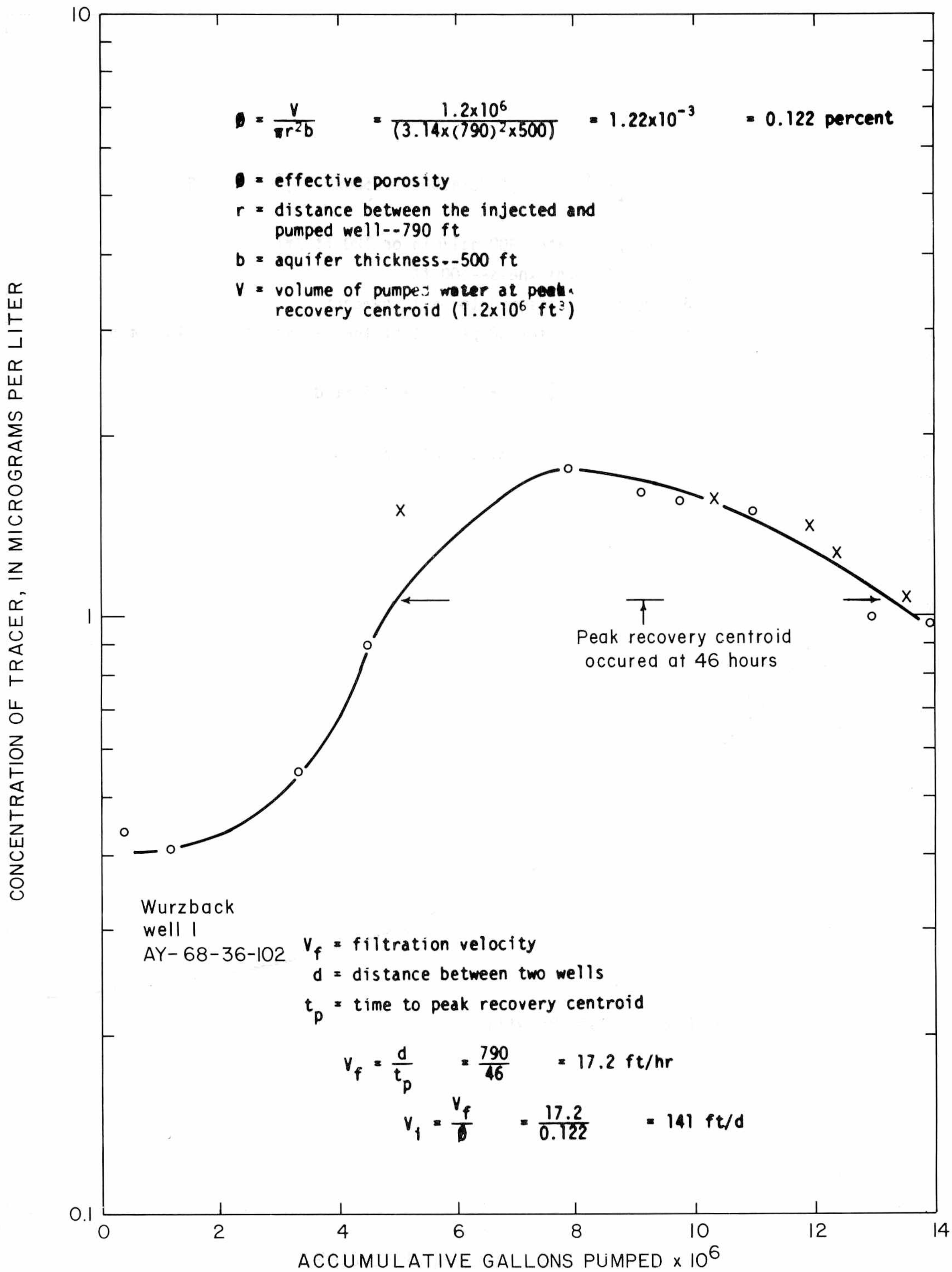


FIGURE 28.-Transit-time test of tracer between two wells at Wurzback station

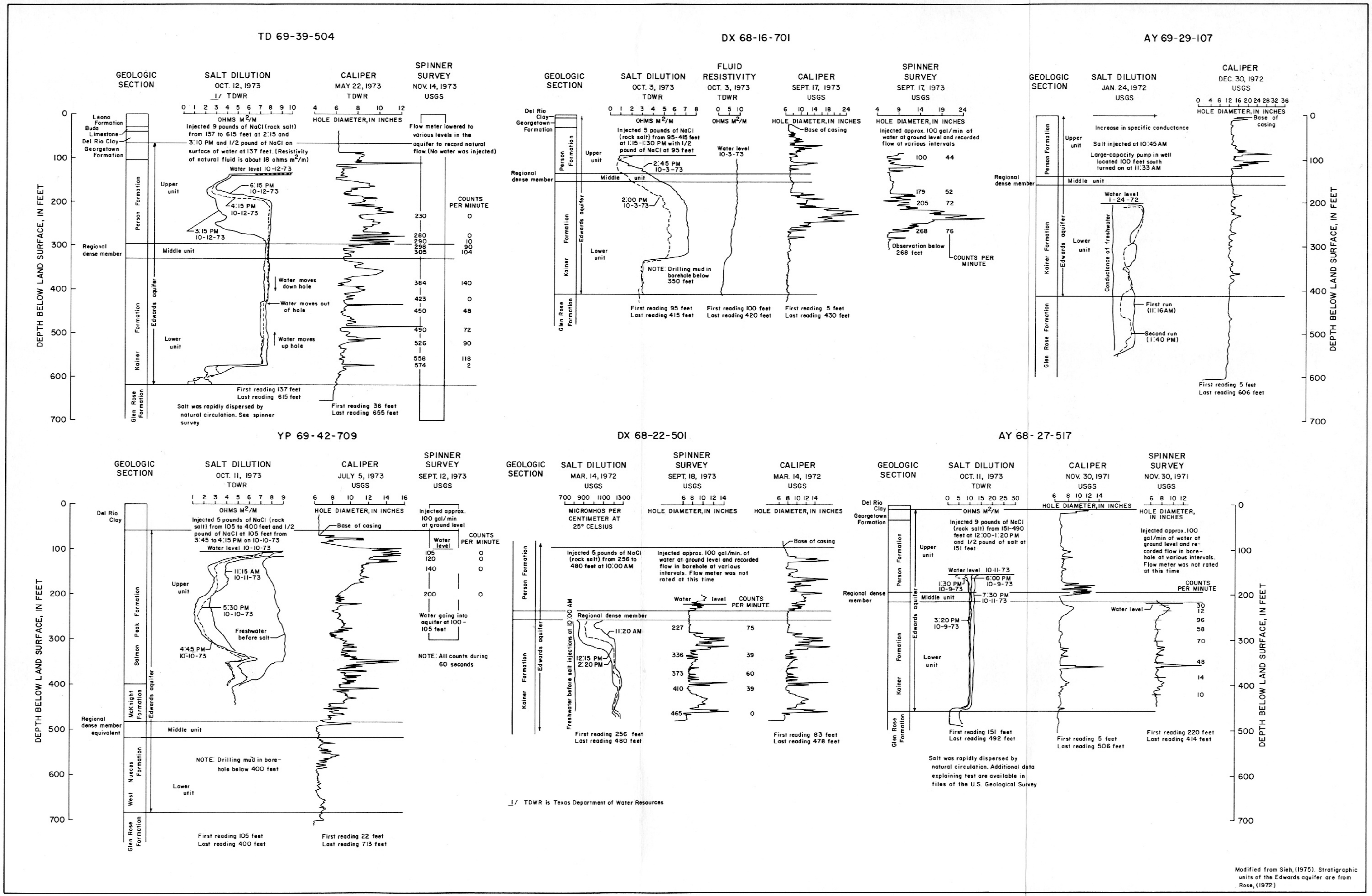


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FIGURE 29.-Logs showing salt-dilution tests in selected wells

The salt-dilution tests were conducted at the time when logging equipment became available to the project. Tracer-dilution tests explained previously were made at the beginning of the project studies. At that time, the logging equipment was not available. The purpose of salt-dilution tests was to investigate the assumption that no vertical flow occurs within the borehole, which is a necessary assumption for the determination of hydraulic conductivity from the tracer-dilution data.

PACKER TESTS

Packer tests are conducted to determine the relative permeabilities of different zones within the aquifer. The tests were conducted by setting inflatable packers at selected points to straddle the zone being investigated. Subsequently, a submersible pump was used to pump water at a constant rate from the straddled zone and the drawdown in water levels were measured.

The results of the packer tests conducted in the Castle Hills test hole, AY-68-28-910, are shown in figure 30. The hole was tested without prior acidization or developmental pumping. The results could change significantly if the well were developed.

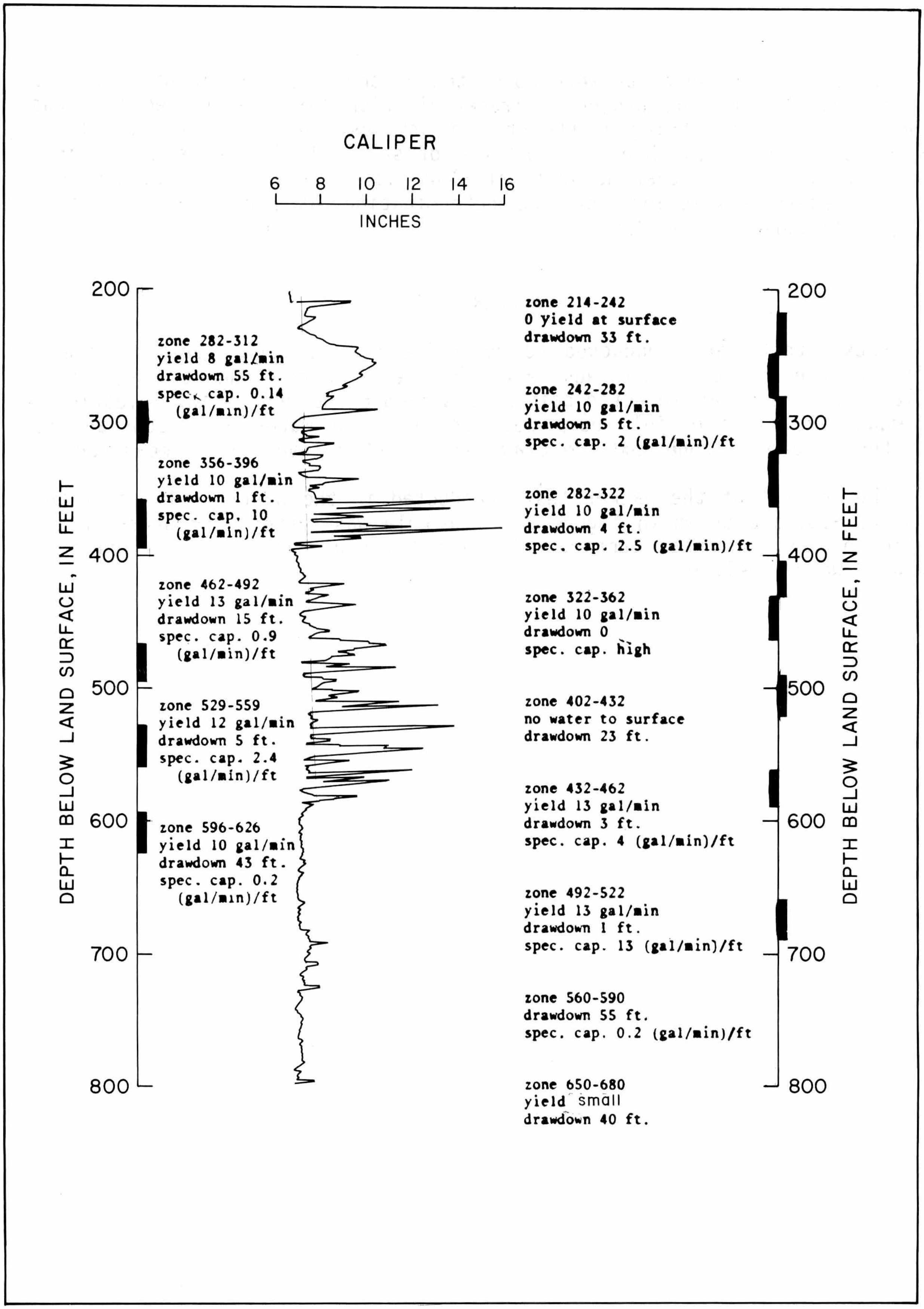

FIGURE 30.-Log showing packer test in the Castle Hills test hole (AY-68-28-910)

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Table 1.--Types of geophysical logs available for wells in the San Antonio area

State well no. 1/	Logged interval (feet)	Log types: Neutron	Gamma-gamma	Gamma	Sonic	Electrical logs: Long-normal	Short-normal	SP	Point resistivity	Lateral	Caliper	Fluid conductivity	Fluid temperature	Other	Other well identification
								BEXAR COUNTY							
AY-68-19-9__	265-520					X		X							
19or20	0-550					X	X	300-550			Micro				Camp Stanley well #11
19or20	290-560					X	X	X			Micro				Camp Stanley well #10
19or20	300-546					X	X	X			X				Camp Stanley well #9
21-4__	0-792			X	X	X		X	X	X	X	X	X		TWDB log
4__	0-1110			X											
5__	0-583			X				X	X		X				MBC Engr. north well
9__	0-560	X	X	X		X	X	X			X				Metcalf & Eddy TW32
22-7__	0-494			X				X	X						Honeycutt
26-804	0-952	X		X				X	X		X				Cecil Sanders
805	0-1000			X		X		X	X		X	X	X	Salt-dilution test	Livingstone
27-2__	0-518			X		X	X	X	X						Simpson
305	0-253			X				X			X				(Reeves well) University Hills #2.
401	0-420			X				X	X			X		Salt-dilution test	San Antonio Ranch
504	0-453	X	X	X		340-453	340-453				X				
505	0-415	X	X	X		X	X					X	X		Toepperwein
512	0-505	X	X	X		X	X	X			X	X		Velocity Salt-dilution test	TWDB "Helotes" test
5__	0-371			X		X	X	X			X				Esparza
5__	0-492			X											Parrigin-Smith
5__	0-399			X				X	X						Miller
6__	0-383			X				X	X		X				Biering (south well)
703	0-633	X	X			X	X	X							
7__	0-355			X		X	X				X				Boyd (Metcalf & Eddy)
8__	0-317			X				X	X		X				Zion Lutheran Church
906	320-764	X	X	X		X	X				X				Concorde #1
907	0-680	X	X	X		X	X	X	X	X	X	X	X		Concorde #2
9__	12-316			X				X	X		X				Lazy Dazy
9__	0-97			X											Braunro
28-102	200-415								WIDCO						
205	0-456			X		X	X	X				X	X	Salt-dilution test	
304	0-376			X				X	X		X				

See footnote at end of table.

Table 1.--Types of geophysical logs available for wells in the San Antonio area--Continued

State well no. 1/	Logged interval (feet)	Log types: Neutron	Gamma-gamma	Gamma	Sonic	Electrical logs: Long-normal	Short-normal	SP	Point resistivity	Lateral	Caliper	Fluid conductivity	Fluid temperature	Other	Other well identification
BEXAR COUNTY--Continued															
AY-68-28-3__	0-250			X							X				Uptmore Cadillac
404	0-546	X	X	X	X	X	X	X			X			Core description	USGS "Lockhill" core test
503	0-340	X	X	X		X	X				X				
504	0-430	X	X	X		X	X	X							
508	0-394			X							X				
605	0-613			X				X	X		X				
606	0-553	X	X	X		X	X	X			X				
6__	0-2132													Sample description	
706	0-656	X	X			X	X	X							
809	0-746	X	X	X		X	X				X			Salt-dilution test	
810	0-666	X	X	X		X	X				X				
8__	0-508			X				X	X		X				Medical Center
903	300-398									X					Schlumberger
909	160-432					X	X	X						Driller's log	Schlumberger
910	200-800	X	X	X		X	X	X			X			Core description Packer tests	USGS "Castle Hills" core test
911	80-372					X	X	X		X					Schlumberger (E-150)
29-102	0-496	X	X	X							X	X	X		
103	0-520	X	X	X		X	X				X	X	X	Eh, pH	
107	0-606			X		X	X	X			X	X		Salt-dilution test with nearby wells pumping	TWDB "Hill Country" test
109	197-590	X		X		X	X				X	X	X		
1__	0-178	X	X	X											Metcalf & Eddy TW#29
2__	700-2099					X	X	X							Renlee (Q-8)
208	0-268	X	X	X				X	X		X	Resistivity	X		EUWD Encino Park #5 TWDB logs
209	0-311	X	X	X							X	Resistivity	X		EUWD Encino Park #3 TWDB logs
303	0-420			X		X	X	X			X				
3__	0-582	X	X	X		X	X	X			X				Metcalf & Eddy test well #33
410	0-346			X										Salt-dilution test with nearby wells pumping	F-38 in Pettit and George (1956)
4__	0-737			X		X	X	X			X				Metcalf & Eddy test well #31

See footnote at end of table.

Table 1.--Types of geophysical logs available for wells in the San Antonio area--Continued

State well no. 1/	Logged interval (feet)	Log types: Neutron	Gamma-gamma	Gamma	Sonic	Electrical logs: Long-normal	Short-normal	SP	Point resis-tivity	Lateral	Caliper	Fluid conduc-tivity	Fluid temper-ture	Other	Other well identification
BEXAR COUNTY--Continued															
AY-68-29-506	0-695	X	X	X		X	X				X			Core description	USGS "Feathercrest" core test
5	0-1944					X	X	X		X					Renlee Oil, O. Pape #1
5	0-337			X							X				
5	0-223			X							X				
5	0-315			X							X				
606	0-654			X		X	X		X						
702	0-847				X	Induction X	X	X							CWB Jones-Maltsberger #1
707	0-450					X	X	X			X				CWB Jones-Maltsberger #3
711	152-593					X	X	X		X					Airport well #2
7_	0-583			X											Sunset Rd. near Jones-Maltsberger
804	0-243					X	X	X		X					
811	161-210					X	X	X							
813	85-244					X	X	X						Driller's log, aquifer test	CPS Perrin #1 (F-142)
913	365-798				X	X	X	X			X				CWB Randolph #1
914	170-433					X	X	X							CWB Walzem Rd. #1
915	382-828			X		Induction X	X	X							CWB Randolph #2
9_	0-550			X				X	X		X				Marshall Courts
30-109	0-702	X	X	X		X	X	X						Aquifer test	Fox Run-Morton SW
211	0-773	X	X	X		X	X	X			X	X	X	Mineralogy, core description	USACE "Selma" core test
2_	0-648			X				X	X		X				Groce-Retama Polo Field
403	0-634			X			X	X						Aquifer test, sample description	Village Public Utility
405	0-790	X	X	X		X	X	X			X				
508	0-765			X									X		
5_	0-618			X							X				Selma
5_	0-775			X							X				Universal City
510	279-394					X	X	X		X					
512	0-600			X										Aquifer test, sample description	Live Oak

See footnote at end of table.

Table 1.--Types of geophysical logs available for wells in the San Antonio area--Continued

State well no. 1/	Logged interval (feet)	Log types: Neutron	Gamma-gamma	Gamma	Sonic	Electrical logs: Long-normal	Short-normal	SP	Point resis-tivity	Lateral	Caliper	Fluid conduc-tivity	Fluid temper-ture	Other	Other well identification
BEXAR COUNTY--Continued															
AY-68-30-5__	0-2581					X	X	X		X					
5__	0-739	X	X	X		X	X	X			X				Metcalf & Eddy test well #21
616	0-950	X	X	X		X	X	X			X				G-19 in Pettit and George (1956)
705	0-400			X							X		X	Chemical analyses	Windcrest
708	0-860			X		X					X				
7__	0-626			X										Mineralogy, aquifer test	Murrey
807	0-1170	X	X	X	X	X	X	X	X	X	X	X	X	Core description	USGS "Randolph" core test
34-3__	0-333			X				X	X						Whitehead water well
6__	265-2640					X	X	X		X					Oil test
35-102	0-792	X	X	X			X	X		X					CWB Anderson Pump Station
1__	500-3001					X	X	X							H-96
307	0-227			X											Van Cleave
308	0-566			X				X	X					Salt-dilution test	
310	0-415			X				X	X	X					
401	0-301			X		X		X			X				
601	0-872			X				X	X						Southwest Research
608	0-627			X							X				
6__	250-5895													Driller's log	H-49a
7__	0-538			X				X	X		X				Jungman (Barnes)
807	0-870	X	X	X		X	X	X			X				
808	20-1005	X	X	X		X	X	X			X			Continuous detection log	Ray Allison
902	0-840							X	X		X				
9__	285-1251					X	X			X					Lackland I-191
9__	0-878			X				X	X						Humble & Texaco stations
	0-276					X		X	X						
36-103	90-795				X	Induction X	X	X			X				Wurzbach Station #2
104	121-814				X	X	X	X			X				Wurzbach Station #3
111	0-666		X	X		X	X	X			X				

See footnote at end of table.

Table 1.--Types of geophysical logs available for wells in the San Antonio area--Continued

State well no. 1/	Logged interval (feet)	Log types: Neutron	Gamma-gamma	Gamma	Sonic	Electrical logs: Long-normal	Short-normal	SP	Point resis-tivity	Lateral	Caliper	Fluid conduc-tivity	Fluid temper-ture	Other	Other well identification
BEXAR COUNTY--Continued															
AY-68-36-113	594-1316					X	X								Woodlawn I-398
205	242-469					X	X	X		X					I-189
206	78-546					X	X	X		X					Cy-258
207	180-498					X	X	X	X	X					Cy-270
208	100-621					X	X	X		X					Cy-290
302	34-636					X	X	X		X					Cy-289
305	80-529					X	X	X						Driller's log	Cy-261
304	80-561					X	X	X							I-202
307	572					X	X	X						Driller's log	Cy-260
407	0-555			X											
503	80-1200					X	X	X						Driller's log	Cy-273
504	85-600					X	X	X		X					I-201
511	83-827					X	X	X							Cy-272
610	40-983					X	X	X							Cy-62
704	414-1521					X	X	X							I-232
707	85-1548					X	X	X							I-190
7__	10-923			X											
802	90-979					X	X	X							Cy-310
803	90-916					X	X	X							Cy-311
8__	185-1224					X	X	X							Cy-309
806	10-1042			X									X		I-78
8__	7-1080			X											I-94
907	0-1227			X											Cy-305
908	76-1228					X	X	X							Cy-306
9__	140-944					X	X	X							I-203
917	100-881					X	X	X						Driller's log	Cy-286
931	30-1033					X	X	X						Driller's log	Cy-287
916	82-756					X	X	X							Cy-230
37-101	567-980				X	X	X	X		X	X				Basin Station #7
102	88-1071					X	X	X							Basin Station #1

See footnote at end of table.

Table 1.--Types of geophysical logs available for wells in the San Antonio area--Continued

State well no. 1/	Logging interval (feet)	Log types: Neutron	Gamma-gamma	Gamma	Sonic	Electrical logs: Long-normal	Short-normal	SP	Point resis-tivity	Lateral	Caliper	Fluid conduc-tivity	Fluid temper-ture	Other	Other well identification
BEXAR COUNTY--Continued															
AY-68-37-104	75-985				X	X	X	X						Driller's log	Basin Station #6
106	75-978				X	X	X	X							Basin Station #5
107	0-810			X							X				
112	0-588			X		X	X	X			X				
1__	70-530					X	X	X						Driller's log	Cy-293
132	0-607			X		X	X	X							Cy-262
1__	0-364			X				X	X						Landa Library
203	0-850	X	X	X		X	X	X	X		X	X	X	Velocity, salt-dilution test, Eh, pH	J-17
207	100-707					X	X	X						Driller's log	J-88
208	165-428					X	X	X							Cy-263
210	20-626	X		X		X	X	X			X				J-19 & J-20
212	130-467					X	X	X						Driller's log	J-89
402	54-1157	X		X										Driller's log	Cy-297 (Pearl #3)
406	210-1076					X	X	X							
413	99-670					X	X	X						Driller's log	Cy-274
4__	85-786					X	X	X						Driller's log	Cy-281
429	176-696					X	X	X						Driller's log	Cy-98
507	90-861					X	X	X							Cy-278
518	100-856					X	X	X						Driller's log	Artesia Rd. #2 (Cy-277)
519	910-1340					Induction X	X	X		X	X				Artesia Rd. #6
520	103-901					X	X	X						Driller's log	Artesia Rd. #1 (Cy-276)
701	197-1475					X	X	X		X					Cy-284, Mission #10
705	100-1798					X	X	X						Driller's log	
706	964-1394					X	X	X		X					Mission Station #13
709	78-1360					X	X	X							Cy-283, Concepcion Park
710	997-1297					X	X	X		X					Cy-285, Concepcion Park
711	1249-1333					X	X	X		X					Mission Station #7
719	80-800					X	X	X		X				Driller's log	Cy-294
7__	898-1292					X	X	X		X				Driller's log	Cy-172, Mission Station #6

See footnote at end of table.

Table 1.--Types of geophysical logs available for wells in the San Antonio area--Continued

State well no. 1/	Logged interval (feet)	Log types: Neutron	Gamma-gamma	Gamma	Sonic	Electrical logs: Long-normal	Short-normal	SP	Point resis-tivity	Lateral	Caliper	Fluid conduc-tivity	Fluid temper-ture	Other	Other well identification
BEXAR COUNTY--Continued															
AY-68-37-717	0-1798			X										Driller's log	Cy-173, Dingman #7
38-108	0-940			X							X	X	X		Walzem Rd.
110	0-1030	X	X	X		X	X	X			X				Doug Saunders
6__	120-4020					Induction X	X	X							Oil test
39-1__	90-990					X	X	X							Oil test
5__	223-2448					X	X	X							Oil test
6__	39-1806					X	X	X						Driller's log	Oil test
7__	80-1810					X	X	X							Oil test
42-216	0-972			X		X	X				X			Salt-dilution test	
3__	0-1320	X	X	X	X	X	X	X			X		X		Metcalf & Eddy test well #3
43-104	0-912			X	X	X	X				X				Meadow Wood Acres
201	10-1250	X		X	X									Cement band	Nentwich
2__	10-1730	X		X											Nentwich #1
3__	10-1714	X		X	X	X	X	X			X				
406	133-1726					X	X	X			X			Driller's log	M-41
4__	83-5272	X	X	X		X	X	X		X					Oil test, Coastal States
602	90-1615				X	X	X			X					
607	82-2140				X	X	X			X	X			Micro-log	
704	200-5140					X	X	X							Oil test
815	0-1767	X		X											M-29
816	140-1759					X	X	X		X					M-40
9__	1698-2222					X	X	X		X					N-28
44-1__	800-4877					X	X	X		X					I-192
1__	2297-3460					X		X							Oil test
204	98-1206					X	X	X							I-204
207	94-1129					X	X	X							I-253
218	67-1265					X	X	X							Cy-223
301	270-1330					X	X	X						Driller's logs	I-266
303	100-1222					X	X	X							Bexar Met. #4
304	342-1274					X	X	X		X					Cy-313

See footnote at end of table.

Table 1.--Types of geophysical logs available for wells in the San Antonio area--Continued

State well no. 1/	Logged interval (feet)	Log types: Neutron	Gamma-gamma	Gamma	Sonic	Electrical logs: Long-normal	Short-normal	SP	Point resis-tivity	Lateral	Caliper	Fluid conduc-tivity	Fluid temper-ture	Other	Other well identification
BEXAR COUNTY--Continued															
AY-68-44-307	76-1308					X	X	X							Bexar Met. #7 (Cy-295)
3__	90-1481					X	X	X		X					Oil test, Barrett and others, #1 Barrett
5__	60-1500					X	X	X		X					Oil test
6__	97-1479					X	X	X		X					Oil test
6__	540-4426					X	X	X		X					Oil test
7__	200-1279					X	X	X		X					Oil test
8__	143-1533					X	X	X		X					Oil test
9__	100-2124					X	X	X							Oil test
45-1__	800-1387	X		X											
301	20-2086	X	X	X		X	X	X		X	X				Holt Machine
3__	200-4300					X	X	X						Sample log	
4__	36-4100					X	X	X							Oil test
8__	60-2000					X	X	X							Oil test
901	100-2873	X	X	X		X	X	X						Driller's log	
46-2__	80-1869					X	X	X		X					Oil test
3__	783-5097					X	X	X		X				Driller's log	Oil test
3__	80-2481					X	X	X		X					Oil test
3__	113-1940					X	X	X		X					Oil test
4__	80-2316					X	X	X		X					Oil test
4__	126-1720					X	X	X							Oil test (O-23)
5__	111-1942														Oil test
7__	100-500					X	X	X		X					
47-1__	100-2166					X	X	X		X					
4__	70-2475					X	X	X		X					
51-1__	150-1640					X	X	X							Cooper #1 Bryan
2__	100-1910					X	X	X		X					
52-3__	50-2480					X	X	X							N-73
3__	48-2400					X	X	X		X					
6__	90-2406					X	X	X							

See footnote at end of table.

Table 1.--Types of geophysical logs available for wells in the San Antonio area--Continued

State well no. 1/	Logged interval (feet)	Log types: Neutron	Gamma-gamma	Gamma	Sonic	Electrical logs: Long-normal	Short-normal	SP	Point resistivity	Lateral	Caliper	Fluid conductivity	Fluid temperature	Other	Other well identification
								BEXAR COUNTY--Continued							
AY-68-52-6__	90-2697					X	X	X		X					
53-1__	90-2604					X	X	X		X					Kelley-Pagenkopf
2__	200-2130					X	X	X		X					H&J Wright
4__	250-3373					X	X	X		X					Arnold Dillon
5__	259-3474					X	X	X		X				Driller's log	Katz-Keepers
6__	303-3109					X	X	X		X					Q-29
6__	220-3310					X	X	X		X					H&J Lamm
8__	100-4204					X	X	X		X					Q-64
54-1__	219-3037					X	X	X		X					Q-5
1__	307-3002					X	X	X		X					Q-55
1__	195-3017					X	X	X		X					Q-42
1__	178-2784					X	X	X		X					
2__	178-2847					X	X	X		X					Q-2
4__	100-2915					X	X	X		X					
4__	210-3489					X	X	X		X					Q-63
								COMAL COUNTY							
DX-68-15-8__	0-564			X							X				Pape
16-602	6-500	X	X	X		X					X				Acapulco Cafe
701	5-427	X	X	X		X	X	X	X		X	Resistivity			TWDB "Gruene" test
22-501	0-480	X	X	X		X	X	X	X		X	X Resistivity	X	Salt-dilution test	TWDB "Lewis" test
802	4-380			X				X	X		X				Garden Ridge
902	6-240			X							X				Green Valley #2
23-202	4-432	X	X	X				X	X		X				TWDB "Stahl" test
214	6-293			X							X				Calentine
217	6-316	X	X	X							X				Applebee
304	100-964					X	X	X		X				Driller's log	LCR Comal Plant #3
3__	0-296	X	X	X		X	X	X			X				EUWD Pollution study
6__	106-579					X	X	X		X					CPSB Comal Plant #1
6__	83-839					X	X	X		X					CPSB Comal Plant #2
706	6-448	X	X	X						X					Swinney

See footnote at end of table.

Table 1.--Types of geophysical logs available for wells in the San Antonio area--Continued

State well no. 1/	Logged interval (feet)	Log types: Neutron	Gamma-gamma	Gamma	Sonic	Electrical logs: Long-normal	Short-normal	SP	Point resis-tivity	Lateral	Caliper	Fluid conduc-tivity	Fluid temper-ture	Other	Other well identification
								COMAL COUNTY--Continued							
DX-68-23-807	5-520			X							X	X	X		Feick
24-113	7-122	X	X	X				X	X		X		X		Seguin city well
								GUADALUPE COUNTY							
KX-67-09-801	500-3080					Induction		X							Parsons #1 Voss, very poor log
10-703	200-3372					X	X	X		X					Weinert #1 Lehman
7_	150-3201					Induction		X							Coates #1 Wolters
17-901	312-4391					X	X	X		X					Hagen #1 Calvert
26-202	339-5431					Induction		X							Texas Southern #1 Turner
2_	538-4500					Induction		X							Sutton #1 Weinang
4_	500-4860					X	X	X							Magnolia #1 Pfulman
33-3_	120-3661					X	X	X		X					Randol & McPeters #1 Holm
68-24-605	120-2957					X	X	X		X					Parsons & Normal #1 Timmerman
30-218	0-570			X				X	X		X				John
31-105	30-2639					X	X	X		X					Stanolind #1 Schmidt
212	164-2499					Induction		X							Blumberg #1 Sanders
32-604	1400-1870	X		X											Hueners #1 Boecker
40-203	100-3767					Induction		X							Sutton #1 Kunde
2_	154-4011					X	X	X		X					Wilson #1 Kubela
								HAYS COUNTY							
LR-58-57-302	3-412			X				X	X						Dalstrom
902	8-363	X	X	X		X	X	X			X				Gregg (E-65)
58-101	0-237			X				X	X						Horton
104	6-230	X	X	X							X				Armbruster (E-31)
105	6-477	X	X	X											Lowke
108	4-332			X				X	X						Leisurewood #2 Ruby
206	8-406			X				X	X						Travis Minerals
4_	6-590	X	X	X							X				Simons
5_	0-530			X				X	X						Keller
59-4_	170-2026					X	X	X							F-24, Gilliam #1 Alexander

See footnote at end of table.

Table 1.--Types of geophysical logs available for wells in the San Antonio area--Continued

State well no. 1/	Logged interval (feet)	Log types: Neutron	Gamma-gamma	Gamma	Sonic	Electrical logs: Long-normal	Short-normal	SP	Point resistivity	Lateral	Caliper	Fluid conductivity	Fluid temperature	Other	Other well identification
								HAYS COUNTY--Continued							
LR-58-59-7__	220-3295					X	X	X			X				F-25, Woodward #1 Schubert
7__	100-1030					X	X	X			X				Q-4, Woodward #1 Graef
67-01-201	6-300	X	X	X		X	X	X			X				Allen
5__	0-1690	X		X											McAlpin #1 Lane
7__	7-332	X	X	X		X	X	X			X				Dr. Gilcrease
805	162-296					Induction									San Marcos city well
8__	5-785			X											Knispel "sulfur prospect"
02-103	5-375			X							X				H-20, Texas Highway Dept.
09-105	5-325			X		X	X				X				Fish Hatchery #1
106	5-396	X		X		X	X				X	Resistivity		Eh, pH	Fish Hatchery #2
110	5-630	X	X	X		X	X	X			X			Core description	USGS "San Marcos" core test
4__	10-855	X	X	X		X	X	X			X				Tate
								KINNEY COUNTY							
RP-70-38-902	4-775	X	X	X		X	X	X	X		X			Core description	TWDB "Tularosa Rd." core test
44-8__	40-1560			X	X						X				Travelers Ins. Co., Brackettville Farms #4
8__	35-1870			X	X						X				Travelers Ins. Co., Brackettville Farms #6
8__	20-2154			X	X										Travelers Ins. Co., Brackettville Farms #7
8__	10-1432			X	X						X				Travelers Ins. Co., Brackettville Farms #25
9__	30-1900			X	X						X				Travelers Ins. Co., Brackettville Farms #2
45-603	6-1130	X	X	X		X	X	X			X				Rose
52-1__	20-1541			X	X						X				Travelers Ins. Co., Brackettville Farm #23
52-2__	20-1838			X	X						X				Travelers Ins. Co., Brackettville Farm #11
52-8__	203-2509					X	X	X		X					Cannon #1 Townsend
53-5__	150-5140					X	X	X							Eltex #1 Beidler CC-5
54-1__	70-1600					Induction		X							Stritex #1 Taft

See footnote at end of table.

Table 1.--Types of geophysical logs available for wells in the San Antonio area--Continued

State well no. 1/	Logged interval (feet)	Log types: Neutron	Gamma-gamma	Gamma	Sonic	Electrical logs: Long-normal	Short-normal	SP	Point resis-tivity	Lateral	Caliper	Fluid conduc-tivity	Fluid temper-ture	Other	Other well identification
										MEDINA COUNTY					
TD-68-26-701	0-741	X	X	X		X	X	X							Borquin
7__	0-576			X		X		X			X				Little "D"
801	0-470					X	X	X	X						TWDB test
8__	0-720			X											Stolte
34-506	0-903	X	X	X		X	X	X	X		X	X	X	Core description	USGS "Rio Medina" core test
41-401	0-1932			X		X	X	X			X				Podevyn
4__	510-1306					X		X							Wells
8__	100-1641					X	X	X							White #1 Bendele (J-4-49)
9__	0-805		X	X											Barnes well
42-112	10-1155			X							X			Sample log	USGS "Castroville airport" test
113	5-612	X	X	X		X		X			X				Castroville airport
213	8-706			X					X			Resistivity	X		Zinsmeyer
403	10-1246			X							X				Jungman
701	100-1448					X	X	X		X					Ruby
702	0-2100	X	X	X		X	X	X			X			Driller's log	J-4-145
7__	100-1479					X	X	X							Gross #8
806	6-2035	X		X		X					X				Lytle city well
49-3__	90-1977					X	X	X		X					Murrell #13
5__	0-2620	X	X	X	X	X	X	X			X				Devine city well
813	5-3190	X	X	X	X	X	X	X		X	X			Core description	USGS "Devine" core test
8__	533-5700					X	X	X		X					Progress #1 Haass
9__	30-605					X	X	X							J-7-21
50-1__	480-2249					X	X	X							Parker & McCune #1 Walker
5__	5200					X	X	X							Moncrief #1 Collins
8__	5110					X	X	X							Teneco #1 Powell
57-102	30-5238			X		X	X	X		X	X				Republic #1A Seale
58-1__	1600-2892					X		X							Campbell #1 McMenery (J-7-48)
69-38-101	7-604	X	X	X		X	X	X			X				Valdina Farms
601	6-524	X	X	X		X	X				X				USGS Seco Creek

See footnote at end of table.

Table 1.--Types of geophysical logs available for wells in the San Antonio area--Continued

State well no. 1/	Logged interval (feet)	Neutron	Gamma-gamma	Gamma	Sonic	Long-normal	Short-normal	SP	Point resis-tivity	Lateral	Caliper	Fluid conduc-tivity	Fluid temper-ture	Other	Other well identification
MEDINA COUNTY--Continued															
TD-69-38-901	6-620			X		X	X	X			X				Foreman
905	5-976			X				X	X		X	X		Salt-dilution test	Amberson
39-504	4-654	X	X	X		X	X	X			X			Core description	TWDB core test
508	0-632	X	X	X		X	X	X			X				Hickey
5__	5-605			X							X				Saathoff
803	6-790	X	X	X		X	X				X				Nester
8__	0-971		X	X		X	X	X			X				Anderson
8__	0-720	X	X	X		X	X	X			X				J. Amberson
901	2-1042			X				X				Resistivity	X		Wiemers
40-202	0-352	X	X	X							X				Heyen
601	6-235	X	X	X							X	Resistivity	X		Reed
703	60-1143							X	X						USGS (C. C. Rogers)
45-301	12-980			X		X		X	X						Anderson
46-403	4-1569			X				X	X		X				Burks
601	7-1282	X	X	X							X				D'Hanis city well
47-102	7-1351			X							X				Elmo Pope
202	4-1464			X				X	X		X	X		Salt-dilution test	Martin
207	1-1204	X	X	X		X	X	X			X				Hondo city well
701	0-1824	X		X		X	X	X			X				Gray & Swanson
48-4	6-1786	X	X	X		X	X	X			X				Cooper
54-6__	0-2340	X	X	X		X	X	X			X				Seco Ranch
55-201	80-1809					X	X	X		X					Chadwick
501	8-2525			X									X		Ward
701	10-2818	X	X	X		X	X	X			X				Baskerville
56-1__	144-4904					X Induction	X	X							Houston Oil & Minerals #1 Neuman

See footnote at end of table.

Table 1.--Types of geophysical logs available for wells in the San Antonio area--Continued

State well no. 1/	Logged interval (feet)	Log types: Neutron	Gamma-gamma	Gamma	Sonic	Electrical logs: Long-normal	Short-normal	SP	Point resis-tivity	Lateral	Caliper	Fluid conduc-tivity	Fluid temper-ture	Other	Other well identification
								MEDINA COUNTY--Continued							
TD-69-56-507	0-2650	X	X	X		X	X	X			X		X	Spinner test	Yanta
5__	120-1986					X	X	X		X					Keator #1 Schmidt
5__	6516					X	X	X							Fair #1 McAnelly
6__	5006					X	X	X							Johnston #1 A. Howard
64-2__	140-2000					X		X							
3__	1800-3250					X		X							Rife #1 Zedich
								UVALDE COUNTY							
YP-69-28-1__	50-6501					X	X	X		X					
33-601	98-385							X	X						
6__	215-620							X	X						
901	120-383	X	X	X		X	X	X			X				
35-2__	33-985							X	X						H-2-16
602	69-237							X	X						
6__	400-582							X	X						H-3-32
901	340-675							X	X						
902	380-785							X	X						
903	0-576	X		X		X	X	X							
9__	0-698	X	X	X		X	X	X	X		X		X		Walter Seidel
9__	640-1125							X	X						
36-3__	97-425							X	X						
601	0-746	X	X	X		X	X	X	X		X			Sample description	
602	0-680	X	X	X		X	X	X			X				
704	0-596	X	X	X		X	X	X			X				
705	0-527			X											David Bishop
7__	0-470		X	X		X	X	X			X				H-3-14
7__	400-855							X	X						H-3-41, D. Rogers
8__	372-686							X	X						H-3-45, Armond
37-402	0-695	X	X	X	X	X	X	X			X			Coriband solution	USGS "Sabinal" core test
7__	663-1352							X	X						I-1-17

See footnote at end of table.

Table 1.--Types of geophysical logs available for wells in the San Antonio area--Continued

State well no. 1/	Logged interval (feet)	Log types: Neutron	Gamma-gamma	Gamma	Sonic	Electrical logs: Long-normal	Short-normal	SP	Point resis-tivity	Lateral	Caliper	Fluid conduc-tivity	Fluid temper-ture	Other	Other well identification
UVALDE COUNTY--Continued															
YP-69-41-3__	250-962							X	X						Shell #2 Winn (H-1-17)
42-703	100-425								X						
707	10-415	X	X	X		X	X	X			X				
709	0-714	X	X	X		X	X	X	X		X				TWDB core test
7__	0-850							X	X						Shell Oil core test (H-4-71)
7__	162-518							X	X						
802	20-160										X				
803	0-540			X		X	X	X			X	X		Salt-dilution test	
8__	13-83							X	X						Marcel Rambie (H-5-186)
901	0-317	X	X	X		X	X	X			X				
902	0-480			X		X	X	X							
906	0-700			X		X	X	X			X				
9__	179-800						X	X							H-5-185
9__	200-370						X	X							Pete Stoy (H-5-184)
9__	200-384						X	X							Clyde Watkins (H-5-188)
43-103	0-700	X	X	X		X	X	X			X				
106	130-454	X	X			X	X	X			X				
202	0-707	X	X	X		X	X	X	X		X				
301	0-698	X	X	X		X	X	X			X				
304	0-753	X	X	X		X	X	X	X		X				
305	0-786	X	X	X		X	X	X			X				
606	0-697	X	X	X		X	X	X			X				Knippa city well
6__	0-286		X	X							X				Knippa city well #2
7__	133-850							X	X						Shell #1 Walcott
909	100-760							X	X						H-6-22
910	325-975							X	X						H-6-23
44-107	0-885	X	X	X		X	X	X			X				
1__	339-701						X	X							H-3-51
401	0-854	X	X	X		X	X	X			X				
405	200-1247	X	X	X		X	X	X			X				Woodley #3
406	0-1136	X	X	X		X	X	X			X				Woodley #4
408	30-581	X	X	X		X	X	X			X				

See footnote at end of table.

Table 1.--Types of geophysical logs available for wells in the San Antonio area--Continued

State well no. 1/	Logged interval (feet)	Log types													Other well identification
						Electrical logs									
		Neutron	Gamma-gamma	Gamma	Sonic	Long-normal	Short-normal	SP	Point resis-tivity	Lateral	Caliper	Fluid conduc-tivity	Fluid temper-ture	Other	
									UVALDE COUNTY--Continued						
YP-69-44-4__	0-918	X	X	X		X	X	X			X				Woodley #2
703	0-1065	X		X		X	X	X			X	X	X		Dolph Briscoe
8__	900-1525							X	X						H-6-44
8__	0-1610	X	X	X		X	X	X			X				
45-401	7-1406	X	X	X		X	X	X	X		X				Davis River Farm
7__	2-1668							X	X		X				I-4-40
8__	70-970							X	X						I-4-41
8__	395-1910					X	X	X	X	X					I-4-42
49-2__	110-651							X	X						H-4-43
50-108	2-1384	X	X	X		X	X	X	X		X		X		OKM Ranch
1__	115-774							X	X						H-4-45
202	97-137							X	X						H-5-209
206	8-342	X	X	X		X	X	X			X				Miyakawa
2__	90-330							X	X						H-5-213
2__	100-295							X	X						H-5-214
2__	100-330							X	X						H-5-133
2__	105-270							X	X						H-5-208
2__	100-187							X	X						H-5-212
2__	125-599							X	X						H-5-210
302	100-287							X	X						H-5-1
303	4-221			X				X	X			Resistivity			Haag
309	6-568	X	X	X		X	X	X			X				Toone #4
310	6-385	X	X	X							X				Olmitos Ranch
3__	135-450							X	X						H-5-126
3__	125-325							X	X						H-5-144
3__	150-291							X	X						H-5-200
3__	105-473							X	X						H-5-206
3__	75-159							X	X						H-5-219
3__	79-600								X						H-5-207

See footnote at end of table.

Table 1.--Types of geophysical logs available for wells in the San Antonio area--Continued

State well no. 1/	Logged interval (feet)	Log types: Neutron	Gamma-gamma	Gamma	Sonic	Electrical logs: Long-normal	Short-normal	SP	Point resis-tivity	Lateral	Caliper	Fluid conduc-tivity	Fluid temper-ture	Other	Other well identification
UVALDE COUNTY--Continued															
YP-69-50-3__	100-426							X	X						H-5-222
3__	70-157							X	X						H-5-218
406	150-1275							X	X						H-4-95
410	112-1121							X	X						H-4-93
4__	118-960							X	X						H-4-88
4__	55-535							X	X						H-4-91
501	94-579							X	X						H-5-163
507	6-750			X		X	X	X			X				Fish Hatchery
5__	62-362							X	X						Fish Hatchery (H-5-174)
5__	73-1207							X	X						H-5-243
5__	87-430							X	X						H-5-216
5__	89-289							X	X						H-5-215
5__	83-387							X	X						H-5-217
601	70-562							X	X						H-5-240
609	100-508							X	X						H-5-53
611	63-203							X	X						H-5-234
612	110-148							X	X						H-5-230
6__	80-534							X	X						H-5-52
6__	61-410							X	X						H-5-220
6__	85-302							X	X						H-5-223
6	83-451							X	X						H-5-236
6	71-388							X	X						H-5-237
802	6-669			X				X	X		X		X		Willoughey
901	105-591							X	X						H-8-69
902	57-579							X	X						H-5-251
9__	55-303							X	X						H-5-255
51-104	4-428	X	X	X		X	X				X				Uvalde airport
1__	140-1480								X						H-5-202
1__	153-370							X	X						H-5-203

See footnote at end of table.

Table 1.--Types of geophysical logs available for wells in the San Antonio area--Continued

State well no. 1/	Logged interval (feet)	Log types													Other well identification
		Neutron	Gamma-gamma	Gamma	Sonic	Electrical logs					Caliper	Fluid conductivity	Fluid temperature	Other	
						Long-normal	Short-normal	SP	Point resistivity	Lateral					
UVALDE COUNTY--Continued															
YP-69-51-2__	149-273							X	X						H-5-196
2__	92-494							X	X						H-5-227
301	8-1026	X	X	X		X	X	X							Winslow
3__	2-693			X							X				Neimeyer
403	8-320			X							X				Carter
407	54-565							X	X						H-5-229
408	35-581	X	X	X		X	X	X			X				J. R. Carnes
4__	4-480	X	X	X		X	X	X			X				Carter
502	4-350							X	X			Resistivity			Turner
503	4-566	X		X				X	X		X				Hargrove
602	6-2208	X	X	X		X	X	X			X		X		LaMoca
603	4-696			X				X	X	X		X	X		Johnson
605	2-81			X											Hargrove
702	5-1000	X		X				X	X		X	Resistivity	X		Briscoe
8__	100-1705					Induction		X							H-8-88
52-1__	650-887							X	X						H-6-18
52-201	682-1528	X		X		X	X	X			X	X	X		Briscoe
403	6-1455	X	X	X		X	X	X			X				Johnson
9__	400-1780	X	X	X							X		X		Maner
53-701	80-3688					Induction		X							Woodley
60-1__	212-4015					X	X	X		X					Steeger #1 Kincaid
3__	115-1050					X	X	X							Phillips #1 Lokin
70-56-8__	50-1500							X	X						Texas Highway Dept.

1/ Incomplete State well number indicates that the exact location of the well is unknown or that no number has been assigned to the well. Additional information on the well location is given in the "Other well identification" column if available.

Table 2.--Averaged measurements of porosity, bulk density, resistivity, and sonic velocity for distributed zones in the San Marcos test hole

Zone	Average limestone neutron porosity (percent)	Average bulk density (g/cm^3)	Average Δt ($\mu s/ft$)	Average resistivity (ohmmeters)
1	15	2.50	66	2,000
2	39	2.18	115	500
3	33	2.35	85	800
4	15	2.50	67	2,000+
5	21	2.45	73	2,000
6	39	2.20	97	400
7	16	2.46	75	900
8	11	2.58	75	850
9	22	2.42	75	600
10	45	2.09	115	60
11	18	2.45	72	300
12	21	2.42	73	250
13	17	2.50	66	250
14	21	2.48	70	200
15	42	2.15	106	50
16	22	2.40	77	100
17	21	2.41	72	150
18	32	2.26	90	350
19	22	2.45	75	95
20	33	2.31	85	50
21	21	2.45	72	150
22	42	2.18	99	300
23	24	2.45	76	90
24	20	2.50	74	80
25	36	2.17	98	75
26	18	2.55	68	110
27	26	2.40	78	50
28	14	2.52	74	100
29	13	2.55	70	180

Table 3.--Averaged measurements of sonic velocity and resistivity for distributed zones in the Sabinal test hole

Zone	Ra, LL-8 (ohmmeters)	Δt ($\mu s/ft$)	Δt-Δt ($\mu s/ft$)
1	500	62	16
2	800	58	12
3	--	--	--
4	1,100	69	23
5	100	74	28
6	1,500	60	14
7	700	61	15
8	900	62	16
9	2,000	56	10
10	700	86	40
11	900	63	17
12	900	78	32
13	500	58	12
14	500	84	38
15	1,900	56	10
16	1,200	74	28
17	--	--	--
18	600	78	32
19	1,500	58	12
20	2,000	63	17
21	2,000	54	8
22	900	65	19
23	700	67	21
24	500	80	34
25	600	63	17
26	200	78	32
27	600	76	30

Δt_m = 46 $\mu s/ft$.

Table 4.--M and N values for distributed zones in the San Marcos and Sabinal test holes
(ρ_b = bulk density, $\emptyset_n$ = neutron porosity, Δt_f = 189 μs/ft, ρ_f = 1.0 g/cm³, $\emptyset_{nf}$ = 1.0)

Zone	ρ_b (g/cm³)	$\emptyset_n$ (percent)	Δt (μs/ft)	M $\frac{\Delta t_f-\Delta t}{\rho_b-\rho_f}$x0.01	N $\frac{\emptyset_{nf}-\emptyset_n}{\rho_b-\rho_f}$	Zone	ρ_b (g/cm³)	$\emptyset_n$ (percent)	Δt (μs/ft)	M $\frac{\Delta t_f-\Delta t}{\rho_b-\rho_f}$x0.01	N $\frac{\emptyset_{nf}-\emptyset_n}{\rho_b-\rho_f}$
		SAN MARCOS						SABINAL			
1	2.50	15	66	0.82	0.57	1	2.50	14	62	0.85	0.57
2	2.18	39	115	.63	.52	2	2.50	16	68	.81	.56
3	2.35	33	85	.77	.50	3	2.71	11	58	.77	.52
4	2.50	15	67	.81	.57	4	2.65	13	62	.77	.53
5	2.45	21	73	.80	.54	5	2.65	21	50	.96	.54
6	2.20	39	97	.77	.51	6	2.45	11	64	.86	.57
7	2.46	16	75	.78	.58	7	2.56	16	--	--	--
8	2.58	11	75	.72	.56	8	2.40	12	57	.94	.63
9	2.42	22	75	.80	.55	9	2.50	12	64	.84	.59
10	2.09	45	115	.68	.50	10	2.60	9	55	.84	.57
11	2.45	18	72	.81	.57	11	2.04	36	74	1.11	.61
12	2.42	21	73	.82	.56	12	2.60	4	53	.85	.60
13	2.50	17	66	.82	.55	13	2.50	12	62	.85	.59
14	2.48	21	70	.80	.53	14	2.21	27	80+	.90	.60
15	2.15	42	106	.72	.50	15	2.50	11	63	.84	.59
16	2.40	22	77	.80	.56	16	2.28	26	78	.87	.58
17	2.41	21	72	.83	.56	17	2.31	28	80+	.83	.55
18	2.26	32	90	.79	.54	18	2.57	8	56	.85	.59
19	2.45	22	75	.79	.54	19	2.36	22	74	.85	.57
20	2.31	33	85	.79	.51	20	2.62	7	55	.83	.57
21	2.45	21	72	.81	.54	21	2.46	18	77	.77	.58
22	2.18	42	99	.76	.49	22	2.57	9	56	.85	.58
23	2.45	24	76	.78	.52	23	2.25	21	68	.97	.63
24	2.50	20	74	.77	.53	24	2.00	38	80	1.09	.62
25	2.17	38	98	.78	.53	25	2.53	13	61	.84	.57
26	2.55	18	68	.78	.53	26	2.54	12	62	.82	.57
27	2.40	26	78	.79	.53						
28	2.52	14	74	.76	.56						
29	2.55	13	70	.77	.56						

Table 5.--Criteria for lithologic interpretations of an overlay of porosity logs derived from density and neutron measurements [1]

($\emptyset$ = porosity, FDC = formation density compensated, CNL = compensated neutron log, P.U. = porosity units (assuming the rock matrix to be pure limestone)

Curve relationship	Approximate difference, in limestone porosity units (P.U.)	Probable matrix material	Approximate true porosity
$\emptyset_{FDC} > \emptyset_{CNL}$	$\emptyset_{FDC} - \emptyset_{CNL} \approx 6$ to 8	chert	$\emptyset \cong \emptyset_{CNL} + 4$
$\emptyset_{FDC} = \emptyset_{CNL}$	0	limestone	$\emptyset = \emptyset_{FDC} = \emptyset_{CNL}$
$\emptyset_{FDC} < \emptyset_{CNL}$	$\emptyset_{CNL} - \emptyset_{FDC} \approx 11$ to 16	dolomite	$\emptyset = \frac{1}{2}(\emptyset_{CNL} - \emptyset_{FDC})$
$\emptyset_{CNL} >> \emptyset_{FDC}$	$\emptyset_{CNL} - \emptyset_{FDC} \approx 10$ to 40	shale	

[1]Adapted from Schlumberger Limited, 1974.

Table 6.--Summary of tracer-dilution, pulse, and transit-time tests

Owner/well	Depth (feet)	Water level (feet)	Confined (c) or unconfined (u)	Type of test	Interstitial velocity (feet/day)	Total percentage of dye recovered
Toperwein (AY-68-27-505)	400	260	u	tracer dilution	2.3*	--
Ippolito (AY-68-27-5)	352	244	u	tracer dilution	5.8*	--
C. B. Peters (AY-68-28-102)	440	206	u	tracer dilution	1.96	--
Lockhill Cemetery (AY-68-28-801)	397	302	u	tracer dilution	3.7	--
do.	--	--	u	pulse	2.4*	30
Hill Country W. W. (AY-68-29-103)	547	260	u	tracer dilution	1.7	--
E. Pape (AY-68-30-107)	--	--	c	pulse	4.6*	91
Wurzbach no. 1 (AY-68-36-102)	786	220	c	pulse	31	15
do.	--	--	c	transit-time 790 feet	141**	10

* Assume porosity of 10 percent.
** Within the cone of depression.

Table 7.--Summary of miscellaneous tracer tests

Date	Location	Type of test	Remarks
1/70	Comal Springs at New Braunfels	From well to springs with salt.	Used salt instead of dye to get some data on how much dye to use. Results negative. (See next test.)
2/70	Comal Springs New Braunfels	From well to springs with dye.	From well to spring--126 minutes to travel 610 feet or about 7,000 feet per day with slope of 0.007 foot per foot. The dye did not issue from the closest spring and this explained not finding the salt.
2/70	Ft. Sam Houston at San Antonio	From well to well with dye.	Results negative. The injection well probably was not within the influence of the sampling well. The distance between the wells is about 1 mile.
3/70	Leona gravel near Uvalde	From well to well with dye.	Made to verify aquifer-test results. For the peak concentration, the travel time was 33 hours to move 530 feet. The Leona gravel is an outflow channel from the Edwards aquifer.
9/70	Helotes Creek Bexar County	Tagged flow in losing reach of creek. Sampled nearby wells.	Results negative. Dye never recovered. The wells were about 200 feet from the creek, and the test duration was 4 months.
11/70	Turtle Creek Country Club at San Antonio	Point dilution in artesian Edwards.	Results inconclusive. Sampling equipment inadequate to sample through artesian zone.
3/71	San Marcos Springs at San Marcos	From well to springs.	Results negative. Dye stayed in or near injection well.
3/71	Fish Hatchery near San Marcos	Point dilution in artesian Edwards.	Results inconclusive. Sampling equipment inadequate to sample through artesian zone.
3/71	Fish Hatchery near San Marcos	Vertical flow measurement in borehole.	Used saltwater and down-hole conductivity probe, flow rose in the borehole at about 10 gal/min.