INTERPRETATION OF "OLD" ELECTRIC LOGS, RED FORK SANDSTONE, PAYNE COUNTY, OKLAHOMA

By

DONALD PETER RAGUSA

Bachelor of Science

State University of New York

Cortland, New York

1985

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
July, 1988

INTERPRETATION OF "OLD" ELECTRIC
LOGS, RED FORK SANDSTONE,
PAYNE COUNTY, OKLAHOMA

Thesis Approved:

Gary F. Stewart
Thesis Adviser

Zuhair al-Shaieb

Jay Patchett

Duncan P. Emmons

Norman N. Durham
Dean of the Graduate College

ACKNOWLEDGMENTS

This thesis is dedicated to my parents, Mr. and Mrs. John Ragusa, and Dr. Gary F. Stewart. My parents have been a source of unending support and understanding throughout my childhood and academic career. Dr. Stewart was kind enough to be my advisor, and to contribute much of his resources to the benefit of my research and course work. I can not adequately express my appreciation, in mere words, to a man who has done so much for me. I will always be indebted to Dr. Stewart for all the kindness he has shown me over the past three years.

I wish to thank the Well Log Consortium of Oklahoma State University, for the financial and academic support of this research. I thank Dr. Zuhair Al-Shaieb for his editorial comments, guidance, support, and friendship throughout the past three years. I wish to extend a great deal of gratitude to Mr. Jay Patchett, from Amoco Production Company, for being a committee member. Mr. Patchett showed a great deal of patience, and extended a considerable amount of his time and expertise in reviewing and interpreting well-log data. Finally, appreciation is expressed to my friends at Oklahoma State University with whom I share many fond memories.

TABLE OF CONTENTS

Chapter Page

LIST OF TABLES

LIST OF FIGURES

Figure Page

NOMENCLATURE

AM	Normal Electrode Array
AO	Lateral Electrode Array
CDL	Compensated Density Log
CNL	Compensated Neutron Log
d	Diameter of the Borehole
Di	Diameter of Invasion
e	Bed Thickness
F	Formation Resistivity Factor
I	Resistivity Index
Io	Resistivity Index with Residual Oil
R(16")	Apparent Resistivity of Short Normal Curve
R(64")	Apparent Resistivity of Long Normal Curve
R(18'8")	Apparent Resistivity of Lateral Curve
Ra	Apparent Resistivity
Rat	Apparent True Resistivity
Ra(lat)	Apparent Resistivity of Lateral Curve
Ra(ln)	Apparent Resistivity of Long Normal Curve
Ra(sn)	Apparent Resistivity of Short Normal Curve
Ri	Resistivity of Invaded Zone
Rl	Peak Resistivity (Lateral Curve)
R(lat)	Resistivity of Lateral Curve
R(ln)	Resistivity of Long Normal Curve

Rm	Resistivity of Drilling Mud
Rmc	Resistivity of Mud Cake
Rmf	Resistivity of Mud Filtrate
Ro	Resistivity of Formation 100 Per Cent Water-Saturated, with Formation Water Resistivity of Rw
Rop	Optimum Resistivity (Lateral Curve)
ROS	Residual Oil Saturation
R(peak)	Peak Resistivity (Lateral Curve)
Rs	Resistivity of Surrounding Beds (Generally "Shale")
R(sn)	Resistivity of Short Normal Curve
Rt	True Resistivity of Uncontaminated Formation
Rw	Formation-water Resistivity
Rxo	Resistivity of Flushed Zone
SP	Spontaneous Potential
SSP	Static Spontaneous Potential
Sw	Water Saturation
Sxo	Water Saturation of Flushed Zone

CHAPTER I

ABSTRACT

The interpretation of "old" electric logs seems to be as much an art as a science. An "expert" with old logs is someone who knows how the tools operated and who knows their limitations, who knows how to select apparent resistivity values from the logs, who has mastered analytical methods and knows the limitations of the analytical methods, and who has acquired additional ability empirically. Many geologic factors contribute an added degree of complexity to the interpretation of old electric logs. As a consequence, an "expert" with these old logs may be uncommonly effective in an area where he is well acquainted with the subsurface geology, geologic setting, individual reservoirs' character, and stratigraphic column.

Development of a fairly easy, robust method to interpret old electric logs is a desired result of this research. In order to refine the problem to manageable proportions, "old" electric logs is limited to logs composed of an Spontaneous Potential (SP) curve, Short Normal (16-inch) curve, Long Normal (64-inch) curve, and Lateral (18-foot 8-inch) curve. The study is also limited to the Red Fork Sandstone of Payne County, Oklahoma.

Calculation of water-saturation in a direct manner using the Archie Equation is possible only if reliable values of porosity (and hence formation factor), Rw, and Rt can be obtained. Obtaining accurate estimates of porosity and Rt from old electric logs is not straightforward. If reliable estimates of porosity and Rw for a specific formation could be obtained from sources other than the old electric logs, these values could be used in the Archie Equation with Rt obtained from old electric logs, to calculate an estimate of water saturation. In doing so, the assumption of transferability of measurements of porosity and Rw is necessary. To be able to estimate water-saturation reliably from old electric logs without assuming values of porosity or Rw obviously would be advantageous.

Where the Red Fork Sandstone of Payne County, Oklahoma is concerned, use of Ri-Rt Conversion Charts (Lane Wells, Inc., 1956) in conjunction with a Saturation Chart (specifically developed for the Red Fork Sandstone) seems to yield favorable results. This method permits the estimation of water saturation from old electric logs without the assumtion of values for porosity or Rw.

CHAPTER II

PRELIMINARY INFORMATION

Introduction

A great wealth of subsurface data in mature petroleum provinces is not used to its full potential. Electric logs of the "old generation" (SP-SN-LN-LAT and Microlog), which were used from 1927 (1948 for the Microlog) until the introduction of the modern induction logs, make up a large amount of the subsurface well control. The number of people in the industry who are proficient with these older logs is decreasing steadily. Many oil companies are re-evaluating old oil fields in order to apply secondary and tertiary recovery methods. Of course, re-entries and recompletions call for re-evaluation of logs, many of which are "old" electrical surveys or electric logs.

Interpretation of "Old" Logs

Interpretation of "old" logs seems to be as much an art as a science. Generally speaking, an "expert" with old electric logs is a person who knows how the tools operated, who knows their limitations, who knows how to select apparent resistivity values from the logs, and who has acquired additional ability empirically. These skills are necessary in order to get the most accurate estimate of water saturation. Familiarity with the character of the reservoir, performance of the reservoir, with regional stratigraphy, and with the geologic history of the area are also essential for accurate interpretations. For this reason, an "expert" with old logs may be provincial; that is to say, an expert may be uncommonly effective in an area where he is well acquainted with the subsurface geology, and with the particular anomalies associated with the stratigraphic column.

Analytical Methods

A variety of analytical methods has been developed by log analysts and electrical engineers over the past few decades. As a consequence, the student of old electric logs can become confused by the different methods, as well as becoming unsure as to which method is best. In general, a fundamental problem with log interpretation is: "How does one know how accurate a proposed method will be?" Even more importantly, how does one estimate the accuracy of a previously proposed method? The problem lies in the fact that most methods of analysis are based on formidable assumptions. Documentation of the methods may not permit the nonexpert user to know what the assumptions are, or where in the sequence of events these assumptions occur. This can lead to serious error, and even more importantly, one can lose perspective on what parameters are reliable and what are merely speculative. Therefore, knowledge of analytic procedures and of the limitations of these procedures also is a necessary attribute of an "expert" with old electric logs.

Objective

The objective of this thesis was to determine an effective method for making dependable estimates of water-saturation from old electric logs, wherein the Red Fork Sandstone of Payne County, Oklahoma is concerned.

Constraints of the Problem

As one learns about old electric logs, the fact becomes apparent that the ways to manipulate data taken from the logs are many. Methods range from simple to complex and tedious. Very early in the investigation this question came to mind: "How does one know which method will yield the most accurate estimate of water-saturation?" In the final evaluation, the controlling factors seem to be related to limitations of the logging tools, the degree of accuracy needed, character of the reservoir, character of adjacent beds, and the amount of historical information available about the geologic parameters.

In order to reduce the problem to manageable proportions, the "old" logs were limited to electrical logs with specific electrode spacings (16-inch short normal, 64-inch long normal, and the 18-foot 8-inch lateral). Research was limited to a sandstone reservoir, the Red Fork Sandstone of Payne County, Oklahoma (Figs. 1 and 2).

Background Information

In 1912, Marcel and Conrad Schlumberger began development of a mineral-prospecting technique based on electrical resistivity measurements (S.P.W.L.A., 1979, p. 13). Interpretations of subsurface conditions were made from surveys conducted at the surface. In September 1927, the first resistivity measurements were obtained from a borehole in France's Pechelbronn oil field by H.G. Doll (Asquith, 1982, p. 2, and Frank, 1986, p. 1). This was the first electric log and the birth of the logging industry.

The first electric logs were composed of a single resistivity curve that was plotted by hand. Resistivity measurements came from a lateral electrode array. Research and development in the logging industry progressed rapidly with the advent of the Spontaneous Potential (SP) curve in 1930, and the Normal curves in 1932 (S.P.W.L.A., 1979, p. 14). The SP, short normal, long normal, and lateral curves composed the classical "electric log".

As technology advanced during the 1940s and 1950s, log analysts described relationships among physical properties of the rocks and responses of the logging tools. Not only was the detection of oil and/or gas possible, but the relative amounts of petroleum and salt water could be

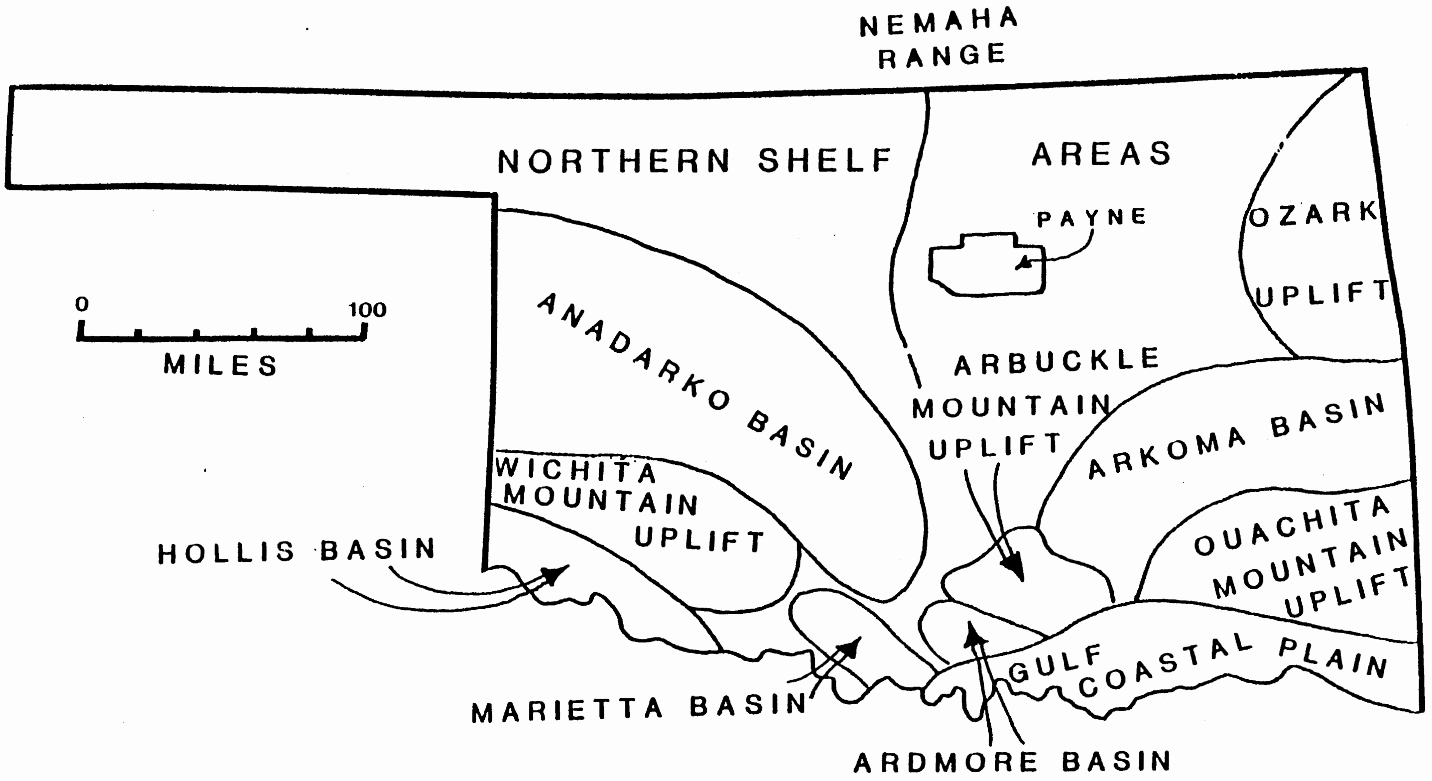


Figure 1. Location Map of Study Area.

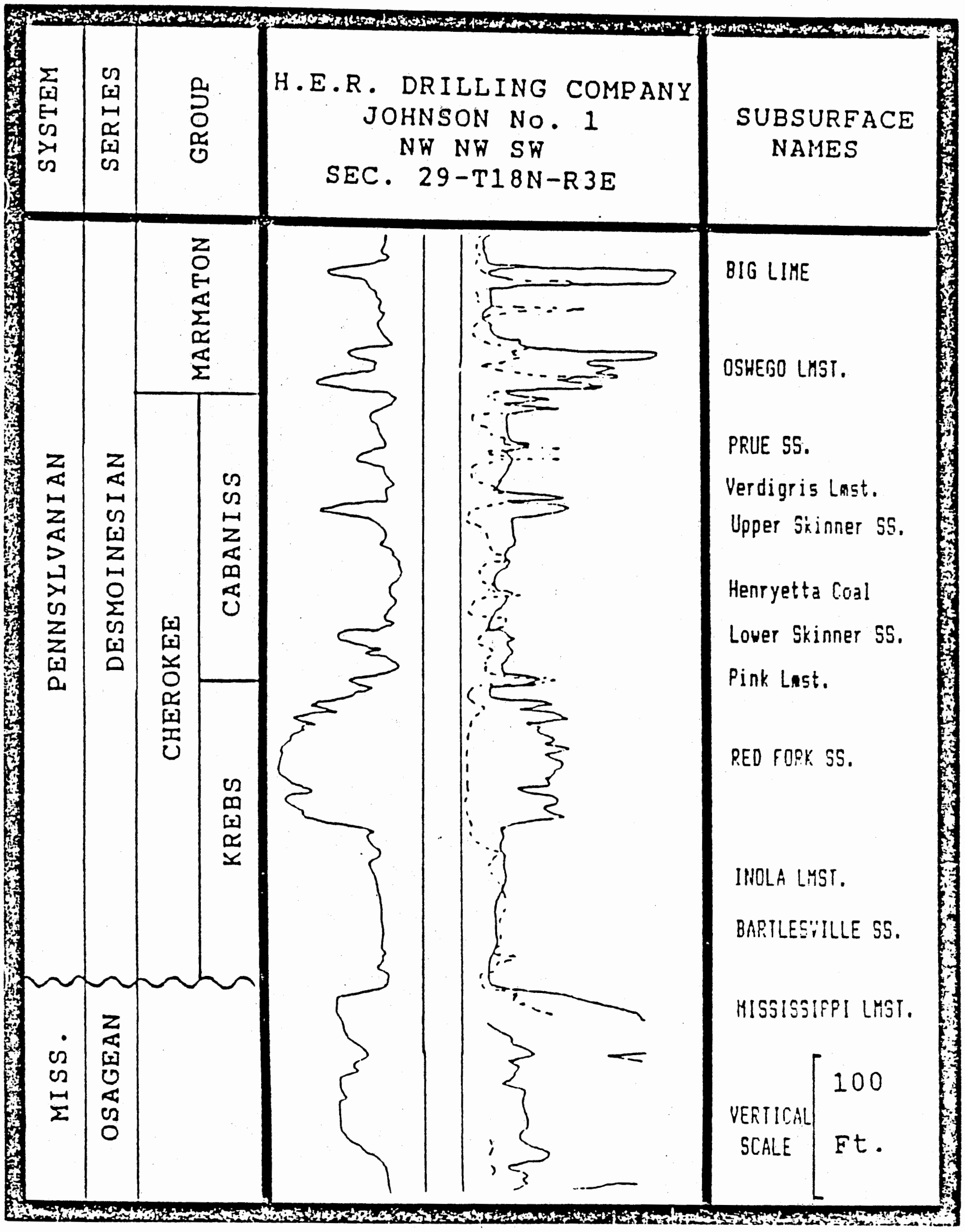


Figure 2. "Type" Electric Log and Stratigraphic Section.

quantified in a fairly reliable manner. Accuracy of the calculated amounts of oil and/or gas in place is related to geologic factors and to variables introduced by the drilling process. Some of these influencing factors are bed thickness, heterogeneity of reservoir rock or adjacent beds, adjacent-bed thickness and resistivity, diameter of the borehole, chemistry of formation water, resistivity of drilling mud, Rmf/Rw ratio, porosity, and "shaliness" of the reservoir.

Basic Approach

The fundamental problem of interpreting old electric logs can be described by analyzing the Archie Equation: Sw = ((F * Rw)/Rt)^0.5. If one intends to calculate water saturation in a straightforward manner using the Archie Equation, values must be obtained for porosity (component of F), Rw, and Rt. Measurement of these three variables (especially porosity and Rt) is the troublesome attribute of the old electric logs. Elimination of as many problematic variables as possible by using modern logs and information obtained from outside sources seems to be a promising course of action.

Formation Resistivity Factor (F)

Essential components of the formation resistivity factor are rock-type and porosity. Rock-type generally can be estimated by evidence from log signatures, bit cuttings, drilling time, side-wall cores, full cores, or prior knowledge of the stratigraphic column. On the other hand, accurate estimations of porosity from old electric logs are quite difficult. Until the advent of the modern porosity tools (Compensated Neutron-Compensated Density log, Acoustic or Sonic logs), porosity was estimated from drilling time, from records of nearby wells, from analyses of cores or bit cuttings, was estimated from the short normal curve (Rocky Mountain Method), or was calculated from the microlog. Only a few reservoirs were cored and not all formations were described by micrologs. Moreover, calculations of porosity from the short normal curve and microlog can be inaccurate. Unreliability of information gained from these sources plagued the logging industry until development of modern porosity tools.

With these facts in mind, to use modern porosity logs for probabilistic estimates of porosity of a stratigraphic unit is reasonable. If reliable data can be used, if the assumptions of the probability distribution are met, and if the data are sampled correctly, then the porosity of a particular stratigraphic unit can be established within set confidence intervals.

Formation Water Resistivity (Rw)

Estimation of formation water resistivity can be a matter of concern in some instances. If logs being analyzed are from a remote area, useful estimates of Rw can be calculated from the SP curve. However, in some instances values of Rw obtained from the SP curve are in serious error. If data from catalogued values and published records of produced water suggest that Rw values are consistent, then reliable estimates of Rw can be obtained from these sources.

True Formation Resistivity (Rt)

Determination of Rt is the major source of trouble in the analysis of old electric logs. Because of limitations of the lateral-electrode array (designed to measure the "true" resistivity of the uncontaminated formation), in many instances one cannot determine this variable accurately. The lateral tool can be affected adversely by enlarged boreholes, mud resistivities, bed thicknesses, adjacent-bed effects, and by invasion of mud filtrate. The lateral tool operates best in thick, "homogeneous" beds that are bounded above and below by isotropic formations (generally referred to as "shales"). Where conditions deviate from this set of circumstances, much interpretation and correction must be applied to the lateral tool's measurement of resistivity. In many instances, reservoirs and surrounding formations do not meet these criteria. As a consequence, logging tools that are not affected as significantly by these variables (modern focused and induction logs) were developed.

Previous Works

References of good quality pertaining to the interpretation of "old" electric logs (i.e. methods to obtain reliable estimates of water saturation from "old" electric logs) are few. Information concerning the SP curve and the lateral and normal electrode arrays is abundant; however, documents that integrate this information with methods for estimating water saturation are not abundant.

Part of the problem probably is due to the fact that these "old" electric logs have been replaced by more advanced logs during the past 30 years. More importantly, the analytic methods found consist mostly of chart books; only small amounts of explanatory text are contained in these chart books. One reference that was relied on heavily is "Old Electric Log Interpretation", by Douglas W. Hilchie (1979).

Guyod and Pranglin (1959) published a large volume of Transformation-and-Analysis Charts for the interpretation of old electric logs. They are very useful.

Jay G. Patchett, Amoco Production Company, kindly furnished a complete set of the Lane Wells Ri-Rt Conversion Charts (1956). Mr. Patchett was also the source of much help and additional information. His paper entitled, "Log Interpretation of the Tertiary and Upper Cretaceous of Wyoming and Surrounding Areas" (1961), was extremely useful.

Log analysts and electrical engineers from Schlumberger Well Surveying Corporation contributed a great deal to the interpretation of old electric logs. Papers entitled "Electric-log Analysis In the Rocky Mountains" (Tixier, 1949), and "A Contribution to Electric Log Interpretation in Shaly Sands" (Poupon and others, 1954) are valuable references.

CHAPTER III

SPECIFIC GEOLOGIC PARAMETERS

Introduction

As previously stated, an "expert" with old electric logs knows how the tools operate, knows the limitations of the tools, knows how to manipulate data taken from the logs, knows the analytic procedures, knows limitations of the analytic procedures, and has a good understanding of the geologic parameters necessary for reliable estimates of water saturation. The important geologic parameters are the geologic setting, the local stratigraphy, and the character of the reservoir. A novice may have little experience working with the logs; however, he(she) may know the geologic parameters or generally he(she) can learn them without much difficulty. For the purpose of this research, a specific reservoir (the Red Fork Sandstone) and a specific study area (Payne County, Oklahoma) were chosen (Figs. 1 and 2).

The Study Area

Payne County, Oklahoma is located on the Central Oklahoma Platform (Fig. 1). The area of study is between the Ozark Uplift to the east, the Arbuckle Uplift and Arkoma Basin to the south, and the Nemaha Range to the west (Fig. 1).

A regional structural contour map of the top of the Pink Limestone (Fig. 2) indicates a general northerly to northwesterly strike and gentle westward dip of approximately 50 feet per mile (Robertson, 1983, p. 11, and Plate 10). The rate of dip varies only slightly, except where interrupted locally by faults or flexures.

Stratigraphic Framework

On the Central Oklahoma Platform, the Red Fork Format is part of the "Cherokee Group", Desmoinesian Series, Pennsylvanian System (Fig. 2). In eastern Oklahoma, the Cherokee Group is divided into the Krebs and Cabaniss Subgroups (Rascoe and Adler, 1983, p. 992). The Krebs Subgroup includes all strata between the Pink Limestone and the top of the Mississippian System, whereas the Cabaniss Subgroup is composed of strata between the base of the Oswego Limestone and the Pink Limestone (Fig. 2). The Red Fork Format Interval is the sand-shale sequence that is between the Pink Limestone and the Inola Limestone (Fig. 2). (Informal stratigraphic names (e.g. Pink Limestone) are capitalized here for the sake of clarity.)

The "Cherokee Group" is made up chiefly of sandstone and shale; the Cherokee is divisible on the basis of laterally persistent limestone marker-beds. During the

Desmoinesian Epoch, sediments were deposited on the Central Oklahoma Platform during an overall, major transgression of the Cherokee Sea (Rascoe and Adler, 1983, p. 992). Within this transgression were several regressive events, recorded by fluvial-deltaic systems. Terminations of these regressive events were marked by thin beds of limestone that are of large extent. Thus, the "Cherokee Group" consists of a series of transgressive-regressive couplets (Shipley, 1975, p. 14); the Red Fork interval is one of the regressive sequences of strata. The overlying Pink Limestone documents one of the regional transgressive events (Fig. 2).

Petrology of the Red Fork Sandstone

Introduction

Much of the information about the petrology of the Red Fork Sandstone contained here was obtained from the work of Robertson (1983) and Balke (1984). The purpose of drawing information from these sources was to add documentation to information that I have gained during my own research. Robertson and Balke compiled information from wells elsewhere than Payne County, and some of this information was used in the study at hand. However, I believe that this will not introduce any serious inconsistencies, because cores from which information was taken were from wells in bordering Pawnee and Noble Counties (Fig. 3).

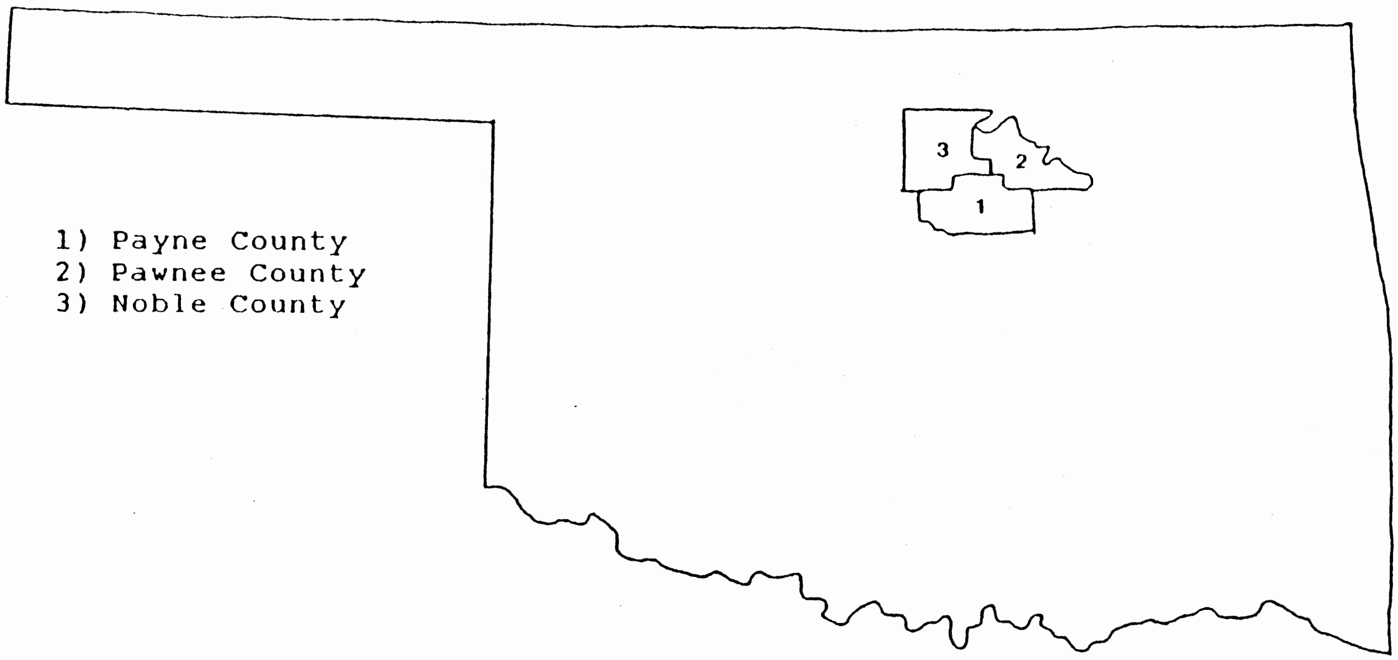


Figure 3. Location Map Showing Payne County, and Adjacent Pawnee and Noble Counties.

Change in general petrography of the Red Fork Sandstone within such a small area should not be significant. General petrography of the Red Fork Sandstone is consistent throughout Payne, Pawnee, and Noble Counties, primarily because the Red Fork in this area has been deposited in the same depositional setting (Robertson, 1983, and Balke, 1984).

Data From Cores and Thin Sections

Seven cores, and thin sections from these cores, were analyzed by Robertson (1983) and Balke (1984) (Table I). Within these sandstones of the Red Fork, laminations of shale and clasts of clay are common. Sandstone generally is fine grained, according to Robertson (1983, p. 56) but Balke (1984) described grain size as varying from silt to coarse grained sand. In general, the sandstone is very fine grained to fine grained (Balke, 1984, p. 31). Analyses of thin sections from various Red Fork cores show that the sandstone mostly is sublitharenite; subarkose and lithic arkose are secondary in abundance (Robertson, 1983, p. 54-55, and Balke, 1984, p. 104-107). (This information is included in Appendix A.)

The main detrital constituent in the Red Fork is monocrystalline quartz, with polycrystalline quartz of minor significance. Other detrital constituents are metamorphic-rock fragments, sedimentary-rock fragments, and feldspars. The rock contains trace amounts of muscovite, pyrite, sphene, zircon, carbonaceous material, and glauconite. Authigenic constituents mainly are calcite, syntaxial quartz overgrowths, kaolinite, illite, chlorite, and pyrite (Balke, 1984, p. 33).

TABLE I

LIST OF WELLS FROM WHICH CORES AND THIN SECTIONS WERE OBTAINED

WELL NAME	OPERATOR	Sec.	T	R
Rhodd No. 1	City Services Comp.	9	23N	1E
Coe-Bailey No. 1	Earth Energy Resources	11	17N	2E
Rogers No. 2	Ames Oil & Gas Comp.	13	22N	4E
Brien No. 3	A & W Production Comp.	26	23N	4E
Martin No. 1-8	Bandera Energy Comp.	8	22N	5E
Shields No. 3	Thompson-Tye Drlg. Co.	2	21N	5E
Buchanan No. 1	Perkins Production Co.	20	21N	5E

Formation-water Resistivity

Formation-water resistivity (Rw) in the Red Fork Sandstone of Payne County, seems to be fairly consistent. Most service companies have tabulated Rw values for various formations within specific areas. According to Gilchrist (1988), Rw values of the Red Fork Sandstone in and near Payne County range from about 0.037 to about 0.042 Ohm-m.

In order to test this information, data from published records of water produced from the Red Fork in Payne County were gathered. The sample size was small; information from only six different wells could be obtained. The six Rw values are 0.041, 0.040, 0.039, 0.040, 0.041, and 0.041 Ohm-m, at 100 degrees F. (U.S. Department of the Interior, 1957, and The Society of Petroleum Engineers AIME, 1975).

The average value from these six wells is 0.040 Ohm-m, at 100 degrees F. Because the data suggest that the variablility in Rw values is small, the factor that is likely to introduce significant variation in Rw from well to well is temperature. The average value of 0.040 Ohm-m (at 100 degrees F.) can be adjusted to different temperatures by using Figure 4.

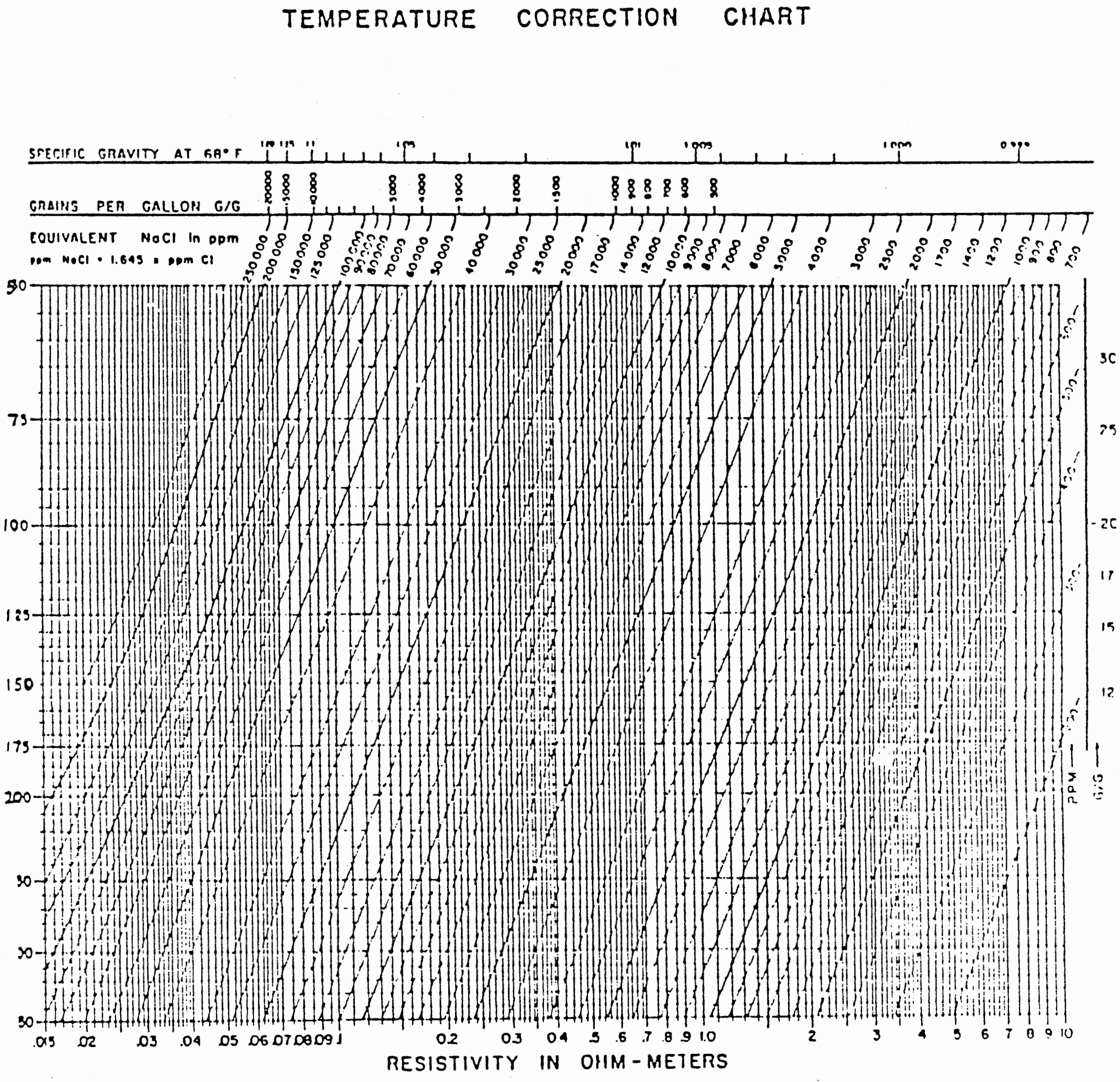


Figure 4. Temperature Correction Chart (Modified after Guyod and Pranglin, 1959).-To adjust Rw values for temperature, plot 100 degrees F. on the ordinate, and the average Rw value of 0.040 on the abscissa. Follow the diagonal trends until the desired temperature is reached, read adjusted Rw value from the abscissa.

CHAPTER IV

USING MODERN POROSITY TOOLS TO DETERMINE A PROBABILISTIC ESTIMATE OF POROSITY IN THE RED FORK SANDSTONE, PAYNE COUNTY

Introduction

Determining an accurate value of porosity was a serious problem for the logging industry, until the advent of modern porosity tools. When our predecessors analyzed old electric logs, porosity necessarily was estimated from core analyses, from records of nearby wells, drilling time, or bit cuttings -- or was calculated from the short normal curve or from the microlog. Many such estimates of porosity were unreliable.

To use present-day resources to minimize variables that could add large error to calculations of water saturation from old electric logs seems prudent. As mentioned previously, modern porosity logs (CNL-CDL) permit reliable estimates of porosity. If one restricts how data are selected, the general results can be improved. Wells that penetrated the Red Fork stratigraphic interval were selected "at random" from a population of wells in Payne

County. The Red Fork was sampled where it is thick and of "reservoir quality" (i.e. the sandstone shows evidence of being porous and permeable by "good" separation of the deep-induction, medium-induction, and laterolog curves, and "good" negative deflection of the SP curve). In brief, a specific facies of the Red Fork generally was sampled, the facies believed to be multistoried channel-fill sandstone. Data from this "random sample" were considered likely to yield statistical information that is representative of the population of supposed channel-fill facies of the Red Fork in Payne County.

Obtaining Porosity Data From the Logs

The compensated neutron-compensated density tool samples approximately at 6-inch intervals; resolution is about 2 feet. Quantities represented by the curves essentially are average values of 2-foot intervals. By averaging measurements of porosity 2 feet above and 2 feet below the depth of interest, one is more likely to isolate representative "true" porosity values. Data-points selected within the Red Fork Sandstone were selected so as to be at least 2 feet above or below detectable beds of shale. To insure that measurement of porosity was not affected significantly by gas is also important. The following guidelines should have insured a random sample of porosity from the so-called channel-fill facies of the Red Fork. Twenty-eight wells were selected, yielding 236 data points. Information from these wells included depth, zone, amount of density-porosity, neutron-porosity, cross-plotted porosity, and corrected density-porosity are shown in Appendix B.

Neutron porosity and density porosity were cross-plotted to correct for lithologic effect on CNL-CDL cross-plot chart (Gearhart) (Fig. 5). The fact became apparent that cross-plotted porosities were not free of the effects of shale. For example, many cross-plotted porosity points were located on or near the limestone line of the Gearhart CNL-CDL cross-plot chart (point "A" Fig. 6). Perhaps small quantities of calcite and/or dolomite cement could drive the cross-plotted porosities toward the limestone line, but inspection of cores indicated only minute quantities of carbonate cement within the Red Fork Sandstone. However, thin interbeds and clasts of shale are numerous (Appendix A), which would move cross-plotted porosity toward the "shale point" ("Box" in Fig. 6). Therefore, correction of either neutron porosities, density porosities, or cross-plotted porosities is necessary.

Correction of Density Porosity

If the neutron and density curves are shown as being superimposed, then the logging tools have evaluated a material that produces the same effects as the matrix upon which the tools were calibrated, provided that the interval is 100 per cent water-saturated. All porosity logs used

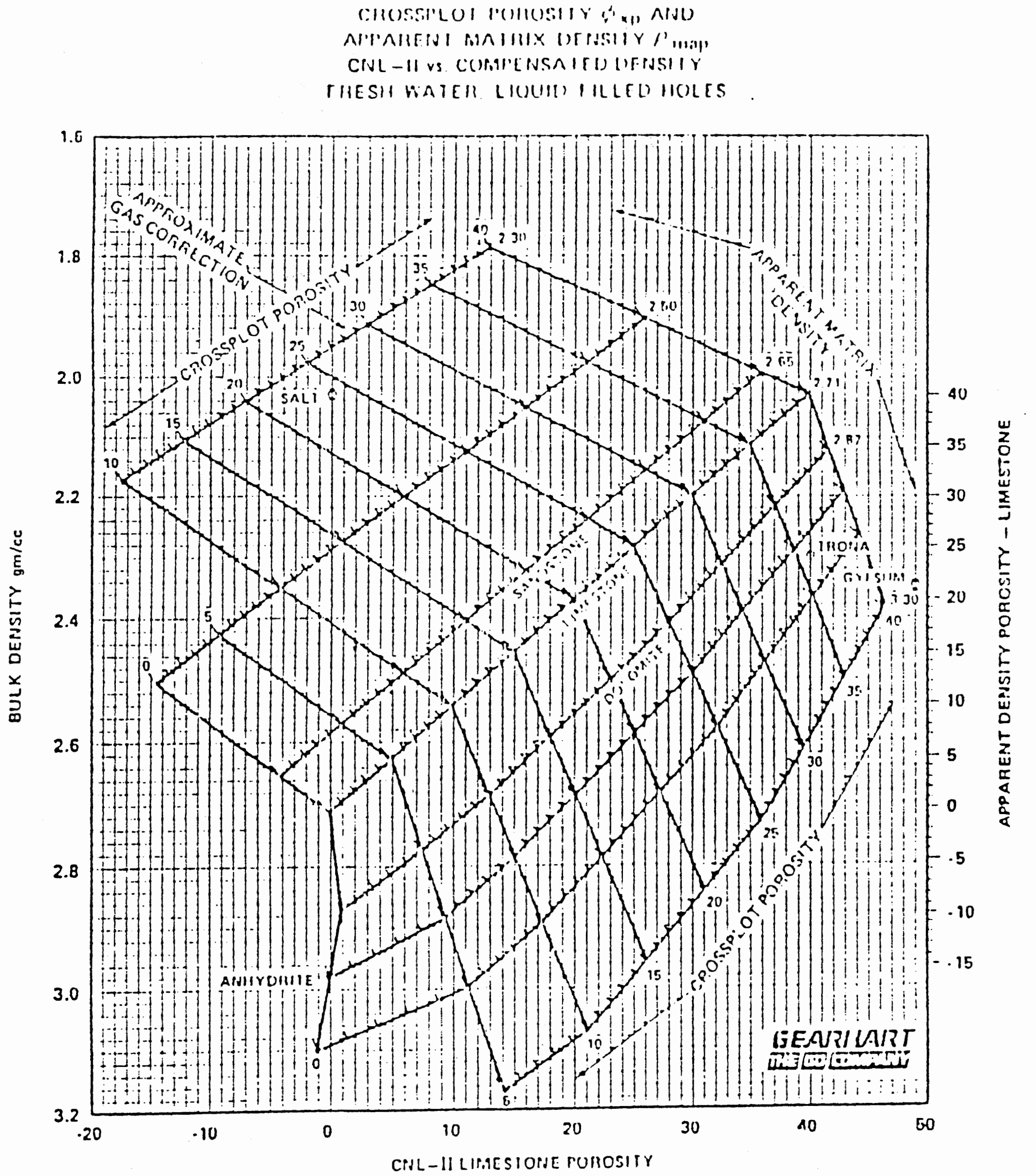


Figure 5. Compensated Neutron-Compensated Density Cross-plot Chart (From Gearhart Chart Book, Undated).

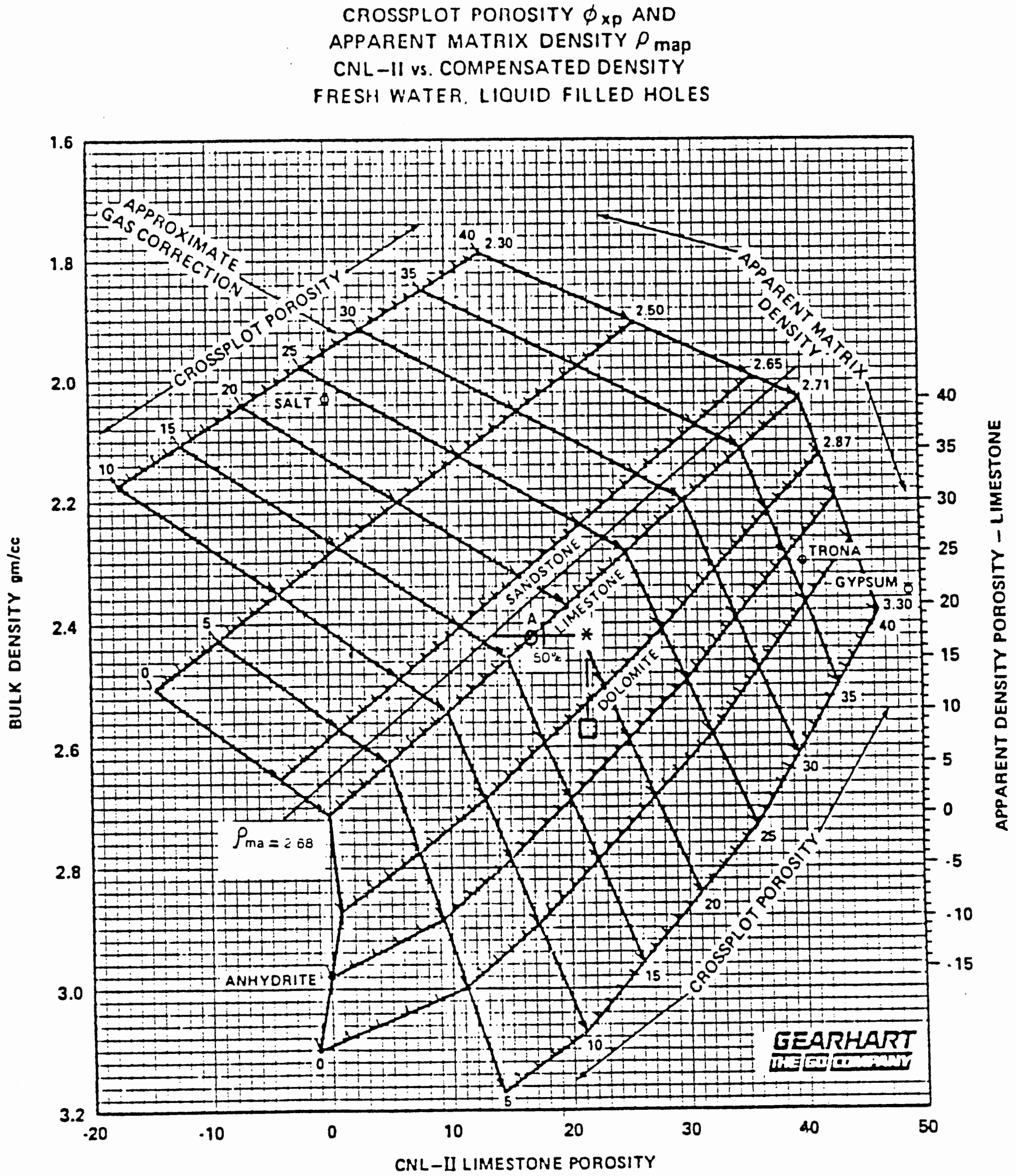


Figure 6. Compensated Neutron-Compensated Density Cross-plot Chart Showing Porosity data From Coe-Bailey No. 1 (Modified After Gearhart Chart Book, Undated).

were based on limestone-matrix calibration at 2.71 gm/cc. If the neutron and density curves are superimposed in a stratigraphic section that is known to be sandstone, if the rock is known not to include limestone, but to include shale, and the rock is known to be 100 per cent water-saturated, then the stacking of the curves is almost certainly due to shale.

Figures 7 and 8 show a dual induction-laterolog and compensated neutron-compensated density logs of the Earth Energy Resources, Coe-Bailey No. 1 in Payne County, Oklahoma. In the interval centered upon 4286-90 ft., the neutron and density curves essentially are stacked (Fig. 8). Inspection of the induction log indicates that this interval should be close to 100 per cent water saturated (Fig. 7). If one cross-plots the neutron and density values from this zone, they plot as limestone (Point "A" in Figure 6).

If one assumes that shale overlying the Pink Limestone (4144-4160 ft.) is similar to shale in the general Red Fork interval (Figs. 7 and 8), then convergence of the density-porosity and neutron-porosity curves can be explained satisfactorily. On the average, neutron and density values in this section of shale are 0.215 and 0.08 respectively (Fig. 8). The neutron and density porosities from the shale interval are plotted in Figure 6 as the "Box".

The cross-plotted porosity value from the sandstone (Point "A") has been moved in some vector component from

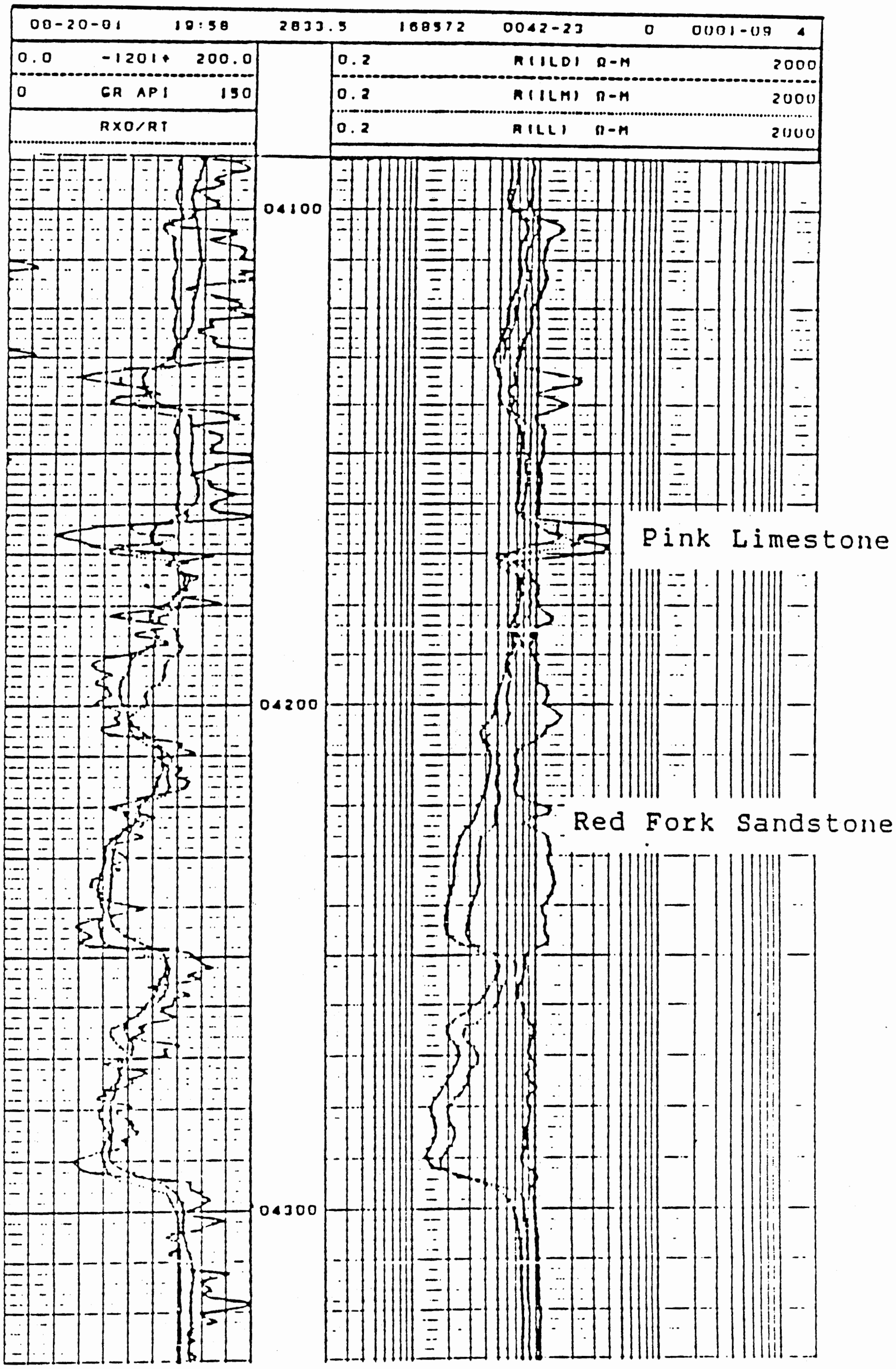


Figure 7. Dual Induction Laterolog From Earth Energy Resourcs, Coe-Bailey No. 1 (2310'FSL, 255'FWL, Sec. 11, T17N, R2E).

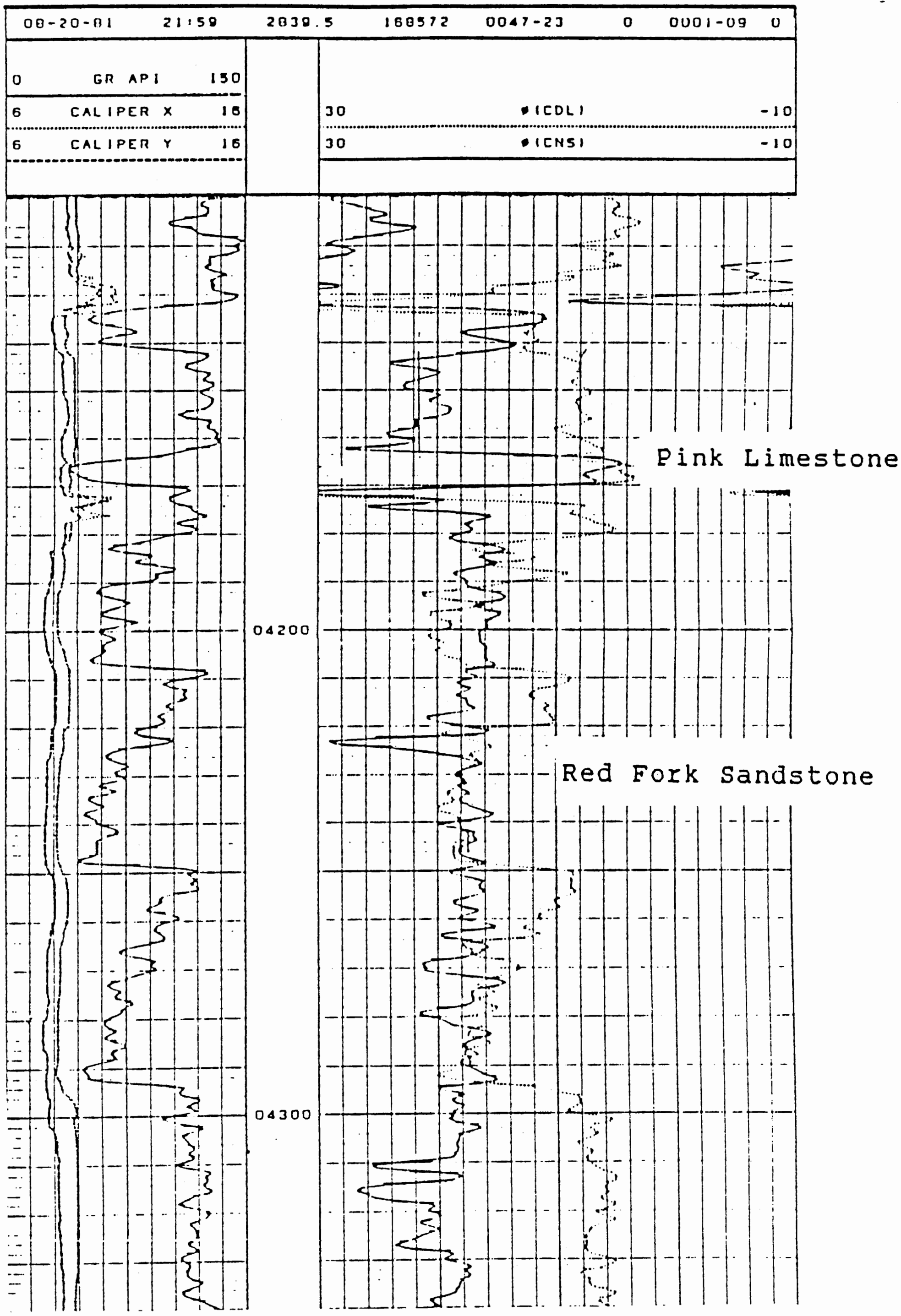


Figure 8. Compensated Neutron-Compensated Density Log From Earth Energy Resources, Coe-Bailey No. 1 (2310'FSL, 255'FWL, Sec. 11, T17N, R2E).

the sandstone line (Fig. 6). Hypothetically, if the shale point ("Box") were moved vertically, to a position laterally equivalent to the sandstone point ("A"), the position of the shale point would represent 100 per cent shale in terms of neutron porosity ("*" on Fig. 6). Therefore, point "A" indicates that some fraction of the rock is shale or clay. The percentage and type of shale (clay) are not determinable by this method. The clay may be interbedded with sandstone, authigenic, or both. If point "A" is moved laterally to the appropriate matrix-density value (2.68 gm/cc), density porosity is corrected to sandstone, but no correction for the effects of shale is made (Fig. 6). (The matrix density of the Red Fork Sandstone is approximately 2.68 gm/cc (Gilchrist, 1987, personal communication)). A matrix density line of 2.68 gm/cc is shown in Figure 6.

Obtaining probabilistic estimates of shale-corrected porosity values within the Red Fork Sandstone is not desired for the purpose of this research. Information gained from modern porosity logs will be used to "check" values of resistivity-derived porosity from analyses of old electric logs. Because shale-correction of resistivity-derived porosity is not possible, to compile probabilistic estimates of shale-corrected porosity within the Red Fork would not be consistent with the experiment. Correction of density porosity by adjustment to the average matrix density of the Red Fork should yield data that are useful for direct comparison with porosity deduced from old electric logs.

Summary Statistics

A sample comprising 236 observations of corrected density porosity shows the following summary statistics: $\overline{Y}$ = 15.08%, s = 2.07%, g(1) = .120336 (n.s.) and g(2) =

produced D-max = 0.04678 (experimental); the critical value is 0.05767. Thus, no compelling reason exists for rejecting the hypothesis that corrected density porosity values from the Red Fork Sandstone were drawn from a population that is normally distributed. Summary statistics and a histogram of the corrected porosity values are shown in Figure 9.

The statistical values of corrected density porosity, obtained from the process above, can be used in the analyses of old electric logs. The mean value can be used, or a "range" of porosity values can be used. Because the mean value of corrected density porosity is 15 per cent and the standard deviation is 2, then approximately 95 per cent of porosity values in "reservoir quality" Red Fork Sandstone should lie between ($\overline{Y}$ + 2s and $\overline{Y}$ - 2s). Therefore, 95 per cent of the porosity values should lie between 11 to 19 per cent. Actual use of these porosity values is explained in Chapter XI.

SUMMARY STATISTICS

n = 236 $\overline{Y}$ = 15.08%

s = 2.07%

g(1) = 0.120336 (n.s.) g(2) = 0.00182 (n.s.)

D-max = 0.04678 (experimental)

Critical Value = 0.05767

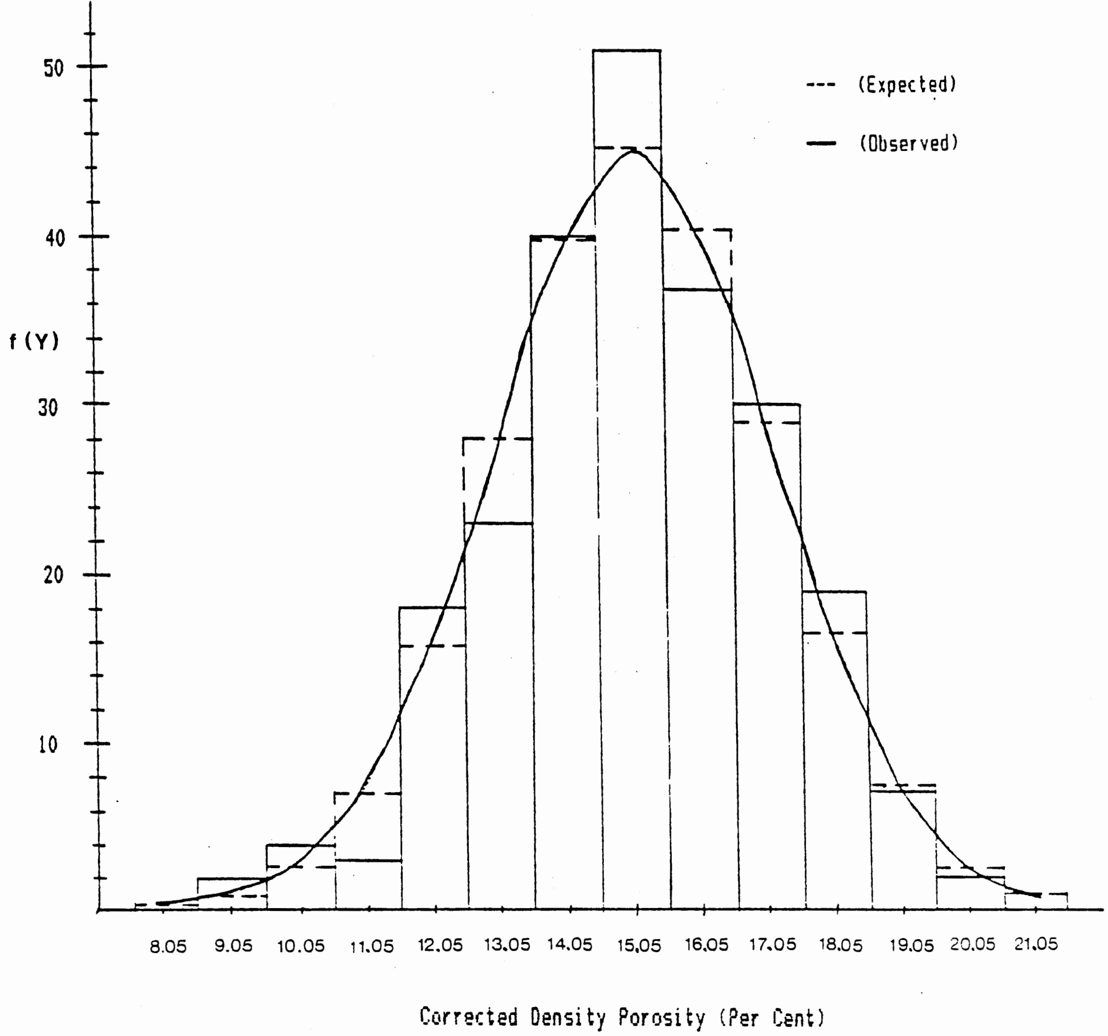


Figure 9. Histogram and Summary Statistics of Corrected Density Porosity, Red Fork Sandstone, From Wells in Payne County, Oklahoma.

Porosity and Formation Factor

Other than data obtained from the logs themselves, the geologic parameter needed is formation resistivity factor (F). The formation resistivity factor is equal to the resistivity of a rock saturated with a conductive fluid divided by the resistivity of the saturating conductive fluid (F = Ro/Rw) (Archie, 1941). As a consequence, the resistivity of the rock itself is desired; this is a function of rock-type and porosity -- more importantly the interconnected porosity.

A variety of "general" formation factors have been derived by log analysts over the years (Table II). the value of (F) that commonly is used in the study area for the Red Fork Sandstone, is F = ((0.81)/(porosity)^ 2.0). This formation resistivity factor was used in this research for calculations of water saturation.

TABLE II

SOME COMMON FORMATION FACTORS

$F = 1/(\text{Porosity})^{2.0}$	For Carbonate Rock
$F = 0.81/(\text{Porosity})^{2.0}$	For Consolidated Sandstones
$F = 0.62/(\text{Porosity})^{2.15}$	Humble Formula for Unconsolidated Sands
$F = 1.45/(\text{Porosity})^{1.54}$	For Average Sands (After Carothers, 1958)
$F = 1.65/(\text{Porosity})^{1.33}$	For Shaly Sands (After Carothers, 1958)
$F = 1.45/(\text{Porosity})^{1.70}$	For Calcareous Sands (After Carothers, 1958)

Table II--Modified After Asquith, 1982

CHAPTER V

THE LATERAL CURVE

Introduction

The lateral log was one of the first resistivity logs used by the Schlumberger brothers. It is a deep-investigation tool and among the "old" logs is the best indicator of "true" resistivity of the formation (Rt), provided that the bed in question is thick enough. The basic electrode arrangement of the lateral device is outlined in Figure 10. The two diagrammatic spheres, at distances L and L + dL from A, are surfaces of constant potential or voltage (Fig. 10). Any voltage change recorded between these two spheres is due to a change in the resistivity of the material (formation) being measured.

The depth of investigation of the lateral tool is equal to the distance between the emitting electrode (A) and the midpoint between the measuring electrodes (M and N) (Fig. 10). The midpoint between M and N is denoted as O. The electrode spacing and the depth of investigation are known as the AO spacing. The depth-reference point is O, the point where resistivity is recorded on the log. The most common AO spacing was the 18-foot 8-inch lateral,

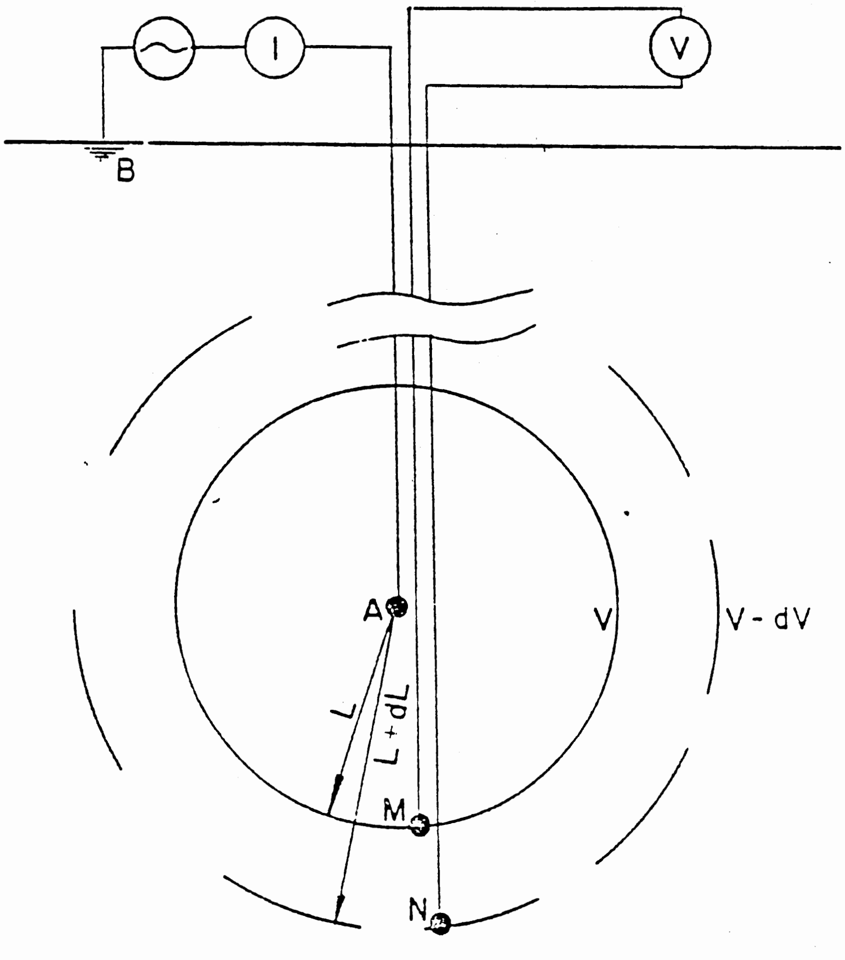


Figure 10. Lateral Electrode Array (Modified After Hilchie, 1979).

although 5, 6, 7.5, 9, 13, 15, 16, and 24-foot spacings were used (Hilchie, 1979, p. 23). Variation of electrode spacings was a function of service company, area, and time period. Because the 18-foot 8-inch lateral was the most common, the following correction charts and figures apply to that electrode spacing.

"Typical" Lateral Curve Signatures

The lateral curve was used for years before its asymmetry in beds of constant resistivity was documented (Hilchie, 1979, p. 23). In a thick, resistive bed of "constant" resistivity, the common lateral signature shows peak resistivity near the bottom of the bed (Fig. 11). Slightly above the top of the bed is a "notch" of lower resistivity; below this (one AO distance) is a transition zone known as the decay zone. Within the decay zone, the tool is influenced by the formation directly above the bed in question. Therefore, readings of the tool in the decay zone are erroneous. The magnitude of resistivity in the decay zone is proportional to the contrast between resistivities of the formation being analyzed and the overlying formation.

This description of a "typical" lateral curve signature is limited to a thick bed of consistent resistivity. A thick bed is defined as being greater than twice the AO spacing (for an 18-foot 8-inch lateral, a bed thicker than 37 feet).

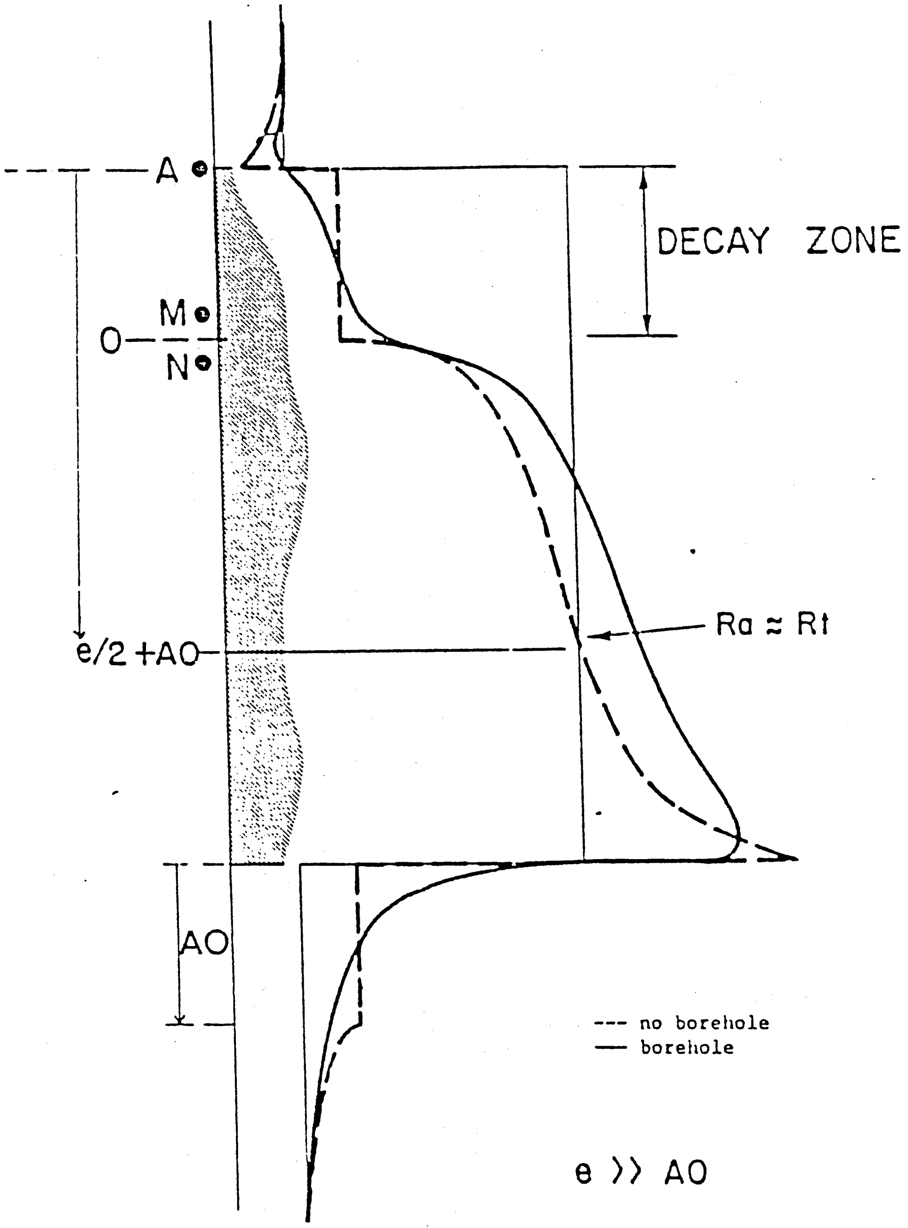


Figure 11. "Typical" Lateral Signature (e >> AO) (Modified After Hilchie, 1979).

Influence of Bed-thickness and Adjacent Beds

The lateral curve is affected strongly by adjacent beds. As a result, the thickness of the bed in question is a matter of exceptional importance. In beds thicker than twice the AO spacing, the influence of adjacent beds is negligible, provided that the contrast in resistivity is not great. It is also important to note that in a thick bed, the notch at the top and the peak at the bottom are displaced upward a distance equal to one-half the MN spacing (Hilchie, 1979, p. 23). For an 18-foot 8-inch lateral, one-half the MN spacing is equal to 16 inches (Fig. 12).

As thickness of a resistive bed decreases, the lateral signature is modified slightly. It appears as if the reduction in thickness is taken from the center of the bed (Figs. 11 and 12). As a resistive bed approaches the AO spacing in thickness, a peak becomes detectable at a distance of one AO spacing below the primary peak (Fig. 12). This peak is known as the "reflection peak." A zone of low resistivity underlies the primary peak; this is the "blind zone" or "dead zone" (Fig. 13). Magnitudes of the reflection peak and of the low resistivity in the blind zone are proportional to contrast in resistivities between the bed being analyzed and the adjacent beds (Fig. 13). As a resistive bed approaches the AO spacing in thickness

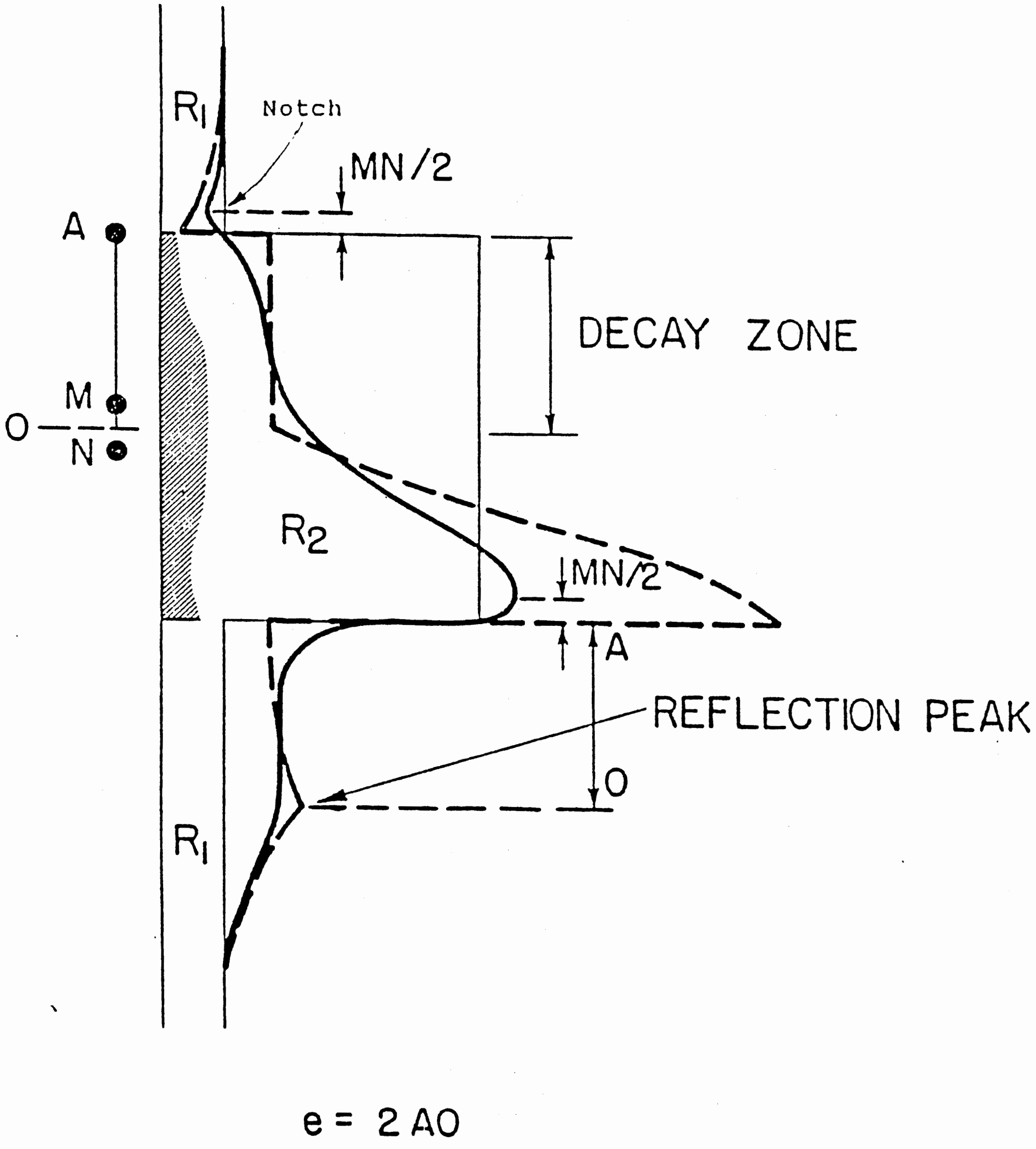


Figure 12. "Typical" Lateral Signature (e = 2AO) (Modified After Hilchie, 1979).

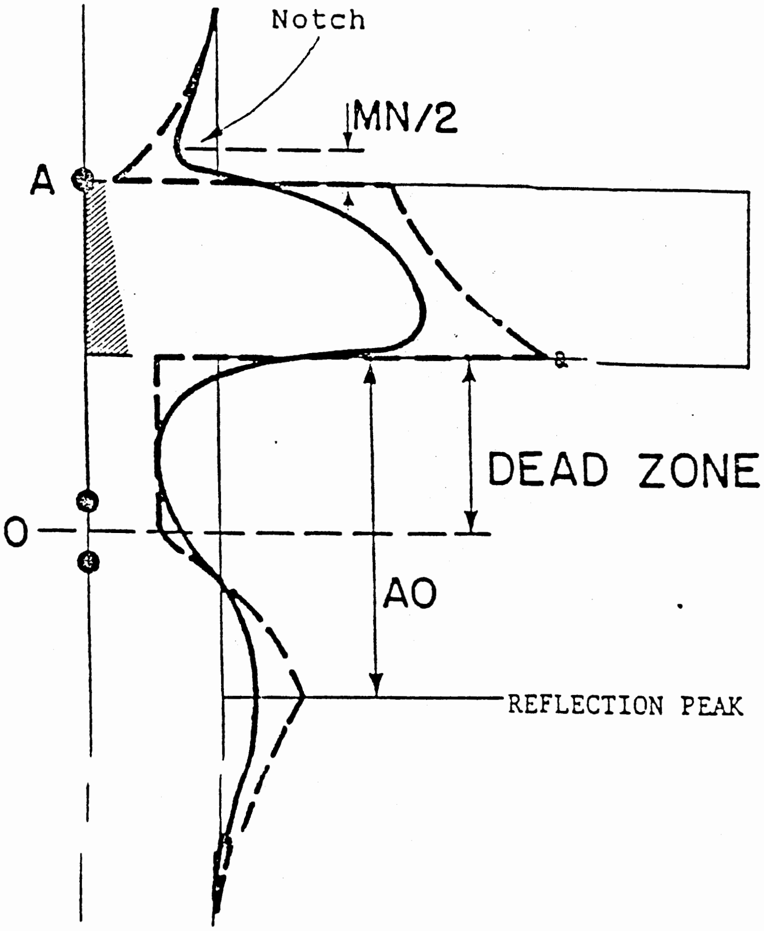


Figure 13. "Typical" Lateral Signature (e < AO) (Modified After Hilchie, 1979).

(known as the critical thickness), the lateral signature becomes merely a peak, with a reflection peak directly below the dead zone (Fig. 13). Unlike thick beds, beds thinner than the AO spacing are "on depth"; there is no upward displacement of the lateral signature. These thin resistive "spikes" are useful for determining the AO spacing in instances where it is not recorded on the header. The distance between the bottom of the primary peak and the crest of the reflection peak is equal to the AO spacing (Figs. 12 and 13).

Borehole and Mud Influences

Thickness of the bed being analyzed and the effects of adjacent beds are directly related. The second major influencing factor on the lateral-log signature is the diameter of the borehole. As the diameter increases, the volume of drilling mud that is incorporated in the lateral's resistivity measurement increases. This tends to reduce the sharpness of the signature, obliterating the notch at the top and rounding the peak at the bottom. The influence of borehole diameter is exemplified in Figure 14. The effects of borehole size on the lateral-log signature are strongly similar to the effects of decreased resistivity of mud (Hilchie, 1979, p. 23). Homogeneity of drilling mud is required for accurate interpretations of electric logs. Just as bed thickness and adjacent bed effects are related, so are borehole influences and mud

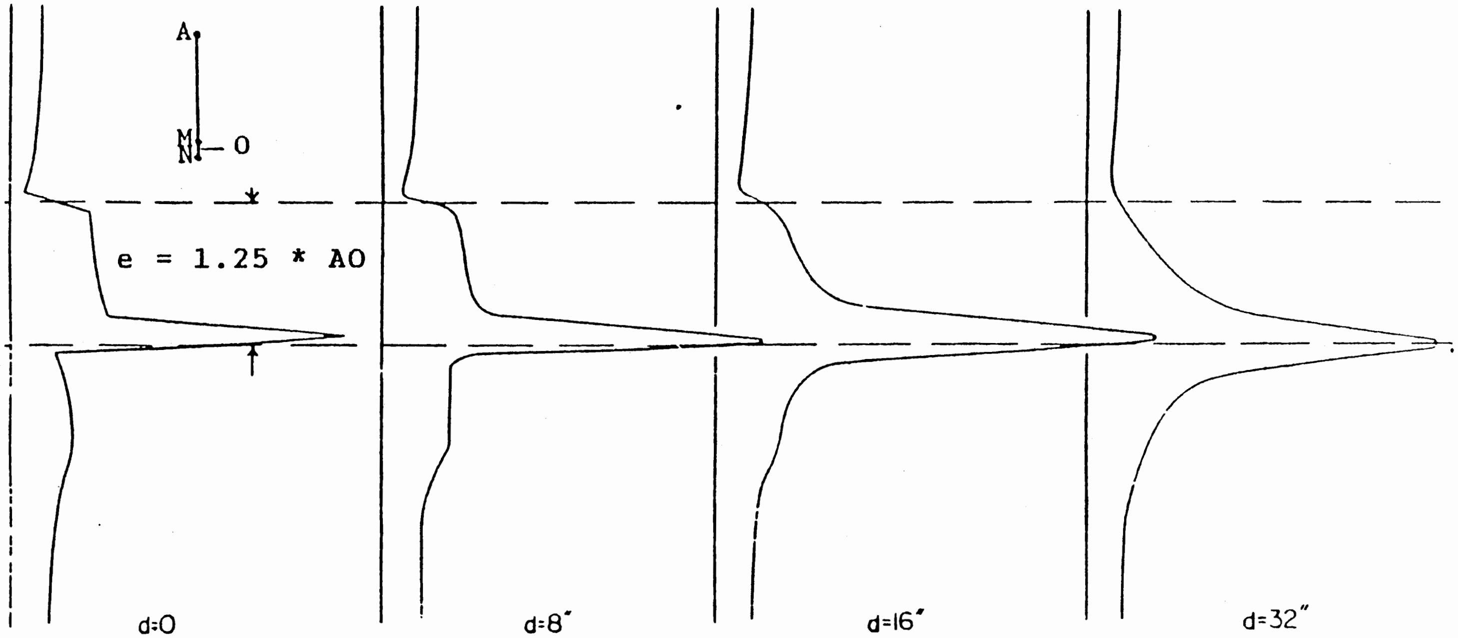


Figure 14. Borehole and Mud Influences on the Lateral Signature (Modified After Hilchie, 1979).

properties. Empirical evidence indicates that optimal conditions for accurate resistivity readings occur when Rm is approximately five-times Rw (Frank, 1986, p. 23).

CHAPTER VI

THE NORMAL CURVE

Introduction

The normal curve was introduced by Schlumberger in order to overcome the problem of asymmetry of the lateral curve (Hilchie, 1979, p. 43). The normal electrode array, referred to as AM, operates in a fashion similar to that of the lateral (Fig. 15). Electric current is emitted from the A electrode and voltage drop is measured between the M and N electrodes. The M and N electrodes are separated by a very large distance (Fig. 15). All material between the M and N electrodes do not have equal influence on the measurements. Material close to the current-emitting electrode (A) has much greater effect on the resistivity measurements than does material farther away. The normal curve is said to have a depth of investigation equal to twice the AM spacing (Hilchie, 1979, p. 44).

A variety of spacings for the normal curve has been used by various service companies. Commonly the sonde has two normal arrays: the "short normal" and the "long normal". Some of the rather common spacings used over the years have been 8, 10, 16, 18, 38, 40, 63, 64, 79, and 84

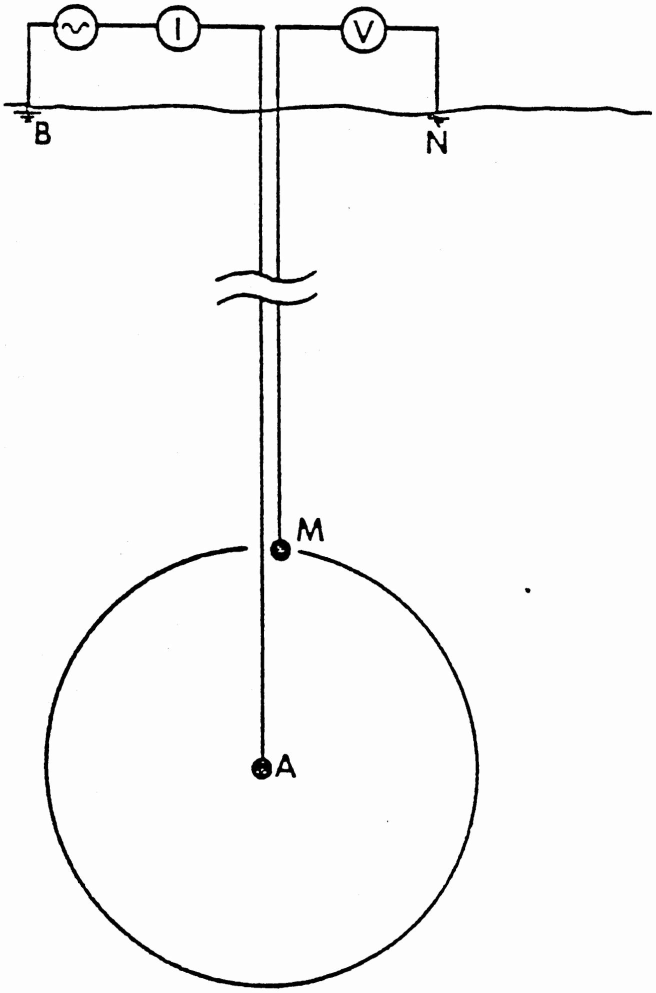


Figure 15. Normal Electrode Array (Modified After Hilchie, 1979).

inches (Hilchie, 1979, p. 44). The most common spacings were the 16-inch short normal and the 64-inch long normal. The short normal, long normal, and the lateral are the three resistivity curves recorded on most of the "old" electrical logs. In the course of this research, these electrode spacings were the only ones studied. All correction charts that were compiled in this research are for this suite of resistivity curves and spacings.

"Typical" Normal Curve Signatures

In a "homogeneous" formation, the normal curve shapes are symmetrical, in contrast to shape of the lateral curve. Figure 16 is an example of a typical normal signature for a resistive bed that is much thicker than the AM spacing (Fig. 16). As in the case of the lateral, bed thickness affects the shape of the normal curve. As thickness of a resistive bed decreases, the curve becomes predominantly a peak (Fig. 17). Where the bed thickness approaches the AM spacing (which is known as the "critical thickness"), the peak seems to "disappear" or "flatten out". If a resistive bed is thinner than the AM spacing, the normal curve shows a "crater" (Fig. 18).

Determination of Bed Thickness

In beds thicker than the AM spacing, the normal curve gives the illusion that a bed is thinner than it actually is (Fig. 16). "Notches" may be above and below the bed in

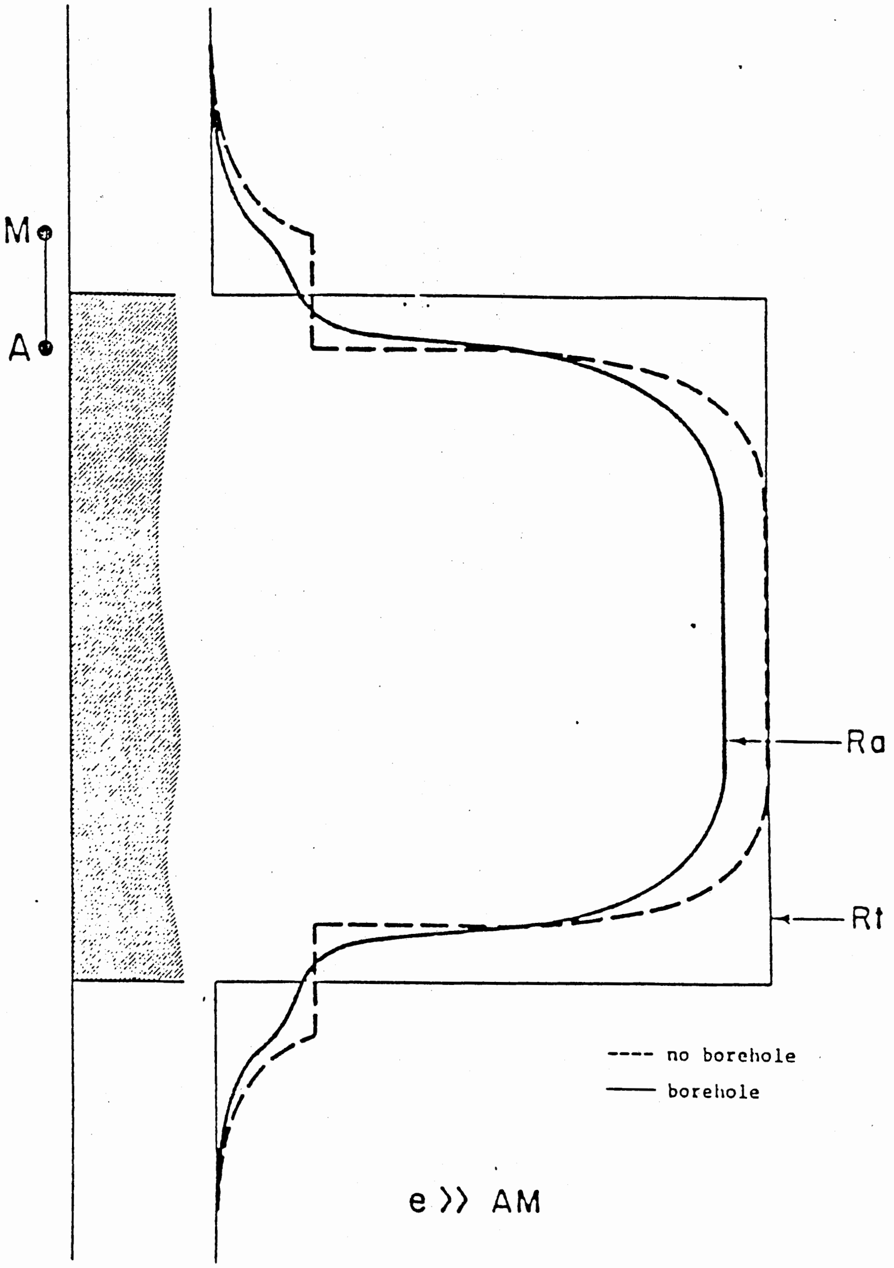


Figure 16. "Typical" Normal Signature (e >> AM) (Modified After Hilchie, 1979).

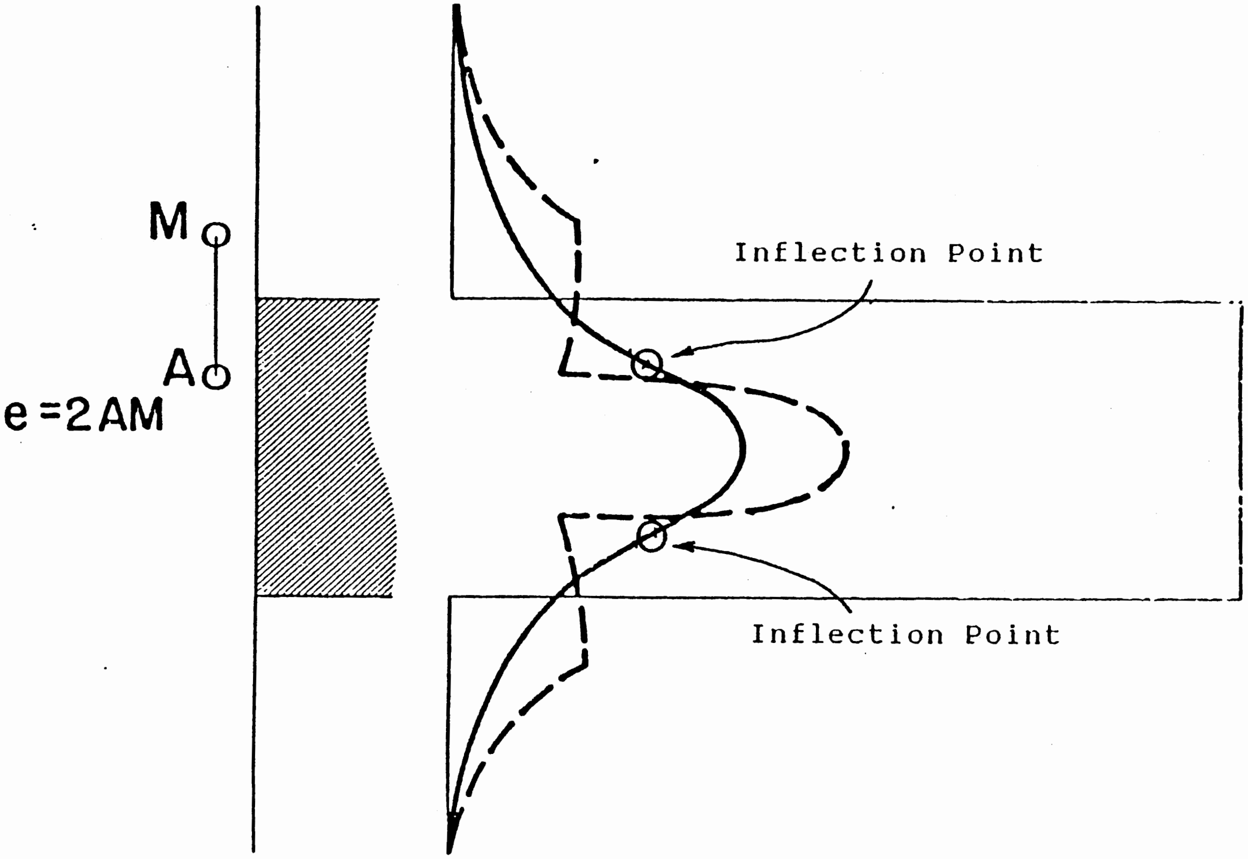


Figure 17. "Typical" Normal Signature (e = 2AM) (Modified After Hilchie, 1979).

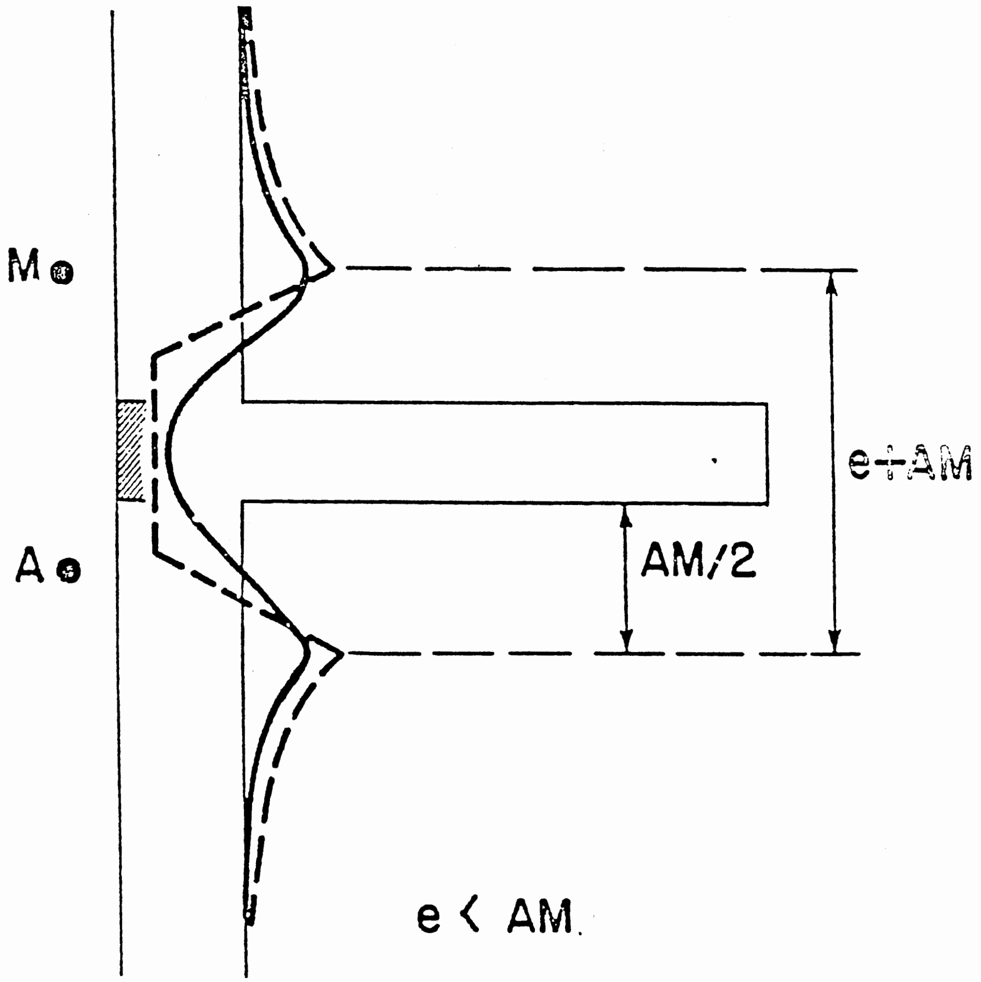


Figure 18. "Typical" Normal Signature (e < AM) (Modified After Hilchie, 1979).

question (Fig. 16). To determine the actual boundaries, simply move vertically (upward for the upper boundary and downward for the lower boundary) a distance of one-half the AM spacing (Fig. 16). In most instances, the notches above and below the bed will not be apparent (Fig. 17). In such a case, find the two inflection points and move vertically (upward for the upper boundary and downward for the lower boundary) a distance of one-half the AM spacing (Fig. 17).

Where beds are thinner than the AM spacing, beds appear thicker than they actually are. Bed boundaries can be located by moving one-half the AM spacing (downward for the upper boundary and upward for the lower boundary) from the two "shoulders" (Fig. 18).

Borehole and Mud Influences

As borehole size increases or mud resistivity decreases, the normal curve becomes less sharply defined. In most cases, the "notches" above and below resistive beds are unnoticeable. This phenomenon is exemplified in Figure 19.

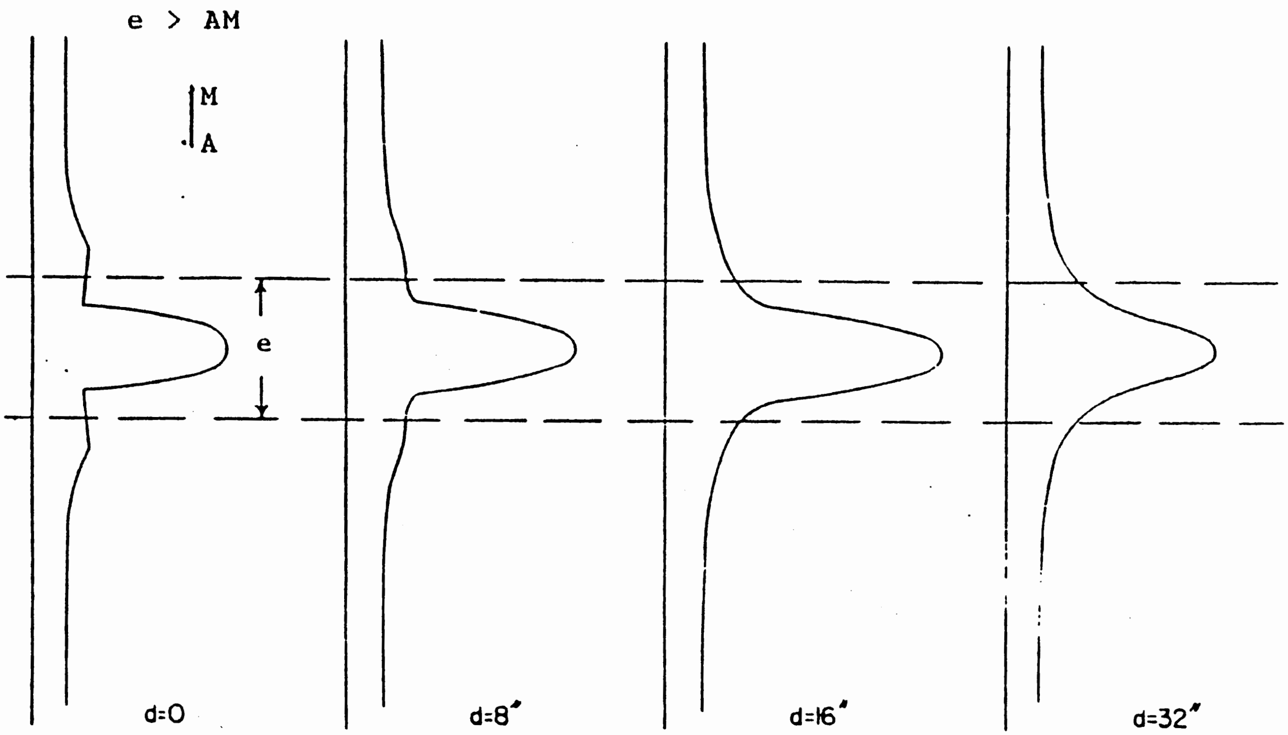


Figure 19. Borehole and Mud Influences on the Normal Signature (Modified After Hilchie, 1979).

CHAPTER VII

ESTIMATING APPARENT RESISTIVITY FROM THE NORMAL AND LATERAL CURVES

Introduction

"Apparent resistivity" (Ra) merely is the value read from the log, without correction for borehole influences, bed thickness, adjacent bed effects, or invasion. Apparent resistivity values are recorded by the short normal, long normal, and lateral curves; these are denoted by Ra(sn), Ra(ln), and Ra(lat). In measurement of apparent resistivity, normal curves are much easier to work with than the lateral curve. To pick an apparent resistivity value from either of the normal curves, merely read the peak value located in the "center" of the bed or zone of interest (Fig. 20). For the normal curves, the peak value may not be at the center of the bed. This circumstance probably is due either to contrasting resistivities of adjacent beds (above and below the bed of interest), varying amounts of oil/gas within the formation, variations in porosity, or variation in shale content. Picking apparent resistivities under these conditions is still fairly straightforward; pick the peak value wherever one

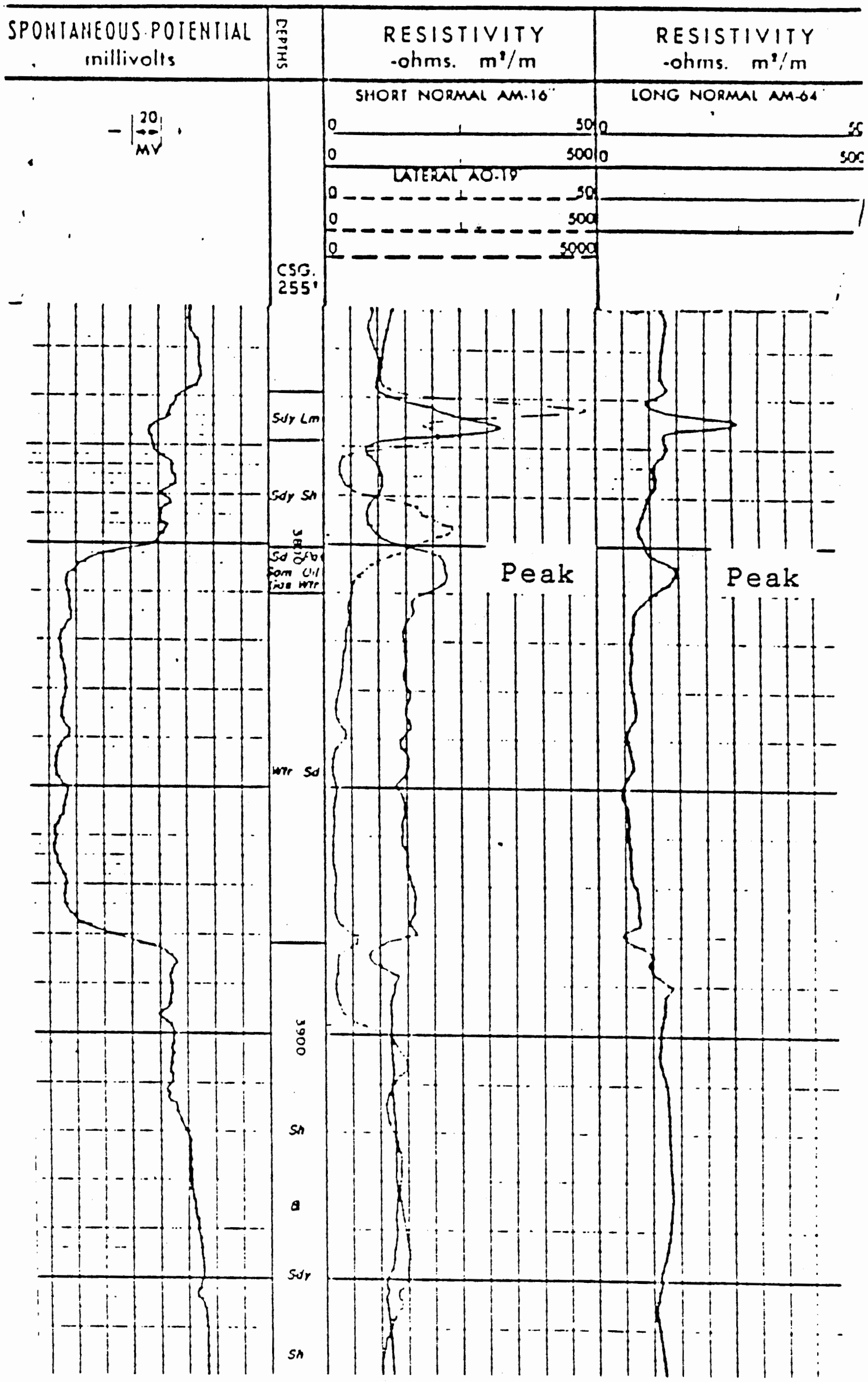


Figure 20. Texas Pacific Coal & Oil Company, Story No. 3 (Sec. 1, T17N, R3E), Showing Peak Resistivity Values in Center of the Zone of Interest (3800-3810 ft.).

occurs, or average the multiple peak values.

The Lateral Curve

The "typical" lateral signatures discussed in Chapter V, apply to resistive, homogeneous sandstones encased in a homogeneous formation, normally referred to as "shale" (Figs. 10, 11, and 12). These hypothetical resistive formations are homogeneous in that they have consistent porosity and permeability throughout; the amount of oil/gas is also consistent throughout. Changes in the morphology of the lateral-curve signature under "homogeneous" conditions primarily is due to bed thickness (e). If the formation of interest has detectable shale breaks, resistive "streaks" (commonly thin beds of limestone), impermeable zones, oil-water contacts, transition zones, or is not encased in homogeneous "shales", then the lateral signature will be quite different. Therefore, bed thickness commonly is not the only factor to be considered when obtaining apparent resistivity from the lateral curve. In order to get an understanding of points from which to take the apparent resistivity values from the lateral curve, one first must learn three different methods for obtaining Ra(lat) under "homogeneous" conditions.

Rop, Rat, and Rl or R(peak)

Various recommendations have been published concerning the position on the lateral curve from which to record the

Ra(lat) value. The Ra(lat) value used on various correction charts is of three types: Rop (used primarily by H. Guyod), Rat, and Rl or R(peak) (Hilchie, 1979, p.32). The Rop (optimum) value is obtained when the lateral tool is centered with respect to the bed. In other words, find the "center" of the bed in question, and move one-half the AO spacing downward; read this value from the lateral curve (Fig. 21). Rat (apparent true) value is obtained when the sonde is in a specific position within beds of specific thicknesses (Fig. 21 and 22). Rl or R(peak) is read from near the base of a resistive bed, regardless of thickness. This is where the peak or maximum value is located in a "homogeneous" formation (Fig. 21).

Determination of Rat

Values of Rat apply to "homogeneous" formations and are dependent on bed thickness (e). Four methods are used by which to estimate Rat. The following explanation can be clarified by reference to Figure 22.

The Mid-point Rule. For beds that are equal to or thicker than twice the AO spacing (for an 18-foot 8-inch lateral, thicknesses of 37 feet or more): Find the center of the bed and move one AO distance downward. Read the resistivity value from the lateral curve (Fig. 22).

The Two-thirds Rule. This rule applies to beds approximately as thick as 1.5 times the AO spacing (for an

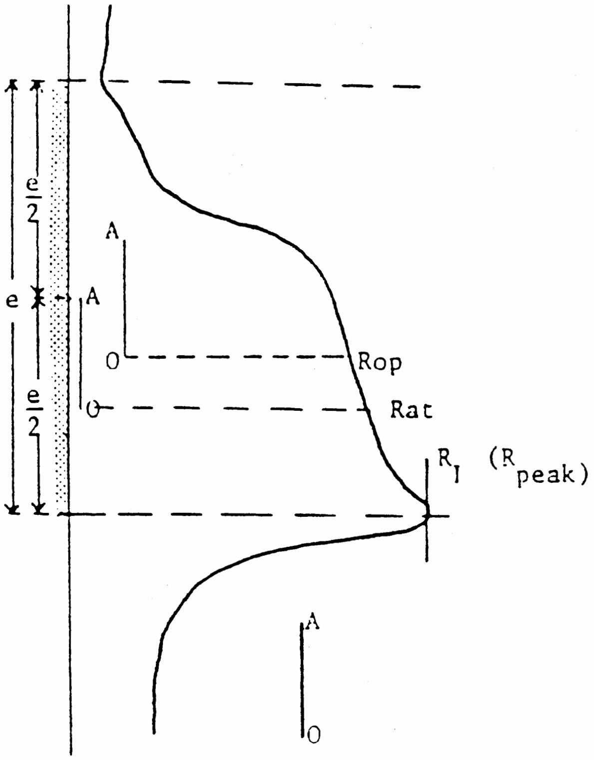


Figure 21. Diagrammatic Illustration Showing the Difference Between Rop, Rat, and R1 or R(peak), Where e >> AO (Modified After Hilchie, 1979).

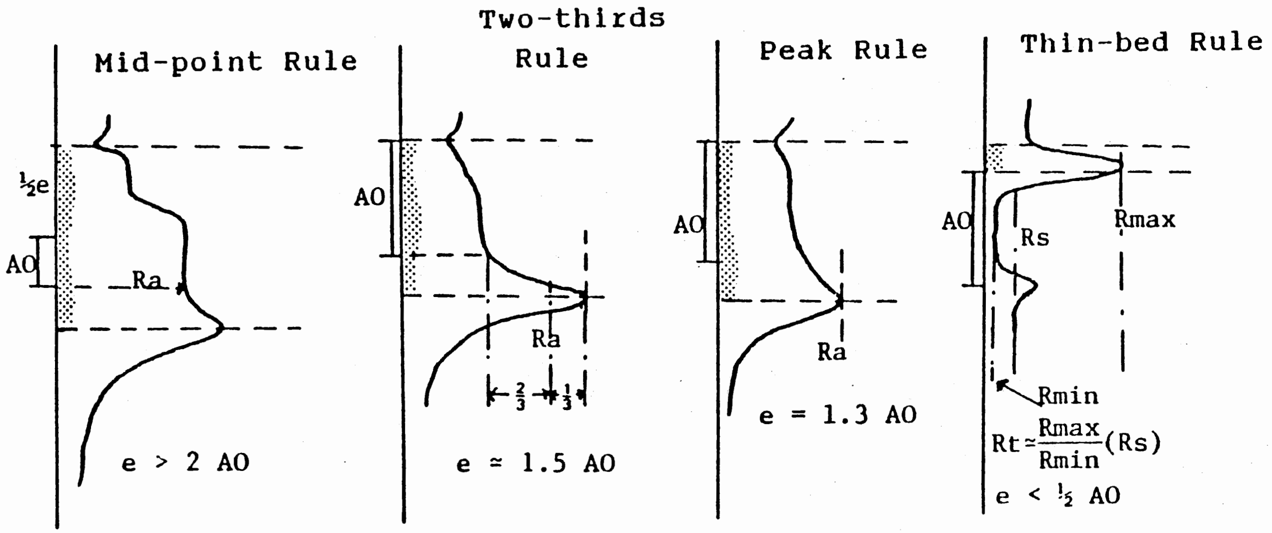


Figure 22. Rat Rules for Determining "Apparent True" Resistivity From the Lateral Curve (Modified After Schlumberger, 1955).

18-foot 8-inch lateral, thicknesses of approximately 28 feet). From the top of the bed, move downward one AO spacing and find that point on the lateral curve. From this point, draw a line parallel to the central depth track of the log, to intersect the lower bed boundary (Fig. 22). From the peak value near the base of the bed, scale the horizontal distance along the base of the bed (Fig. 22). The Rat value is recorded as being two-thirds of the distance from the pencilled vertical line toward the peak value (Fig. 22).

The Point Rule. In beds that are as thick as approximately 1.3 times the AO spacing (approximately 24 feet), the Point Rule is appropriate. Use the peak value obtained from near the base of the resistive bed (Fig. 22).

The Thin Rule. Where beds are thinner than the AO spacing (thinner than 18 feet 8 inches), the Thin Rule should be used. Values needed from the log are the maximal or peak value (Rmax), the minimal resistivity in the dead zone (Rmin), and resistivity of adjacent beds (generally shales) (Rs). In beds thinner than the AO spacing, Rat can be approximated from the formula (Rmax/Rmin) * Rs (Fig. 22). Note that this estimate is only a basic approximation.

The rules for Rat apply straightforwardly to formations of various thicknesses, but one can easily see that transitional thicknesses could be problematic. A chart has been devised (Hilchie, 1979, p. 32) to make the choosing of a rule easier (Fig. 23). For bed thicknesses that fall directly between two rules (e.g. 27 feet), one should estimate Rat value by each rule and use limiting values of Rat (express Rat value to lie between a "high" and "low" range).

Examples of Estimating Rt

Introduction

At this juncture the use of logs from the study area should be effective for hueristic purposes. Log signatures of the Red Fork Sandstone are quite different from the "homogeneous" signatures previously discussed. Therefore, the procedure for taking Ra values from the logs necessarily are subjective.

Texas Pacific Coal & Oil Company, Story No. 3

Figure 24 shows the log of the Texas Pacific Coal & Oil Company, Story No. 3, in Sec. 1, T17N, R3E, Payne County, Oklahoma. Thick Red Fork sandstone is bounded above and below by sandy shales (Fig. 24). The Red Fork has an extensive transition zone, seemingly being very close to 100 per cent water-saturated near the base, decreasing in water saturation (or increasing in saturation of oil and/or gas) upward, with an oil/gas column in the

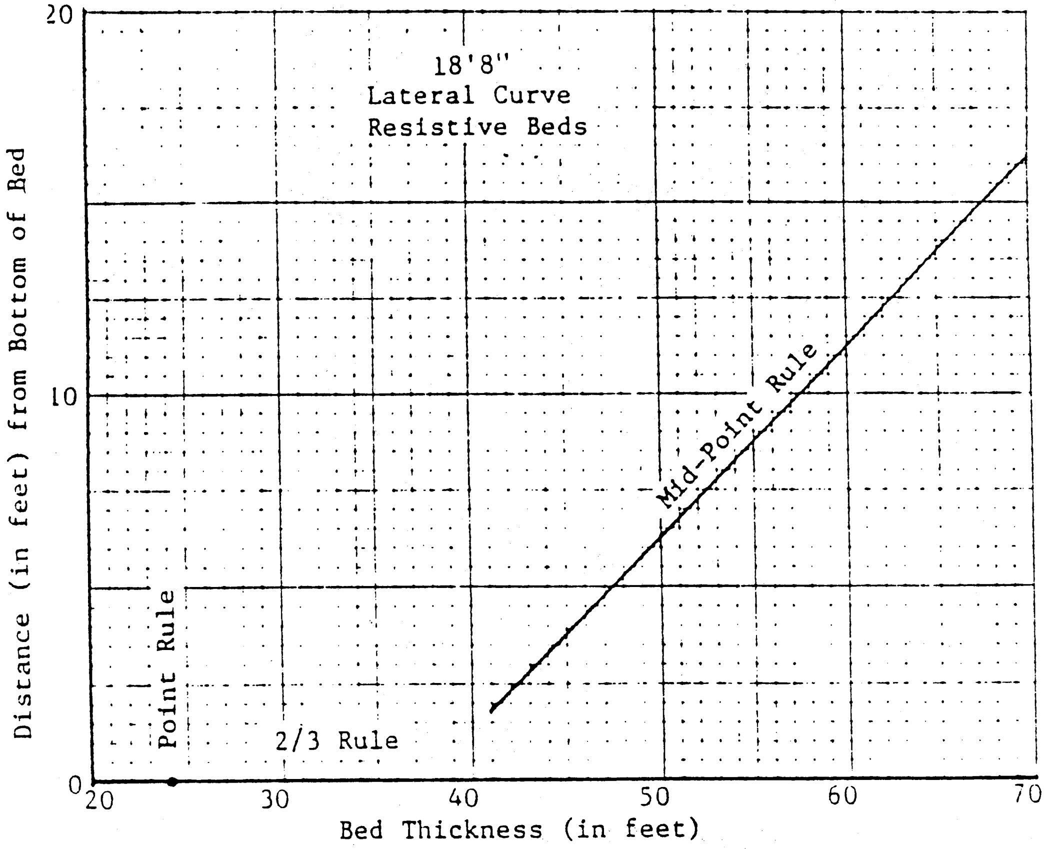


Figure 23. Chart to Help Determine Which Rat Rule to Use (After Hilchie, 1979).

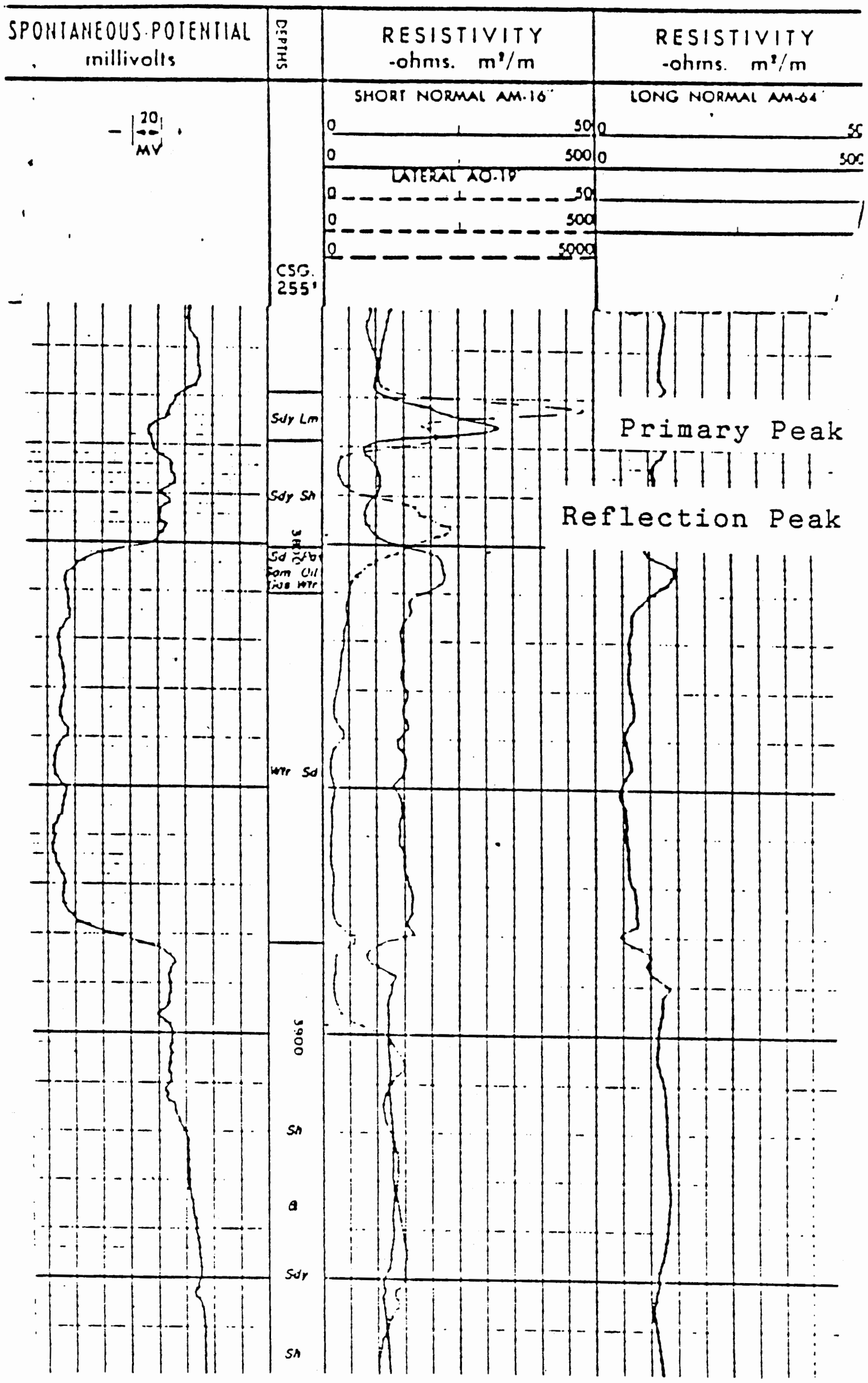


Figure 24. Texas Pacific Coal & Oil Company, Story No. 3 (Sec. 1, T17N, R3E).

uppermost 10 feet of the formation (Fig. 24). About 20 feet above the Red Fork is the resistive Pink Limestone (Fig. 24).

Statement of the Problem. The Red Fork is approximately 80 feet thick; it is "wet" in the lowermost 40 feet, with an extensive transition zone. The uppermost 10 feet seem to contain petroleum. A "reflection peak" from the Pink Limestone obscures the lateral curve's "true" signature in the uppermost 10 feet (Fig. 24). As described previously, the lateral tool operates best in thick, "homogeneous" formations, a rare occurrence in the Red Fork of Payne County. Consequently the zone within the Red Fork where oil and gas seems to be localized is where the lateral curve is affected by a reflection peak (Fig. 24).

Experimental Procedure. The lateral curve is influenced by the reflection peak of the Pink Limestone at the depth of interest. Presumably, the position at which the lateral curve is influenced initially by the Pink Limestone's reflection peak can be determined. At that point, the Ra(lat) value will be a minimal, uncorrupted value. In Figure 25, a straight line perpendicular to the central depth track is shown at the base of the primary peak (A). A distance of one AO spacing downward from this line should be the base of the reflection peak. Another line perpendicular to the central depth track extends from this point (line B, Fig. 25). Upward from

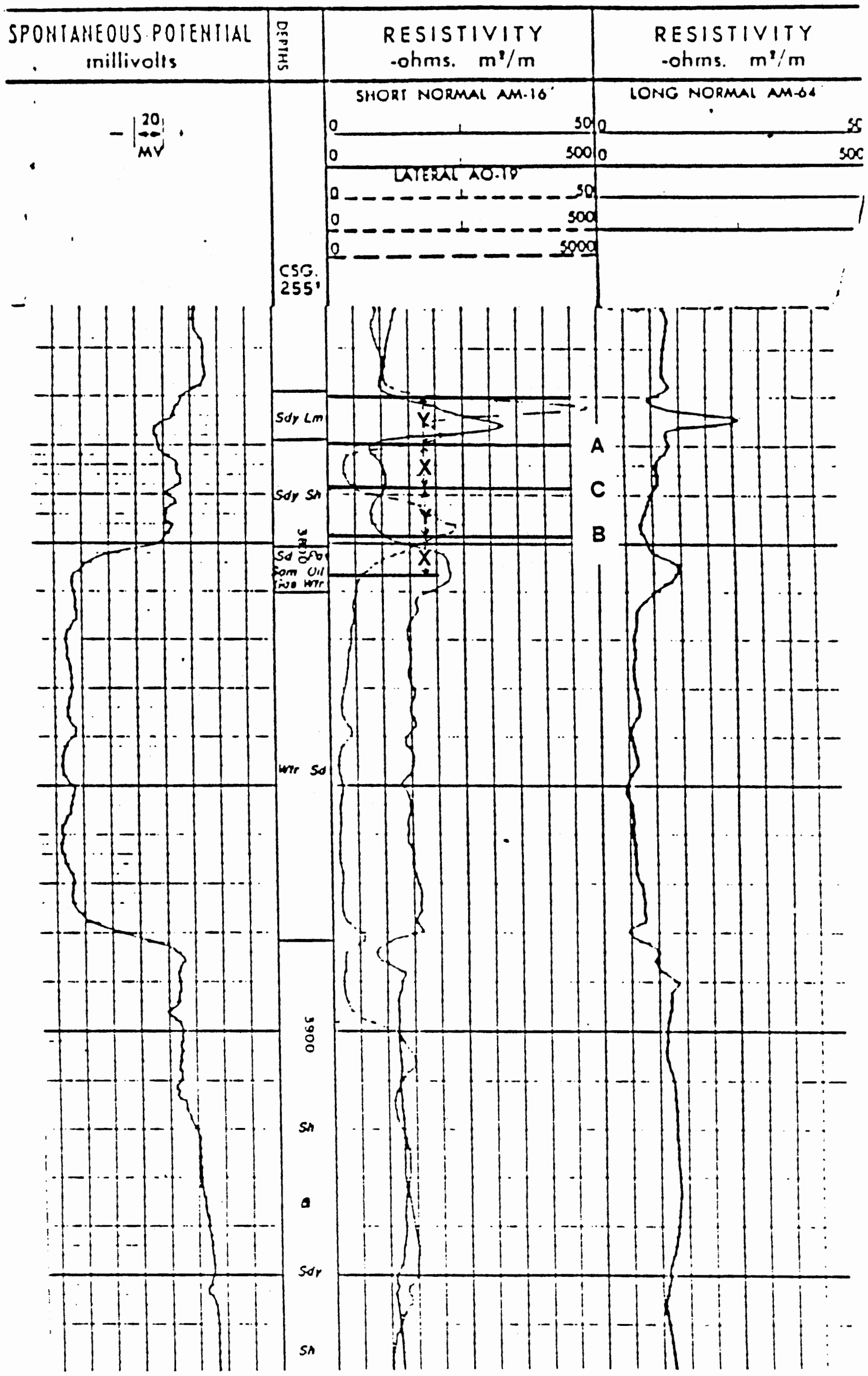


Figure 25. Texas Pacific Coal & Oil Company, Story No. 3 (Sec. 1, T17N, R3E), Experimental Procedure.

line B a distance equal to the thickness of the Pink Limestone is line C (Fig. 25). Thus, the AO distance has been divided into the "dead zone" (X), and a sector equivalent to the thickness of the Pink Limestone (Y) (Fig. 25). Downward from line B by a distance equal to the thickness of the "dead zone" (X), should locate the position on the lateral curve where the lateral tool was initially influenced by the reflection peak (Fig. 25).

Conclusion. From the above method, the Ra(lat) value is estimated as 5.5 Ohm-m. Note that this is a minimal estimate. The lateral curve might have increased to a value larger than 5.5 Ohm-m, due to the presence of oil and gas; however, this statement is conjectural, because of interference of the reflection peak with the lateral curve.

H. Waggoner & Company, Wilson No. 1

The Red Fork in this well (Sec. 29, T18N, R4E) consists of interbedded sandstone and shale (Fig. 26). Most excursions of the lateral and short normal curves probably are due to the influence of beds of shale within the Red Fork (Fig. 26). As a result, selection of Ra(lat) and Ra(sn) values is not straightforward. The zone of interest is from 3626 to 3651 feet (Fig. 26). In actuality, this zone consists of two rock units of sandstone separated by shale; however, the zone will be treated as a single entity (Fig. 26). The values from this

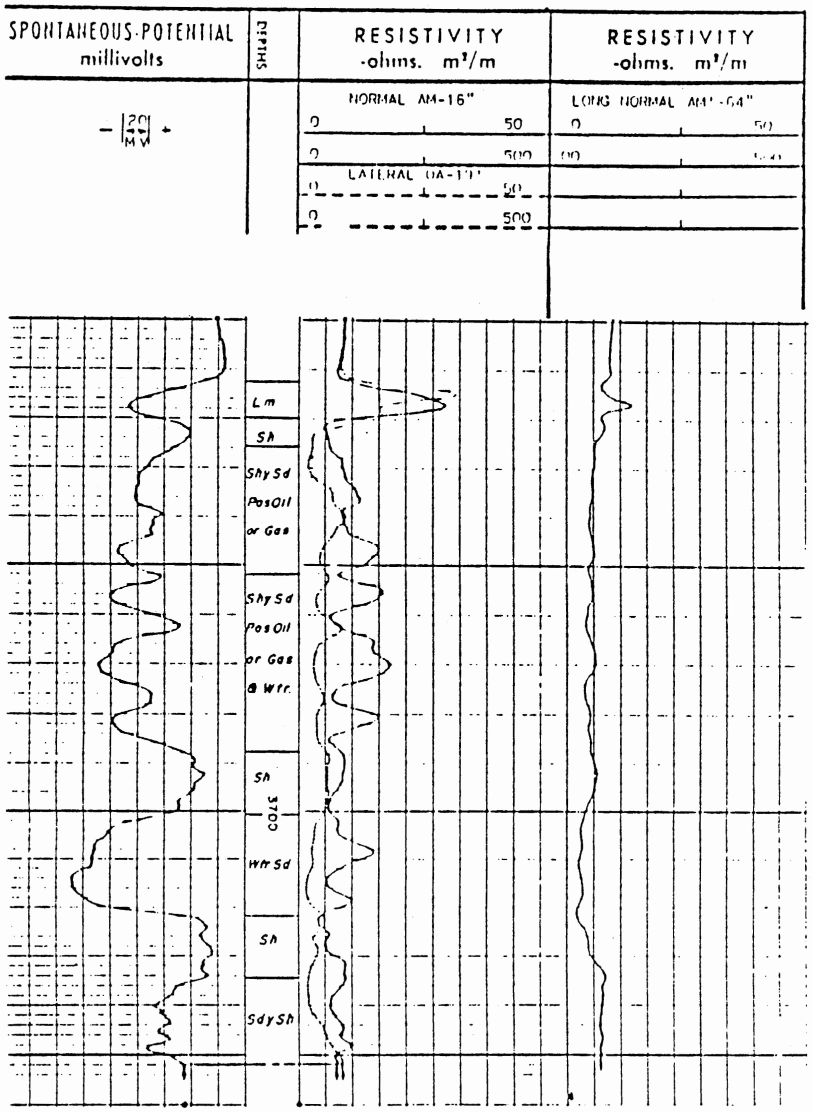


Figure 26. H. Waggoner & Company, Wilson No. 1 (Sec. 29, T18N, R4E).

interpretation will be an "average" value. A further complication is the reflection peak located at 3640 feet (Fig. 26). This high resistivity value is developed at the stratigraphic position of a shale break, thus possibly adding to the magnitude of the resistivity reading (Fig. 26).

Experimental Procedure. To get an Ra(lat) value, one should use the procedure that was used to analyze the log of the Story No. 3. The position on the lateral curve where the reflection peak began to influence the lateral tool (Fig. 25) should be determined first. Estimating an apparent resistivity value from the short normal and long normal curves can be done as follows.

Observe the magnitudes of the short normal and SP curves in the uppermost unit of sandstone, and compare these curves to their counterparts in sandstones beneath (Fig. 26). The SP curve in the uppermost sand has less negative deflection than in sandstones beneath (Fig. 26). However, the magnitude of the short normal curve is less in the uppermost sandstone than in those beneath (Fig. 26). This difference probably is due to an increase upward in shaliness. Because an average value of Ra(sn) is sought, split the difference between the peaks of the short normal curves within the two sandstones (Fig. 26). Ra(sn) approximately is equal to 13.5 Ohm-m within the zone of interest. Apparent resistivity of the long normal (Ra(ln)) is much easier to obtain. The "average" Ra(ln) value across this zone is approximately 5 Ohm-m (Fig. 26).

CHAPTER VIII

CORRECTION CURVES

Introduction

Laboratory results show that resistivity measurements by a given device are dependent on the geometry, and resistivity of media near the electrodes (Frank, 1986, p. 23). Presumably, what Frank means by "geometry" is such factors as bed thickness, thickness of adjacent beds, proximity of resistive "streaks" and shale laminations, and diameter of the borehole. Resistivity of drilling mud, resistivity of adjacent beds, and amount of invasion also influence the resistivities recorded by the normal and lateral devices. As previously mentioned, the resistivities recorded on the log actually are "apparent resistivities". These apparent resistivities vary considerably from "true" values. The "true" resistivity value of the normal and lateral devices can be obtained by correcting the apparent resistivity values for the effects of bed thickness, adjacent beds, borehole influences, and invasion. These corrections are essential for obtaining accurate values of Rt ("true" resistivity) for use in water-saturation calculations. The order in which one corrects the raw data is controlled by the specific analytic procedure used to interpret the log.

Borehole Correction Charts

Borehole Correction Charts have been devised in order to adjust apparent resistivity values (Ra) for influence of the borehole. Essentially, the charts adjust apparent resistivities for the influence of drilling mud, which is incorporated in the resistivity readings. If the sonde is centered in the borehole, mud-filled space is between the wall of the borehole and the sonde. Diameter of the sonde and diameter of the borehole determine the volume of drilling mud that is incorporated into measurement of resistivity. Because drilling mud has such an important influence, resistivity of the mud at formation temperature must be known. The effects of borehole diameter and mud resistivity on the lateral and normal signatures are shown in Figures 14 and 19.

Use of the Borehole Correction Charts

Separate borehole correction charts are used for the lateral (18-foot 8-inch), long normal (64-inch), and short normal (16-inch) curves (Figs. 27, 28, and 29). To use these charts, one must first adjust the resistivity of mud (Rm) to formation temperature. Then divide the Ra value by the corrected Rm value and enter the ordinate of the appropriate chart (Figs. 27 and 29), or the abscissa of

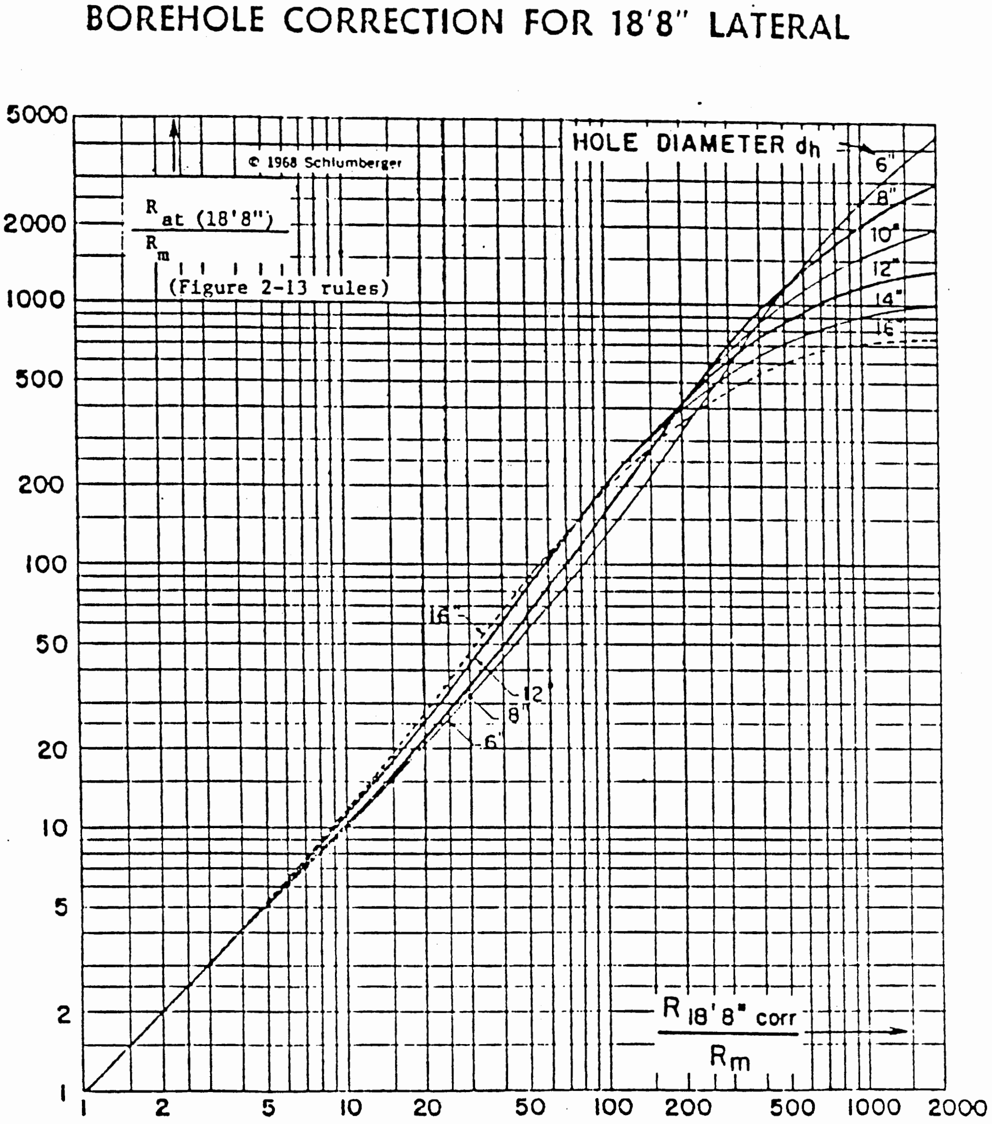

BORHOLE CORRECTION FOR 18'8" LATERAL

Figure 27. Borehole Correction Chart (18-foot 8-inch Lateral) (Modified After Schlumberger, 1972).

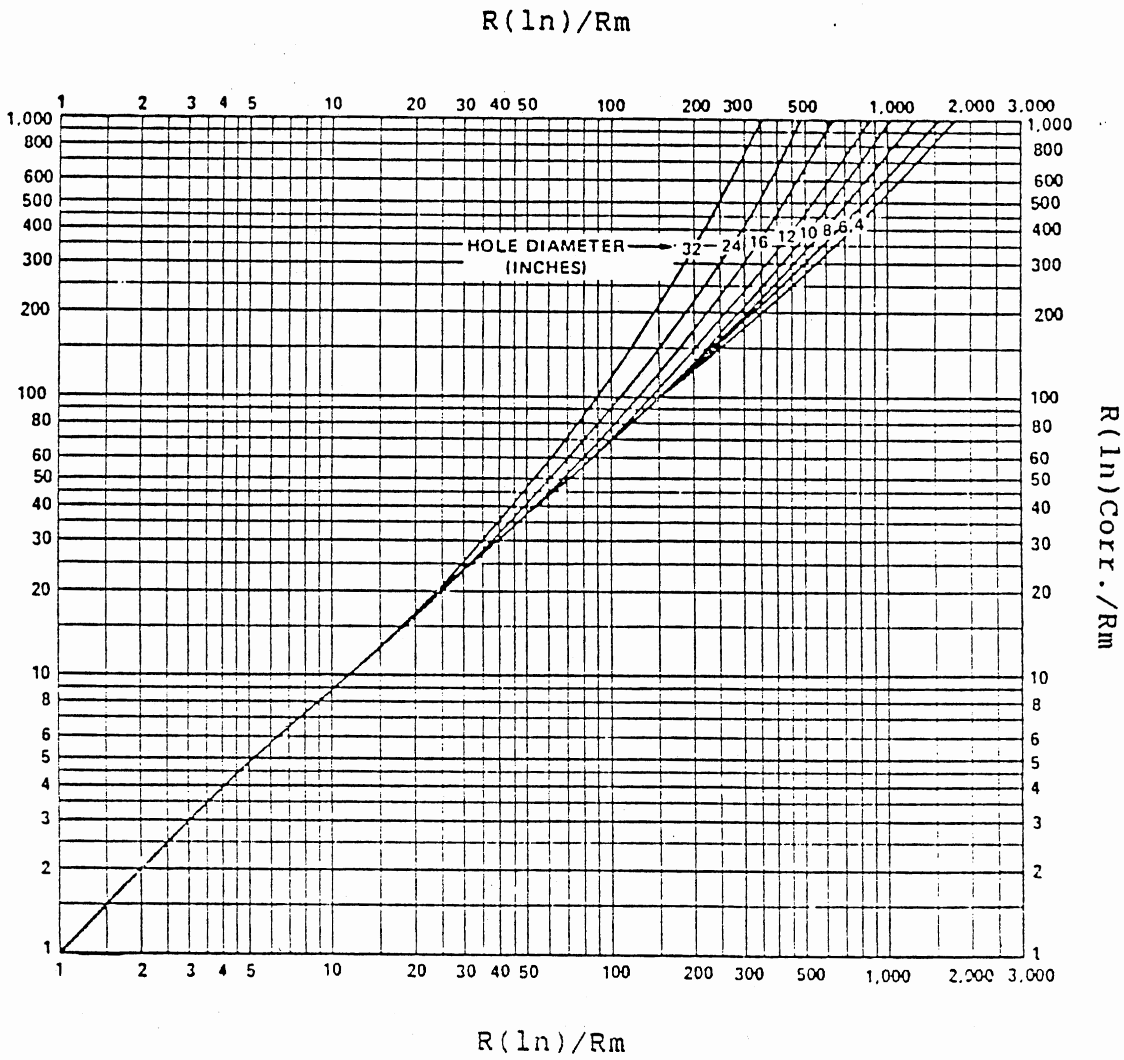


Figure 28. Borehole Correction Chart (64-inch Long Normal) (Modified After S.P.W.L.A., 1979).

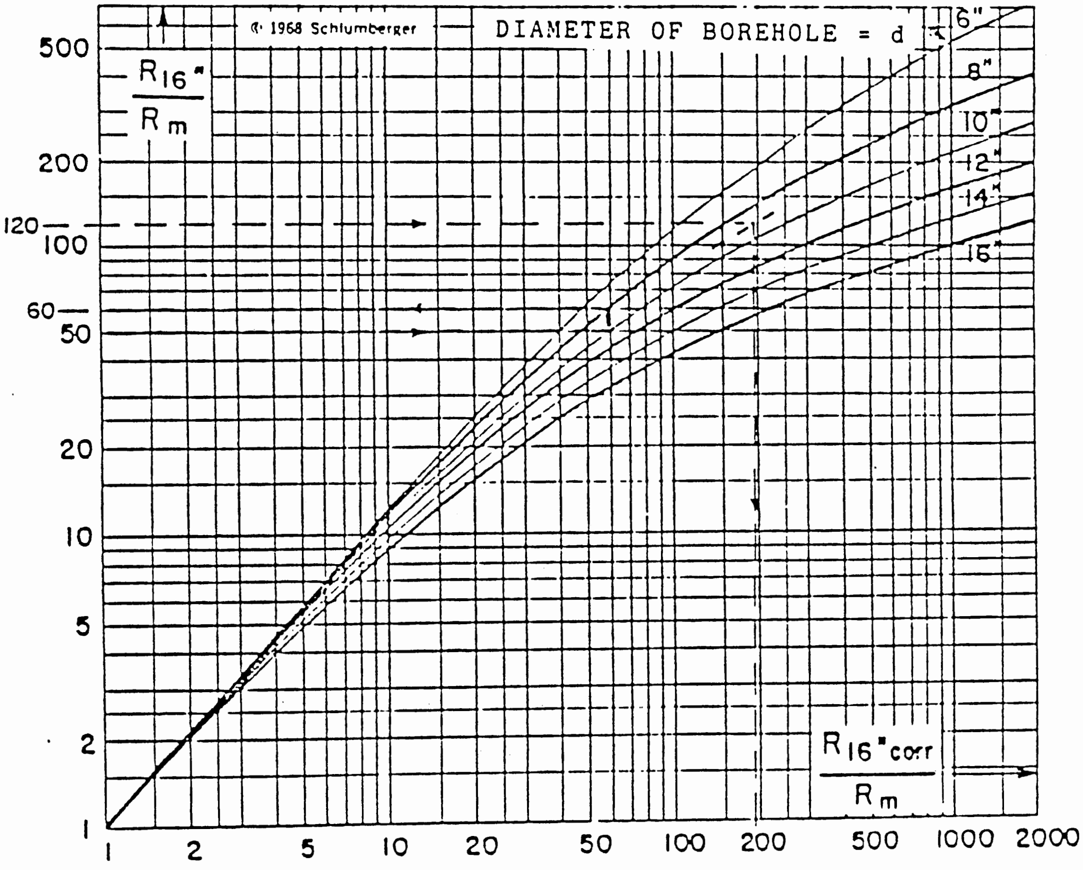


Figure 29. Borehole Correction Chart (16-inch Short Normal) (Modified After Schlumberger, 1972).

appropriate chart (Fig. 28). Move horizontally to the line showing borehole diameter of the well. In Figures 27 and 29, move downward vertically or, in Figure 28, move horizontally to read the corrected Ra/Rm value.

Correction Charts for Bed Thickness and Adjacent Beds

As previously stated, bed thickness and adjacent-bed effects are related directly. Thickness of the bed in question and contrasting resistivities between this bed and those above and below control the amount of error in the apparent resistivity values. Electrode arrangement and spacing also influence how much effect bed thickness and adjacent beds have on the apparent resistivities; therefore, separate charts are used for the lateral (18-foot 8-inch), long normal (64-inch), and short normal (16-inch). The joint effects of bed thickness and adjacent beds are combined in one correction chart for each of the electrode spacings (Figs. 30, 31, and 32). The chart for the lateral curve uses Rl or R(peak) values; charts for the normal curves use simply peak values from "centers" of beds.

Use of Bed-thickness and Adjacent-bed Correction Charts

Bed-thickness and adjacent-bed correction charts were designed to correct the apparent resistivities of

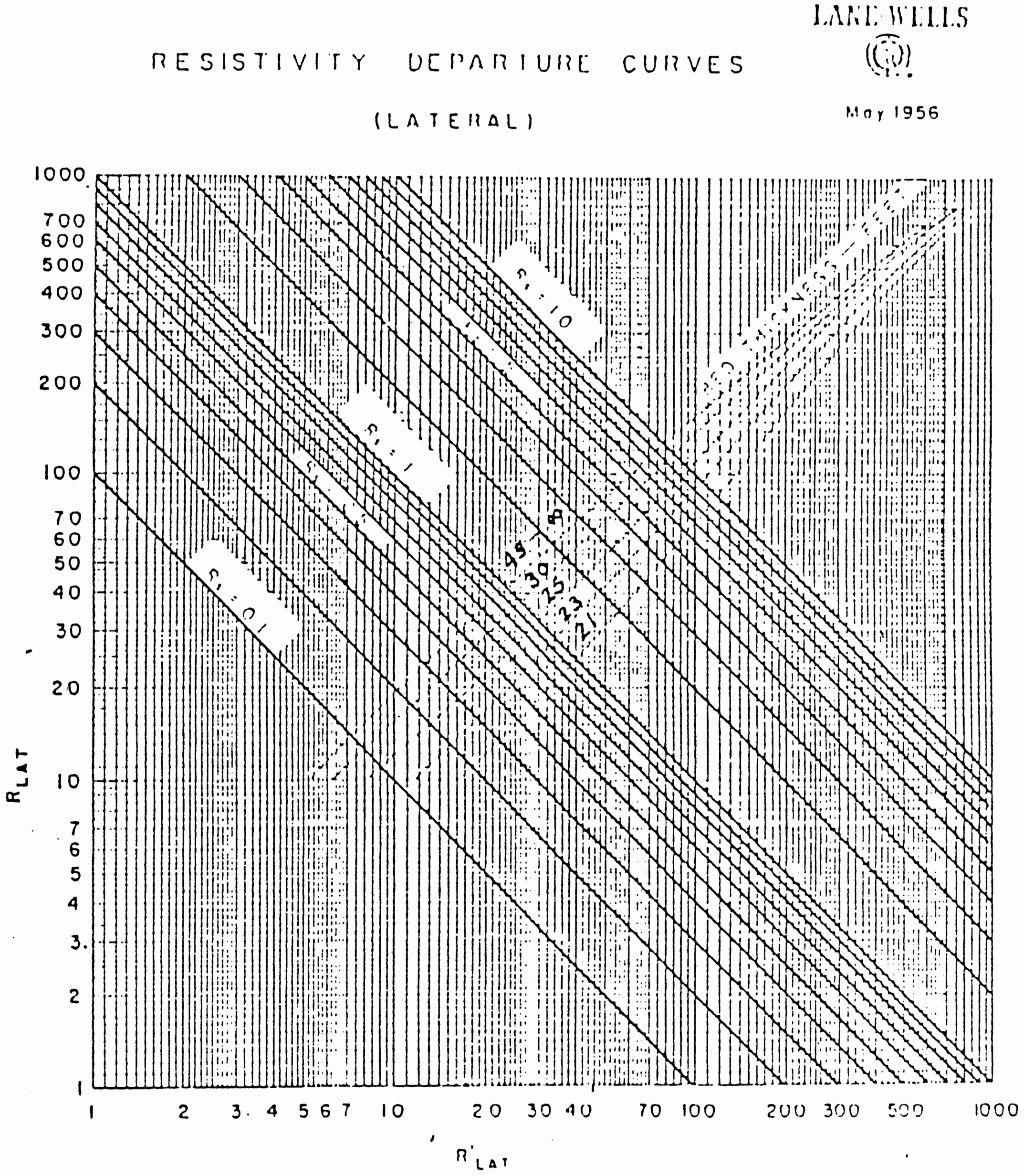


Figure 30. Bed Thickness and Adjacent Bed Correction Chart (18-foot 8-inch Lateral) (After Lane Wells, 1956).

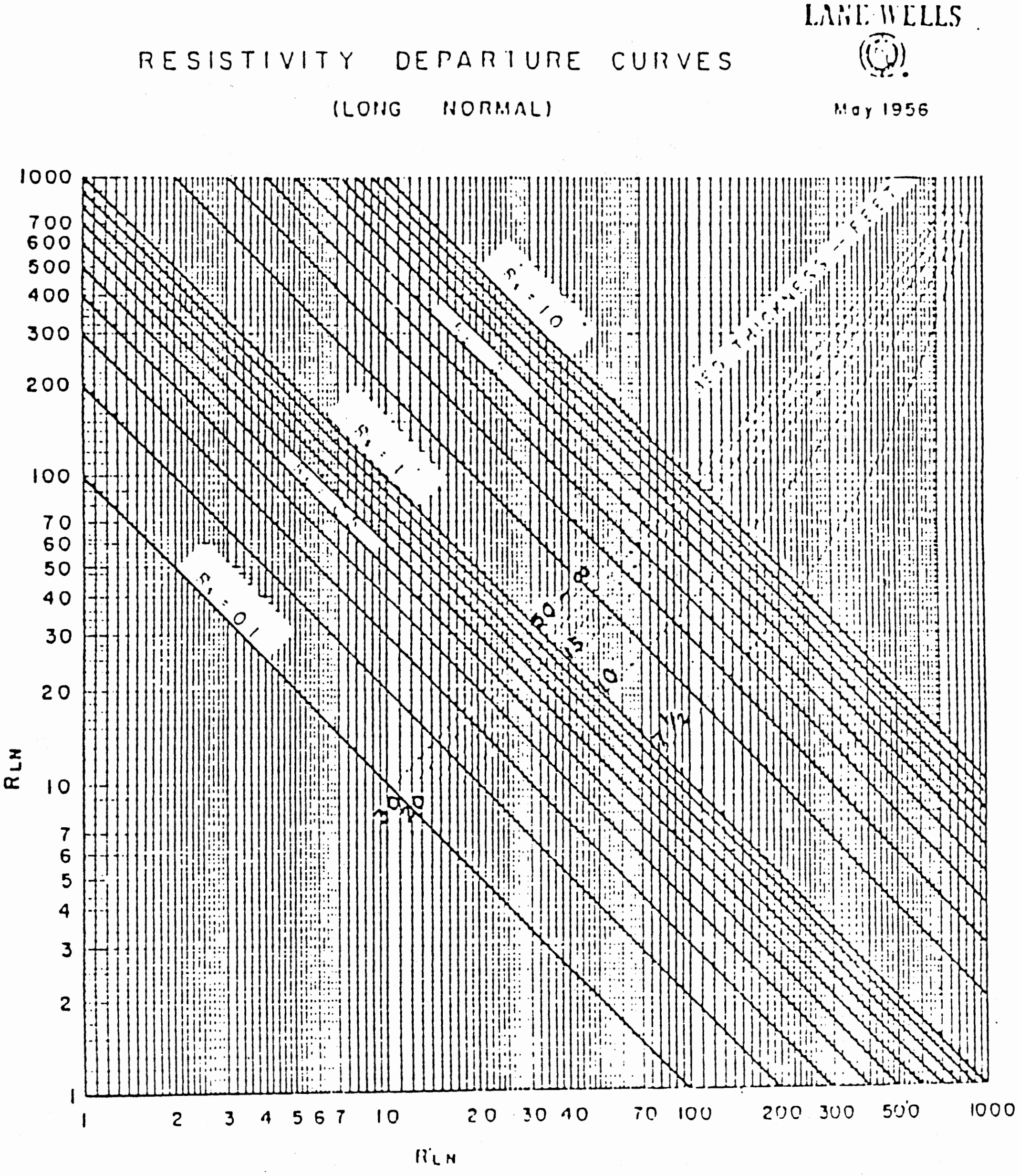


Figure 31. Bed Thickness and Adjacent Bed Correction Chart (64-inch Long Normal) (After Lane Wells, 1956).

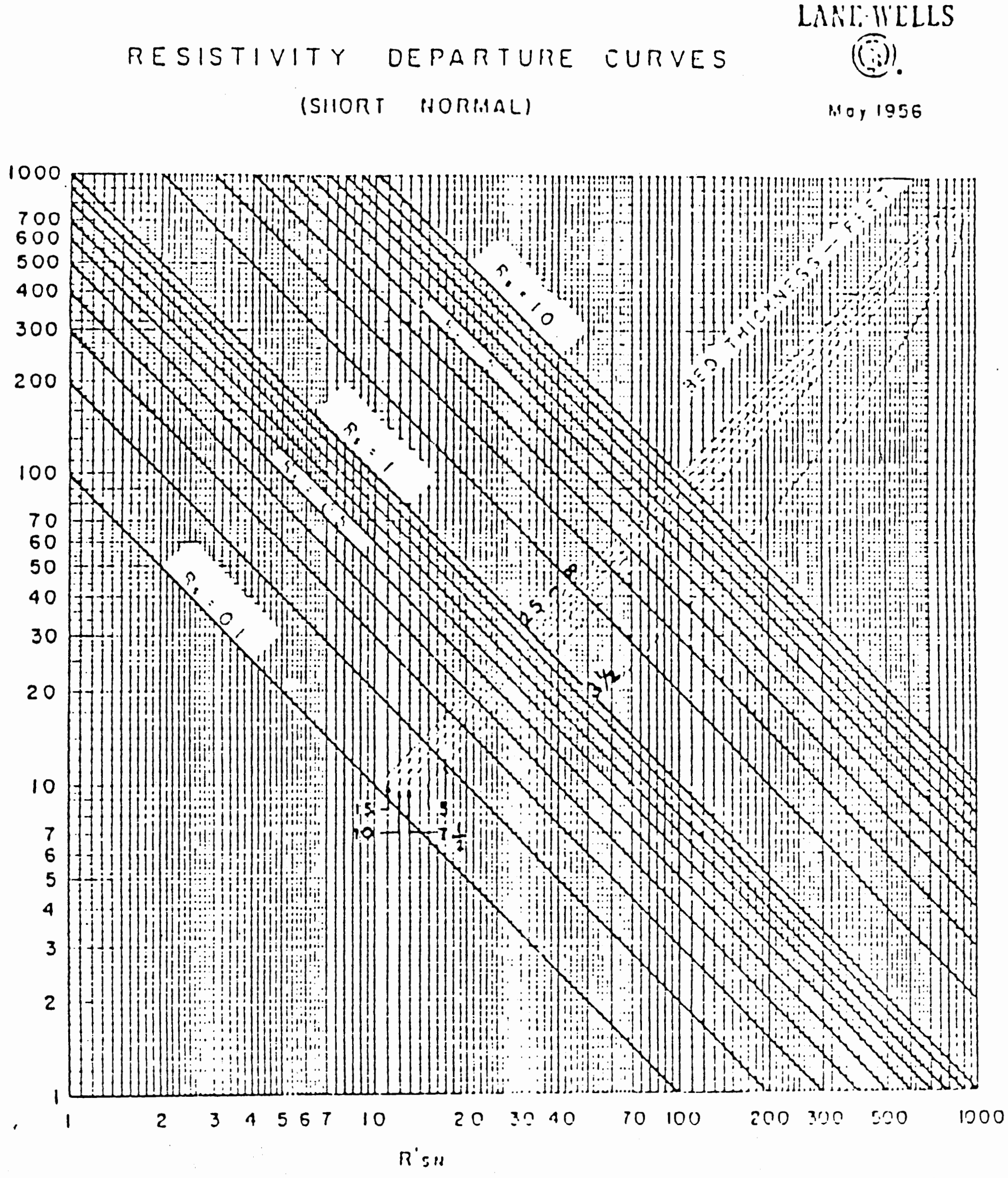


Figure 32. Bed Thickness and Adjacent Bed Correction Chart (16-inch Short Normal) (After Lane Wells, 1956).

formations bounded by shale. Therefore, resistivity of surrounding formations (shale) (Rs) must be recorded. Of course, anisotropy of formations (whether shale or sandstone) is much more common than isotropism (indeed, in the strict sense, isotropism does not exist in natural rock). As a result, Rs values used in bed-thickness and adjacent-bed correction charts will be "average" values. For the normal charts, Rs should be determined from the long normal curve. This value of Rs should be entered into bed-thickness and adjacent-bed charts for correction of the short and long normal curves (Guyod and Pranglin, 1959, p. 14). Rs value from the lateral curve should be used for the lateral's bed-thickness and adjacent-bed correction chart. Once Rs values have been obtained, the next step is to mark bed boundaries, in order to determine bed thickness (e), and apparent resistivities (Ra(lat), Ra(ln), and Ra(sn)). Select the appropriate chart for the Ra that is being corrected (Figs. 30, 31, and 32). Enter the Ra value on the ordinate. Move horizontally to the line that shows resistivity of surrounding beds (shale). Move vertically, either upward or downward, to the line that shows appropriate bed thickness. Move horizontally to the line that shows resistivity of surrounding beds (shale). Finally, move downward vertically to the abscissa and read the corrected Ra value (Figs. 30, 31, and 32).

Limitations of Bed-thickness and Adjacent-bed Correction Charts

The charts described above are limited seriously. Representative values of Rs are not straightforward to obtain. For example, in some instances shales above and below the formation of interest are of significantly different resistivities. In other instances shales above and below the formation are too thin for accurate estimation of Rs. If the Rs value of shale adjacent to the bed being analyzed is of resistivity markedly different than adjacent shales elsewhere in the nearby stratigraphic column, then the shale adjacent to the bed being analyzed is probably too thin for accurate judgment of Rs (Guyod and Pranglin, 1959, p. 12).

In the Red Fork interval, shales above and below the sandstones commonly are too thin for accurate measurement of Rs. Moreover, in many wells, shales above the Red Fork sandstone are in the blind zone of the Pink Limestone.

Another matter of concern about Rs values is that the largest Rs value the charts described above are designed to correct is 10 Ohm-m. In Pennsylvanian strata of central Oklahoma, average resistivities of shales are approximately 10 Ohm-m; in some localities Rs exceeds 10 Ohm-m. At places where the shales above and below the Red Fork are too thin for reliable estimation of Rs, estimates must be made from beds elsewhere in the stratigraphic column. Of course, this procedure assumes that shales adjacent to the bed in question and those elsewhere in the stratigraphic column are of the same lithology.

Bed-thickness and adjacent-bed effects must be corrected before adjustment can be made for the effects of invasion. Due to limitations in the correction charts described here, the thinnest bed for which the lateral curve can be corrected is 21 feet (Fig. 30). Where bed thickness (e) is less than 21 feet, the bed-thickness and adjacent-bed correction chart can not be used. Therefore, the following methods to correct for effects of invasion on the lateral curve are not usable where formations are thinner than 21 feet.

One of the more important variables for which correction is necessary (especially for accurate estimates of Rt) is the effect of invasion. Effects of invasion are corrected by use of resistivity departure curves. Correction of the effects of invasion is addressed in the following chapter.

CHAPTER IX

METHODS OF ANALYSIS

Introduction

An analytic method for old electric logs is a means of obtaining the parametric values necessary for the calculation of water saturation. As described previously, the necessary parametric values are formation resistivity factor (F), formation water resistivity at formation temperature (Rw), and "true" resistivity of the uncontaminated formation (Rt). These parameter values can be obtained from the old electric logs and micrologs themselves, but measurement of porosity and Rw from these logs commonly is not accurate. If estimates of porosity and Rw can be drawn more reliably from elsewhere, then of course determination of an accurate estimation of Rt becomes the "root" of the analytic method.

Measuring Rt accurately from old electric logs is a process that involves a significant amount of interpretation. Problems inherent with the lateral tool are the main reason why determination of Rt generally is difficult. Log analysts have devised many techniques for improving the estimates of Rt. Some methods are simple and straightforward; others are complex and tedious. The method proposed in Chapter X is robust and reasonably easy to work with -- at least wherein study of the Red Fork Sandstone in Payne County, Oklahoma is concerned. Of course, in order to support this statement, a variety of methods should be evaluated for comparison.

For the most part, analytic methods consists of procedures based on correction charts. As previously stated, these charts correct for borehole influences, bed-thickness and adjacent-bed effects, and invasion. Discussion of effects of invasion has purposely been left until now because in most analytic methods this variable is corrected in the last step, or else the correction is incorporated as a nonspecific procedure.

Three analytic methods will be discussed in this chapter. The importance of these three methods is that the effect of invasion is addressed in some manner. Accurate estimates of Rt are of significant importance; however, two of the analytic methods also provide corrected values of Ri and Di. Borehole influences, mud influence, bed-thickness effects, and adjacent-bed effects are incorporated in these analytic methods.

Estimation of Rt From Electric Logs

The Schlumberger Well Surveying Corp., (1955) has devised a generalized set of catagories or rules from which accurate determinations of Rt will result. Rules for obtaining Rt from electrical logs are based on resistivity of the bed in question relative to resistivity of the mud (Rm) and of the bounding formations (Rs) (S.P.W.L.A., 1979, p. 57). Resistivity of the formation in question, relative to resistivities of mud and surrounding formations has been determined from study of resistivity departure curves. In general, departure curves are used to correct apparent resistivity readings for the effects of invasion; however, in some instances bed-thickness and adjacent-bed effects are also corrected. Depending on which set of departure curves is used, resistivity of the invaded zone (Ri) and diameter of the invaded zone (Di) also can be determined (Hilchie, 1979, p. 89).

Analytic Method

Formations are divided into three catagories, depending on the ratio of R(sn)/Rm: (1) Low Resistivity: R(sn)/Rm < 10, (2) Medium Resistivity: 10 < R(sn)/Rm < 50, and (3) High Resistivity: R(sn)/Rm > 50 (S.P.W.L.A., 1979, p. 57). Apparent resistivities of the short normal, long normal, and lateral must be corrected to those of a borehole 8 inches in diameter (Figs. 27, 28, and 29). Also necessary is the adjustment of apparent resistivity of the short normal (Ra(sn)) for bed thickness before using the general rules of obtaining Rt (Fig. 33). Perhaps the reader can understand the following rules better by referring to Figure 34.

BED THICKNESS CORRECTION CHARTS 16-INCH SHORT NORMAL

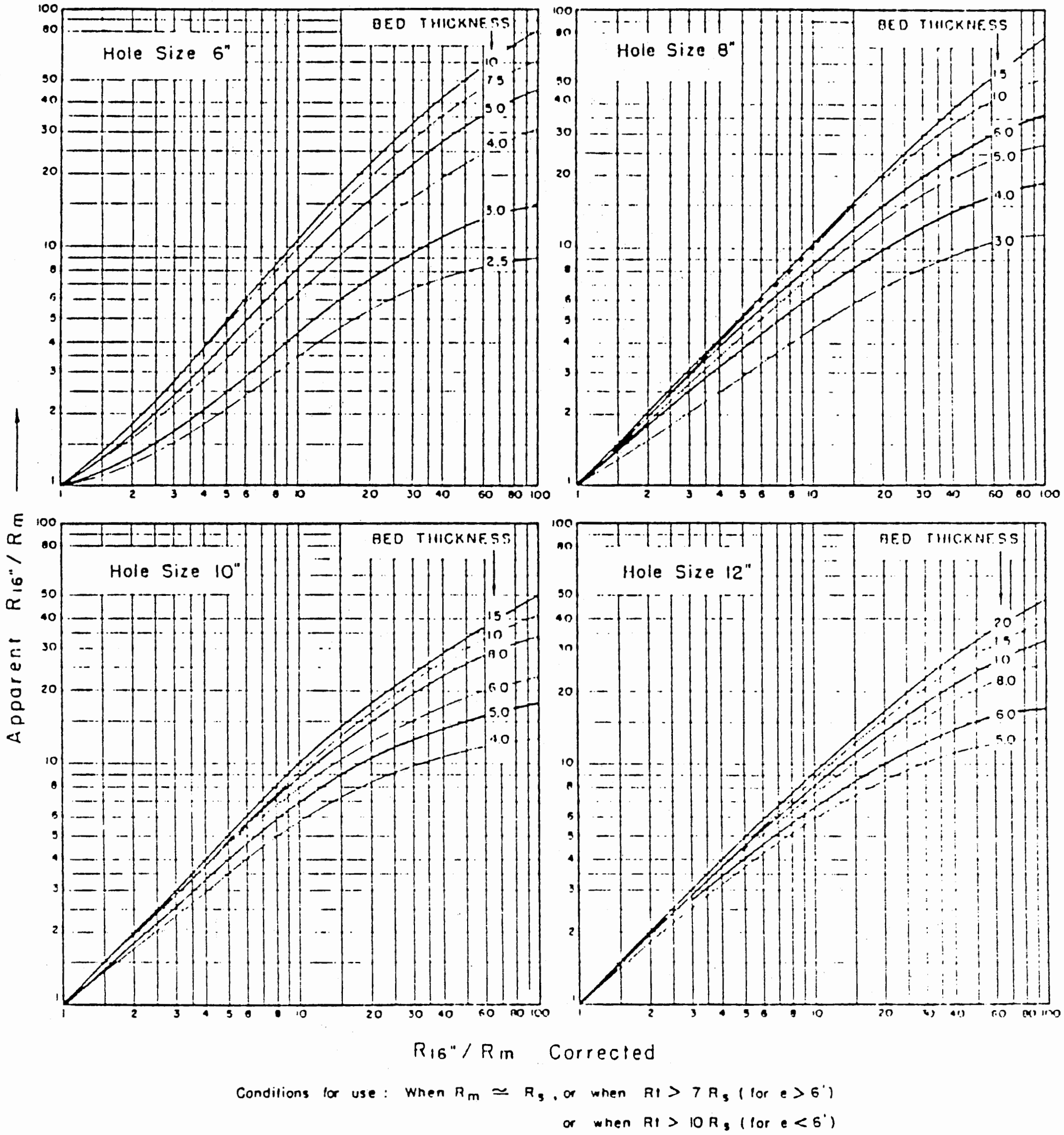


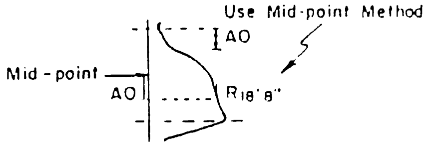
Figure 33. Bed Thickness Correction Chart (16-inch Short Normal) (Modified After S.P.W.L.A., 1979).

ESTIMATION OF Rt FROM ELECTRIC LOGS

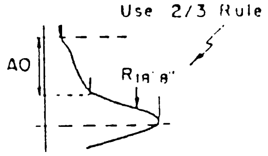
BED THICKNESS (e)	QUALIFICATIONS	DEVICE	RESPONSE
A. IN LOW RESISTIVITY, WHEN $R_{16''}/R_m < 10$ (INVASION UP TO 2d)			
$e > 20'$ (> 4 AM')		Long Normal	$R_{64''} = R_t$
$e \simeq 15'$ (3 AM')	$R_m \simeq R_s$ $R_{64''}/R_s \geq 2.5$	Long Normal	$R_{64''} = 2/3\ R_t$
$e \simeq 15'$ (3 AM')	$R_m \simeq R_s$ $R_{64''}/R_s \leq 1.5$	Long Normal	$R_{64''} = R_t$
$e \simeq 10'$ (2 AM')	$R_m \simeq R_s$ $R_{64''}/R_s \geq 2.5$	Long Normal	$R_{64''} = 1/2\ R_t$
$e \simeq 10'$ (2 AM')	$R_m \simeq R_s$ $R_{64''}/R_s = 1.5$	Long Normal	$R_{64''} = 2/3\ R_t$
$5' < e < 10'$	When oil bearing and SP is -50 – 80 MV	Short Normal	$R_{16''} \simeq R_t$
$5' < e < 10'$	Surrounding beds homogenous	Lateral in resistive bed	$R_t \gtrsim R_{Max} \times R_s/R_{Min}$
Thin beds (in general)	Surrounding beds homogenous	Lateral in conductive bed	$R_{19''} \simeq R_t$

B. RULES FOR USING LATERAL (AO = 18'8")

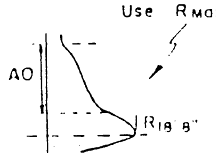
$e > 40'$ (> 2.0 AO)



$e \simeq 28'$ ($= 1.5$ AO)



$e \simeq 24'$ ($= 1.3$ AO)



$5' < e < 10'$ Resistive bed and surrounding beds homogeneous

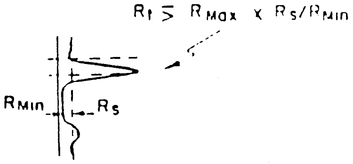


Figure 34. Estimation of Rt From Electric Logs (Modified After Schlumberger, 1955).

Low-resistivity Formations. In low-resistivity formations, the normal curves are most useful for determining a value of Rt (the normal curve to be used is dependent on bed thickness). The qualifications for this category are: (1) Rm ~ Rs, (2) R(sn)/Rm < 10, and (3) invasion is no more than twice the diameter of the borehole (2d) (Fig. 34).

Medium-resistivity Formations. Under conditions of medium resistivity the R(ln) is very useful in the lower portion of this resistivity range, but where R(sn)/Rm > 20, use of the R(lat) becomes important, either to measure Rt or to confirm the apparent value of Rt from the long normal curve (S.P.W.L.A., 1979, p. 57) (Fig. 34). Use of the lateral curve demands using the Rat rules described in Chapter VII. Refer to the lower portion of Figure 34.

High-resistivity Formations. In formations of high resistivity, R(ln) is affected by invasion; therefore, the R(lat) is the best choice for estimation of Rt. Use of the Rat rules (from Chapter VII) is necessary to obtain a reliable value from the lateral curve (Fig. 34, lower portion).

Limitation and Application

The generalized rules and categories described above are designed for judgment about effects of invasion. This judgment is to be based on resistivity departure curves.

Apparent resistivity values of the lateral, long normal, and short normal must be corrected to those of an 8-inch borehole; therefore, borehole influences are incorporated into the analyses. The Ra(sn) value must be corrected for bed thickness before implementing the generalized rules (Fig. 33). A bed-thickness correction factor almost certainly is integrated into the "response" column and Rat rules of Figure 34. If one observes the "conditions for use" set out in Figure 33, bed-thickness correction charts for the R(sn) apply where Rm ~ Rs, or where Rt > 7Rs (for e > 6 ft.), or where Rt > 10Rs (for e < 6 ft.) (Fig. 33). Do these criteria commonly apply to analysis of the Red Fork Interval, Payne County, Oklahoma?

Within the Red Fork Interval, Rm values range from approximately 0.5 to about 2.0 Ohm-m, whereas resistivities of shales range approximately from 5 to 15 Ohm-m. Is this range close enough merit use of Figure 33? Where e > 6 ft., Rt must be greater than 7Rs. (For the range of observed Rs values, Rt values should range from 35 to 105 Ohm-m). Where e < 6 ft., Rt must be greater than 10Rs. (For the range of Rs observed, Rt values should range from 50 to 150 Ohm-m). Accordingly, application of Figure 33 to analysis of the Red Fork Sandstone is judged to be inappropriate.

Guyod's and Pranglin's Method

Hubert Guyod is regarded as one of the founding fathers of log analysis. Guyod and Pranglin (1955 and 1959) studied extensively the relationship between "true" resistivity of subsurface formations and the apparent resistivities recorded by the logging tools. This research was conducted through use of an analogue computer. The computer was designed to determine the relationship between the "true" resistivity of a ground formation and the apparent resistivity obtained from various electrode arrangements (Guyod and Pranglin, 1955, p. 615). The overall product of this research is a set of Transformation and Analysis Charts that can be used to determine Rt, Di, and Ri from electric logs with electrode arrangements consisting of a 16-inch short normal, 64-inch long normal, and 18-foot 8-inch lateral. These charts were designed to correct the apparent resistivity readings for borehole influences, bed-thickness and adjacent-bed effects, and invasion.

Of the two sets of Analysis Charts, one is for an Rm/Rs ratio of 0.2, and the other for an Rm/Rs ratio of 1.0; both sets are for a borehole diameter of 8 inches. Each set is divided into Normal Charts, which are plots of R(ln)/Rs vs. R(sn)/Rs, and Lateral Charts, which are plots of R(lat)/Rs vs. R(sn)/Rs. Normal and Lateral Charts were published for twelve thicknesses of beds (2, 3, 4, 5, 7, 10, 13, 16, 20, 24, 35, and 50 feet). Each bed thickness (e) is matched with Normal and Lateral Charts for four Di/d values (1.3, 2, 5, and 10 inches), where Di/d signifies the ratio of diameter of invasion to diameter of the borehole. Figure 35 is intended to help the reader understand the grouping of these charts. In total, 192 Analysis Charts can be applied to 24 combinations of e, d, and Rm/Rs. A small sample of these charts is available in Appendix C.

To have Analysis Charts for all combinations of Rm/Rs, d, and e that could be encountered in actual practice would be almost impossible. Transformation Charts were included with the 192 Analysis Charts in order to permit adjustment of conditions of Rm/Rs, d, and e to the values contained in the 24 sets of Analysis Charts (Appendix C).

The following procedure is designed for use of Guyod's Analysis and Transformation Charts. The procedure is abbreviated somewhat, in the sense that complications for which additional steps are necessary are mentioned, but not discussed in great detail. (See Guyod and Pranglin (1959) for detailed information). The purpose of explaining the use of these charts is to demonstrate how much manipulation of data is necessary to achieve an accurate interpretation.

Use of the Analysis and Transformation Charts

1) Calculate Rm at formation temperature.

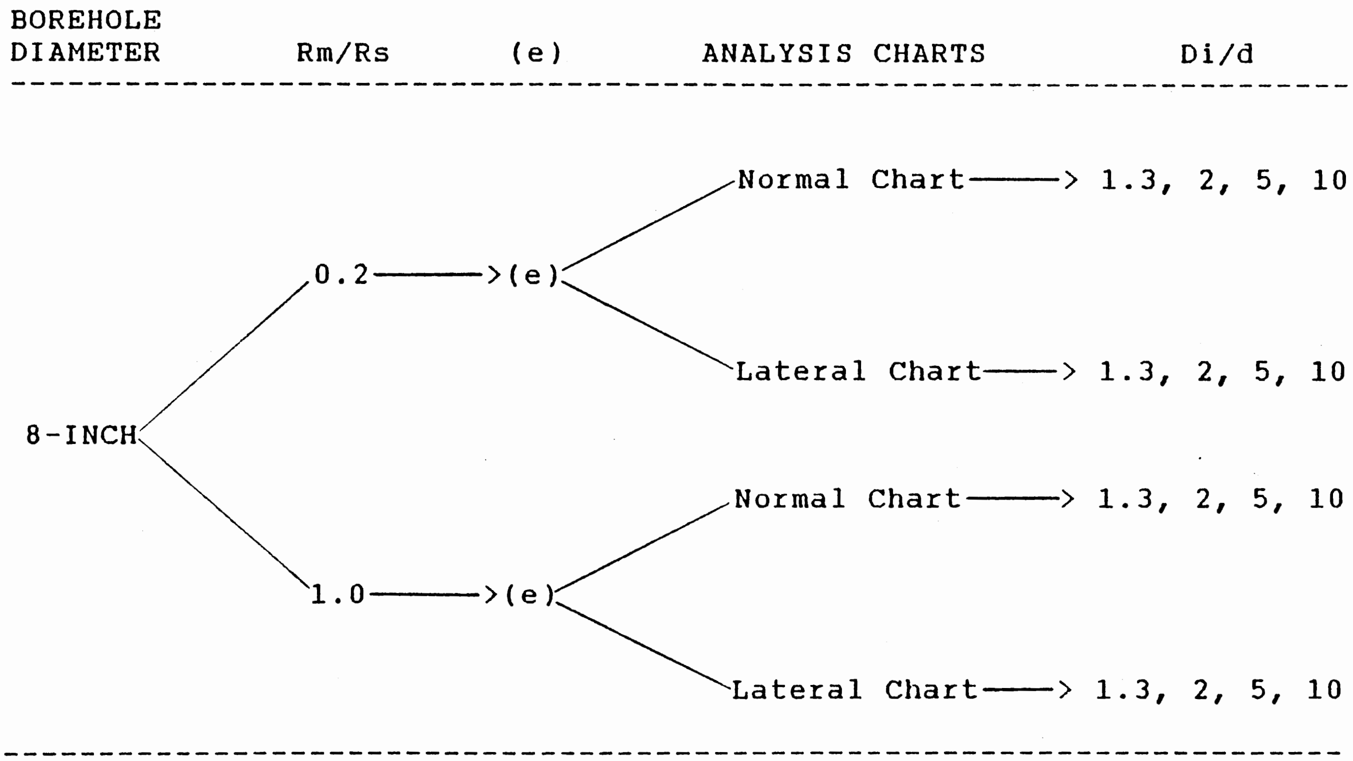


Figure 35. Grouping of Guyod's and Pranglin's Analysis Charts.

2) Observe the bit size from log header. If bit size is not 8 inches, transform the Rm value for an 8-inch borehole (using "D" Transformation Chart).

3) Record bed thickness (e), Ra(sn), Ra(ln), and Ra(lat) from the log in the formation of interest. Use the peak value for the lateral curve R(peak).

4) Record Rs of shales above and below the formation of interest (Rs(sn), Rs(ln), and Rs(lat)). If the shales above and below the formation of interest are of different resistivities, use the Equivalent Shale Resistivity Transformation Chart; if the shales are not sufficiently thick (at least 8 ft. for the normals, and 8 ft. or 23 minus bed thickness (whichever is greater) for the lateral), additional considerations are necessary.

5) If Rm/Rs for the short normal, long normal, and lateral devices are not equal to 0.2 or 1.0, use the Rm Transformation Charts to obtain R(sn)/Rs, R(ln)/Rs, and R(lat)/Rs values for an Rm/Rs value of 0.2 or 1.0 at a bed thickness of e. Note: If the thickness of the bed in question is not equal to one of the twelve given, additional transformations are necessary ("e" Transformation Charts).

6) Choose the Normal and Lateral Analysis Charts for the given Rm/Rs (0.2 or 1.0) and e. Plot the transformed R(ln)/Rs vs. R(sn)/Rs on the Normal Charts for Di/d = 1.3, 2, 5, and 10. Plot transformed R(lat)/Rs vs. R(sn)/Rs on the Lateral Charts for Di/d = 1.3, 2, 5, and 10. Tabulate the results of these plots (Rt/Rs (normals), Rt/Rs (lateral), Ri/Rs(normals), and Ri/Rs (lateral)) for the Di/d values of (1.3, 2, 5, and 10).

7) On 2-cycle log vs. log paper, plot results from the Normal and Lateral Analysis Charts (Rt/Rs vs. Di/d and Ri/Rs vs. Di/d).

8) Connect points with curved line. Four curves should be generated: Rt/Rs(normals) vs. Di/d, Rt/Rs(lateral) vs. Di/d, Ri/Rs(normals) vs. Di/d, and Ri/Rs(lateral) vs. Di/d.

9) On resulting curves, the point at which Rt/Rs(normals) intersects Rt/Rs(lateral) is the "true" value of Rt/Rs. If there is no intersection, look for a "flatness" in the Rt/Rs curves and estimate Rt/Rs as as being shown by the "flat" section of the curve.

10) Perform the same process (as in step 9) on the Ri/Rs (normals) and Ri/Rs(lateral) curves, using the same

rules for obtaining a "true" value of Rt/Rs for Ri/Rs.

Is Guyod's and Pranglin's method applicable to the Red Fork Sandstone, in Payne County? This question can be answered by evaluating the operating assumptions that were used for construction of the Analysis and Transformation Charts (Guyod and Pranglin, 1959, p. 4): (1) The bed of interest is uniform, isotropic and situated in a very thick, uniform and isotropic formation called "shale" for the sake of simplification. (2) The bed is perpendicular to the borehole. No mud cake and no low-resistivity annulus exists. (3) The hole diameter is 8 inches.

The first operating assumption is highly idealized; the makeup of natural reservoirs generally is nonuniform. If oil and gas are present, but not in consistent quantities throughout, the normal and lateral curves must be averaged. Because lithologic uniformity is nonexistent in the Red Fork Sandstone, the final results could only be "average" values of Rt, Ri, and Di. As for the assumption that shales above and below the formation of interest are thick and homogeneous, such an occurrence is also rare wherein the Red Fork Sandstone of Payne County is concerned. In many instances, shales that bound the Red Fork Sandstone are thin and interbedded with thinner strata of siltstone, sandstone, and limestone. This fact leads to additional modifications that decrease the accuracy of results and add to an already lengthy process.

Guyod's and Pranglin's procedure (1959) is a means of obtaining very accurate estimates of Rt, Ri, and Di under specific conditions. As this procedure is applied to the Red Fork interval, the stratigraphic and lithologic character of this interval should reduce measurements to "average" values of Rt, Ri, and Di. Now if this is the case, why should such an involved method be implemented? Moreover, would such a high level of effort and precision be necessary to interpret old electric logs?

Lane Wells Ri-Rt Conversion Charts

Lane Wells, Inc. (1956) published a set of Ri-Rt Conversion Charts for determining an accurate estimate of Rt, Ri, and Di for old electrical logs consisting of a 16-inch short normal, 64-inch long normal, and 18-foot 8-inch lateral curves (Lane Wells, Inc., 1956). Normal and Lateral Conversion Charts are designed for borehole diameters of 6, 7, 7-7/8, 8-3/4, 9-7/8, 11, and 12-1/4 inches. For each borehole diameter there are Normal Charts (R(sn)/Rm vs. R(ln)/Rm) and Lateral Charts (R(sn)/Rm vs. R(lat)/Rm) for several Di/d values (2, 5, 10, and 15 inches). (Di/d signifies the ratio of diameter of invasion to the diameter of the borehole.) Therefore, for each borehole diameter, there are four Normal Charts and four Lateral Charts. In total, seven borehole diameters are matched by four Normal Charts (Di/d = 2, 5, 10, and 15) and four Lateral Charts (Di/d = 2, 5, 10, and 15), totaling 56

Ri-Rt Conversion Charts. These charts are in Appendix D.

Because the Ri-Rt Conversion Charts were devised for different borehole diameters, a borehole correction is integrated with every set of charts. Bed-thickness and adjacent-bed effects must be corrected before use of the Ri-Rt Conversion Charts. Bed-Thickness and Adjacent-Bed Correction Charts are discussed in Chapter VIII; for convenience, additional copies of these charts are in Appendix D. The effects of invasion are corrected in using the Ri-Rt Conversion Charts.

Employment of the charts is fairly straightforward. Values needed from the log are Ra(sn), Ra(ln), and Ra(lat) in the formation of interest. For the Ra(lat), select the peak value. Resistivity of surrounding formations (Rs) is needed in order to use the Bed-thickness and Adjacent-bed Correction Charts. The use of these charts and the means of obtaining Rs values was discussed in Chapter VIII. Once Ra(sn), Ra(ln), and Ra(lat) are adjusted for the effects of bed thickness and adjacent beds, these corrected apparent resistivities are divided by Rm (corrected to formation temperature). The resulting ratios are R(sn)/Rm, R(ln)/Rm, and R(lat)/Rm.

Select the appropriate set of Ri-Rt Conversion Charts for the borehole diameter of the well in question. Plot R(sn)/Rm vs. R(ln)/Rm for each of the Normal Charts (Di/d = 2, 5, 10, and 15), and R(sn)/Rm vs. R(lat)/Rm for each of the Lateral Charts (Di/D = 2, 5, 10, and 15). The values that will be obtained from these plots are Rt/Rm and Ri/Rm for each value of Di/d. These values should be tabulated for convenience (Table III).

TABLE III

EXAMPLE OF HOW TO TABULATE DATA FROM Ri-Rt CONVERSION CHARTS

	Normals		Lateral	
Di/d	Rt/Rm	Ri/Rm	Rt/Rm	Ri/Rm
2				
5				
10				
15				

To interpret the results, one should use 2-cycle log vs. log paper to get a graphic representation of the data. The plots will be Rt/Rm vs. Di/d and Ri/Rm vs. Di/d from the Normal and Lateral Conversion Charts. Four curves will result: Rt/Rm(normals) vs. Di/d, Rt/Rm(lateral) vs. Di/d, Ri/Rm(normals) vs. Di/d, and Ri/Rm(lateral) vs. Di/d. The point of intersection of the Ri/Rm(normals) and Ri/Rm(lateral) is taken as the "true" value of Ri/Rm. The point of intersection of the Rt/Rm(normals) and Rt/Rm(lateral) is taken as the "true" value of Rt/Rm. If the normal and lateral curves do not intersect (for either the Rt/Rm or Ri/Rm), then look for "flatness" of the curves, or points of near-convergence in order to estimate Rt/Rm or Ri/Rm. If there is no intersection, "flatness", or point of convergence, then probably an error exists in estimation of apparent resistivity, bed-thickness and adjacent-bed corrected values, or adjustment of Rm to formation temperatures; perhaps an incorrect borehole diameter has been selected. The heterogeneous lithic composition of the Red Fork Interval probably also contributes to complications in interpreting results.

Limitations of Method

Limitations of this method primarily are due to limitations in Bed-thickness and Adjacent-bed Correction Charts. The largest Rs value these charts can correct is 10 Ohm-m. As resistivity of shales pertains to the Red Fork Format, Rs values greater than 10 Ohm-m are rather common. As for bed thickness, the thinnest bed the lateral's Bed-thickness and Adjacent-bed Correction Chart can adjust is 21 feet (Appendix D). If the bed in question is less than 21 feet thick, the Lateral Charts can not be used; however, useful estimates can still be obtained from the Normal Charts.

Another factor to consider is thickness of the bounding formations (Rs). How thick must the surrounding beds be in order to get accurate results? As mentioned previously, most analytic methods consist of correction charts accompanied by a minimal amount of explanatory text. A satisfactory answer to the question of adequately thick bounding formations and to the question of Rs values greater than 10 Ohm-m was not discovered during study of the assumptions underlying design of correction charts.

I believe that the Ri-Rt Conversion Charts were designed in a similar fashion to Guyod's and Pranglin's Analysis Charts (i.e. designed for homogeneous and isotropic formations encased in a homogeneous and isotropic formation -- "shale"). The lithic makeup of the Red Fork varies significantly; however, "average" apparent resistivity values should yield approximate values of Ri, Rt, and Di/d. This is speculation of course, but to correct "average" apparent resistivity values for borehole influences, bed-thickness and adjacent-bed effects, and for invasion seems better than to not correct the apparent resistivity values at all.

If one wanted to calculate water saturation for the Red Fork Sandstone in a straightforward manner using the Archie Equation, probability-weighted values of porosity (from modern porosity logs) and reliable estimates of Rw (from temperature-adjusted "average" Rw) could be entered into the equation. Rt can be corrected for various influencing factors and estimated by one of the analytic methods. Therefore, calculation of water-saturation is possible from the information above. If estimates of water saturation could be obtained without making assumptions about porosity or Rw, this would be most advantageous; this is possible by using a Saturation Chart.

CHAPTER X

Proposed Method of Analysis

Introduction

In a "clean" formation (a clay-free, rock-fragment-free formation), the matrix material is an electrical insulator; therefore, the ability of a formation to conduct electric current is due to electrolytes in the pore fluids. In shaly sandstones, the shale constitutes a part of the rock matrix; clays of the shale are conductors of electricity. In some provinces, shale (clay) in sandstone reservoirs tends to decrease resistivity of that formation, but in other provinces the opposite is true. If enough shale were present in a formation, resistivity anomalies associated with the presence of oil and gas could be masked by the conductance of shale. Secondly, the SP curve is also affected by shale. The amount of negative deflection of the SP curve is less in shaly formations than in clean formations, all other factors being the same. At the very least, shale in a reservoir adds an additional degree of complexity to the interpretation of logs. The Red Fork Sandstone is a shaly reservoir; therefore, interpretation of old electric logs in the Red Fork is complicated further by the influence of shale.

Before the advent of logging tools that could measure matrix properties of a formation (modern porosity tools), log analysts had a difficult time determining accurate values of F, Rw, and Rt. Log analysts developed techniques to circumvent this problem through manipulation of the Archie Equation: $Sw = (Ro/Rt)^{0.5}$, where $Ro = F * Rw$, the resistivity of a formation that is 100 per cent water saturated, with a formation-water resistivity of Rw (Patchett, 1961 p. 60). Comparisons could be made between formations that are believed to be 100 per cent water-saturated and formations believed to contain oil and gas. Such comparisons would be limited to reservoirs of similar grain size and matrix composition, with consistent values of Rw. Such a relationship has been used for many years; it commonly is referred to as the "Ratio Method". How can this method be modified and used to estimate water saturation from old electric logs?

Rationale

In many wells in Payne County the Red Fork Sandstone is of "reservoir quality" and is very close to being 100 per cent water-saturated. Valuable data can be obtained from logs of these wells; comparison can be made among wells that are believed to contain oil and gas in the Red Fork and wells where the Red Fork is believed to be 100 per cent water-saturated. Such a comparison can be made by plotting on semi-log paper Rxo/Rt vs. SSP deflection (Poupon, and others, 1954, p. 139). Rxo/Rt is plotted on the logarithmic ordinate and SSP deflection, in millivolts, on the abscissa (Fig. 36). This type of chart is referred to as a Saturation Chart (Fig. 36).

If logs are selected where the formation of interest is 100 per cent water-saturated or is very close to 100 per cent water-saturated, then plotting of Rxo/Rt vs. SSP deflection within this specific "wet" formation should produce a cluster of points (Fig. 37). A straight line through this cluster of points should approximate the position of a line of 100 per cent water saturation for that specific reservoir. This line commonly is referred to as the Ro line (Fig. 37).

Consider the plotting of Rxo/Rt vs. SSP deflection from a well that is believed to contain oil and gas within the same formation, or from a formation of similar grain size and matrix composition (provided that Rw is consistent). This point will plot below the Ro line (point "A" Fig. 37). The moving of point "A" along the ordinate of SSP deflection to intersect with the Ro line yields the following relationship: (Rxo/Ro)/(Rxo/Rt) = Rt/Ro. Rt/Ro is known as the resistivity index "I" (Wyllie, 1954, p. 14).

The resistivity index can be converted easily to water saturation by the formula Sw = (1/(I))^0.5, or by use of a nomograph (Fig. 38). However, an oil-bearing zone will

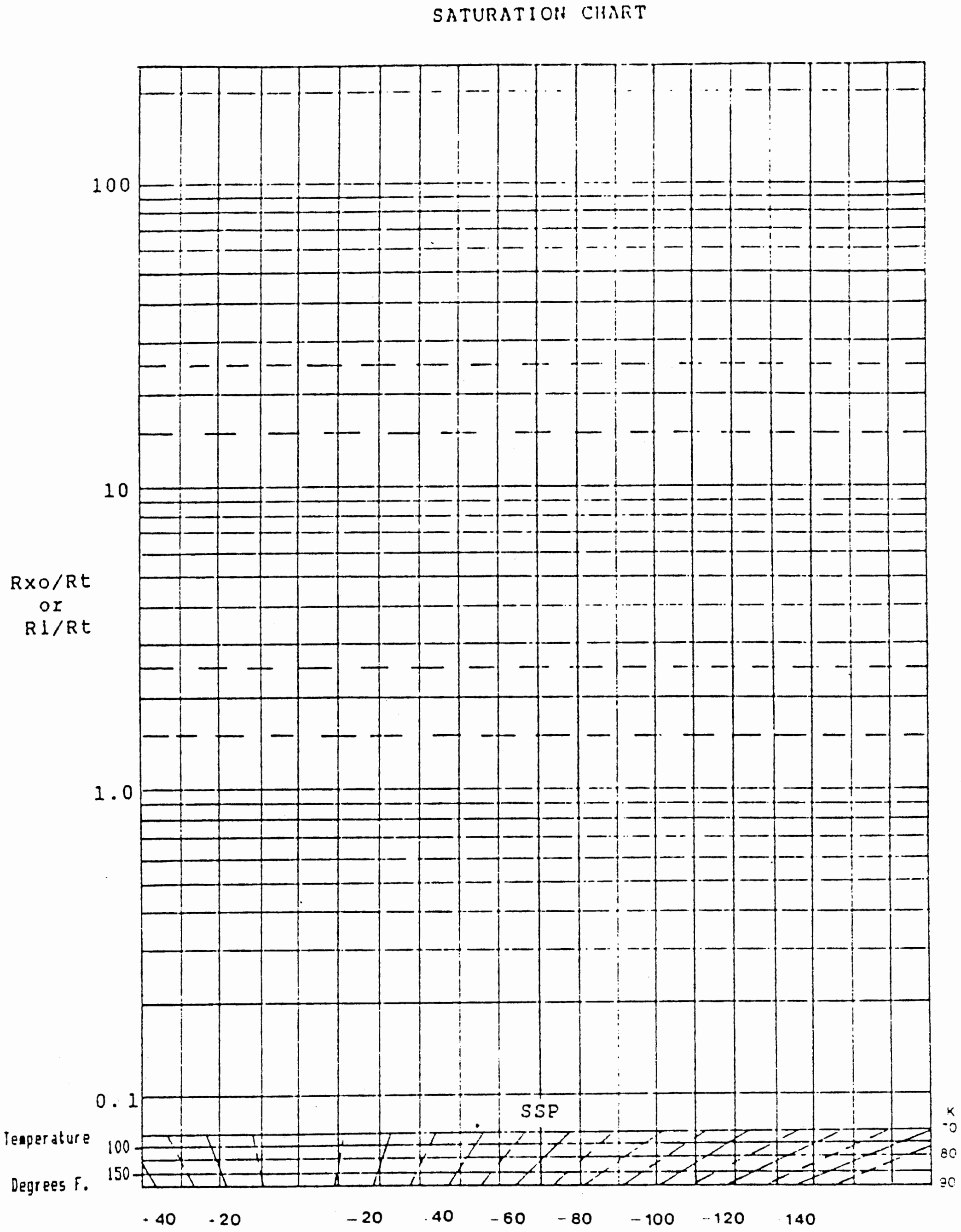


Figure 36. Saturation Chart (Modified After Schlumberger, 1955).

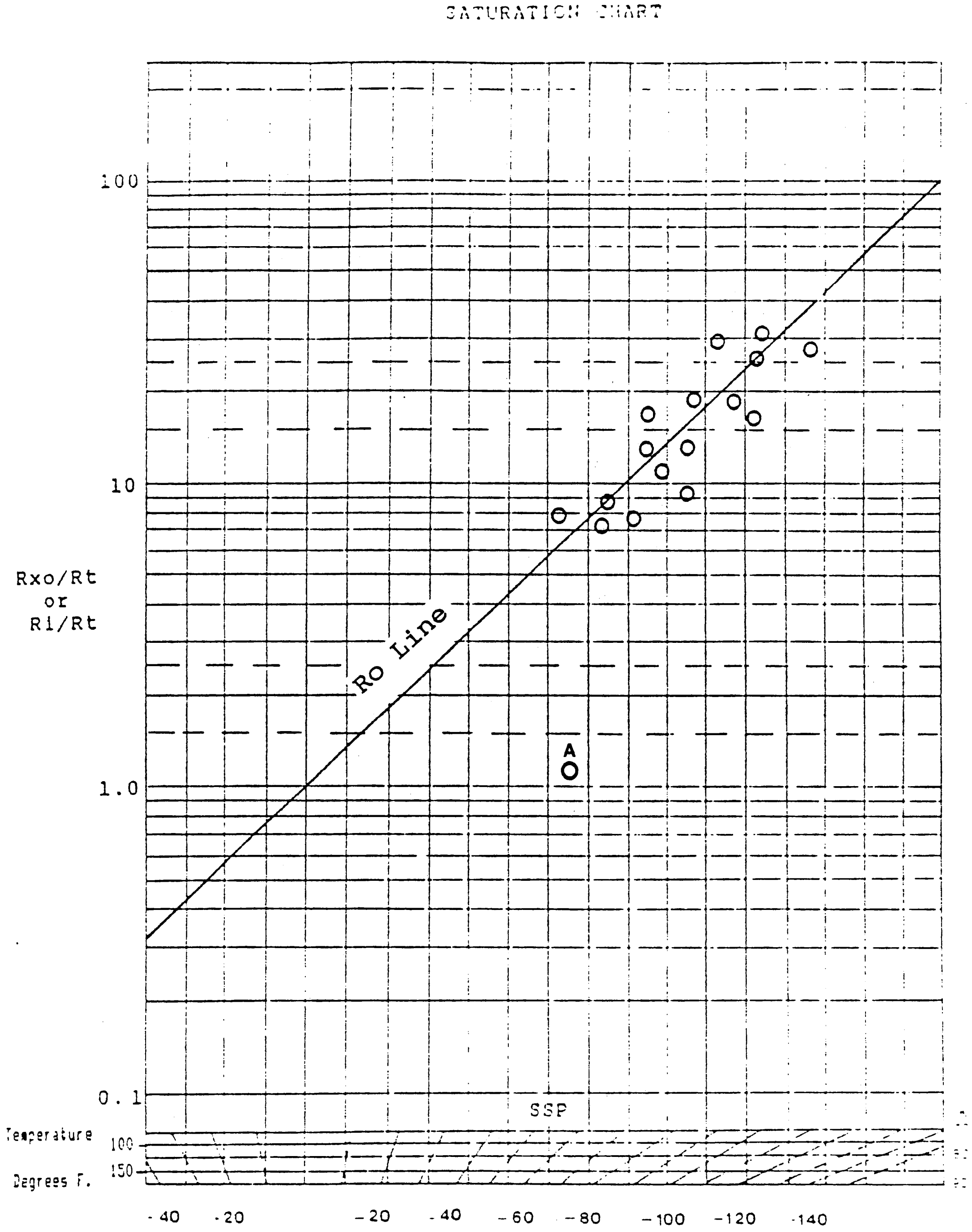


Figure 37. Saturation Chart Showing Hypothetical Plot of Rxo/Rt vs. SSP From "Wet" Formation.

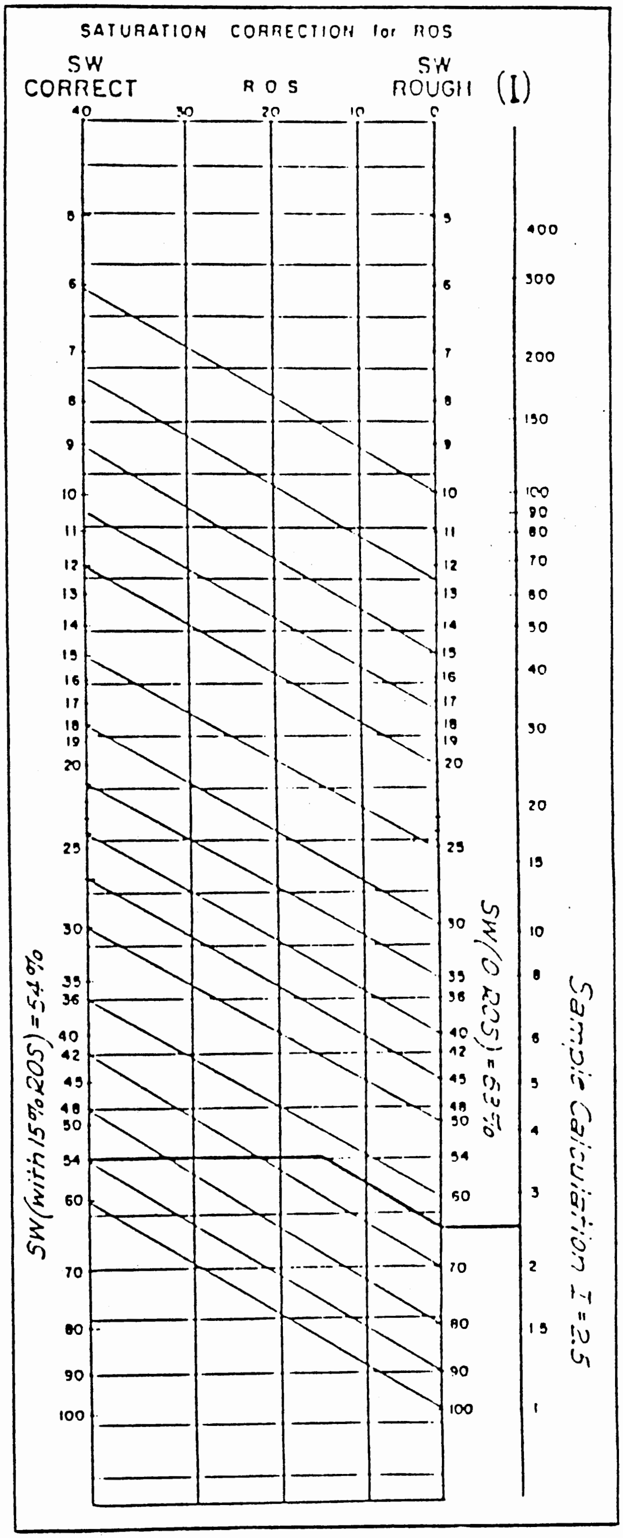


Figure 38. Nomograph to Convert "I" to Sw With or Without Considering ROS (After Schlumberger, 1955, as Modified by Patchett, 1961).

have a larger Rxo value than a "wet" zone, due to residual oil saturation (ROS). The residual oil saturation must be corrected in order to make an accurate estimate of water saturation. Patchett (1961, p. 63) proposed that the "I" from the Saturation Chart should be denoted as "Io", thus differentiating "Io" from Wyllie's "I". According to Patchett (1961, p. 63), "I" = "Io" if residual oil saturation is zero; if not, "I" = "Io"/(Sxo^2.0). If ROS is equal to 20 per cent, water saturation can be adjusted by the formula: Sw = ((1/Io) * (0.8)^ 2.0)^ 0.5, or from a nomograph (Fig. 38).

One benefit of using a Saturation Chart to estimate water saturation is that the formation resistivity factor (F), and hence porosity, are eliminated from the calculation. In doing so, the Saturation Chart also circumvents some effects of shale; elimination of the variable F removes the effects of shale from formation-matrix resistivity. Since F is removed from the calculation of water-saturation, the effect of shale on the formation resistivity factor does not have to be determined. The effects of shale on Rt are not necessary to determine, because a comparison is being made between values of Rt in zones of equivalent grain size and matrix composition (and consistent values of Rw) -- the variation in resistivity between these two zones is assumed to be due to petroleum. This is accomplished by making a comparison between the value of Rxo/Rt of a suspected oil- or gas-bearing zone to Rxo/Ro. Rxo/Ro essentially represents what the Rxo/Rt value of the oil- or gas-bearing zone would be if it were 100 per cent water-saturated. An additional benefit is that Rw is also eliminated from the calculation.

Obtaining the Necessary Parametric Values From Old Electric Logs

The values necessary to construct a Saturation Chart are Rxo, Rt, and SSP deflection. SP deflection is obtained easily from the log. Draw the shale base line on the log and count the number of chart divisions to the maximal negative SP deflection. The SP deflection must be converted to SSP (Static Spontaneous Potential) by taking into consideration the influence of bed thickness on SP deflection (Fig. 39).

Rxo and Rt are somewhat more difficult to determine from old electric logs. As stated previously, apparent resistivities obtained from the logs must be corrected for borehole influences, bed thickness, adjacent-bed effects, and invasion. To do this, one must use the analytic methods discussed in Chapter IX. For the Red Fork Sandstone in Payne County, Oklahoma, the Lane Wells Ri-Rt Conversion Charts are the best means of obtaining accurate estimates of Ri, Rt, and Di (Appendix D).

In order to use the Saturation-chart Method to

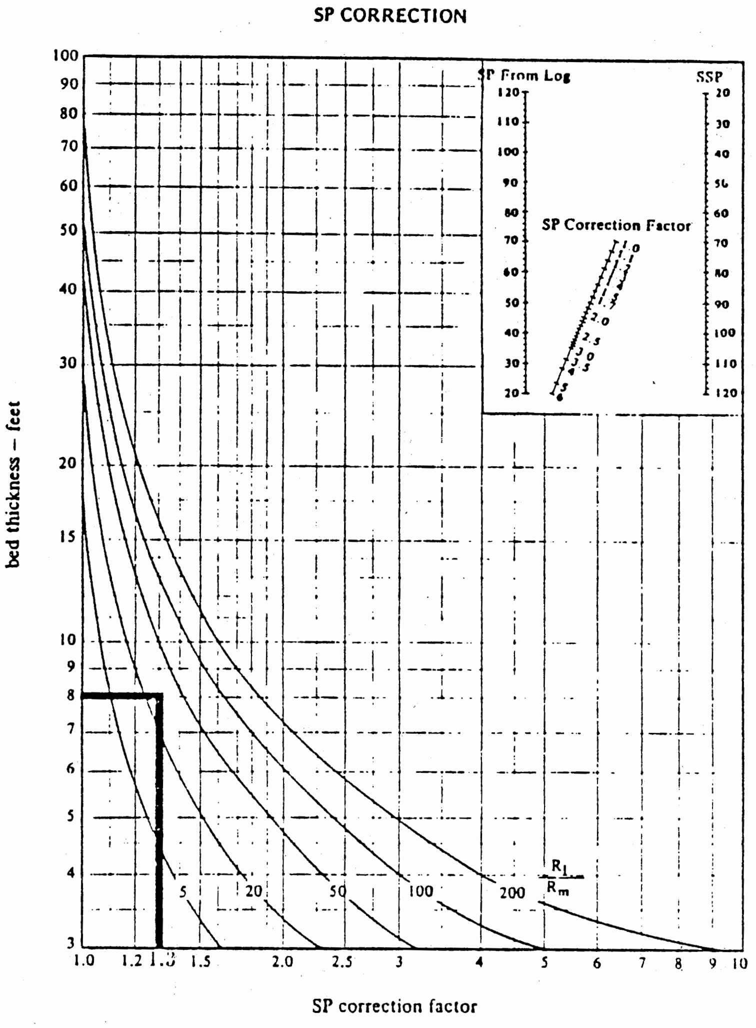


Figure 39. SP to SSP Correction Chart (After Asquith, 1982).

obtain estimates of water saturation, a critical assumption was necessary: Ri obtained from the Ri-Rt Conversion Charts (Lane Wells, 1956) essentially is equal to Rxo. As stated previously, most analytic methods consist almost entirely of correction charts with only small amounts of explanatory text. Ri obtained from the Ri-Rt Conversion Charts actually may be Rxo (Patchett, 1987, personal communication). If this is true, then use of the Ri-Rt Conversion Charts will provide the necessary corrected parametric values for use on a Saturation Chart (Ri/Rt ~ Rxo/Rt).

CHAPTER XI

APPLICATION OF SATURATION-CHART METHOD OF ANALYSIS

Introduction

The first step in practical analysis of electric logs by a Saturation Chart is to generate a chart from data based on records of local wells. To do this, one needs a "random sample" of old electric logs from Payne County, where the Red Fork Sandstone appears to be 100 per cent water-saturated, or very close to 100 per cent water-saturated. From these data the position of an Ro line can be approximated on the Saturation Chart (Fig. 40). A random sample of eight wells was selected from Payne County, where the Red Fork Sandstone appears to be "wet". These wells are listed in Table IV.

The logs were processed using the Lane Wells Ri-Rt Conversion Charts in order to obtain accurate estimates of Ri and Rt (Appendix D). Data sheets for the eight logs are given in Appendix E. The "true" values of Ri and Rt derived from the conversion charts (for each well) were put in the ratio Ri/Rt (which, for all practical purposes, is equal to Rxo/Rt) and were plotted against the Static

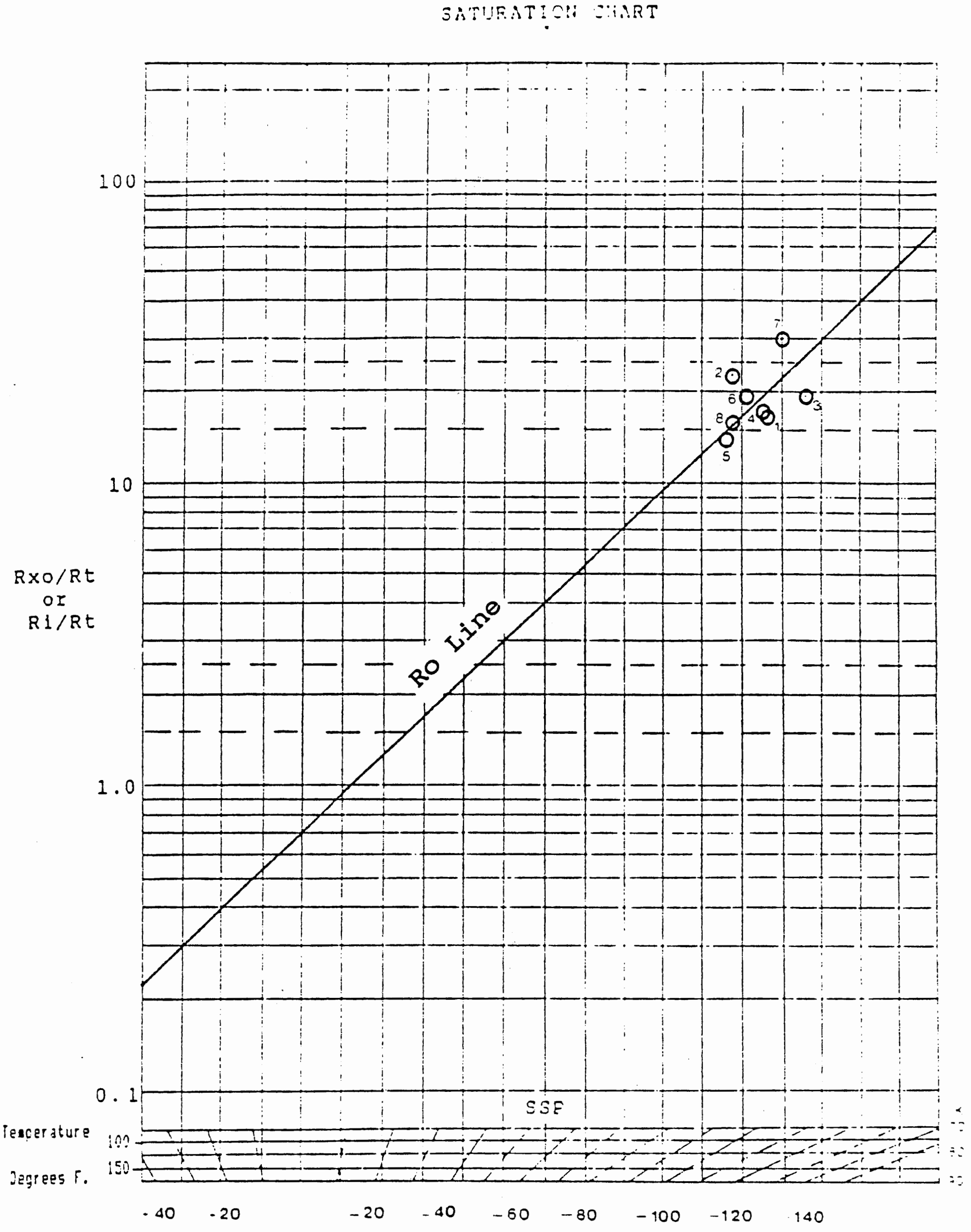


Figure 40. Plot of Rxo/Rt vs. SSP for Old Electric Logs From "Wet" Red Fork Sandstone, Payne County.

Spontaneous Potential for each well (Fig. 40).

TABLE IV

WELLS IN WHICH THE RED FORK SANDSTONE IS JUDGED TO BE AT OR NEAR WATER SATURATION OF 100 PER CENT

	WELL NAME	OPERATOR	Sec.	T	R
1)	W.H. Martgan	Goom No. 1	30	19N	3E
2)	W.O. Allen	Caldwell No. 1	25	18N	2E
3)	Wilcox Oil Co.	W.B. Davis No. 1	2	18N	3E
4)	Gulf Oil Co.	Hattie Offield No. 1	31	18N	3E
5)	W.H. Martgan	Schroeder No. 1	34	19N	3E
6)	Texas Pacific Coal & Oil Co.	Story No. 3	2	17N	3E
7)	Home Gas Company of Cushing	Lovell Bros. No. 1	35	18N	3E
8)	Russel McGuire	Testerman No. 2	10	18N	3E

Figure 40 shows that the data from these eight wells form a fairly tight cluster. To position an Ro line through this cluster of points is not difficult, but the logic of placement involves consideration of the cluster of points and the "necessary" position of an Ro line. Because the Ro line is defined as the resistivity of water-saturated Red Fork Formation with formation-water resistivity of Rw, and because the magnitude of the Static Spontaneous Potential curve (as used here) is based on the assumption of water-saturated rock, the Ro line must be positioned parallel to a line that is a function of the relation of Rxo/Rt and Rmf/Rw in the static-spontaneous-potential equation: SSP = -k * log Rmf/Rw (see Appendix F). The approximate position of the Ro line is shown in Figure 40. The slope of this line is fixed; the line is placed through a cloud of points on the assumption that the scatter of points is due to several uncontrolled random variables. Some of these variables can be differing mud properties from well to well, inaccuracy in obtaining apparent resistivity values from the logs due to visual limitations of the scale, logs not calibrated (zeroed) properly with galvanometer, and invasion effects not adequately corrected (in some instances) by the Ri-Rt Conversion Charts.

Problems in Obtaining Ri and Rt

Some problems were encountered when processing the so-called "wet" wells (Sw ≃ 100 per cent) with the Lane Wells Ri-Rt Conversion Charts. These charts were devised to determine the "true" resistivity of oil- and gas-bearing rock formations; therefore, when trying to obtain the "true" resistivity of low resistivity "wet" formations, one is operating near the graphic limits of the Ri-Rt

Conversion Charts. In most instances this was not a significant problem. Where invasion is shallow, apparent resistivities shown by the long normal and lateral curves, as compared to that of the short normal curve, commonly are quite different. Under such conditions, data points may plot off the charts and interpolation of Rt and Ri may be necessary. This may contributed to scatter of the data points, although the scatter is not large (Fig. 40).

Comparison Using Modern Logs

Modern induction logs generally are considered to be far superior to old electric logs in obtaining accurate values of Rt. To use modern induction logs in an attempt to corroborate the empirical position of the Ro line on the Saturation Chart (for old electric logs) seemed prudent. Modern dual induction-laterologs were selected from a population of wells in Payne County where zones within the Red Fork Sandstone were believed to be 100 per cent water-saturated. Resistivity values within these "wet" zones were corrected for invasion using a "tornado" chart (Fig. 41) in order to obtain accurate values of Rxo and Rt. SP deflections within the zones of interest also were measured and corrected to SSP using Figure 39. Corrected values of Rxo/Rt were plotted against SSP deflection for each of the zones of interest. A data sheet for each of the wells analyzed is in Appendix G. Table V is a list of the wells that were used.

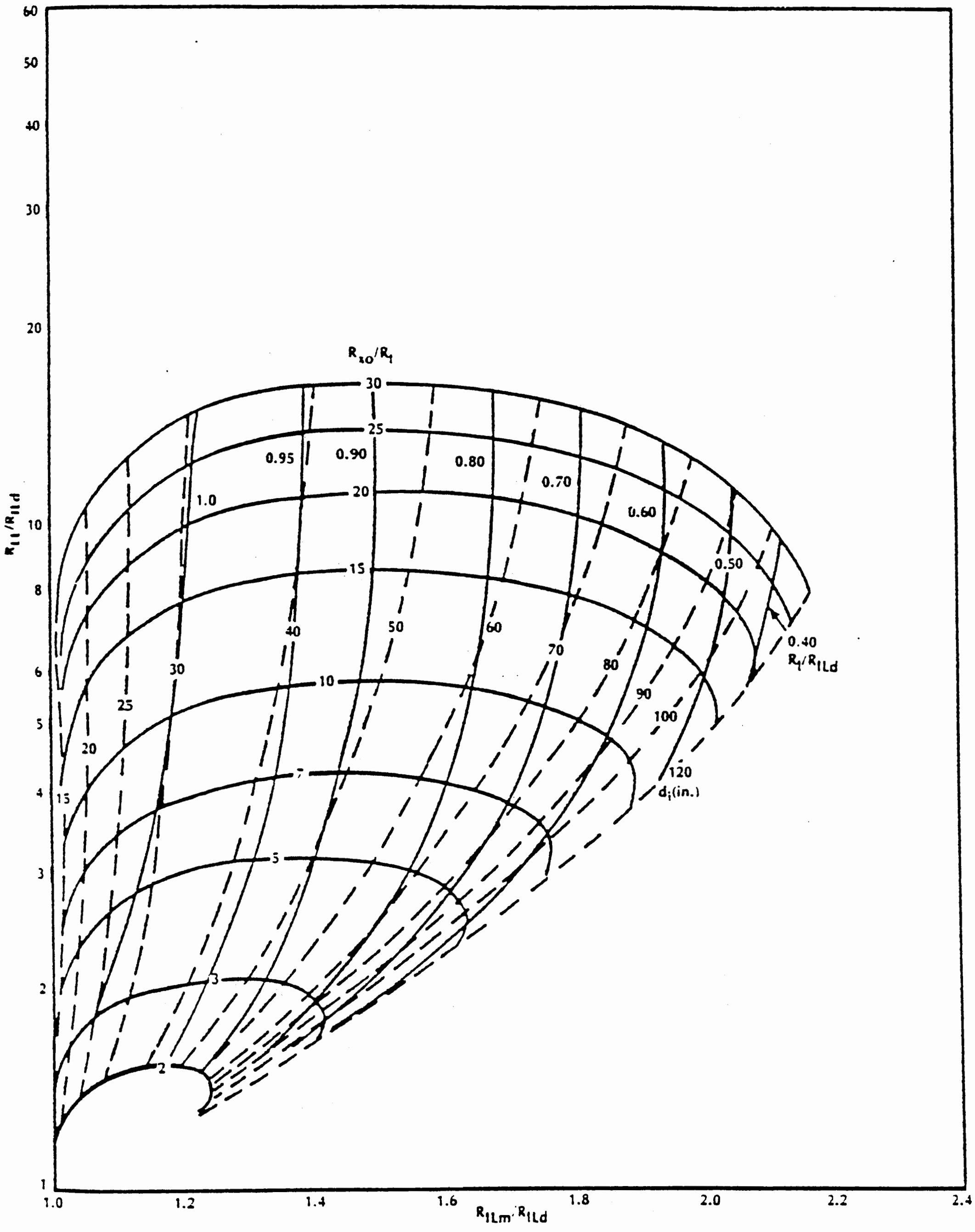
GEARHART
THE GO COMPANY

DUAL INDUCTION—LATEROLOG

THICK BEDS SKIN EFFECT CORRECTED

$R_{xo}/R_m = 20$

8- INCH BOREHOLE



RES-4a

Figure 41. "Tornado" Chart (Gearhart Chartbook, 1985).

Figure 42 shows the resulting plots of Rxo/Rt vs. SSP deflection from the "wet" zones within the Red Fork Sandstone. Fourteen modern induction logs were used and multiple data points within the Red Fork Sandstone were obtained from each well; therefore, more data points were used to construct this Saturation Chart (Fig. 42) than the Saturation Chart derived using old electric logs (Fig. 40). The reason for this procedure was that modern logs allow analyses of much thinner strata than do old electric logs. Bed thickness, adjacent-bed effects, proximity of shale partings, and resistive "streaks" do not affect modern logs as adversely as old electric logs.

Comparison of the Saturation Chart derived from old electric logs and the Saturation Chart derived from modern induction logs shows evidence of a subtle difference in position of the Ro line (Figs. 40 and 42). The Ro line for the old electric logs is positioned slightly lower than the Ro line for the modern induction logs (Figs. 40 and 42). Data from the induction logs seems to be more scattered than data from old electric logs (Figs. 40 and 42). This could be due to the larger number of points plotted from the modern logs. Another possibility is that the SP tool used on old electric logs is of better quality than the SP tool used on modern induction logs (Patchett, 1988, personal communication).

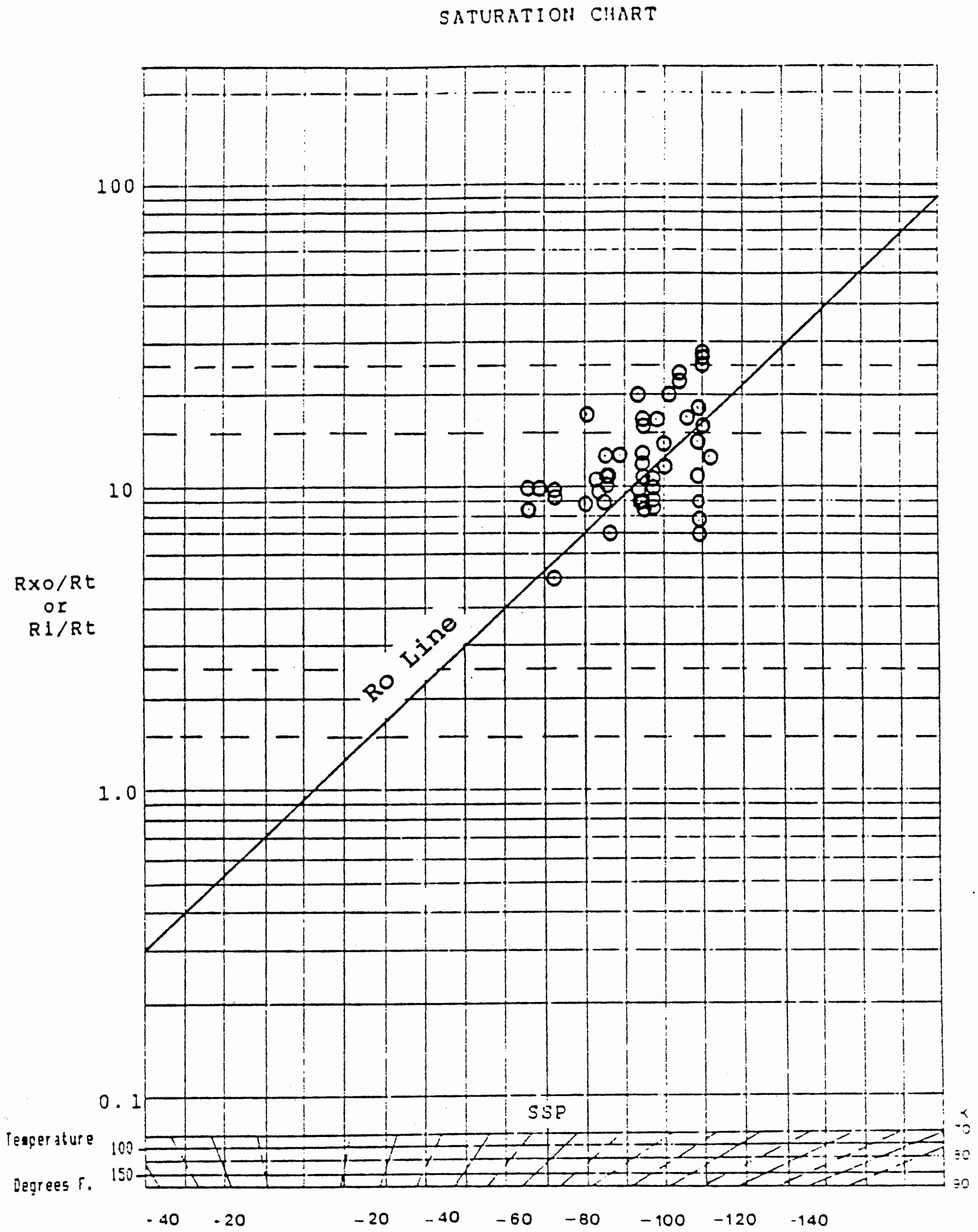


Figure 42. Plot of Rxo/Rt vs. SSP for Modern Induction Logs From "Wet" Red Fork Sandstone, Payne County.

TABLE V

LIST OF WELLS FROM WHICH MODERN LOGS WERE USED TO ESTIMATE Rxo AND Rt WITHIN "WET" ZONES OF RED FORK SANDSTONE

	WELL NAME	OPERATOR	Sec.	T	R
1)	C.E. Wall No. 1	Earth Energy Resources	10	17N	2E
2)	R. Wall No. 5-A	Berry Operating Co.	10	17N	2E
3)	R. Tucker No. 3-A	Earth Energy Resources	12	18N	3E
4)	R. Wall No. 1-A	Berry Operating Co.	10	17N	2E
5)	C.E. Wall No. 3	Walter A. Kelly Jr.	10	17N	2E
6)	R. Wall No. 3-A	Berry Operating Co.	10	17N	2E
7)	Coe-Bailey No. 1	Earth Energy Resources	11	17N	2E
8)	O'Hern No. 2	Earth Energy Resources	26	17N	3E
9)	Tucker No. 4	Earth Energy Resources	12	18N	3E
10)	McKenzie No. 10	Earth Energy Resources	13	18N	3E
11)	Berry Fee No. 8	Thomas N. Berry	13	18N	3E
12)	C.E. Wall No. 4	Walter A. Kelly Jr.	10	17N	2E
13)	Shively No. 1	Southport Exploration	21	19N	3E
14)	Tucker No. 2	Earth Energy Resources	12	18N	3E

Conclusions Drawn From Comparison

Positions of Ro lines determined from old electric logs and from modern induction logs are strongly similar (Fig. 43). The Ro line from old electric logs is positioned slightly lower than the Ro line from modern induction logs. Possible reasons for this phenomenon are: (1) Values of Rxo and Rt obtained from "tornado" chart are not accurate. (2) Values of Ri and Rt obtained from Ri-Rt Conversion Charts are not correcting the effects of invasion accurately. (3) Ri obtained from the Ri-Rt Conversion Charts is not equal to Rxo. If the last alternative is true, Ri should be less than Rxo; therefore, Ri/Rt would be less than Rxo/Rt and the position of the Ro line for old electric logs should plot below the Ro line for modern logs (Fig. 43).

Use of Saturation Chart to Estimate Water Saturation From Old Electric Logs

A Saturation Chart with an Ro line for the Red Fork Sandstone can be used to estimate water saturation from old electric logs. The obvious question is: "How well will this Saturation Chart work on the formation of interest, in the study area?" To answer this question, 15 wells were selected within Payne County where the Red Fork is believed to contain petroleum. To test this procedure objectively, selection of wells where the Red Fork is exceptionally

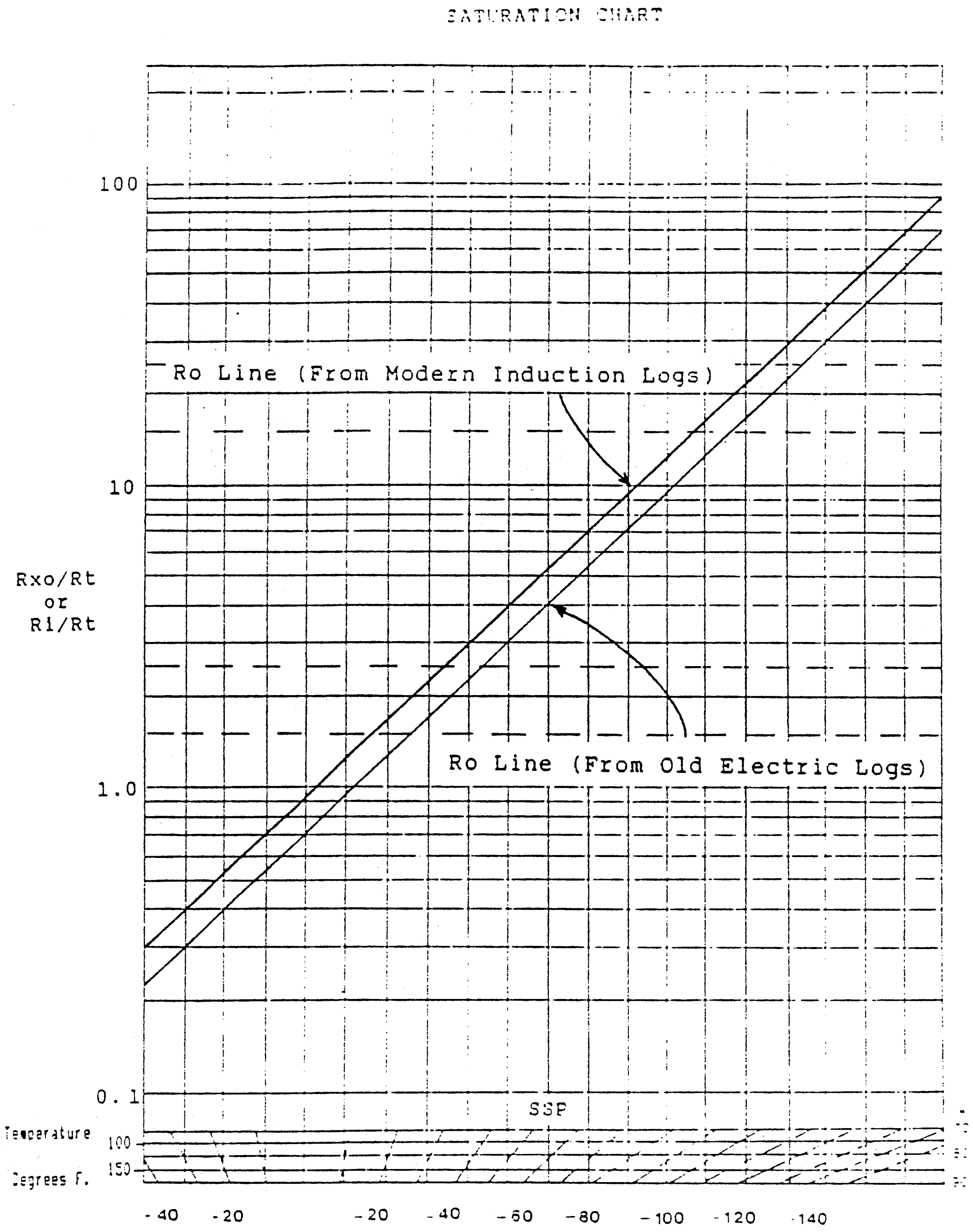


Figure 43. Comparison of the Relative Positions of Ro Lines From Old Electric Logs and Modern Induction Logs From "Wet" Red Fork Sandstone, Payne County.

thick, obviously contains significant quantities of petroleum, and is somewhat "homogeneous" would not be good practice.

I believe that to test this proposed method adequately, the Red Fork signatures should "typify" the circumstances likely to be encountered in the area of study. Therefore, wells where the Red Fork is "broken" by thin beds of shale, where reflection peaks from the overlying Pink Limestone interfere with interpretation of the lateral curve, and where the Red Fork is thinner than 21 feet were included in the analyses -- in addition to wells where the Red Fork is thick and obviously contains large quantities of petroleum. A list of these "problematic" wells is given in Table VI.

Data from the old electric logs were processed using the Lane Wells Ri-Rt Conversion Charts (Appendix D). Data sheets from these analyses are in Appendix H. Values of Ri/Rt or Rxo/Rt were plotted versus SSP deflection for each of the wells in question (Fig. 44). The number by each data point signifies the listing in Table VI. Estimates of water saturation can be made by projecting each data point along the ordinate (same SSP deflection) to the position of the Ro line. At this point, the values of Rxo/Rt and Rxo/Ro will be known. The resistivity index "I" is equal to (Rxo/Ro)/(Rxo/Rt); therefore, (1/"I")^0.5 = Sw. It is important to note that ROS is assumed to be zero in the above equation.

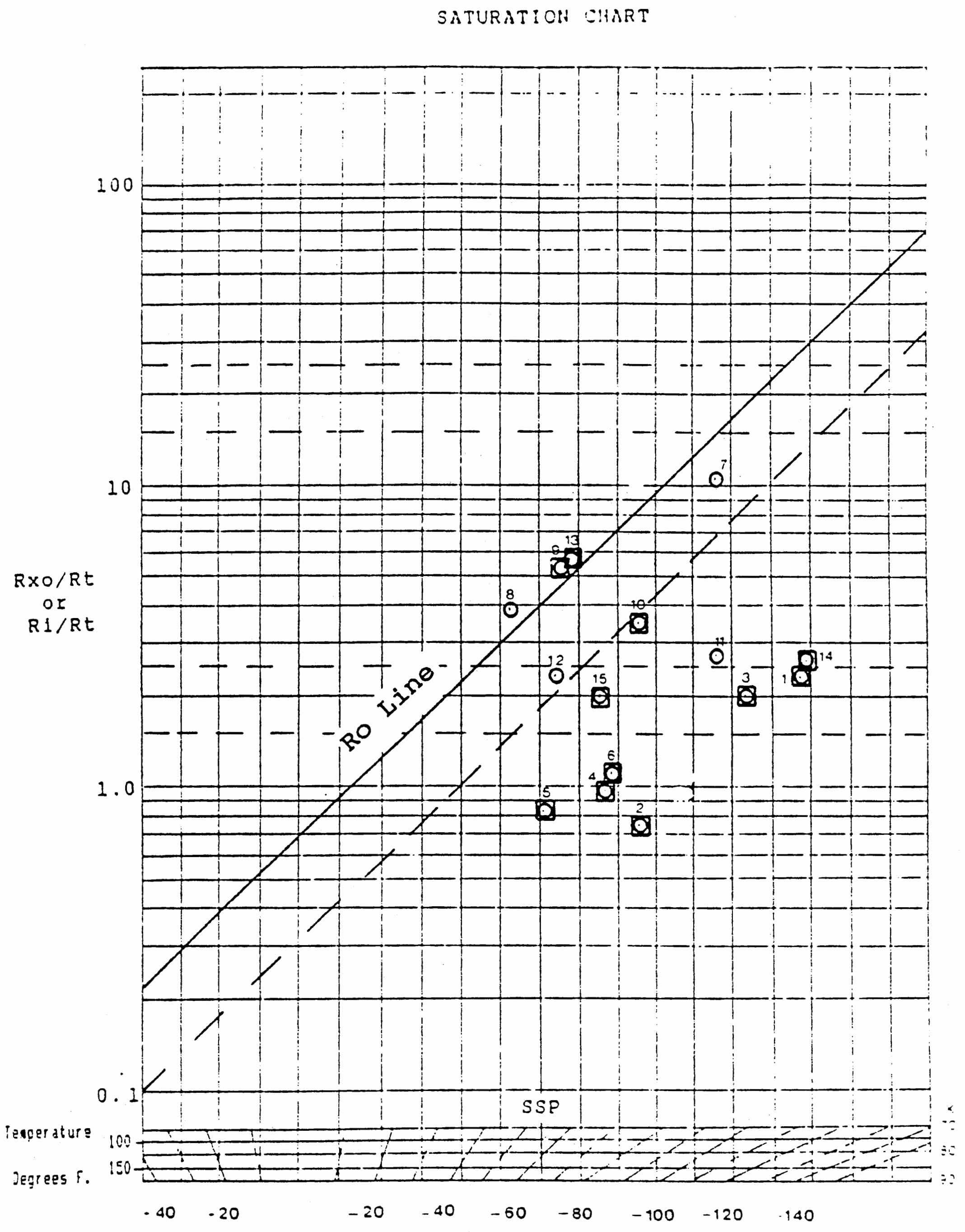


Figure 44. Plot of Rxo/Rt vs. SSP for Old Electric Logs From "Productive" Red Fork Sandstone, Payne County. Dashed line Represents Approximate Position of a line that separates "Productive" Wells from "Nonproductive" Wells.

TABLE VI

WELLS USED TO TEST RELIABILITY OF ESTIMATES OF WATER-SATURATION FROM SATURATION CHART

WELL NAME	OPERATOR	Sec.	T	R
1) Skelly Oil Co.	Martha Berry No. 4	22	19N	3E
2) Midstates Oil Corporation	State-Penny No. 2	36	19N	4E
3) Simon Lebow	Orvis No. 4	22	19N	4E
4) McCollister & Rahal	Moore No. 4	17	18N	6E
5) Harris & Suppes	Vickery No. 4	2	18N	5E
6) McCollister & Rahal	Moore No. 3	17	18N	6E
7) Texas Pacific Coal & Oil Co.	Story No. 3	1	17N	3E
8) C.U. Bay - T.W. & J.M. Loffland & Patton	Bellis No. 1	27	18N	4E
9) Wilcox Oil Co.	Sam No. 1	3	18N	2E
10) T.W. & J.M. Loffland	Stanolind-Amerada No. 2	27	18N	4E
11) Foster Drlg. Co.	Grimm No. 1	31	18N	4E
12) C.E. McCaughey et al.	Stanolind - et al. No. 1	28	18N	4E
13) H. Waggoner Co.	Wilson No. 1	29	18N	4E
14) Simon Lebow	Orvis No. 3	22	19N	4E
15) Magnolia Ptrl. Company	W.H. Grove No. 12	27	19N	4E

If ROS is unknown, then the value could be estimated to lie between 0 and 20 per cent. As a result, estimates of water-saturation should be expressed in a "range". That is to say, water-saturation should be calculated for ROS of 0 and 20 per cent. To incorporate ROS into calculations of water saturation, the formula is as follows: $Sw = ((1/\text{"I"}) * (Sxo)^{2.0})^{0.5}$. Using the Saturation Chart and the equations above, "high" and "low" values of water-saturation can be determined.

At this point, values of water-saturation have been determined without "formidable" assumptions. The underlying assumptions are: (1) Ri-Rt Conversion Charts yield reliable estimates of Ri and Rt, (2) Ri from Ri-Rt Conversion Charts is equal to Rxo, (3) Rw is consistent within the Red Fork Sandstone from well to well, and (4) the position of the data-fitted Ro line on the Saturation Chart is reliable.

Once high and low values of water saturation have been determined, porosity can be "backed out" of the Archie Equation by using the appropriate formation factor ($F = 0.81/(\text{porosity})^{2.0}$), and estimating a value of Rw as outlined in Chapter III. Modifying the Archie Equation to solve for porosity yields: $\text{Porosity} = ((0.81 * Rw) / ((Sw)^{2.0} * Rt))^{0.5}$. Solving for porosity is a useful way to judge the accuracy of water saturation obtained from the Saturation Chart. Because a statistical analysis of porosity values obtained from modern CNL-CDL logs in the

Red Fork Sandstone of Payne County yielded an average porosity value of 15 per cent and a standard deviation of approximately 2 per cent (Fig. 9), then approximately 95 per cent of the porosity should lie within the range of 11 to 19 per cent. Estimates of porosity more deviant than 11 and 19 per cent should be held in suspicion.

A value (or values) of formation factor can be derived using probabilistic estimates of porosity for the Red Fork Sandstone (Chapter IV). In turn, this value of (F) can be compared to the value that can be "backed out" of the Archie Equation using information from the Saturation-Chart Method. Such a comparison, of "resistivity derived" formation factor to so called "known values", is very similar to "Porosity Balance" (Tixier, 1958).

Analyzing Data Obtained From Saturation Chart

For the fifteen wells in question (Table VI), a summary of the values obtained from the Ri-Rt Conversion Charts, from the Saturation Chart, values of Rw, and records of initial production obtained from scout tickets is shown in Table VII. Estimates of water saturation and porosity were based on ROS of 0 and 20 per cent (Table VII). The "boxes" that surround most of the plotted data points of each well indicate production from the Red Fork Sandstone (Fig. 44). Inspection of Figure 44 indicates some "problem wells" that do not plot as expected from

TABLE VII

DATA FROM Ri-Rt CHARTS, Rw-TEMPERATURE CHART, SATURATION CHART, AND SCOUT TICKETS

WELL NAME	Rxo/Rt	Rt	Rxo/Ro	Rw	Sw(ROS = 0%)	POROSITY (ROS = 0%)	Sw(ROS = 20%)	POROSITY (ROS = 20%)	SCOUT TICKET INFORMATION
1) Martha Berry No.4	2.3	11.5	30	.0395	28	19	22	24	38 BO/5Hrs. ~ 182 BOPD
2) State-Penny No.2	0.74	17.3	8.9	.040	29	15	23	19	136 BO & 90 BWPD
3) Orvis No.4	2.0	16.9	19.5	.035	32	13	26	16	10 BO & 30 BWPD, GRAV. 39
4) Moore No.4	0.98	16.8	6.5	.041	39	11	31	14	240 BOPD
5) Vickery No.4	0.82	14.2	4.6	.044	42	12	34	15	25 BOPD
6) Moore No.3	1.16	19.2	7.0	.0416	41	10	33	13	42 BO/6Hrs. (No Water) IP = 168 BOPD
7) Story No.3	10.5	3.7	15.0	.0375	84	11	67	14	Gas 27"(No Est.) Rec.165' SLI & O&GCM,30'O&GCM D&A
8) Bellis No.1	3.9	3.5	> 100	.0395	≃ 100	10	80	12	Red Fork Not Tested (D&A)
9) Sam No.1	5.3	5.25	> 100	.037	≃ 100	8	80	9	100,000 CFGPD, 85'HOCM; BHP 1750/15Min FL 31 BOPD
10) Stanolind-Amerada No.2	3.5	7.4	8.8	.039	63	10	50	13	60 BOPD GRAV. 40
11) Grimm No.1	2.7	12.5	15	.0385	42	12	34	15	80' GCM (D&A)
12) Stanolind et al No.1	2.3	9.9	4.7	.041	70	8	56	10	Open 1 Hr. Rec 34' OCM, No Water, No Red Fork Prod.
13) Wilson No.1	5.8	5.25	> 100	.039	≃ 100	8	80	10	12 BOPD Open Casing
14) Orvis No.3	2.6	21.3	30	.040	29	13	24	16	60 BOPD
15) W.H. Grove No.12	2.0	13.8	6.5	.039	55	9	44	11	23 BO & 129 BSWPD

information obtained from scout tickets. The wells in question are (9) Sam No. 1, (13) Wilson No. 1, and (11) Grimm No. 1 (Table VII and Fig. 44).

The Wilson No. 1 and Sam No. 1 produce from the Red Fork, but they plot slightly above the Ro line (Fig. 44). One obvious similarity between the two wells is that the signatures are much alike (Figs. 26 and 45). In both wells, the Red Fork is "broken" by thin beds of shale, and the Red Fork of the Sam No. 1 seems to be very shaly (Figs. 26 and 45). The anomalous positions of the plots from these two wells might be explained correctly by shaliness of the formation. Clay in the formation may have suppressed the SP curve significantly. Correction of SP deflection to SSP should correct bed-thickness effects on the SP curve, but may not compensate adequately for suppression due to shaliness or petroleum. In the Wilson No. 1 well (Fig. 26), porosity in the uppermost sandstone may be greater than in the strata below. This inference is suggested by a decrease in resistivity shown by the short normal, whereas resistivity indicated by the long normal remains approximately the same. Perhaps depth of invasion is less in the presumedly more porous uppermost sandstone. Saturation by petroleum in this productive well may have been enough to suppress the SP curve. Configuration of the curves could be explained equally well by shaliness. In any case, migration of the plotted point onto the Ro line seems to be due to suppression of the SP curve.

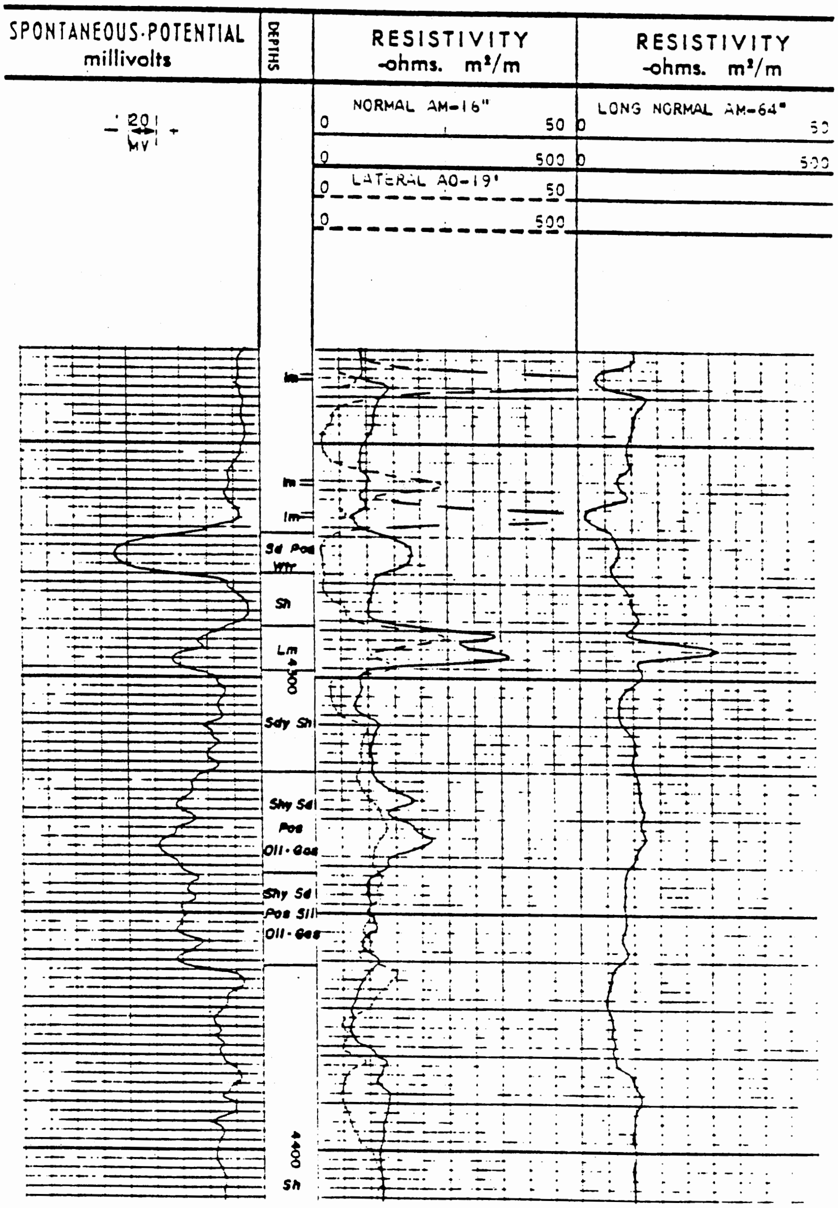


Figure 45. Wilcox Oil Co., Sam No. 1.

Another possible explanation is that the Ri-Rt Conversion Charts are not giving reliable estimates of Ri and Rt from these formations. As stated previously, these correction charts probably were devised to operate most effectively where formations are thick, "homogeneous", and encased in a thick "isotropic" formation (shale). The Red Fork does not meet this description. As a consequence, the Ri-Rt Conversion Charts generally do not work well in heterogeneous formations, such as the Red Fork. Obtaining accurate parametric values from the Ri-Rt Conversion Charts may be a "hit or miss" relationship to some degree.
One should note that porosity values obtained from the Saturation Chart can also be used to detect anomalous conditions, wherein the Red Fork Sandstone is concerned (Table VII). The porosity values from the Wilson No. 1 well lie within the range of 8 - 10 per cent. The probability of occurrence of porosity so small is approximately 2 to 3 chances in one hundred. Therefore, the values of Ri and Rt obtained from the Ri-Rt Conversion Charts are suspect.

The Grimm No. 1 well does not produce from the Red Fork, but the data plot in a position that indicates favorable estimates of water saturation (Table VII and Fig. 44). Indeed, solely visual inspection of the log suggests that the well should have been commercially productive (Fig. 46). A reflection peak at 3600 feet interferes with the lateral curve, but the lateral shows an increasing

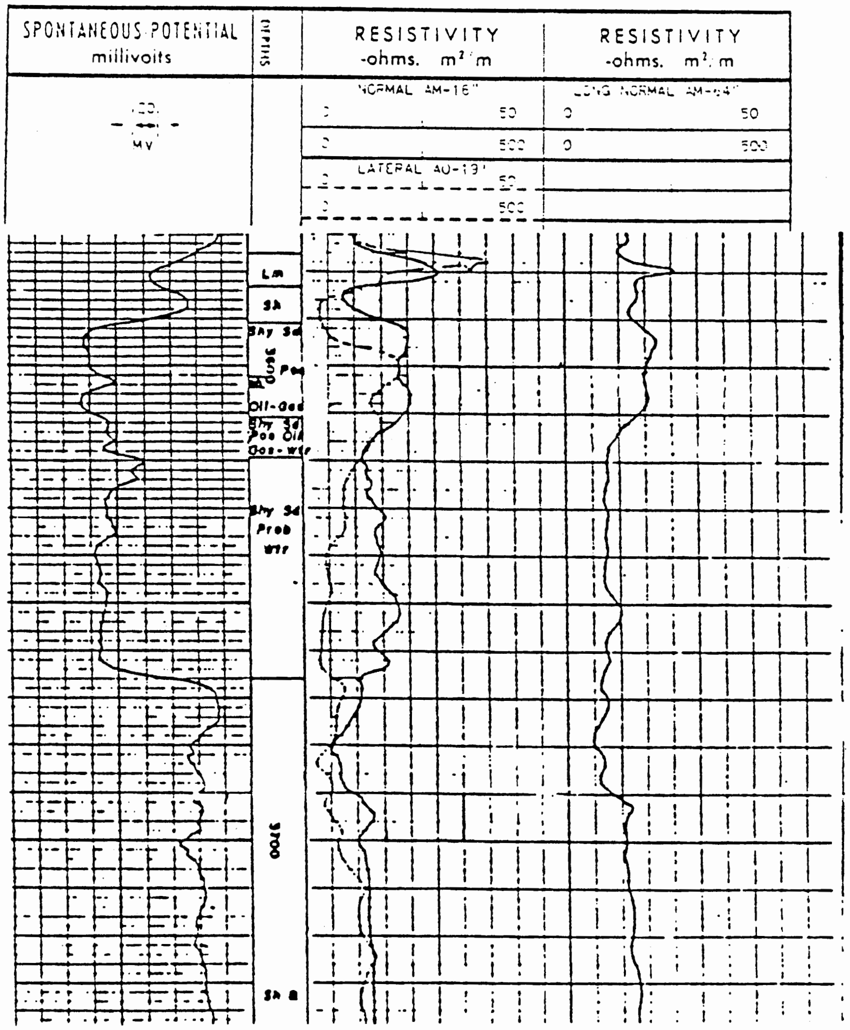


Figure 46. Foster Drlg. Co., Grimm No. 1.

resistivity profile from the bottom of the formation to the top (Fig. 46). The normal curves show relatively high resistivities in the uppermost 24 feet. Evidence from the log is indicative of accumulation of petroleum in the upper part of the formation. However, a drill-stem test produced only 80 feet of gas-cut mud.

Conclusions About the Analytical Method

Use of the Lane Wells Ri-Rt Conversion Charts in conjunction with a Saturation Chart seems to yield favorable results wherein the Red Fork Sandstone of Payne County is concerned. Estimated values of water saturation can not be quantified in a straightforward manner to predict initial-production potential from old electric logs or from modern induction logs. The method clearly "breaks down", as exemplified by analyses of the Sam No. 1 and the Wilson No. 1. Efficient use of this method could be to indicate wells that should produce. Positioning of a line on the Saturation Chart that separates productive wells from nonproductive wells would be advantageous. From the 15 wells analyzed, such a line could be positioned as is the dashed line on Figure 44. This method might be described as "quick and dirty", but the results should be as consistent as the Ri-Rt Conversion Charts are for estimating reliable parametric values. In the general absence of measured porosity, the Archie Equation cannot be used to estimate water saturation from old electric logs.

Therefore, the general estimates of water saturation that can be made from the Saturation-chart Method -- whatever their limitations -- are a marked advantage.

CHAPTER XII

CONCLUSIONS

Accurate interpretation of old electric logs requires knowledge of the logging tools and their limitations, knowledge of analytical methods and their limitations, of individual reservoirs, of the geologic setting, and of the stratigraphic section. The "root" of analytical methods is determination of reliable estimates of Rt. Reliability of estimates of Rt, Ri, and Di, obtained from the particular analytic method, is based on obtaining "representative" apparent resistivity values from the logs and on adjusting the apparent resistivities for influences of borehole conditions, mud conditions, bed thickness, and adjacent-bed effects. After this has been done, the effects of invasion can be addressed.

Where the Red Fork Sandstone of Payne County, Oklahoma is concerned, the best analytical method seems to employ the Lane Wells Ri-Rt Conversion Charts, used in conjunction with a Saturation Chart. Reliability of this procedure is hindered by heterogeneity of the Red Fork, Sandstone, limitations of Bed-thickness and Adjacent-bed Correction Charts, and possibly by variation in mud resistivities from well to well.

Clearly, instances arise where this method "breaks down", and limitations are defined. Similarly, there are instances where the logging tools did not operate accurately. If we can understand the conditions under which logging tools were likely to have measured erroneously, or if we can predict when an analytic method is likely to fail, then compensatory adjustments can be made.

SELECTED REFERENCES

Al-Shaieb, Z., 1987-88, Personal Communication.

Archie, G.E., 1942, The Electrical Resistivity Log as an Aid in Determining Some Reservoir Characteristics: Journal of Petroleum Technology, Tech. Pub. 1422, Vol. 5, No. 1, Jan., 1942, p. 54-62.

Asquith, G.B., 1982, Basic Well Log Analysis For Geologists: The American Association of Petroleum Geologists, Tulsa, Oklahoma, 216 p.

Balke, S.C., 1984, The Petrology, Diagenesis, Stratigraphy, Depositional Environment, and Clay Mineralogy of the Red Fork Sandstone in North-Central Oklahoma: Unpublished M.S. Thesis, Oklahoma State University, 118 p.

Carothers, J.E., 1958, A Statistical Study of the Formation Factor Relation to Porosity: The Log Analyst, V. 9, p. 38-52.

deWitte, L., 1956, Ri-Rt Conversion Charts, Lane Wells, Inc., 65 p.

Dresser Atlas Division, 1975, Log Interpretation Fundamentals: Dresser Atlas Inc., p. 1.1 - 13.10, Plus Charts.

Dresser Atlas Division, 1982, Well Logging and Interpretation Techniques: Dresser Industries Inc., p. 75.

Frank, R.W., 1986, Prospecting With Old E-Logs: Schlumberger Educational Services, 1331 Lamar Suite 1175, Houston, Texas, 161 p.

Gearhart Industries Inc., 1985, Formation Evaluation Chart Book: Gearhart Industries Inc.

Gearhart Industries Inc., Undated, Chart Book: Gearhart Industries Inc., p. 25.

Gilchrist, R., 1987-88, Personal Communication.

Guyod, H., and Pranglin, J.A., 1955, Electric Analogue of Resistivity Logging: Geophysics, Vol. XX, No. 3, July, p.615-629.

Guyod, H., and Pranglin, J.A., Undated, True Resistivity Determination From Conventional Electric Logs: Society of Petroleum Engineers (AIME), No. 1622G, 25p.

Guyod, H., and Pranglin, J.A., 1959, Analysis Charts for the Determination of True Resistivity From Electric Logs: Copyright 1959 by H. Guyod, 280 p.

Hilchie, D.W., 1979, Old Electric Log Interpretation: Douglas W. Hilchie, Inc., Colorado School of Mines, Golden Colorado, 161 p.

Patchett, J.G., 1961, Log Interpretation of the Tertiary and Upper Cretaceous of Wyoming and Surrounding Areas: Wyoming Geological Association, Symposium on Late Cretaceous Rocks p. 59-67.

Patchett, J.G., 1987-88, Personal Communication.

Poupon, A., Loy, M.E., and Tixier, M.P., 1954, A Contribution to Electrical Log Interpretation in Shaly Sands: Journal of Petroleum Technology (AIME), Vol. 6, p. 138-145.

Rascoe, B., and Adler, F.J., 1983, Permo-Carboniferous Hydrocarbon Accumulations, Mid-Continent, U.S.A.: Am. Assoc. Petroleum Geologists Bull., V. 67, No. 6, p. 979-1001

Robertson, K.S., 1983, Stratigraphy, Depositional Environment, Petrology, Diagenesis, and Hydrocarbon Maturation Related to the Red Fork Sandstone in North Central Oklahoma: Unpublished M.S. Thesis, Oklahoma State University, 137 p.

Schlumberger Well Surveying Corp., 1955, Log Interpretation Charts: Houston, Texas.

Schlumberger, Limited, 1972, Log Interpretation Charts: Houston, Texas, 92 p.

Shipley, R.D., 1975, Local Depositional Trends of "Cherokee" Sandstones Payne County, Oklahoma: Unpublished M.S. Thesis, Oklahoma State University, 49 p.

Society of Petroleum Engineers, AIME, 1975, Survey of Resistivities of Water From Subsurface Formations in

Oklahoma: Oklahoma City Section, 132 p.

Society of Professional Well Log Analysts, 1979, The Art of Ancient Log Analysis: Society of Professional Well Log Analysts, Houston, Texas, 131 p.

Stewart, G.F., 1987-88, Personal Communication.

Tixier, M.P., 1949, Electric Log Analysis in the Rocky Mountains: Oil & Gas Journal, June 23, 1949, 6 p.

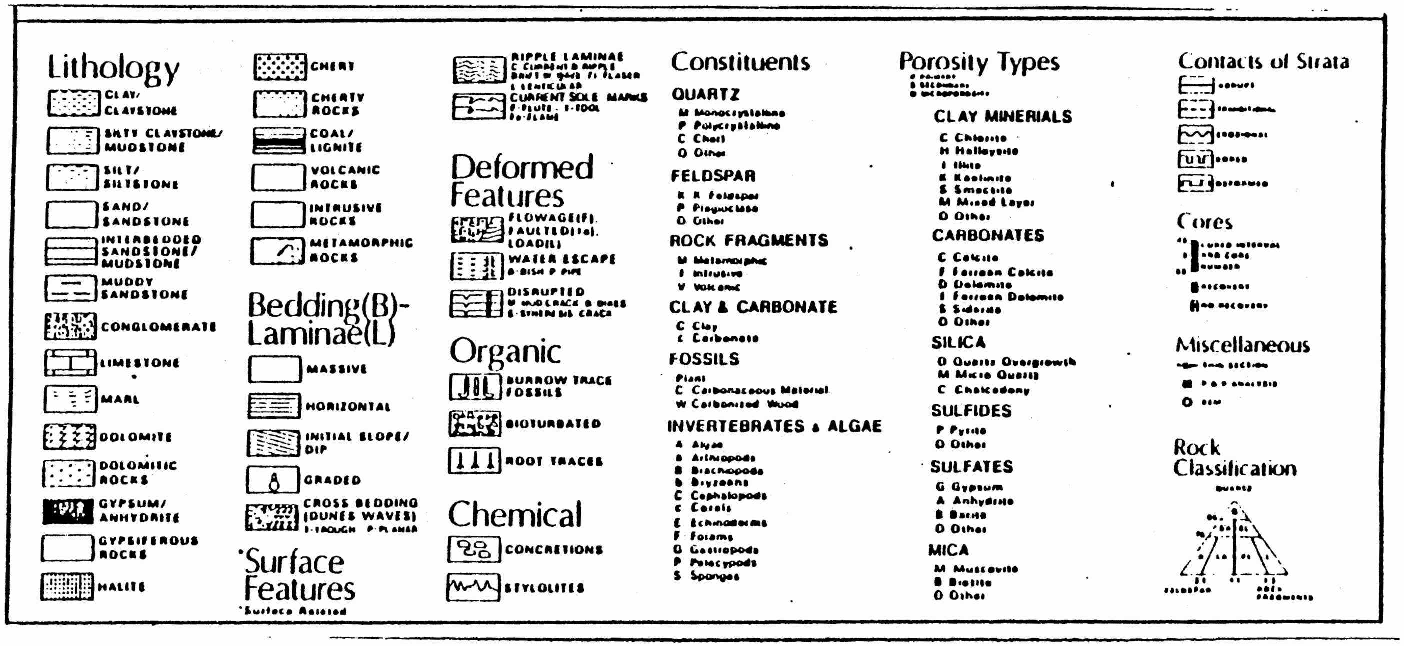
Tixier, M.P., 1958, Porosity Balance Verifies Water Saturation Determined From Logs: SPE of AIME, Denver, March 3-5, 1958, 10 p.

U.S. Department of the Interior, 1957, Analysis of Brines From Oil-Productive Formations in Oklahoma: Report of Investigations 5326, 70 p.

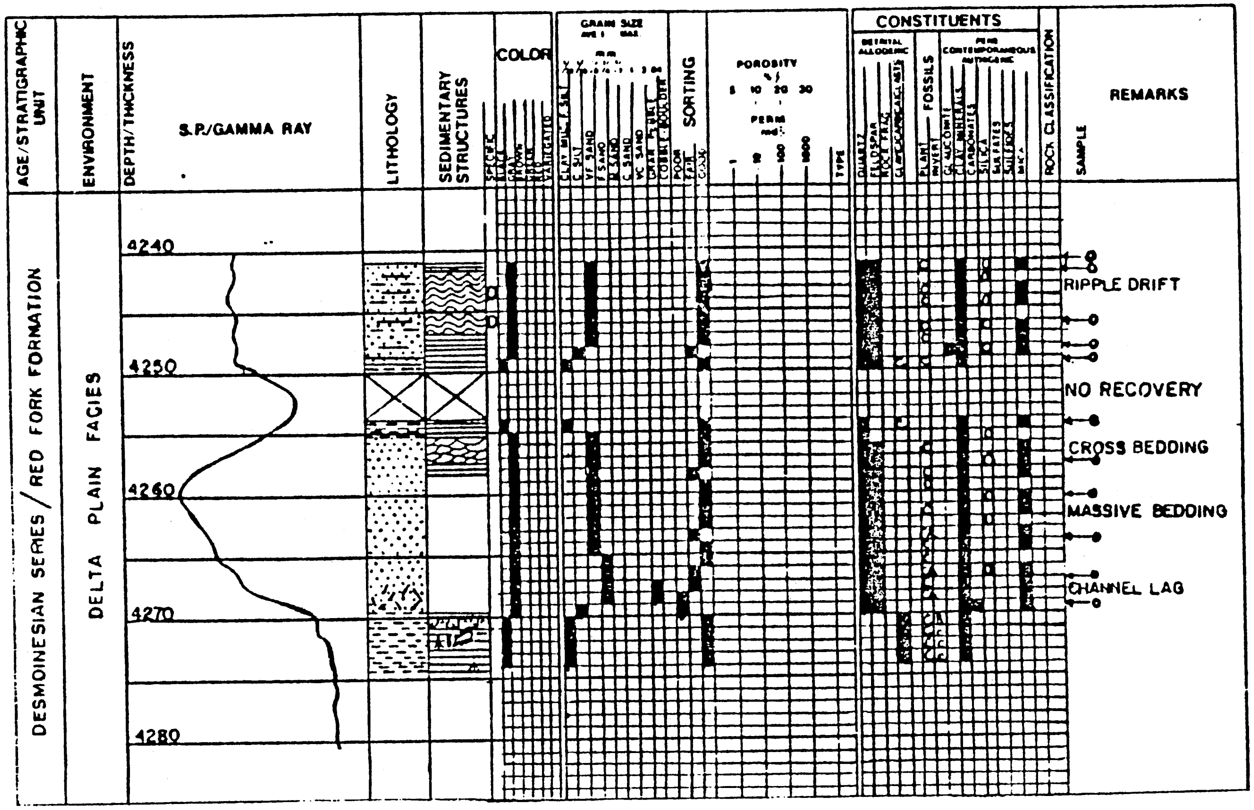
Wyllie, M.R.J., 1954, The Fundamentals of Electric Log Interpretation: Academic Press Inc., New York, 121 p.

APPENDIX A

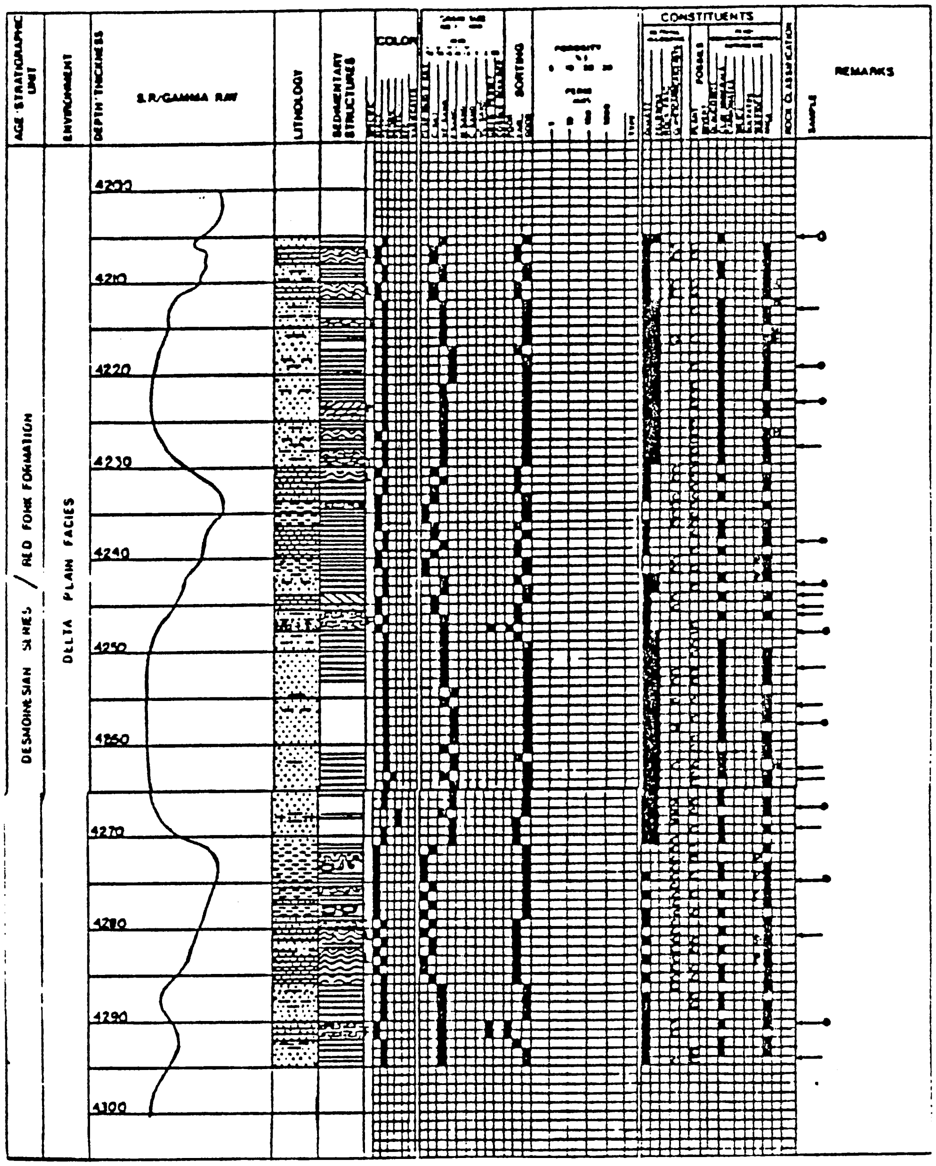
INFORMATION FROM THIN SECTIONS AND CORES PERTAINING TO THE RED FORK SANDSTONE, PAYNE, PAWNEE, AND NOBLE COUNTIES (ROBERTSON, 1983, AND BALKE, 1984).



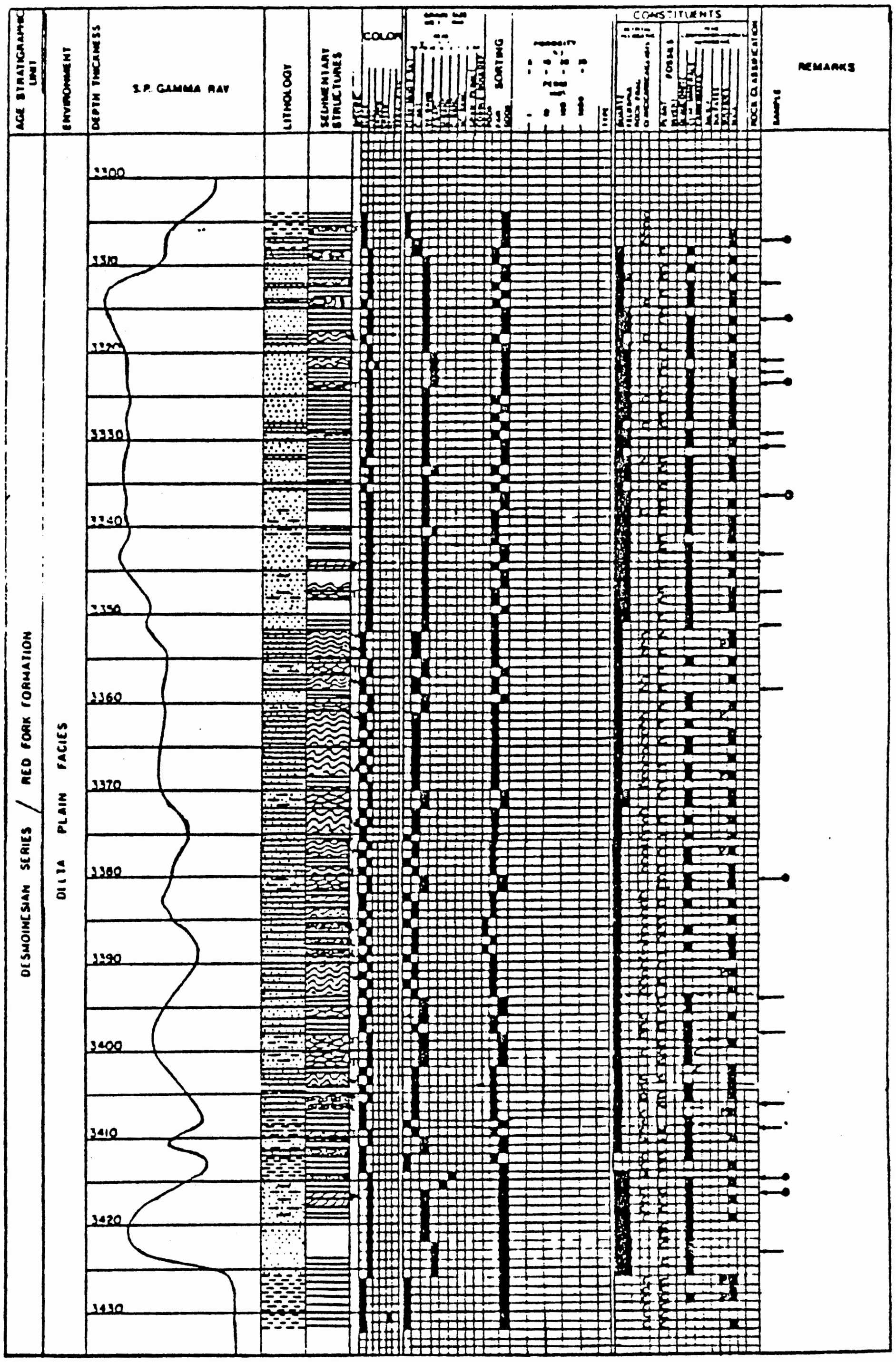
Lithology
CLAY/ CLAYSTONE
SILTY CLAYSTONE/ MUDSTONE
SILT/ SILTSTONE
SAND/ SANDSTONE
INTERBEDDED SANDSTONE/ MUDSTONE
MUDDY SANDSTONE
CONGLOMERATE
LIMESTONE
MARL
DOLOMITE
DOLOMITIC ROCKS
GYPSUM/ ANHYDRITE
GYPSIFEROUS ROCKS
HALITE
CHERT
CHERTY ROCKS
COAL/ LIGNITE
VOLCANIC ROCKS
INTRUSIVE ROCKS
METAMORPHIC ROCKS
Bedding(B)- Laminae(L)
MASSIVE
HORIZONTAL
INITIAL SLOPE/ DIP
GRADED
CROSS BEDDING (DUNES WAVES)
T-TROUGH P-PLANAR
*Surface Features
*Surface Related
RIPPLE LAMINAE
CURRENT SOLE MARKS
Deformed Features
FLOWAGE(F), FAULTED(fa), LOAD(L)
WATER ESCAPE
D-DISH P-PIPE
DISRUPTED
Organic
BURROW TRACE FOSSILS
BIOTURBATED
ROOT TRACES
Chemical
CONCRETIONS
STYLOLITES
Constituents
QUARTZ
M Monocrystalline
P Polycrystalline
C Chert
O Other
FELDSPAR
K K Feldspar
P Plagioclase
O Other
ROCK FRAGMENTS
M Metamorphic
I Intrusive
V Volcanic
CLAY & CARBONATE
C Clay
c Carbonate
FOSSILS
Plant
C Carbonaceous Material
W Carbonized Wood
INVERTEBRATES & ALGAE
A Algae
a Arthropods
B Brachiopods
b Bryozoans
C Cephalopods
c Corals
E Echinoderms
F Forams
G Gastropods
P Pelecypods
S Sponges
Porosity Types
CLAY MINERALS
C Chlorite
H Halloysite
I Illite
K Kaolinite
S Smectite
M Mixed Layer
O Other
CARBONATES
C Calcite
F Ferroan Calcite
D Dolomite
I Ferroan Dolomite
S Siderite
O Other
SILICA
O Quartz Overgrowth
M Micro Quartz
C Chalcedony
SULFIDES
P Pyrite
O Other
SULFATES
G Gypsum
A Anhydrite
B Barite
O Other
MICA
M Muscovite
B Biotite
O Other
Contacts of Strata
Cores
Miscellaneous
Rock Classification



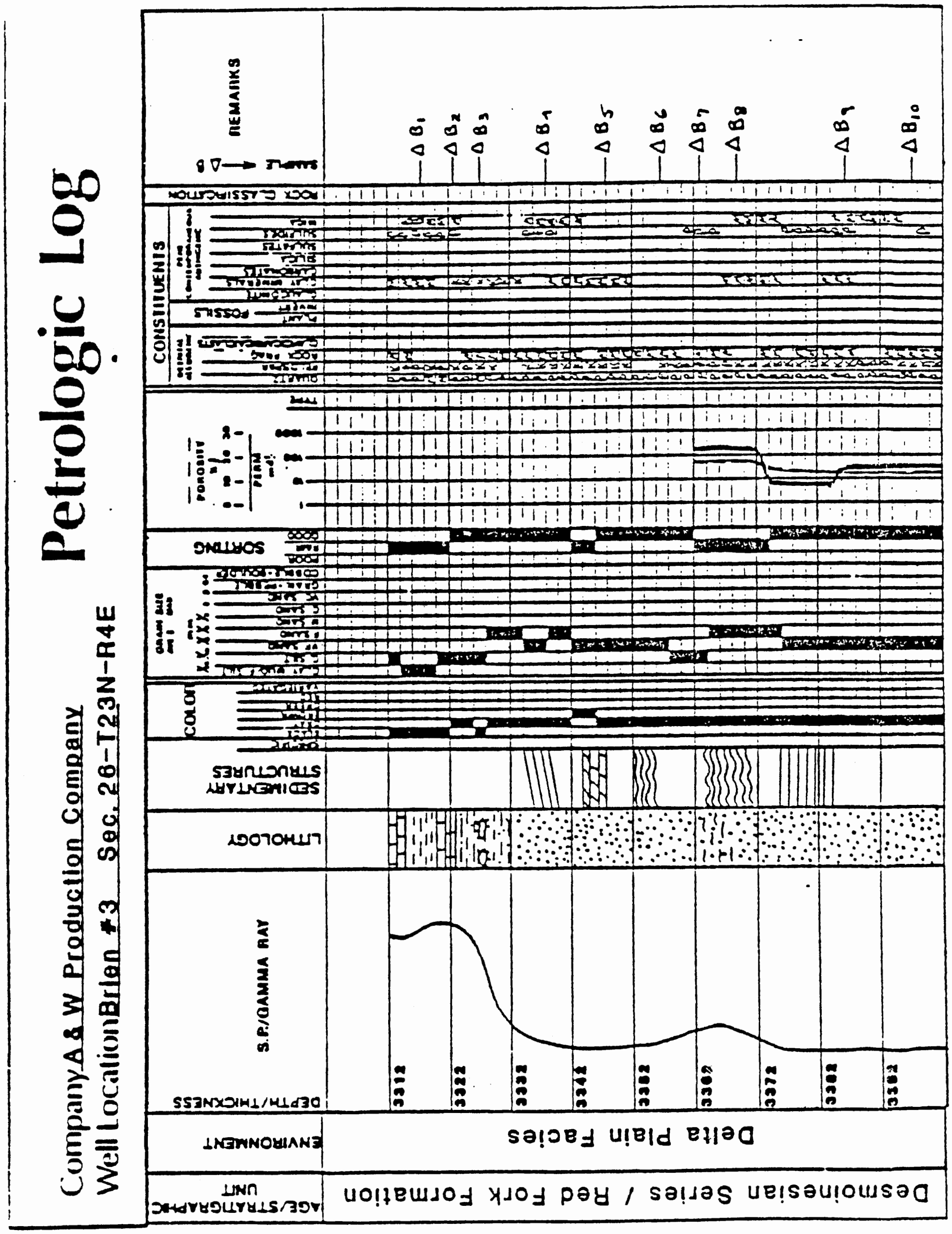
-Core description of the Cities Service Company, Rhodd #1 (NE NE NE Sec. 9-T23N-R1E).

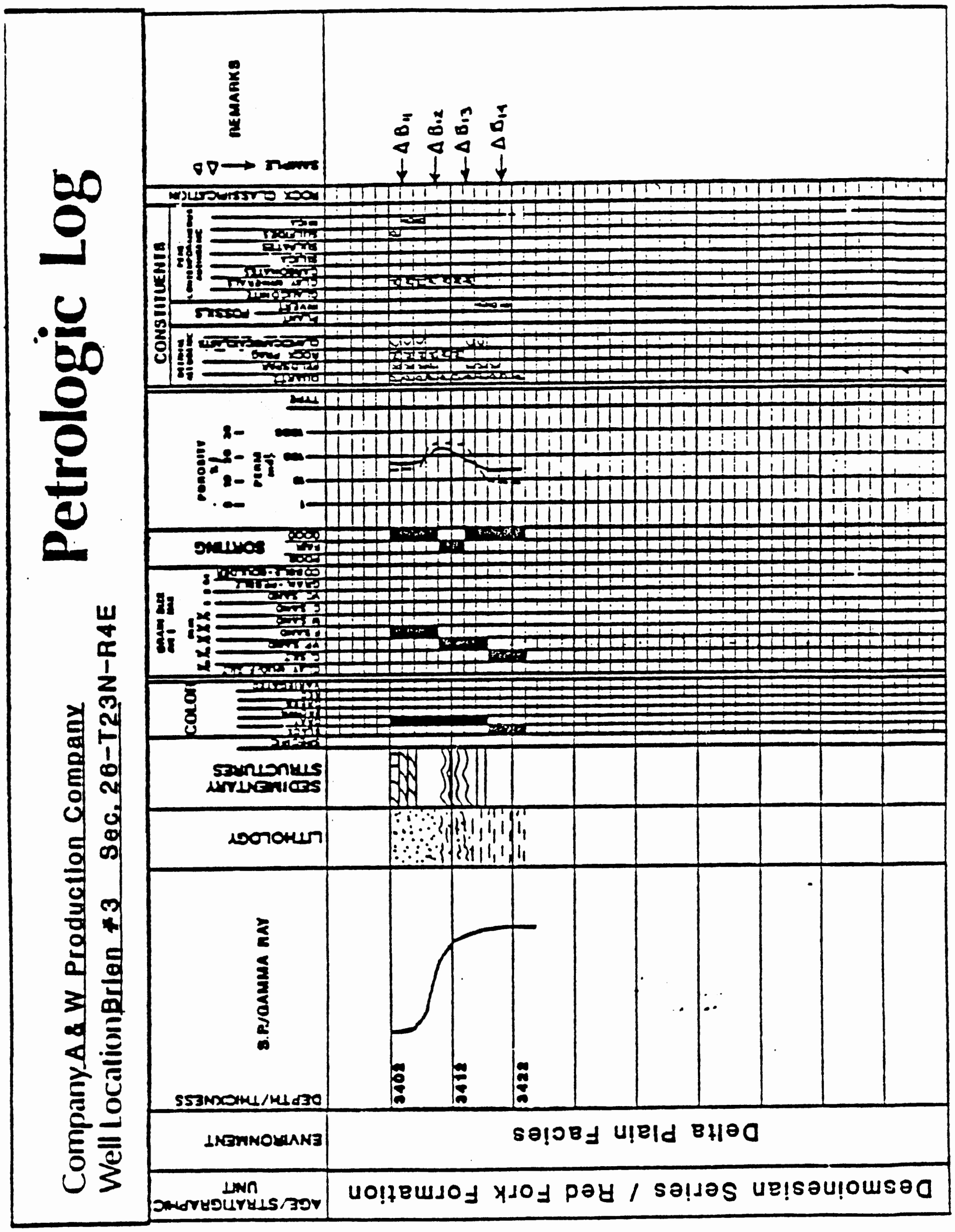


-Core description of the Earth Energy Resources, Inc., Coe Bailey #1, (NW NW SW Sec. 11-T17N-R2E).



-Core description of Ames Oil and Gas Company, Rogers #2,(SE NE NW Sec 13-T22N-R4E).


Petrologic Log
Company A & W Production Company
Well Location Brien #3 Sec. 26-T23N-R4E
AGE/STRATIGRAPHIC UNIT
ENVIRONMENT
DEPTH/THICKNESS
S.P./GAMMA RAY
LITHOLOGY
SEDIMENTARY STRUCTURES
COLOR
GRAIN SIZE
SORTING
POROSITY
PERM
CONSTITUENTS
FOSSILS
ROCK CLASSIFICATION
SAMPLE ΔB
REMARKS
3312
3322
3332
3342
3352
3362
3372
3382
3392
ΔB1
ΔB2
ΔB3
ΔB4
ΔB5
ΔB6
ΔB7
ΔB8
ΔB9
ΔB10
Delta Plain Facies
Desmoinesian Series / Red Fork Formation



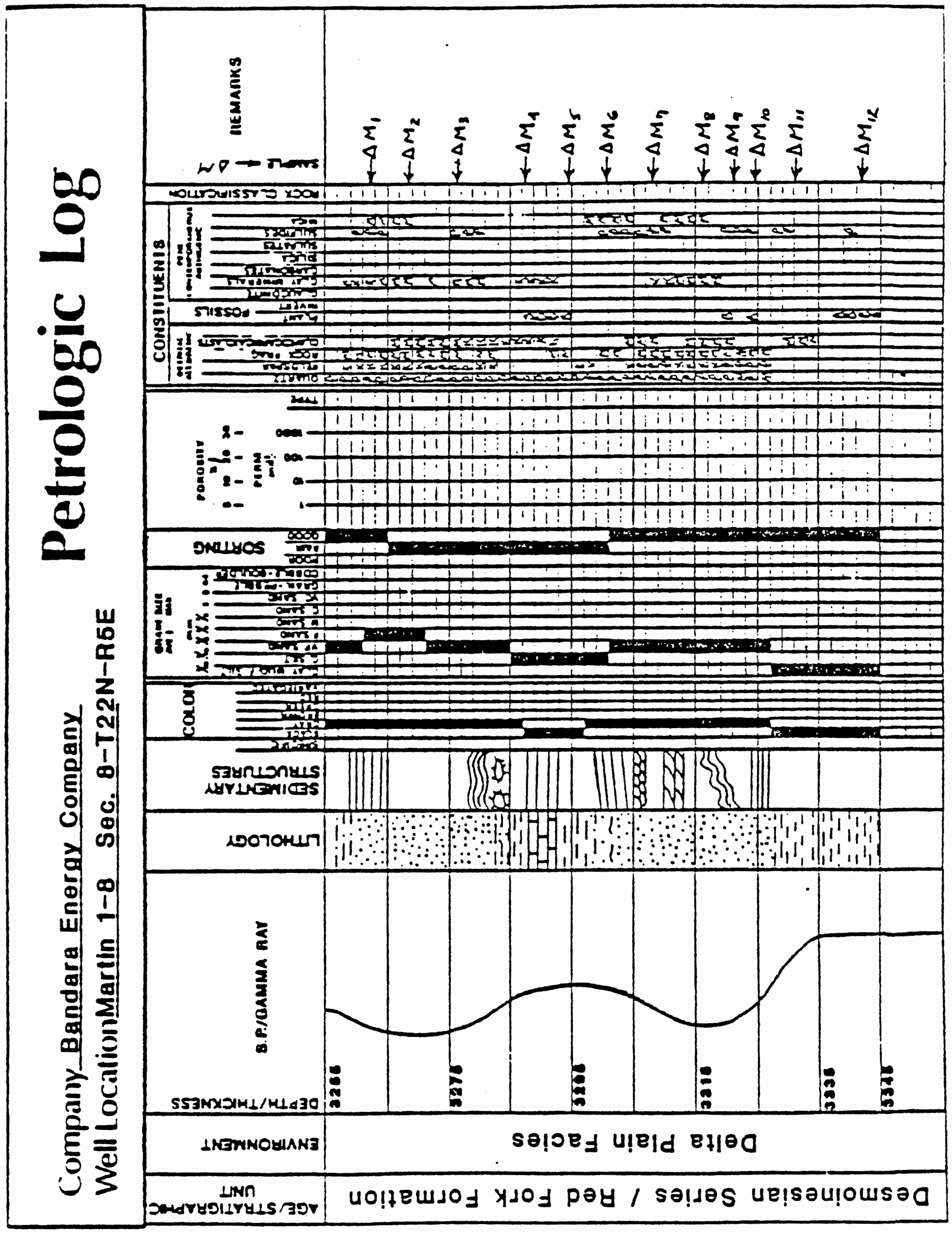
Petrologic Log

Company A & W Production Company

Well Location Brien #3 Sec. 26-T23N-R4E

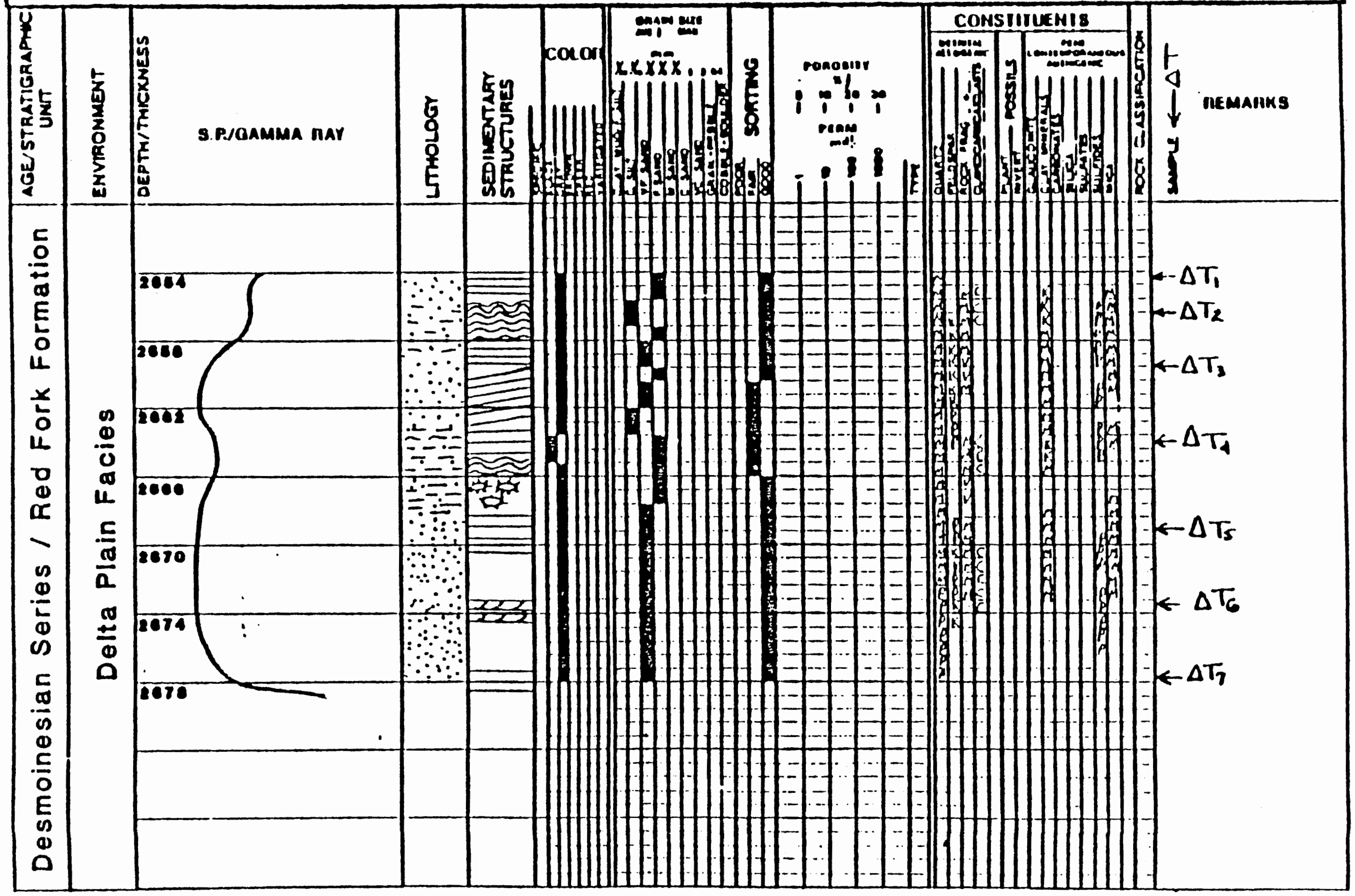
Desmoinesian Series / Red Fork Formation

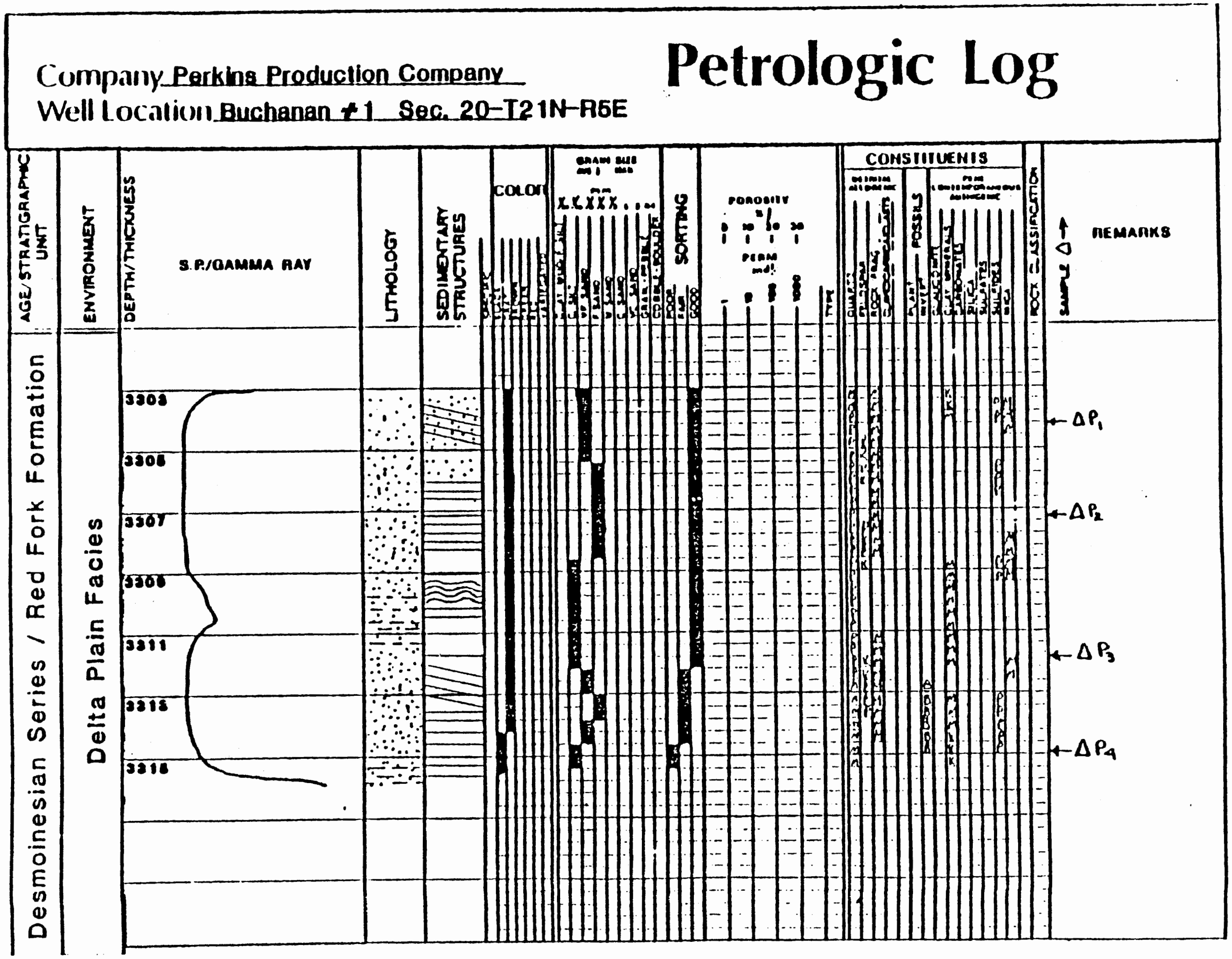
Delta Plain Facies

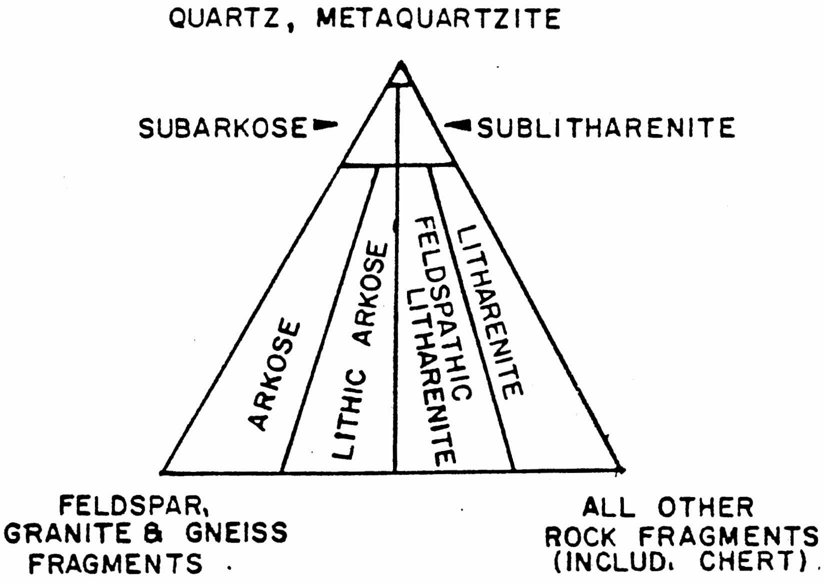

Petrologic Log
Company Bandara Energy Company
Well Location Martin 1-8 Sec. 8-T22N-R5E
AGE/STRATIGRAPHIC UNIT
ENVIRONMENT
DEPTH/THICKNESS
S.P./GAMMA RAY
LITHOLOGY
SEDIMENTARY STRUCTURES
COLOR
SORTING
POROSITY
PERM
CONSTITUENTS
FOSSILS
ROCK CLASSIFICATION
SAMPLE → ΔM
REMARKS
3266
3276
3286
3316
3336
3346
Delta Plain Facies
Desmoinesian Series / Red Fork Formation
ΔM1
ΔM2
ΔM3
ΔM4
ΔM5
ΔM6
ΔM7
ΔM8
ΔM9
ΔM10
ΔM11
ΔM12

Petrologic Log

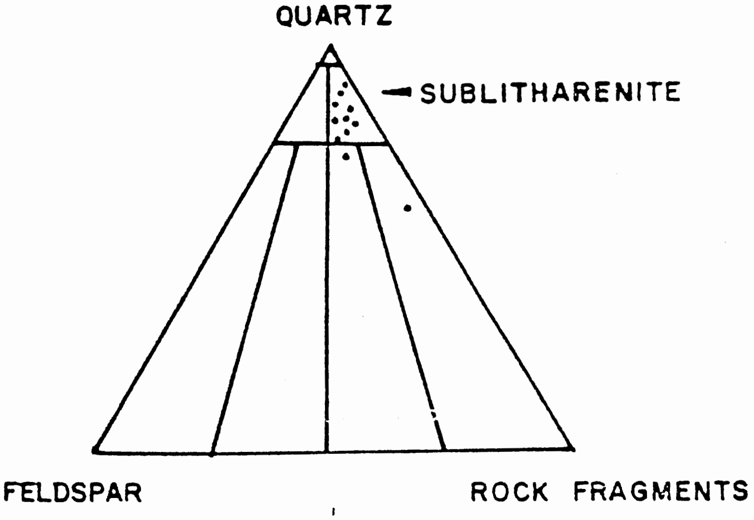
Company Thompson-Tye Company
Well Location #3 Shields Sec. 2-T21N-R5E



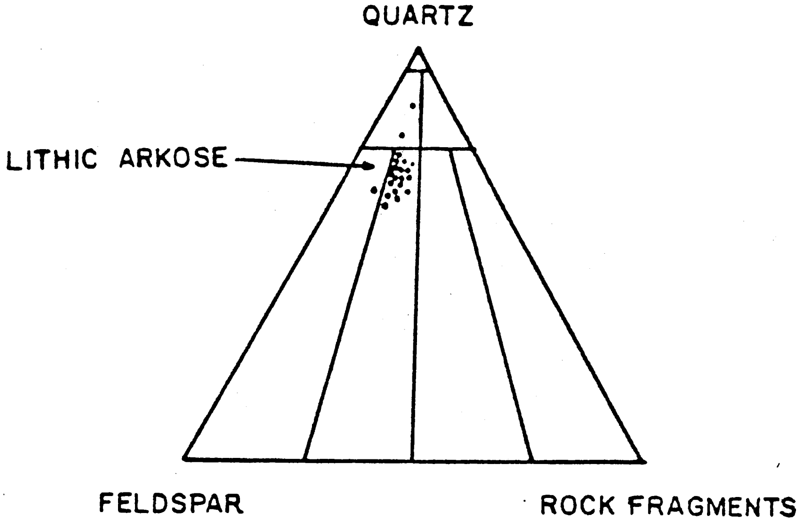

Company Perkins Production Company
Well Location Buchanan #1 Sec. 20-T21N-R5E
Petrologic Log
AGE/STRATIGRAPHIC UNIT
ENVIRONMENT
DEPTH/THICKNESS
S.P./GAMMA RAY
LITHOLOGY
SEDIMENTARY STRUCTURES
COLOR
GRAIN SIZE
SORTING
POROSITY
PERM
CONSTITUENTS
FOSSILS
ROCK CLASSIFICATION
SAMPLE
REMARKS
Desmoinesian Series / Red Fork Formation
Delta Plain Facies
3303
3305
3307
3309
3311
3313
3315
ΔP1
ΔP2
ΔP3
ΔP4



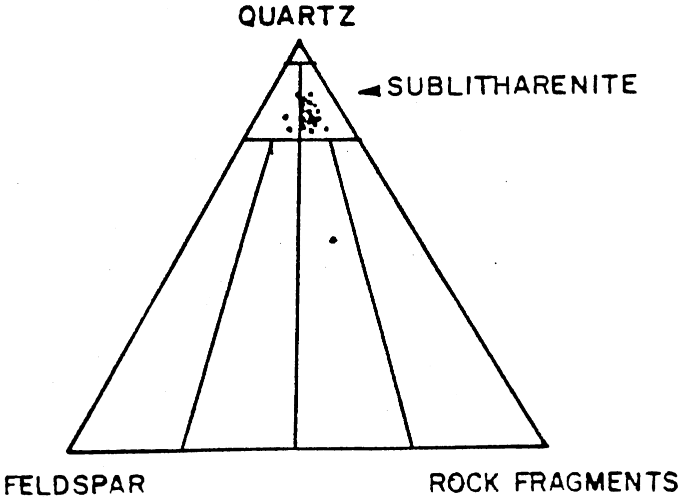
CITIES SERVICE COMPANY
RHODD No. 1
NE NE NE SEC. 9 – T23N – R1E



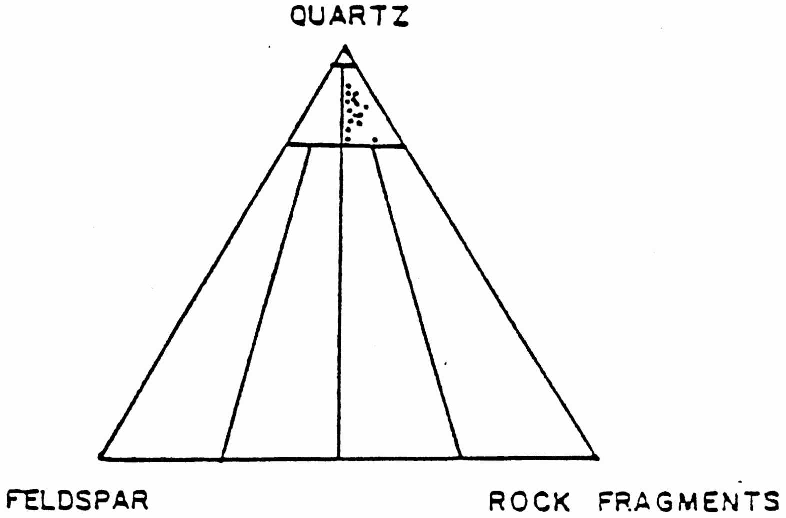
EARTH ENERGY RESOURCES, INC.
COE BAILEY No. 1
NW NW SW SEC. 11-T17N-R2E



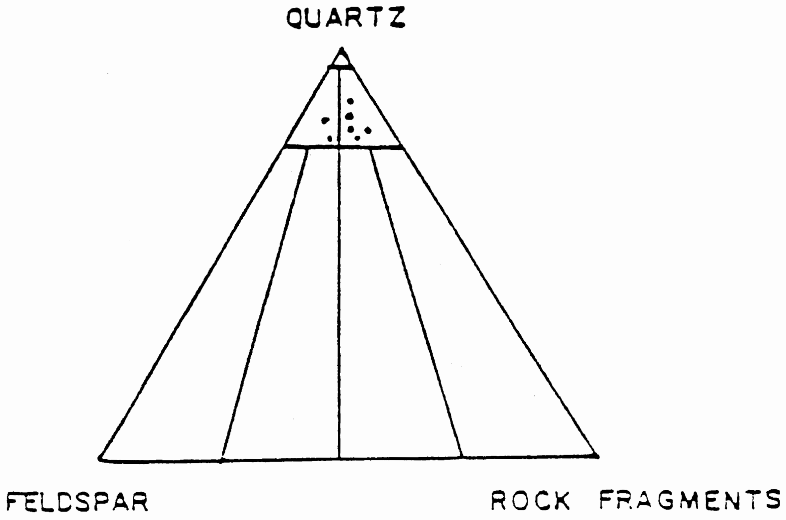
AMES OIL & GAS COMPANY
ROGERS No. 2
SE NE NW SEC. 13-T22N-R4E



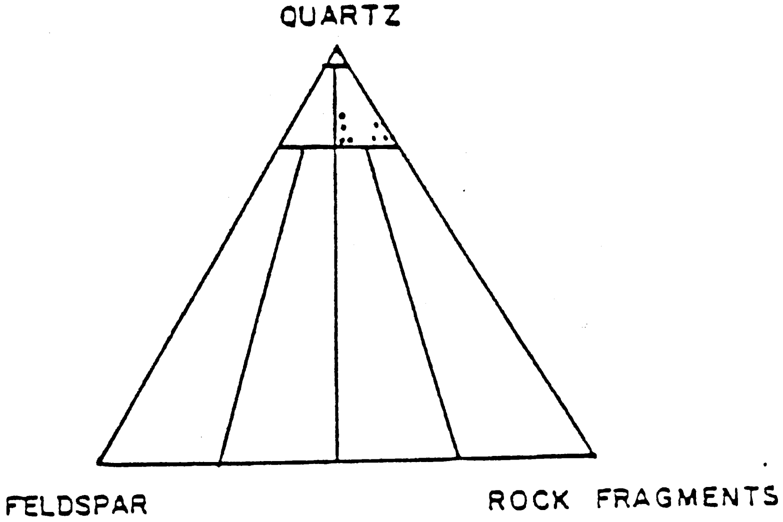
A & W PRODUCTION COMPANY
BRIEN No. 3
SEC. 26-T23N-R4E



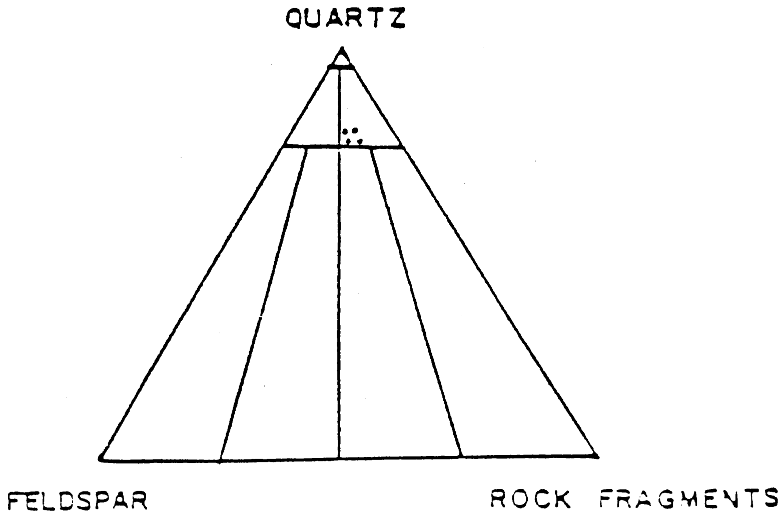
BANDERA ENERGY COMPANY
1-8 MARTIN
SEC. 8-T22N-R5E



THOMPSON-TYE DRILLING COMPANY
No. 3 SHIELDS
SEC. 2-T21N-R5E



PERKINS PRODUCTION COMPANY
BUCHANAN No. 1
SEC. 20-T21N-R5E



APPENDIX B

DATA SHEETS: POROSITY OBTAINED FROM COMPENSATED NEUTRON-COMPENSATED DENSITY LOGS, RED FORK SANDSTONE, PAYNE COUNTY, OKLAHOMA

COMPANY : Cottonwood Oil & Supply Company

WELL : REDDING No. 2 C

FIELD : Southeast Stillwater

LOCATION : 895' FNL, 415' FEL Sec. 31, T 19N, R 3E; Payne Co., Okla.

FORMATION : Red Fork Sandstone

DEPTH	ZONE	DENSITY POROSITY	NEUTRON POROSITY	X-PLOTTED POROSITY	DENSITY CORRECTED
4034	4032-36	11.9	20.4	18.1	10.5
4040	4038-42	13.8	20	18.4	12.4
4046	4044-48	15.3	20.1	19	13.9
4052	4050 54	13.3	20.4	18.5	11.9
4058	4056-60	16	19.7	18.8	14.6
4064	4062-66	16.4	20.1	19.2	15
4070	4068-72	15.7	20.2	19	14.3
4076	4074-78	14.9	19.5	18.2	13.5
4082	4080-84	16.3	19.7	18.8	14.9
4088	4086-90	13.1	19.2	17.7	11.1

COMPANY : Southport Exploration

WELL : KEYS No. 2

FIELD : wildcat

LOCATION : 700' FNL - 440' FWL Sec. 22, T 19N, R 3E ; Payne Co., Okla.

FORMATION : Red Fork Sandstone

DEPTH	ZONE	DENSITY POROSITY	NEUTRON POROSITY	X-PLOTTED POROSITY	DENSITY CORRECTED
3936	3934 - 38	14.7	19.8	18.3	13.3
3942	3940 - 44	15.5	19.1	18.1	14.1
3948	3946 - 50	16.5	18.6	18	15.1
3954	3952 - 56	17.3	18.6	18.3	15.9
3960	3958 - 62	15.8	18.7	18	14.4
3966	3964 - 68	15.9	18.9	18	14.5
3972	3970 - 74	17.4	19.8	19.1	16
3978	3976 - 80	15.4	20.7	19.2	14
3986	3984 - 88	14.8	19.4	18.1	13.4

COMPANY : WALTER KELLY Jr. Oil Producing Company

WELL : C.L. WALL No. 5

FIELD : WEST VINCO

LOCATION : NW, SE, SE Sec. 10, T 11N, R 2E; Payne Co., Okla.

FORMATION : Red Fork Sandstone

DEPTH	ZONE	DENSITY POROSITY	NEUTRON POROSITY	X-PLOTTED POROSITY	DENSITY CORRECTED
4270	4268-72	18	18.4	17.3	16.6
4276	4274-78	18.1	16.8	17.6	16.7
4282	4280-84	17.1	16.7	17	15.7
4288	4286-90	16.7	17.1	17.5	15.3
4294	4292-96	16.8	15.1	16.2	15.4

COMPANY : WALTER A. KELLY JR. Oil Producing Company

WELL : C.E. WALL No. 4

FIELD : WEST VINCO

LOCATION : C, NE, SE Sec. 10, T 17N, R 2E; Payne Co., Okla.

FORMATION : Red Fork Sandstone

DEPTH	ZONE	DENSITY POROSITY	NEUTRON POROSITY	X-PLOTTED POROSITY	DENSITY CORRECTED
4216	4214-18	12.4	16.3	15.3	11
4222	4220-24	15.9	16.6	16.3	14.5
4228	4226-30	16	16	16	14.6
4234	4232-36	13.5	17.6	16.6	12.1
4240	4238-42	14.2	15.9	15.5	12.8
4246	4244-48	14	17	16.2	12.6
4252	4250-54	15.3	16	16	13.9
4258	4256-60	15.5	16.8	16.4	14.1
4264	4262-66	15.6	16.2	16.1	14.2

COMPANY : WALTER A. KELLY Jr. Oil Producing Company

WELL : C.C. WALL No. 3

FIELD : WEST VINCO

LOCATION : C, SE, NW, SE Sec. 10, T 17N, R 2E; Payne Co., Okla.

FORMATION : Red Fork Sandstone

DEPTH	ZONE	DENSITY POROSITY	NEUTRON POROSITY	X-PLOTTED POROSITY	DENSITY CORRECTED
4194	4192-96	17.3	12.4	15.3	15.7
4200	4198 4202	16.8	11.9	14.5	15.4
4206	4204-08	18.4	12.5	15.9	17
4212	4210-14	18.1	13	16	16.7
4218	4216-20	16.7	15.1	16.1	15.3
4224	4222-26	14	15.8	15.2	12.6
4230	4228-32	17.7	15.4	16.8	16.3
4236	4234-38	16.4	17	16.9	15
4242	4240-44	17.2	16	16.9	15.8
4248	4246-50	16	15.8	15.9	14.6
4254	4252-56	14.3	16.2	15.9	12.9
4260	4258-62	16.6	14	15.5	15.2
4266	4264-68	16.1	14	15.1	14.7

COMPANY : EARTH ENERGY RESOURCES, INC.

WELL : C.E. WALL No. 1

FIELD : West Vinco

LOCATION : C, SW, SE Sec. 10, T17N, R2E; Payne Co., Okla.

FORMATION : Red Fork Sandstone

DEPTH	ZONE	DENSITY POROSITY	NEUTRON POROSITY	X-PLOTTED POROSITY	DENSITY CORRECTED
4208	4206-10	11.8	14.6	13.9	10.4
4214	4212-16	14	14.3	14.3	12.6
4220	4218-22	16.2	17.5	17.1	14.8
4226	4224-28	13.4	17.1	16.2	12
4232	4230-34	16	20.3	19.2	14.6
4238	4236-40	17.3	17.3	17.3	15.9
4244	4242-46	16.5	16.5	16.5	15.1
4250	4248-52	17.4	16.5	17	16
4256	4254-58	17.3	16	16.9	15.9
4262	4260 64	16.9	16.4	16.9	15.5
4268	4266-70	14	17.3	16.3	12.6
4274	4272-76	16.2	15.2	15.9	14.8
4280	4278-82	17.5	16.9	17.1	16.1
4286	4284-88	16.3	15.3	16	14.9
4292	4290-94	16.5	17.1	17	15.1
4298	4296-4300	14	18	17	12.6

COMPANY : BERRY OPERATING COMPANY

WELL : R. WALL No. 5-A

FIELD : WEST VINCO

LOCATION : C, E/2, NE, SW, SW Sec. 10, T 17N, R 2E; Payne Co., Okla.

FORMATION : Red Fork Sandstone

DEPTH	ZONE	DENSITY POROSITY	NEUTRON POROSITY	X-PLOTTED POROSITY	DENSITY CORRECTED
4248	4246-50	14.2	19.3	18	12.8
4254	4252-56	16.3	20.8	19.5	14.7
4264	4262-66	15.1	20	18.8	13.7
4270	4268-72	16.4	21.3	20	15
4276	4274-78	14.4	20.7	19	13

COMPANY : BERRY OPERATING COMPANY

WELL : R. WALL No. 4 A

FIELD : WEST VINCO

LOCATION : SE, NW, SW Sec. 10, T 17N, R 2E; Payne Co., Okla.

FORMATION : Red Fork Sandstone

DEPTH	ZONE	DENSITY POROSITY	NEUTRON POROSITY	X-PLOTTED POROSITY	DENSITY CORRECTED
4228	4226 - 30	13.7	20.3	18.7	12.3
4234	4232 36	17	20.7	19.8	15.6
4240	4238 - 42	15.5	20.7	19.2	14.1
4246	4244 - 48	18.1	20.5	20	16.7

COMPANY : BERRY OPERATING COMPANY

WELL : R. WALL No. 3 A

FIELD : WEST VINCO

LOCATION : C, S/2, SE, NW Sec. 10, T 17N, R 2E : Payne Co., Okla.

FORMATION : Red Fork Sandstone

DEPTH	ZONE	DENSITY POROSITY	NEUTRON POROSITY	X-PLOTTED POROSITY	DENSITY CORRECTED
4194	4192-96	19.9	19.7	19.8	18.5
4200	4198 4202	19.4	20.2	20	18
4206	4204-08	20	20.9	20.7	18.7
4212	4210-14	20.6	19.8	20.1	19.3
4218	4216-20	20.7	20	20	19.4
4224	4222-26	21.5	17.3	20.2	20.2
4230	4228-32	19.7	19.7	19.7	18.3
4236	4234-38	17.5	18	18	16.1
4242	4240-44	10.8	13.8	17.9	9.4
4248	4246-50	15.8	20	19	14.4
4254	4252-56	15.4	20.6	19.1	14
4260	4258-62	16.7	21.2	20	15.3

COMPANY : BERRY OPERATING COMPANY

WELL : R. WALL No. 2 A

FIELD : WEST VINCO

LOCATION : C, S/2, NE, SW Sec. 10, T 11N, R 2E; Payne Co., Okla.

FORMATION : Red Fork Sandstone

DEPTH	ZONE	DENSITY POROSITY	NEUTRON POROSITY	X-PLOTTED POROSITY	DENSITY CORRECTED
4218	4216-20	10.8	18	16	9.4
4224	4222-26	15.5	21.3	19.9	14.1
4230	4228-32	16.8	20.2	19.3	15.4
4236	4234-38	16.4	20.4	19.4	15
4242	4240-44	18.8	20.9	20.3	17.4

COMPANY : BERRY OPERATING COMPANY

WELL : R. WALL No. 1-A

FIELD : WEST VINCO

LOCATION : 150' N of SE, SW Sec. 10, T 11N, R 2E; Payne Co., Okla.

FORMATION : Red Fork Sandstone

DEPTH	ZONE	DENSITY POROSITY	NEUTRON POROSITY	X-PLOTTED POROSITY	DENSITY CORRECTED
4240	4238-42	17.4	20.8	19.9	16
4246	4244 48	18.7	20.6	20	17 3
4254	4252-56	19.4	19.4	19.4	18
4260	4258-62	17.7	20.5	19.9	16.5
4266	4264-68	16.8	22.8	21	15.4
4272	4270-74	18	21.3	20.4	16.6
4278	4276-80	17	22.2	20.9	15.6
4284	4282-86	16	22.8	20.9	14.6
4290	4288-92	17.9	21.5	20.5	16.4
4296	4294-98	18.7	21.3	20.6	17.3

COMPANY : WALTER A. KELLY, Jr. Oil Producing Company

WELL : SASSER BAILEY No. 1

FIELD : WEST VINCO

LOCATION : C,SW,NW Sec. 11, T 17N, R 2E; Payne Co., Okla.

FORMATION : Red Fork Sandstone

DEPTH	ZONE	DENSITY POROSITY	NEUTRON POROSITY	X-PLOTTED POROSITY	DENSITY CORRECTED
4210	4208-12	15.3	18.4	17.6	13.7
4216	4214-18	13.6	18.9	18	12.2
4222	4220-24	15	17.8	17	13.6
4228	4226-30	13.2	18.3	17	11.8
4234	4232-36	13.8	17.8	16.7	12.4
4240	4238-42	15.3	19.1	18.2	13.4
4246	4244-48	15.3	18	17.2	13.9
4252	4250-54	16	18.5	17.9	14.6

COMPANY : BERRY OPERATING COMPANY

WELL : AMERADA BOBCAT No. 1

FIELD : wildcat

LOCATION : SE, SW, SW Sec. 16, T 19N, R 3E: Payne Co., Okla.

FORMATION : Red Fork Sandstone

DEPTH	ZONE	DENSITY POROSITY	NEUTRON POROSITY	X-PLOTTED POROSITY	DENSITY CORRECTED
3930	3928-32	16.5	18.1	18	15.1
3942	3940-44	14.7	20.9	19.1	13.3
3948	3946-50	15.3	20	18.9	13.9
3954	3952-56	16	20.6	18.4	14.6
3960	3958-62	15.3	20.9	19.3	13.9
3966	3964-68	16.3	20.5	19.4	14.9
3972	3970-74	16	21.3	20	14.6
3978	3976-80	16.3	19.9	19	14.9
3984	3982-86	16.2	20.8	19.5	14.8
3990	3988-92	16.1	21.2	19.9	14.1
3996	3994-98	16.2	19.6	18.8	14.8
4002	4000-04	14.8	18.4	17.5	14.8

COMPANY : BERRY OPERATING COMPANY

WELL : AMERADA POLECAT No. 1

FIELD : wild cat

LOCATION : NW, SE, SW Sec. 16. T 19N. R 3E: Payne Co., Okla.

FORMATION : Red Fork Sandstone

DEPTH	ZONE	DENSITY POROSITY	NEUTRON POROSITY	X-PLOTTED POROSITY	DENSITY CORRECTED
3954	3952-56	13.7	20.2	18.7	12.3
3960	3958-62	14.2	18.8	17.6	12.8
3966	3964-68	16.3	18.4	18	14.9
3972	3970-74	16.2	17.2	18.5	14.8
3978	3976-80	16.0	19.6	18.8	14.6
3984	3982-86	15.8	18.9	15	14.4
3990	3988 92	17.1	19.6	19	15.7
3996	3994-98	16.8	18.3	18	15.4

COMPANY : BURRY OPERATING COMPANY

WELL : COPYCAT No. 1

FIELD : wildcat

LOCATION : SE, NW, SW Sec. 16 , T 19N , R 3E ; Payne Co., Okla.

FORMATION : Red Fork Sandstone

DEPTH	ZONE	DENSITY POROSITY	NEUTRON POROSITY	X-PLOTTED POROSITY	DENSITY CORRECTED
3980	3978 - 82	12.1	19.8	17.7	10.7
3988	3986 - 90	14	22.4	20.1	12.6
3994	3992 - 96	14.3	21.3	19.3	12.9
4000	3998 - 4002	13.9	20.7	18.9	12.5
4006	4004 - 08	15.2	20.2	19	13.8
4012	4010 - 14	14.9	19.2	18.1	13.5
4018	4016 - 20	15.7	19.3	18.2	14.3
4022	4020 - 24	15.6	20.4	19.1	14.2
4030	4028 - 32	13.8	20.3	18.8	12.4
4036	4034 - 38	15.8	20.5	19.1	14.4
4042	4040 - 44	16.8	19.7	19	15.4
4048	4046 - 50	13.8	18	16.9	12.4

COMPANY : UNIT ENERGY RESOURCES, Inc.

WELL : Honnold TRUST No. 1

FIELD : Wildcat

LOCATION : NE, NW Sec. 12, T 19N, R 1E; Payne Co., Okla.

FORMATION : Red Fork Sandstone

DEPTH	ZONE	DENSITY POROSITY	NEUTRON POROSITY	X-PLOTTED POROSITY	DENSITY CORRECTED
4400	4398-4402	13.6	17.7	16.6	12.2
4406	4404-08	14.5	16	15.6	13.1
4412	4410-14	11.7	17.2	15.8	10.3
4434	4432-36	14	17.8	16.8	12.6
4440	4438-42	15.5	18	17.2	14.1
4446	4444-48	12.8	17.5	16.2	11.4

COMPANY : EARTH ENERGY RESOURCES, INC.

WELL : Coe Bailey No. 1

FIELD : West Vinco

LOCATION : 2310' FSL + 255' FWL Sec. 11, T 17N, R 2E; Payne Co., Okla.

FORMATION : Red Fork Sandstone

DEPTH	ZONE	DENSITY POROSITY	NEUTRON POROSITY	X-PLOTTED POROSITY	DENSITY CORRECTED
4192	4190-94	18.6	15.7	17.4	17.2
4198	4196-4200	19.8	15.7	18	18.4
4204	4202-06	19.9	16.1	18.3	18.5
4230	4228-32	18	18	18	16.6
4236	4234-38	19.3	17.2	18.5	17.9
4244	4242-46	18	17.3	17.7	16.6

COMPANY : EARTH ENERGY RESOURCES, INC.
WELL : Simmons No. 3
FIELD : Quay
LOCATION : C,NE,SE,NE Sec. 2, T19N, R5E; Payne Co., Okla.
FORMATION : Red Fork Sandstone

DEPTH	ZONE	DENSITY POROSITY	NEUTRON POROSITY	X-PLOTTED POROSITY	DENSITY CORRECTED
3182	3180-84	11	23.5	20	9.6
3188	3186-90	16.4	19	18.4	15
3194	3192-96	15.5	22	20.1	14.1
3200	3198-3202	16.8	22.2	20.9	15.4
3206	3204-08	17	20.4	19.5	15.6
3212	3210-14	18	21.3	20.3	16.6
3218	3216-20	11	20.4	19.5	15.6
3224	3222-26	19	23.4	22.1	17.6
3230	3228-32	19.5	21	20.7	18.1
3236	3234-38	19.1	17	19.3	18.3
3242	3240-46	17.3	15.3	17.5	15.9
3254	3252-56	18	20.4	19.9	16.6
3258	3256-60	17.6	19.3	19	16.2
3266	3264-68	15.4	20.4	19.1	14

COMPANY : WALTER A. KELLY OPERATING COMPANY INC.

WELL : AMERADA ARRINGTON No. 2

FIELD : WEST MULHAN

LOCATION : C, NE, SE Sec. 15 . T 18N. R 3E ; Payne Co., Okla.

FORMATION : Red Fork Sandstone

DEPTH	ZONE	DENSITY POROSITY	NEUTRON POROSITY	X-PLOTTED POROSITY	DENSITY CORRECTED
3742	3740-44	15.7	21.9	20	14.3
3748	3746-50	14.7	22.2	20.2	13.3
3752	3750-54	15.5	21	19.5	14.1
3758	3756-60	18	21	20.1	16.6
3764	3762-66	17	21.5	20.3	15.6
3770	3768-72	18.4	23	21.8	17
3776	3774 78	17.5	21.6	20.5	16.1
3782	3780-84	17.4	21.8	21.3	16
3788	3786-90	19.2	23.6	22.4	17.8
3794	3792-96	19	22.2	21.3	17.6
3806	3804-08	20	22.8	21.9	18.7
3812	3810-14	18.4	23.5	22.1	17
3818	3816-20	15.2	23	20.9	13.8

COMPANY : THOMAS N. BERRY

WELL : BERRY MEL No. 8

FIELD : MULHAN

LOCATION : NE, SW, SW Sec. 13, T 19N, R 3E; Payne Co., Okla.

FORMATION : Red Fork Sandstone

DEPTH	ZONE	DENSITY POROSITY	NEUTRON POROSITY	X-PLOTTED POROSITY	DENSITY CORRECTED
3746	3744-48	17	17	17	15.6
3752	3750-54	15.8	16.6	16.4	14.4
3758	3756-60	17.5	17.6	17.5	16.1
3764	3762-66	19.4	17.8	18.8	18
3770	3768-72	18	17	17.7	16.6
3776	3774-78	18.2	17.2	18	16.8
3188	3786-90	16	16.7	16.5	14.6

COMPANY : Thomas N. Berry & Company

WELL : Berry Fee No. 7

FIELD : Mehan

LOCATION : SE, NE, NW, SW Sec. 13, T 18N, R 3E: Payne Co., Okla.

FORMATION : Red Fork Sandstone

DEPTH	ZONE	DENSITY POROSITY	NEUTRON POROSITY	X-PLOTTED POROSITY	DENSITY CORRECTED
3660	3658-62	13	18.6	17	11.6
3666	3664-68	15	19.5	18.5	13.6
3672	3670-74	16	16.5	16.4	14.6
3678	3676-80	14.6	16.5	16	13.2
3684	3682-86	17.3	16	17	15.9
3690	3688-92	14	17	16.1	12.6
3696	3694 98	15.5	16.8	16.5	14.1
3702	3700-04	17	16.5	16.9	15.6
3708	3706-10	16.8	17.8	17.6	15.4
3714	3712-16	14	15.5	15.1	12.6

COMPANY : EARTH ENERGY RESOURCES, INC.

WELL : RANDOLPH No. 3

FIELD : MEHAN

LOCATION : C, NW, SE Sec. 12, T 18N, R 3E: Payne Co., Okla.

FORMATION : Red Fork Sandstone

DEPTH	ZONE	DENSITY POROSITY	NEUTRON POROSITY	X-PLOTTED POROSITY	DENSITY CORRECTED
3732	3730-34	18.6	15	17.1	17.2
3738	3736-40	17.5	16	16.9	16.1
3744	3742-46	17	16	16.6	15.6
3750	3748-52	18.2	16	17.3	16.8
3756	3754-58	17.5	15.7	16.8	16.1

COMPANY : CAREIL ENERGY RESOURCES, Inc.

WELL : ROBERT TUCKER No. 3-A

FIELD : MEHAN

LOCATION : C, NE, SE, SW Sec. 12, T 18N, R 3E; Payne Co., Okla.

FORMATION : Red Fork Sandstone

DEPTH	ZONE	DENSITY POROSITY	NEUTRON POROSITY	X-PLOTTED POROSITY	DENSITY CORRECTED
3714	3712-16	17.3	19.5	19	15.7
3720	3718-22	17	21	20	15.6
3726	3724-28	18	20.2	19.7	16.6
3732	3730-34	18	20.2	19.7	16.6
3738	3736-40	18	17.7	17.4	16.6
3744	3742-46	18	18	18	16.6
3750	3748-52	17	18.7	18.3	15.6

COMPANY : EARTH ENERGY RESOURCES, INC.

WELL : ROLSTON RATTLESNAKE No. 1

FIELD : MEHAN

LOCATION : C, NW, NW, SW Sec. 24. T 19N. R 3E; Payne Co., Okla.

FORMATION : Red Fork Sandstone

DEPTH	ZONE	DENSITY POROSITY	NEUTRON POROSITY	X-PLOTTED POROSITY	DENSITY CORRECTED
3832	3830-34	15.4	17	16.5	14
3838	3836-40	17.5	17	17.3	16.1
3844	3842-46	18.2	15	17	16.8
3850	3848-52	16.4	15	15.9	15
3856	3854-58	16.6	15.6	16.2	15.2
3862	3860-64	18.4	14.6	16.8	17
3868	3866-70	17.3	16	16.9	15.9
3874	3872-76	13.6	12	12.8	12.2
3880	3878-82	15	13.6	14.3	13.6

COMPANY : EARTH ENERGY RESOURCES, Inc.

WELL : Mitchell No. 1

FIELD : Northeast Mehan

LOCATION : C, SE, SE, NE Sec. 12, T 11N, R 3E; Payne Co., Okla.

FORMATION : Red Fork Sandstone

DEPTH	ZONE	DENSITY POROSITY	NEUTRON POROSITY	X-PLOTTED POROSITY	DENSITY CORRECTED
3728	3726-30	15.3	19	18.1	13.9
3734	3732-36	13.4	19.5	17.9	12
3740	3738-42	13.4	19.5	17.9	12
3746	3744-48	16.4	18	17.5	15
3752	3750-54	15	18	17.2	13.6

COMPANY : Waller A. Kelly Jr. Oil Producing Company

WELL : BARKER No. 6

FIELD : MEHAN

LOCATION : C, NE, NW Sec. 13, T 18N, R 3E; Payne Co., Okla.

FORMATION : Red Fork Sandstone

DEPTH	ZONE	DENSITY POROSITY	NEUTRON POROSITY	X-PLOTTED POROSITY	DENSITY CORRECTED
3678	3776-80	18	18	18	16.6
3686	3684-88	17.5	17.6	18.6	18.1
3696	3694-18	19.6	17.5	18.6	18.2
3704	3702-06	19.6	16.2	18.2	18.2
3712	3710-14	18.4	16.3	17.8	17

COMPANY : EARTH ENERGY RESOURCES, INC.

WELL : McKenzie No. 10

FIELD : South Mehan

LOCATION : C, NW, SW, SE Sec. 13, T 18N, R 3E; Payne Co., Okla.

FORMATION : Red Fork Sandstone

DEPTH	ZONE	DENSITY POROSITY	NEUTRON POROSITY	X-PLOTTED POROSITY	DENSITY CORRECTED
3708	3706-10	15	23	21	13.6
3726	3724-28	16	20.5	19.3	14.6
3732	3730-34	17.5	22.5	22	16.1

COMPANY : EARTH ENERGY RESOURCES, INC.

WELL : Tucker No. 4

FIELD : North Mehan

LOCATION : SW, SW, NE Sec. 12 , T 18N . R 3E : Payne Co., Okla.

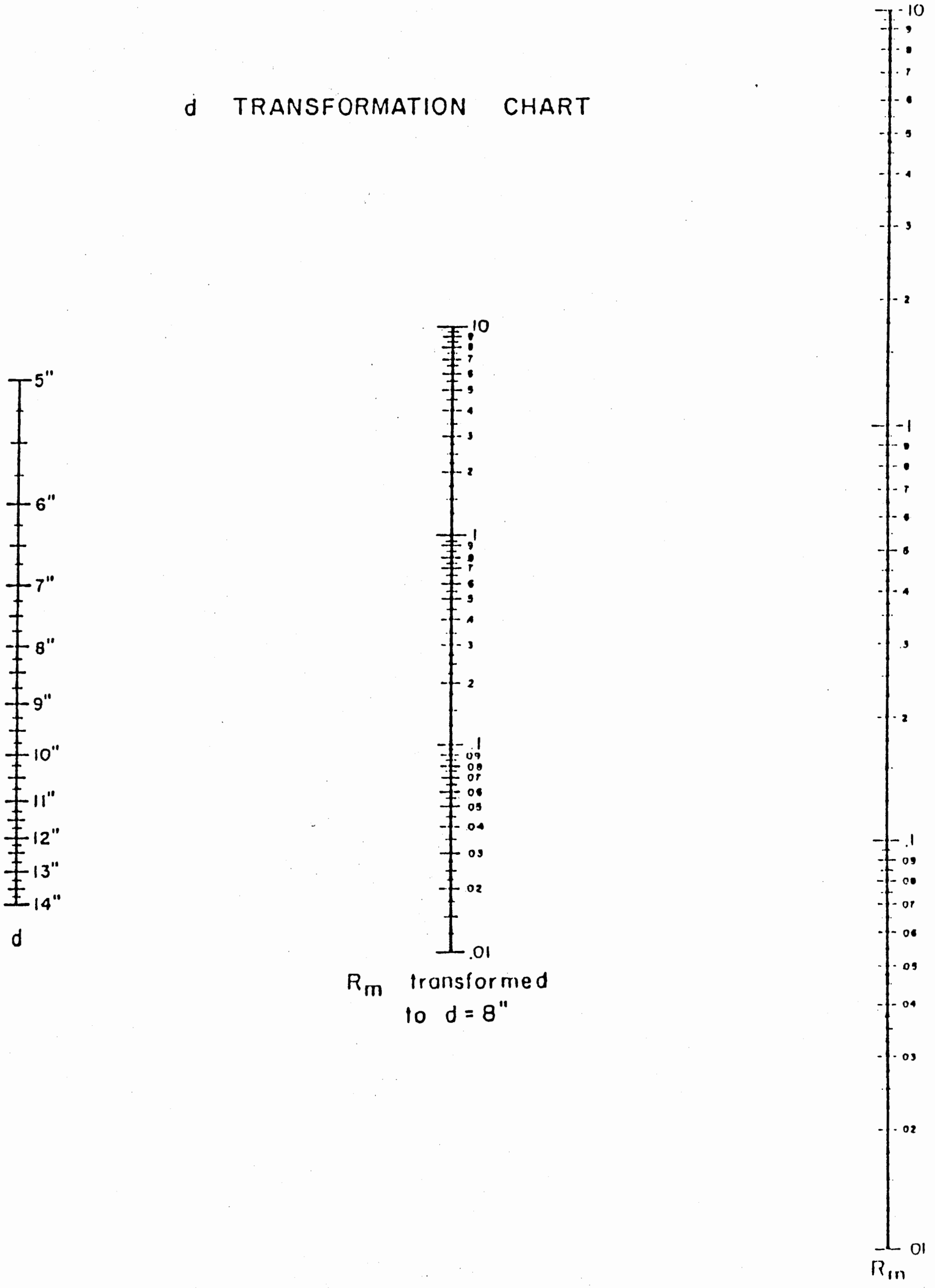
FORMATION : Red Fork Sandstone

DEPTH	ZONE	DENSITY POROSITY	NEUTRON POROSITY	COMBINED POROSITY	DENSITY CORRECTED
3718	3716-20	20.5	17	19	19.2
3724	3722-26	19	17	18	17.6
3730	3728-32	21	17	19.4	19.7
3738	3736-40	20	17	18.7	18.7
3744	3742-46	20	17	18.7	18.7
3750	3748-52	19.7	17	18.7	18.3
3758	3756-60	19.7	17.8	19.1	18.3
3763	3761-65	18.5	15	17.1	17.1

APPENDIX C

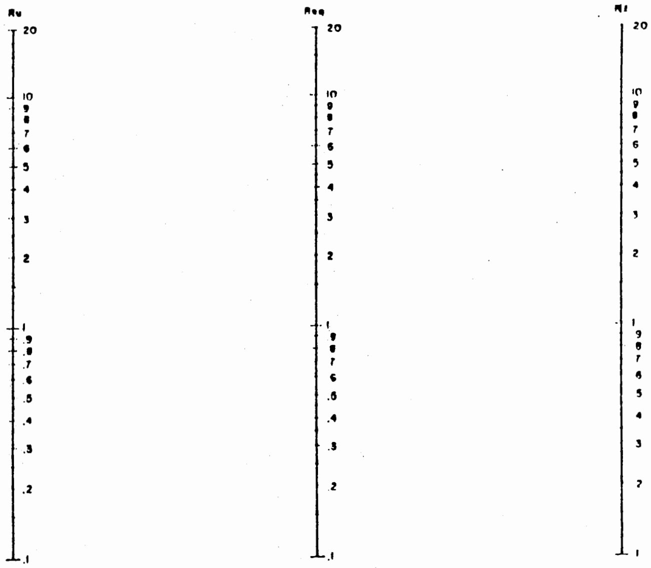
SAMPLE OF TRANSFORMATION AND ANALYSIS CHARTS (GUYOD AND PRANGLIN, 1959)

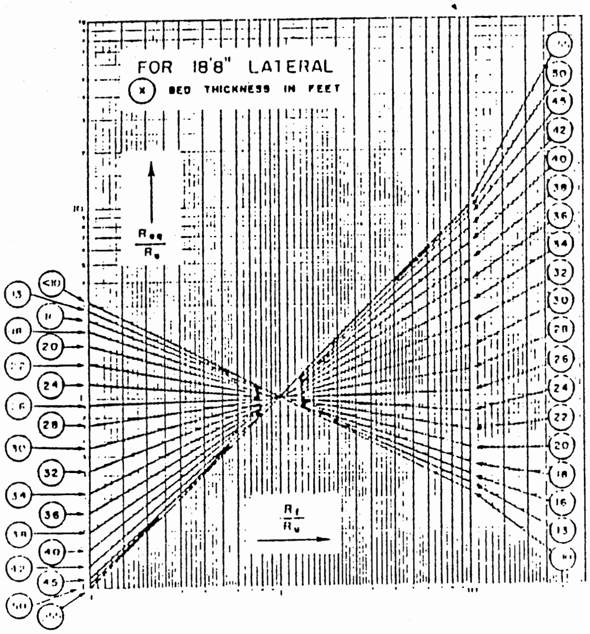
d TRANSFORMATION CHART

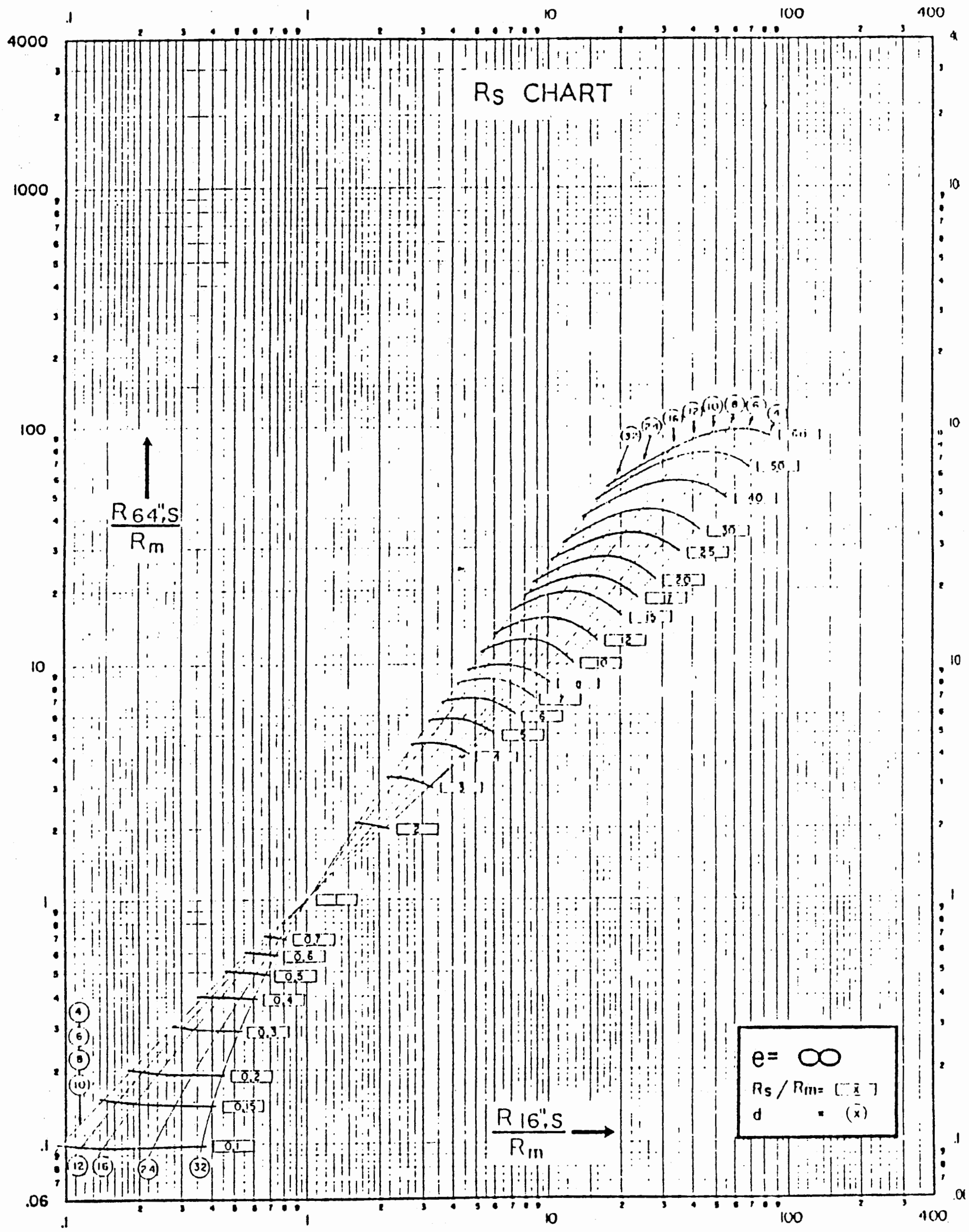


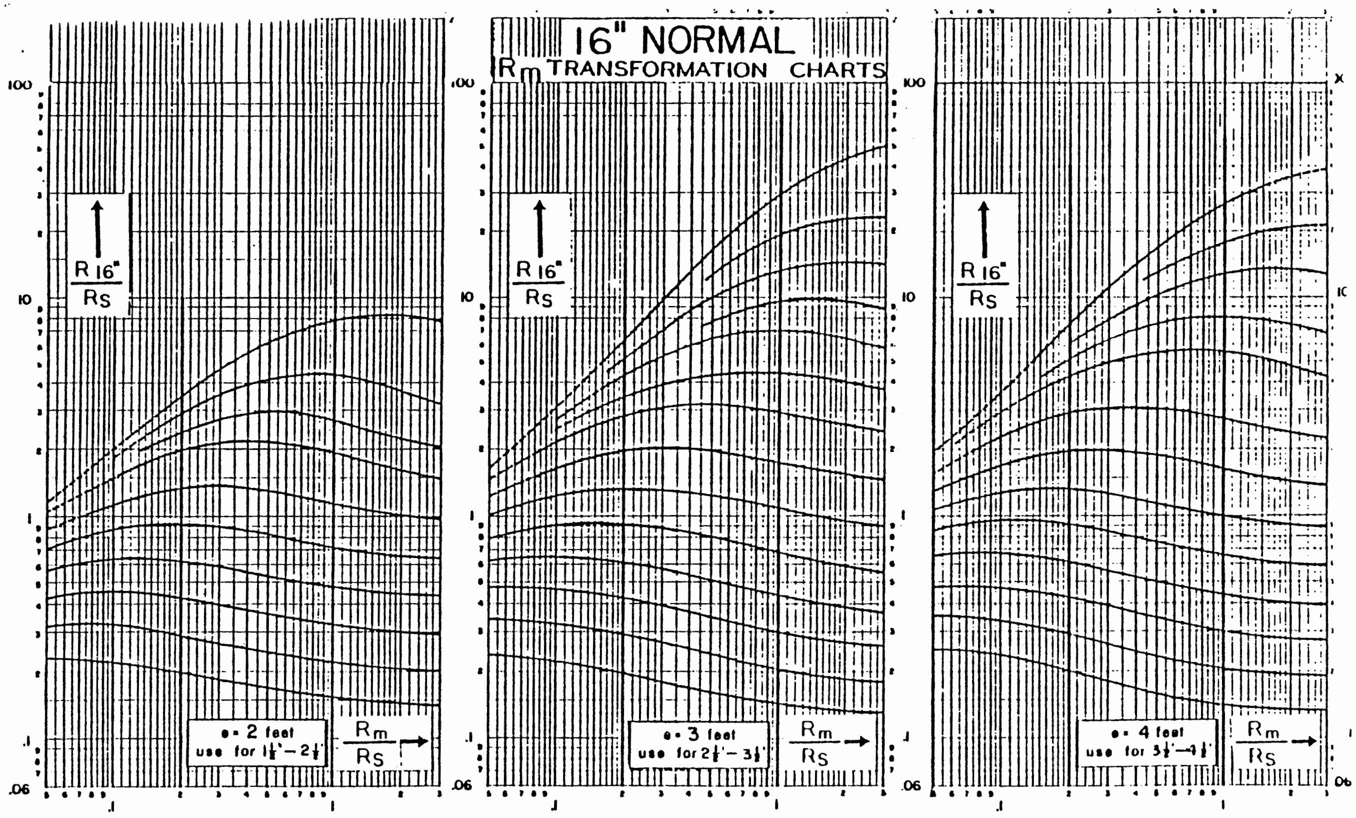
EQUIVALENT SHALE RESISTIVITY CHARTS

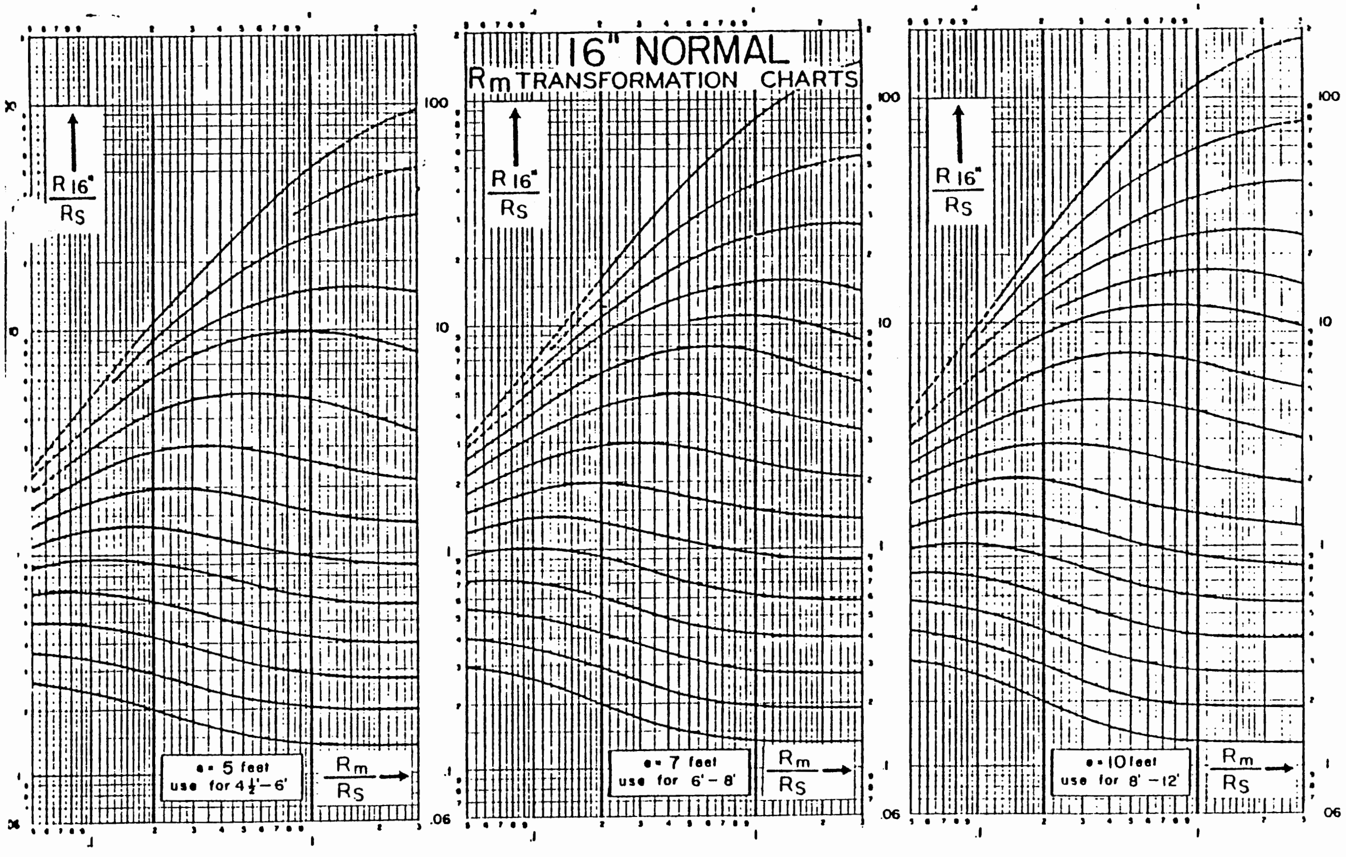
FOR NORMALS



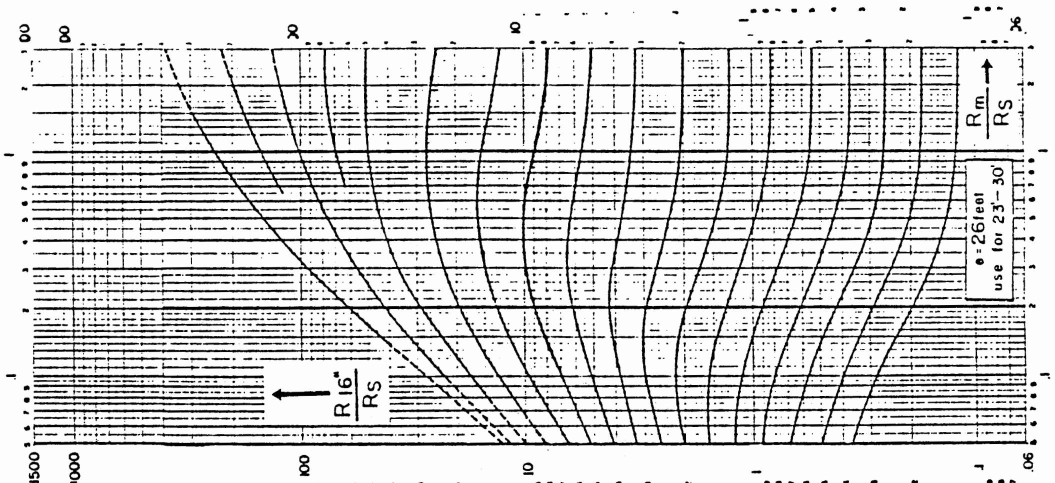


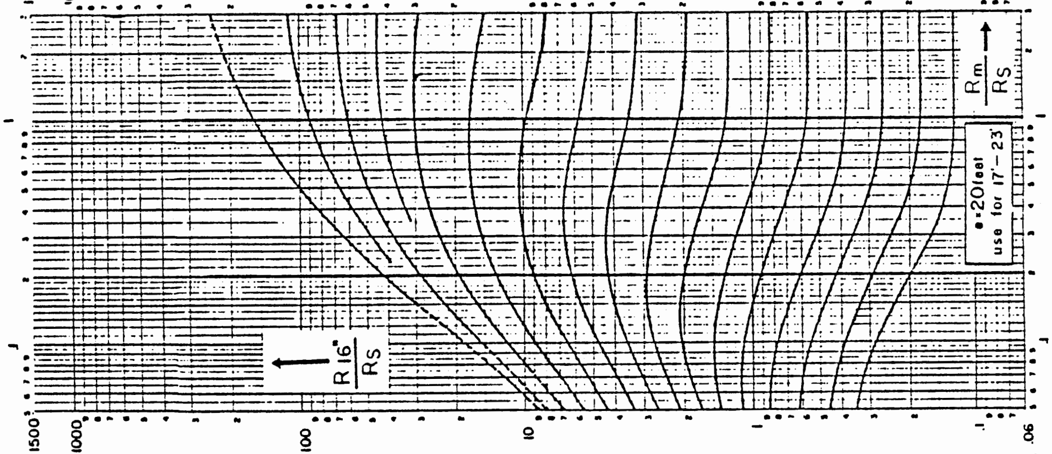

Rs CHART
R 64"s / Rm
R 16"s / Rm
e= ∞
Rs / Rm= [x]
d = (x)
.1
1
10
100
400
4000
1000
100
10
1
.1
.06
(32)
(24)
(16)
(12)
(10)
(8)
(6)
(4)
60
50
40
30
25
20
17
15
12
10
9
7
6
5
4
3
2
1
0.7
0.6
0.5
0.4
0.3
0.2
0.15
0.1
(4)
(6)
(8)
(10)
(12)
(16)
(24)
(32)

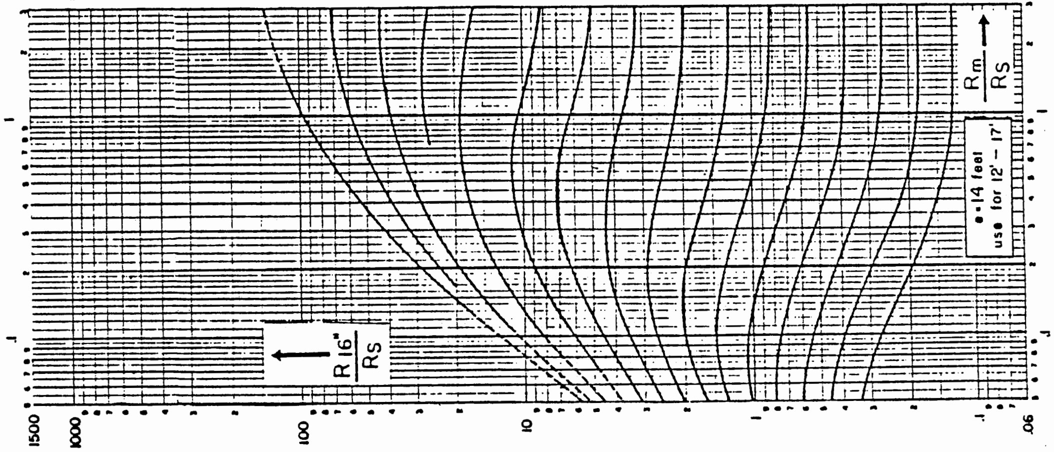

16" NORMAL R_m TRANSFORMATION CHARTS

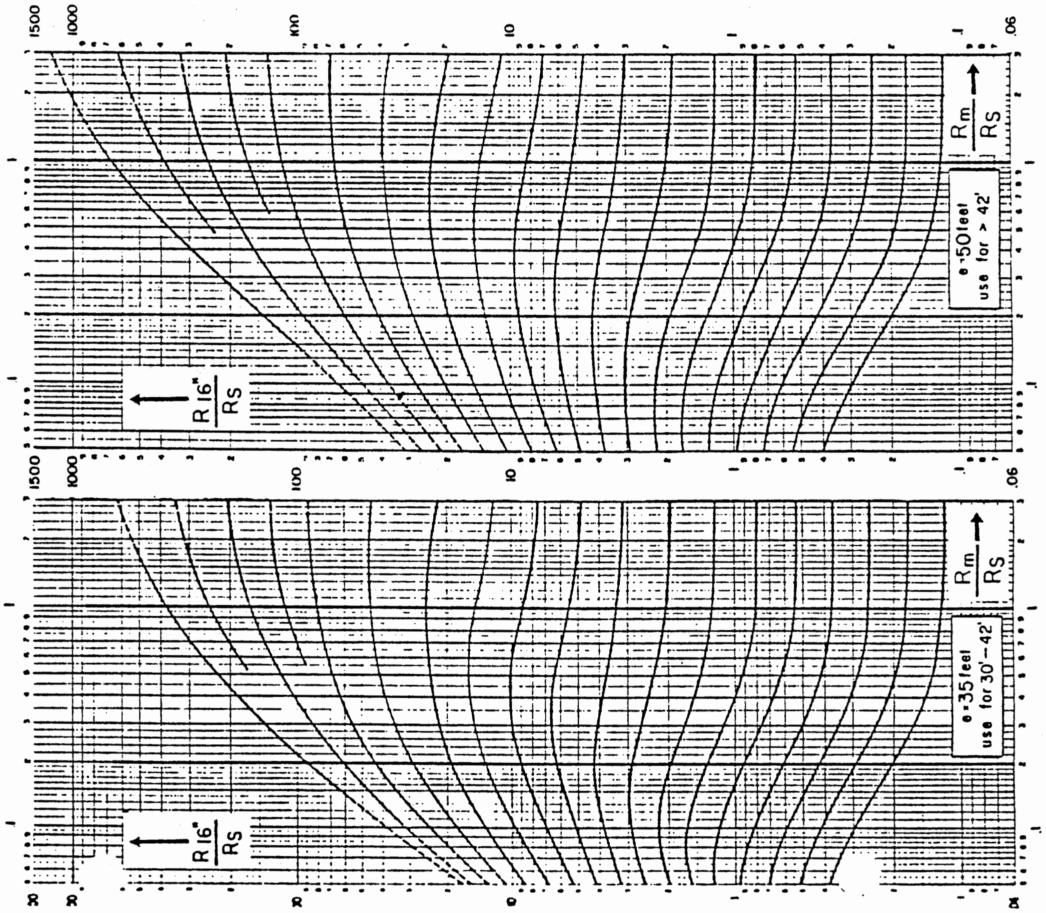


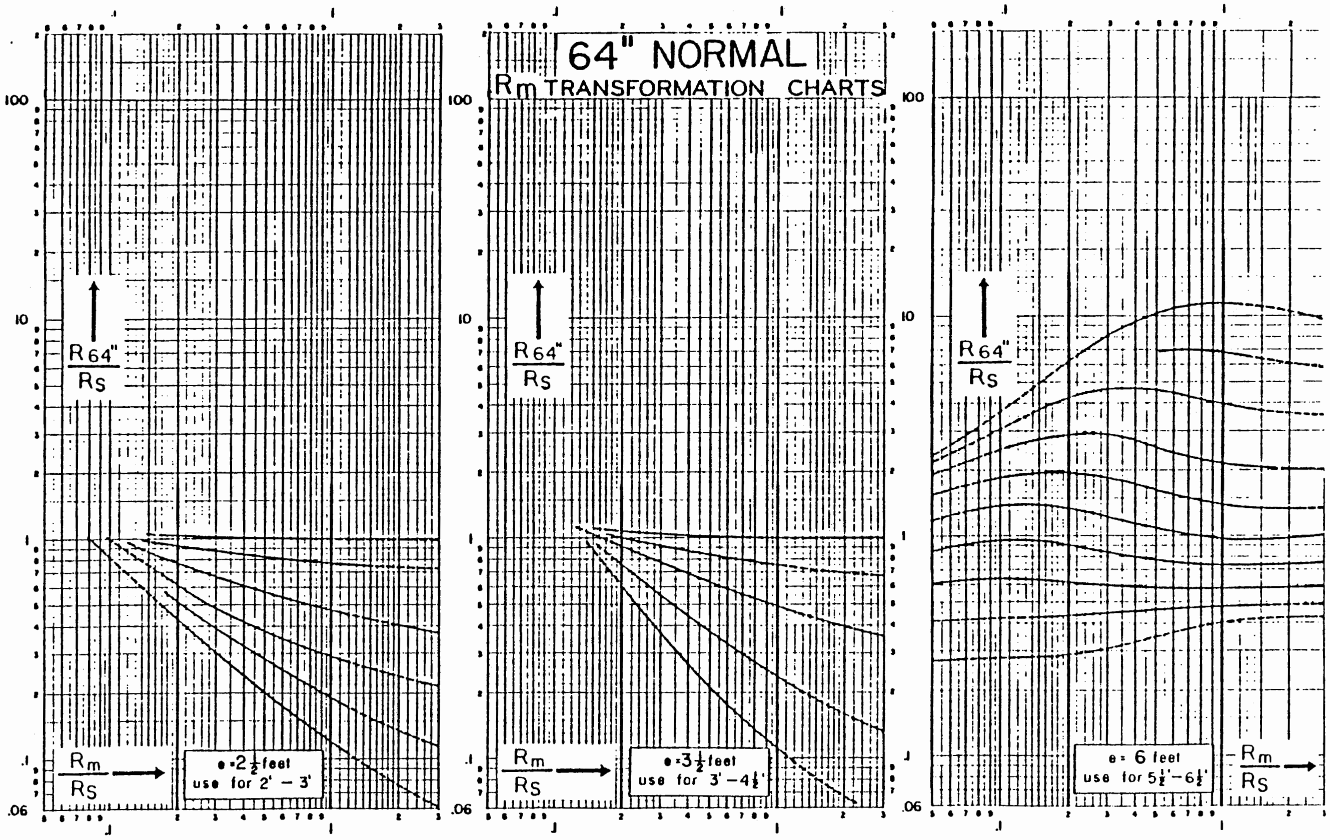
16" NORMAL
Rm TRANSFORMATION CHARTS


e = 26 feet
use for 23'-30'
R 16"/Rs
Rm/Rs
1500
1000
100
10
1
.1
.06


e = 20 feet
use for 17'-23'
R 16"/Rs
Rm/Rs
1500
1000
100
10
1
.1
.06

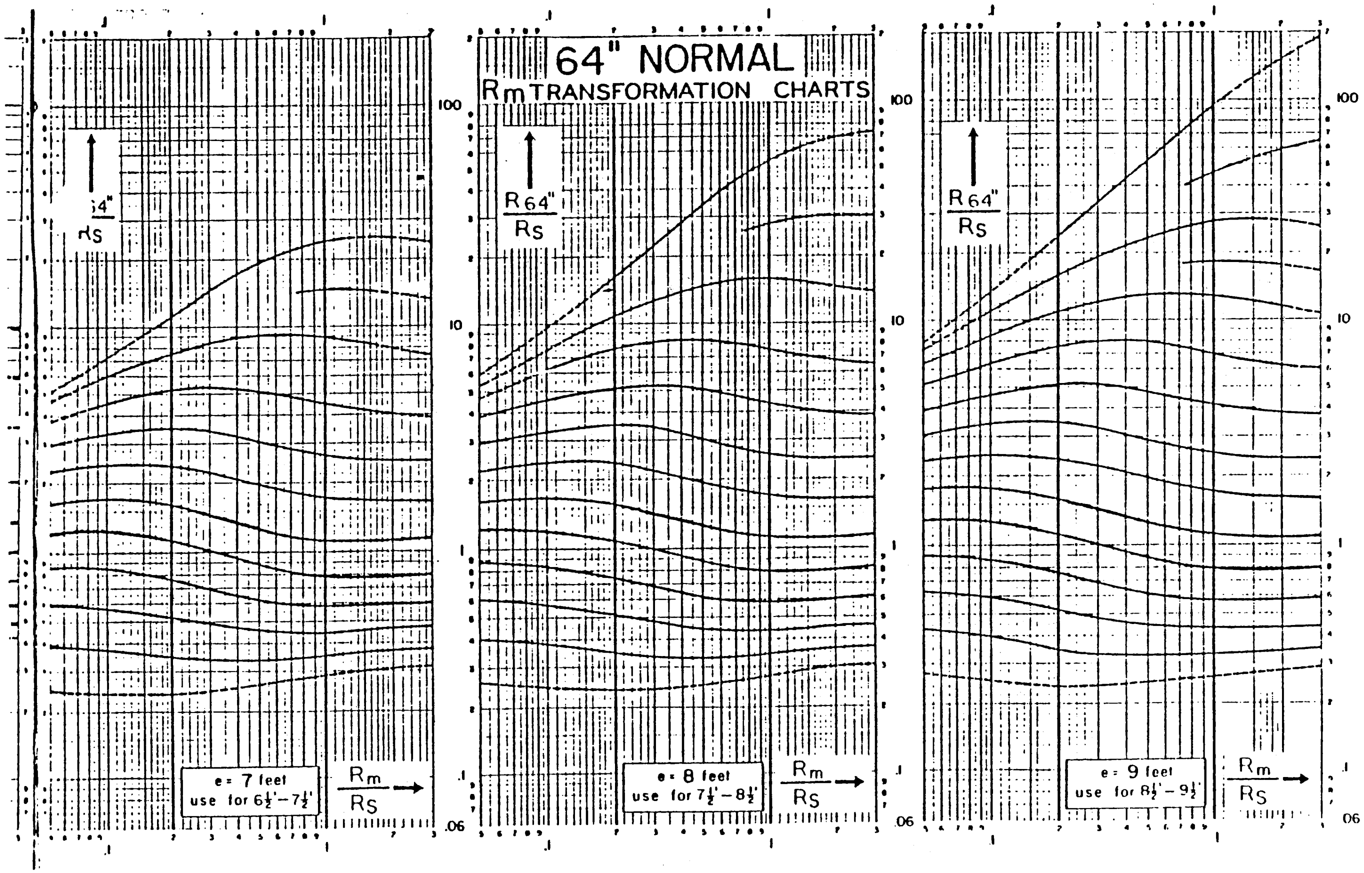

e = 14 feet
use for 12'-17'
R 16"/Rs
Rm/Rs
1500
1000
100
10
1
.1
.06

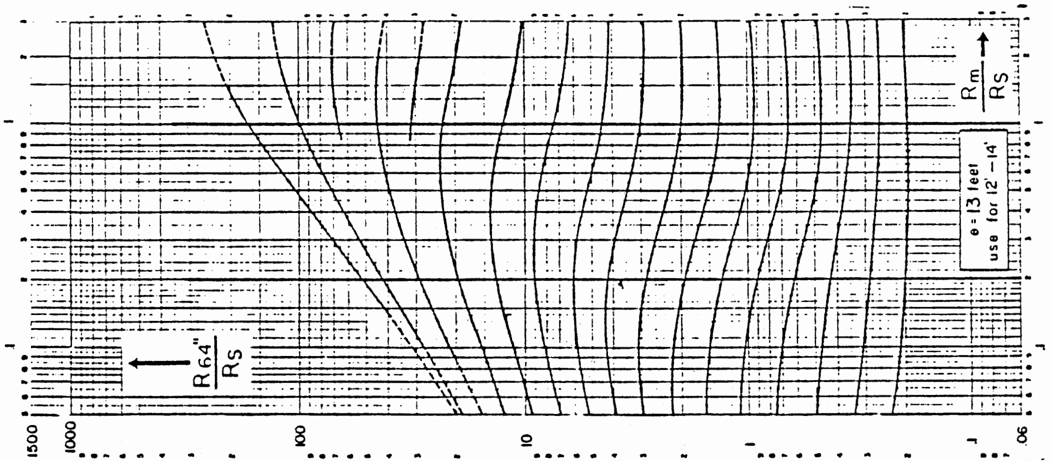

R16"/Rs
Rm/Rs
e = 50 feet
use for > 42'
e = 35 feet
use for 30' - 42'
1500
1000
100
10
1
.06

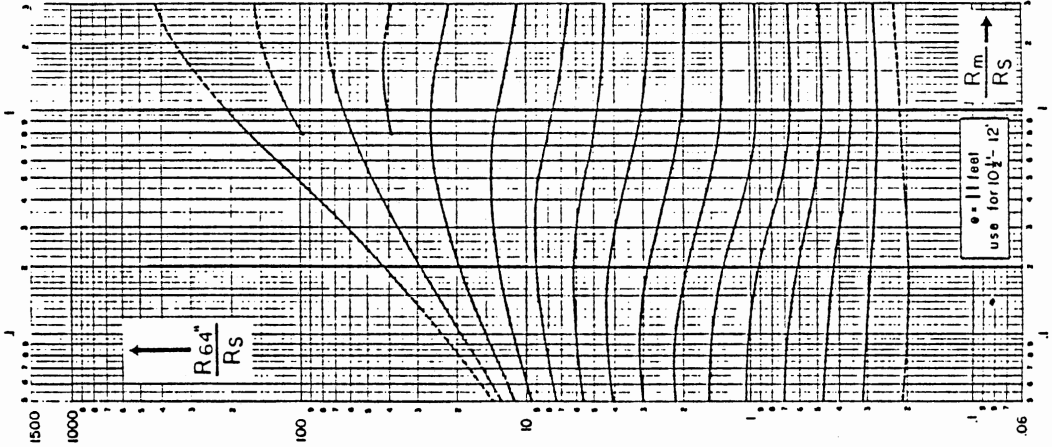


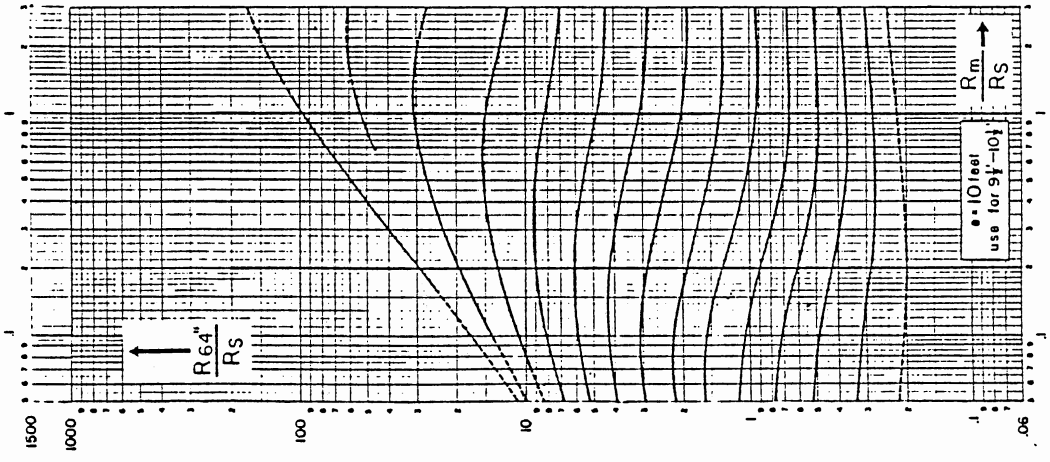
64" NORMAL

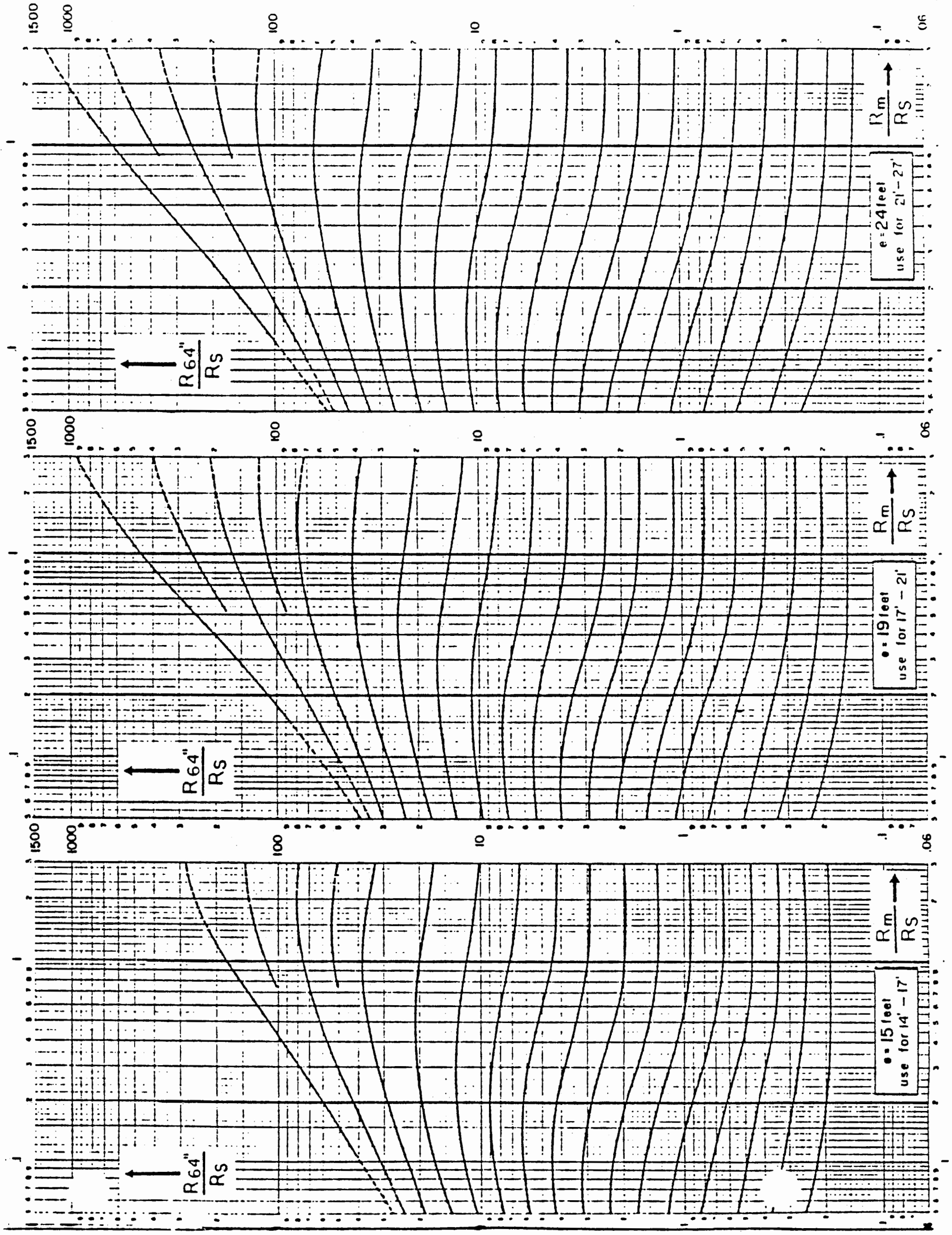
R_m TRANSFORMATION CHARTS


64" NORMAL
Rm TRANSFORMATION CHARTS
R64" / Rs
Rm / Rs
e = 7 feet use for 6½'–7½'
e = 8 feet use for 7½'–8½'
e = 9 feet use for 8½'–9½'
100
10
1
.1
.06

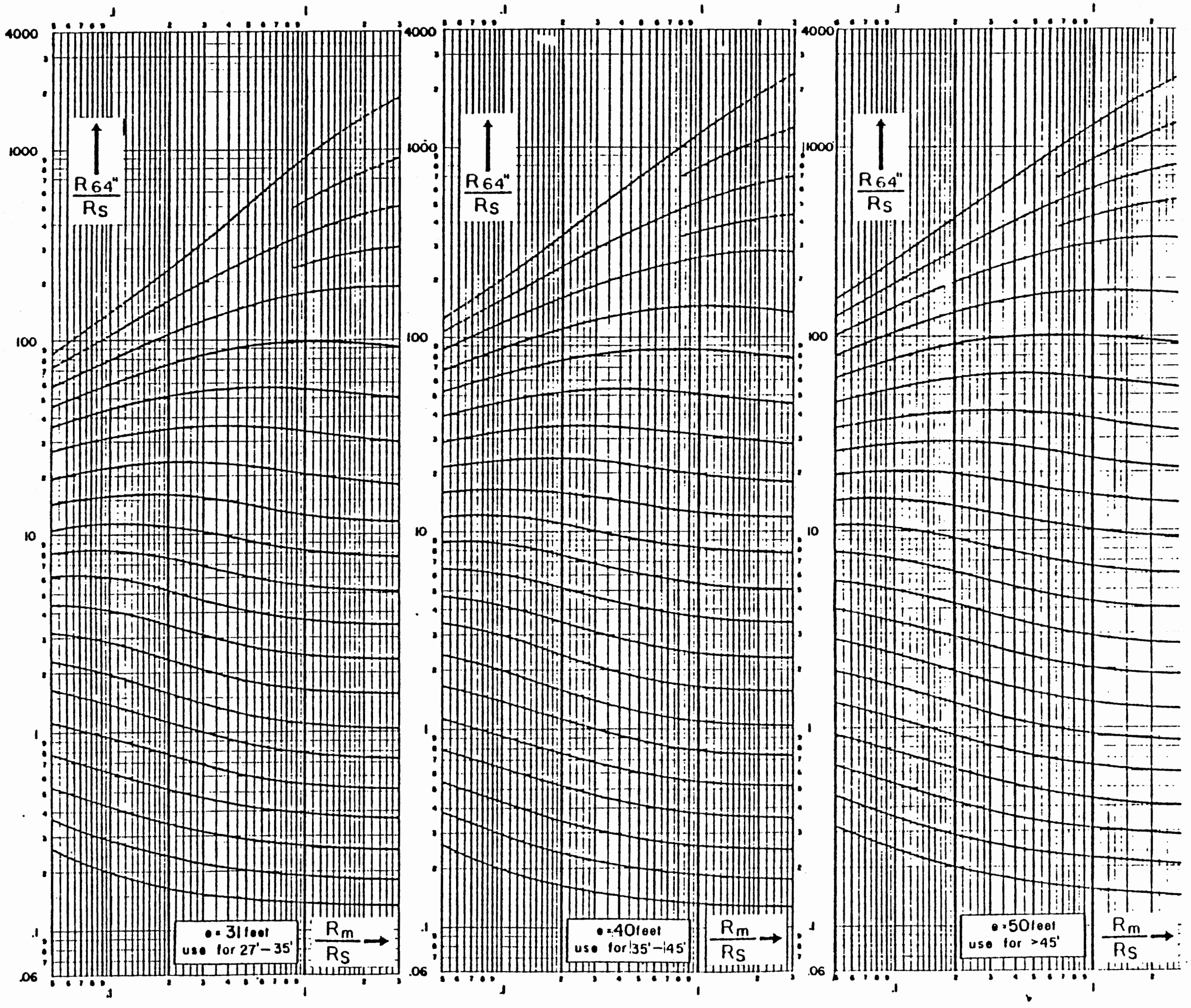

R64"/Rs
Rm/Rs
e = 13 feet
use for 12'-14'
1500
1000
100
10
1
.1
.06


R64"/Rs
Rm/Rs
e = 11 feet
use for 10½'-12'
1500
1000
100
10
1
.1
.06

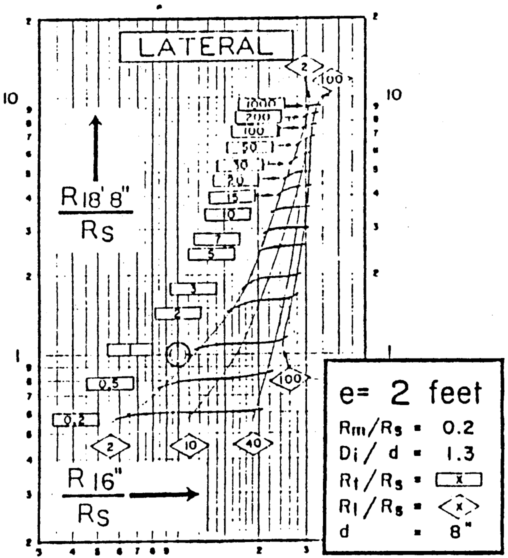

R64"/Rs
Rm/Rs
e = 10 feet
use for 9½'-10½'
1500
1000
100
10
1
.1
.06

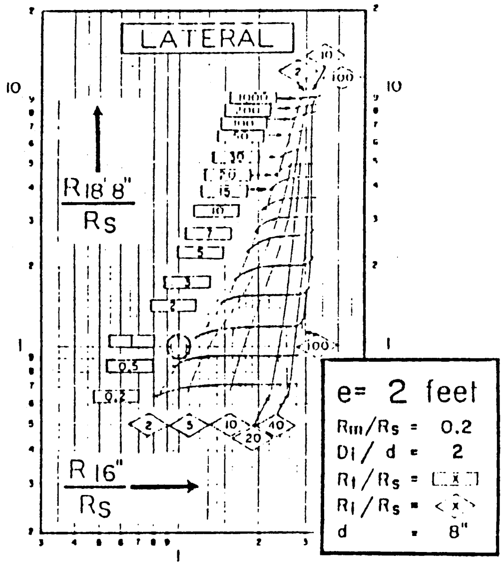

1500
1000
100
10
1
.1
.06
R64"/Rs
Rm/Rs
e=24 feet
use for 21'-27'
e=19 feet
use for 17'-21'
e=15 feet
use for 14'-17'

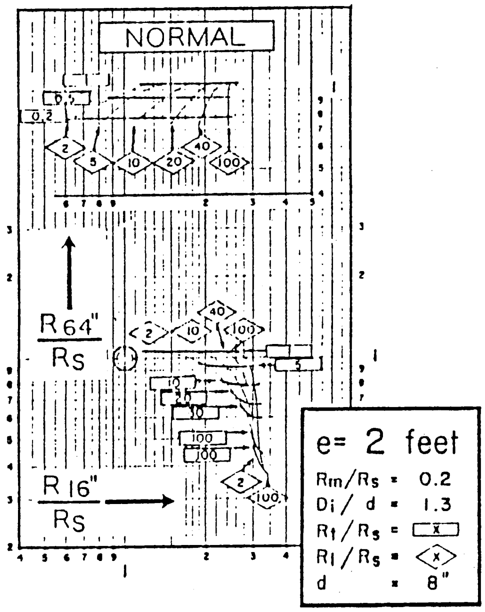
64" NORMAL
Rm TRANSFORMATION CHARTS

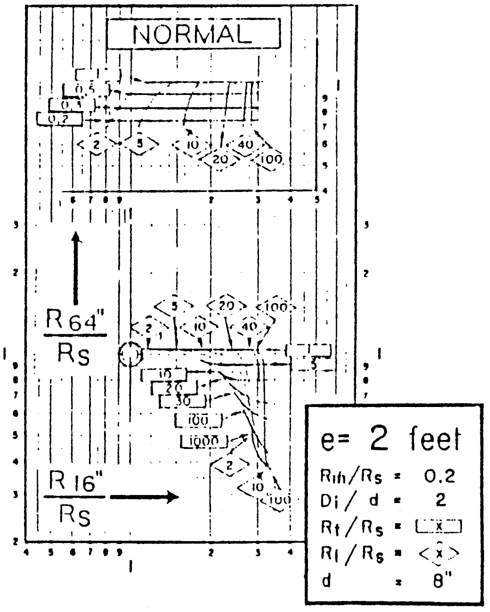


INVASION ANALYSIS CHARTS

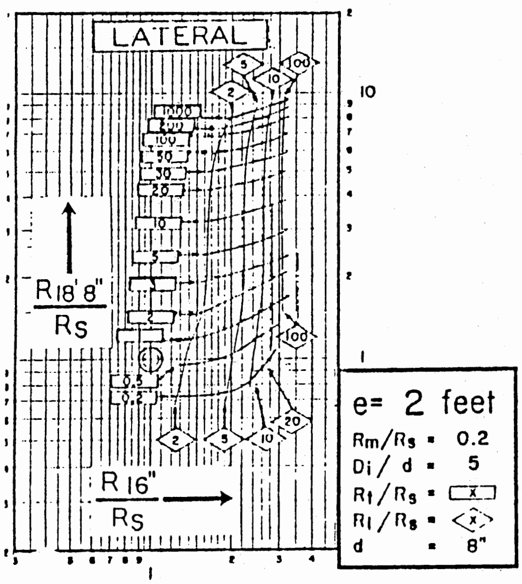


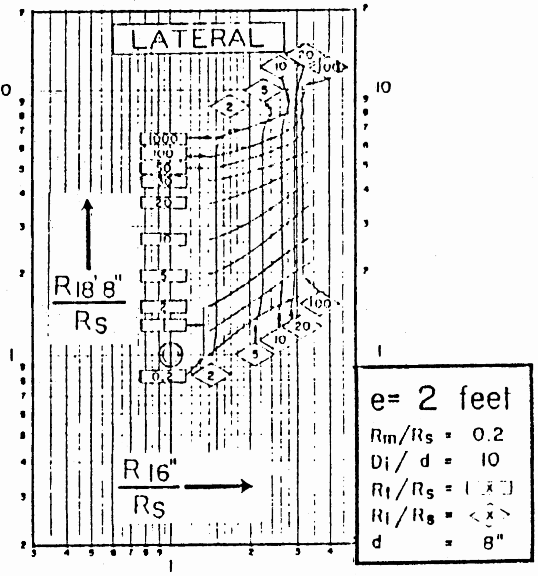


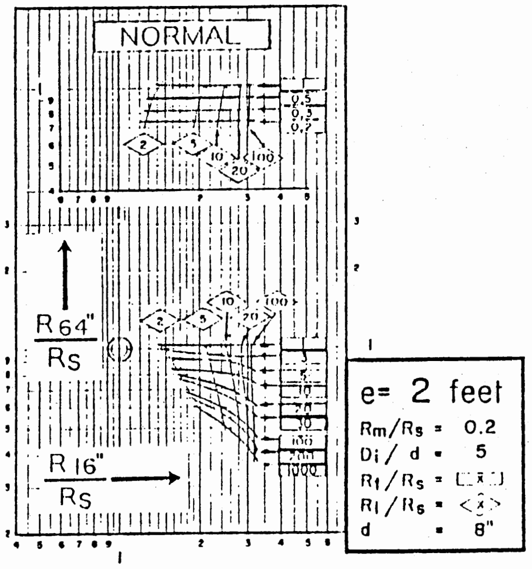


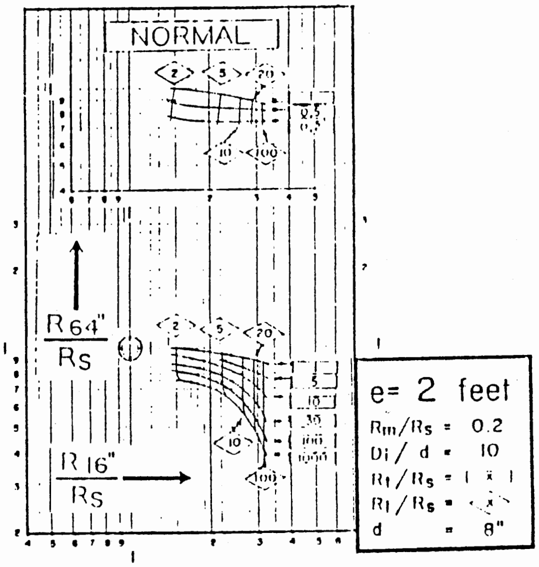


INVASION ANALYSIS CHARTS

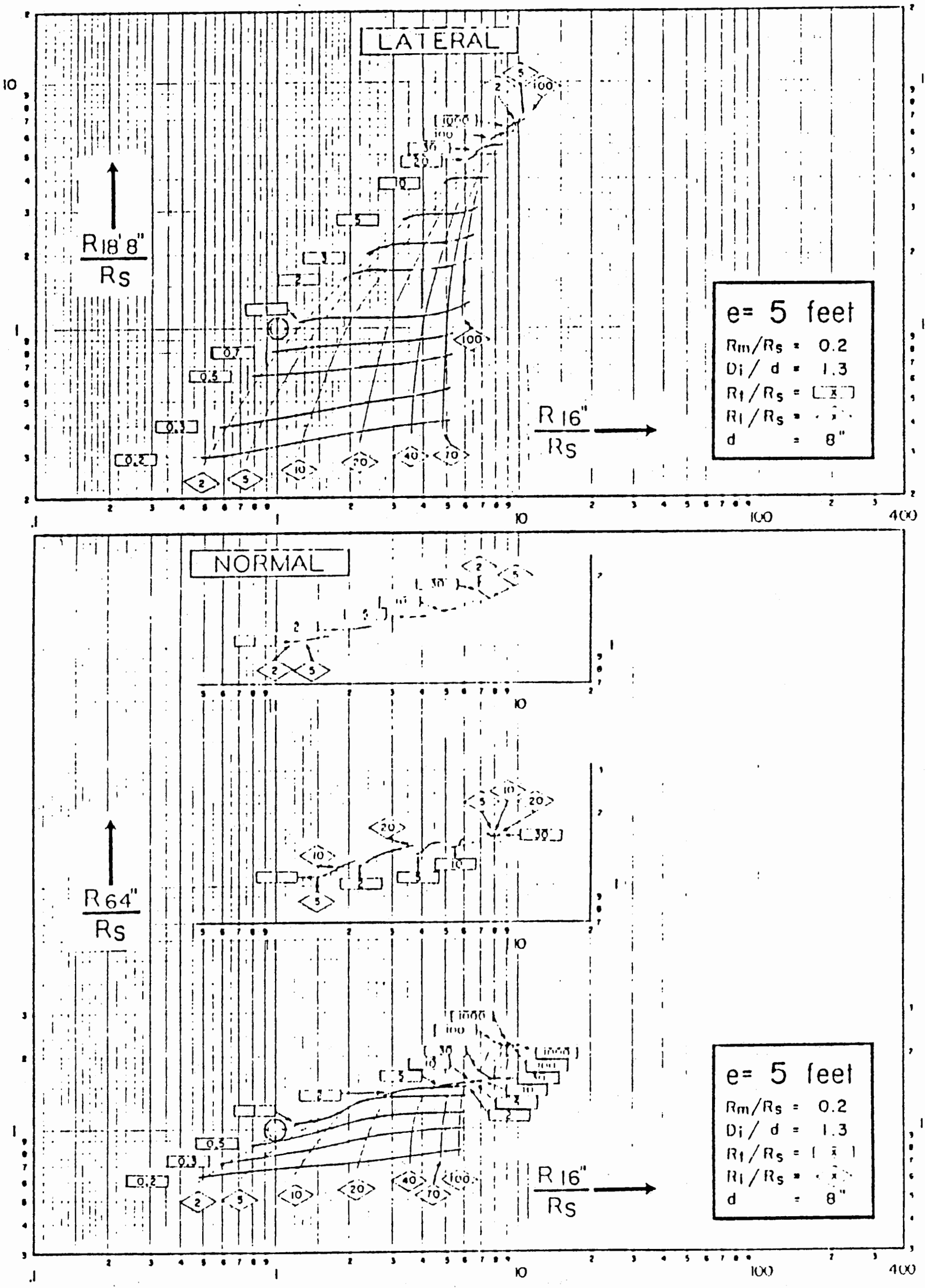




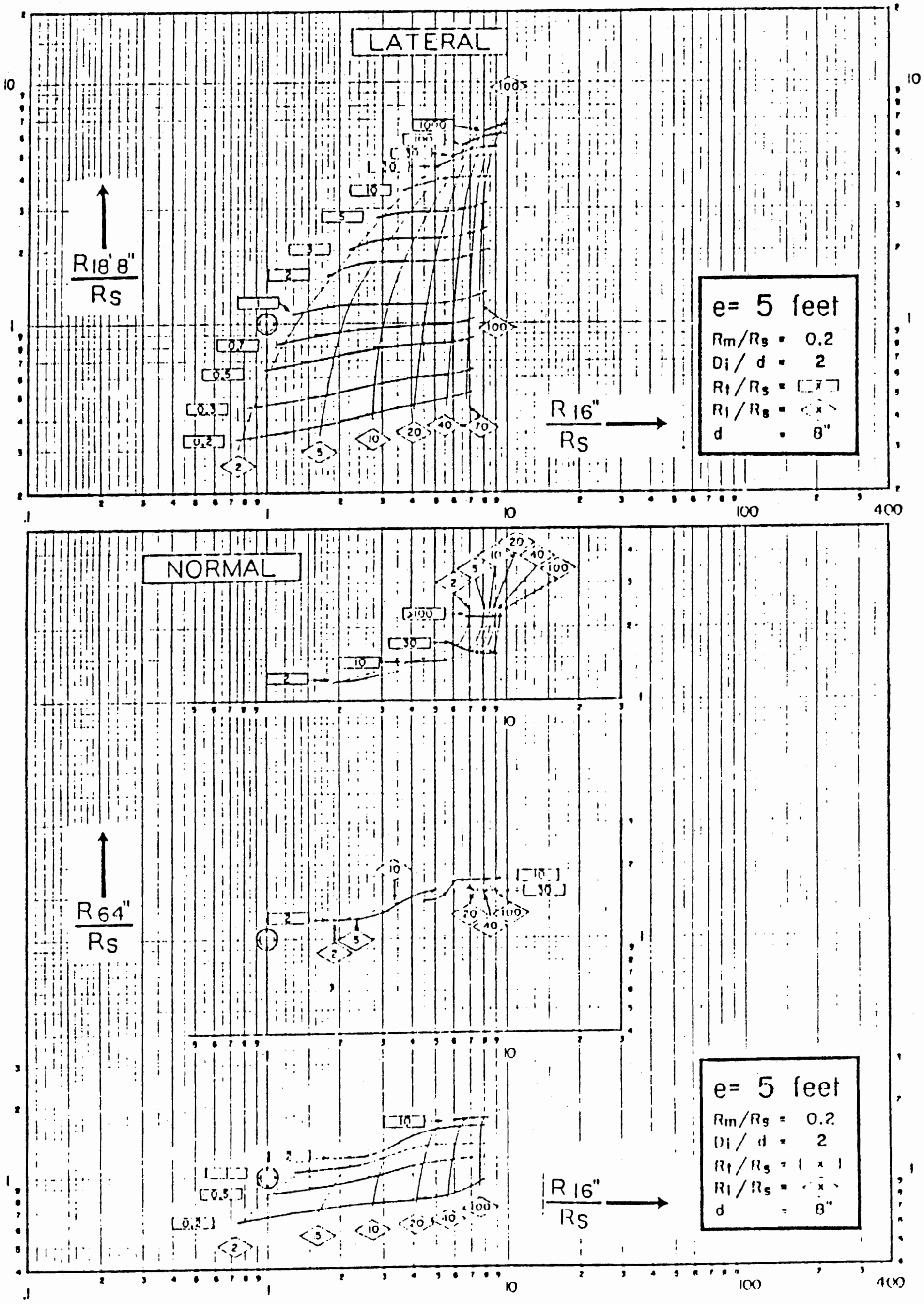




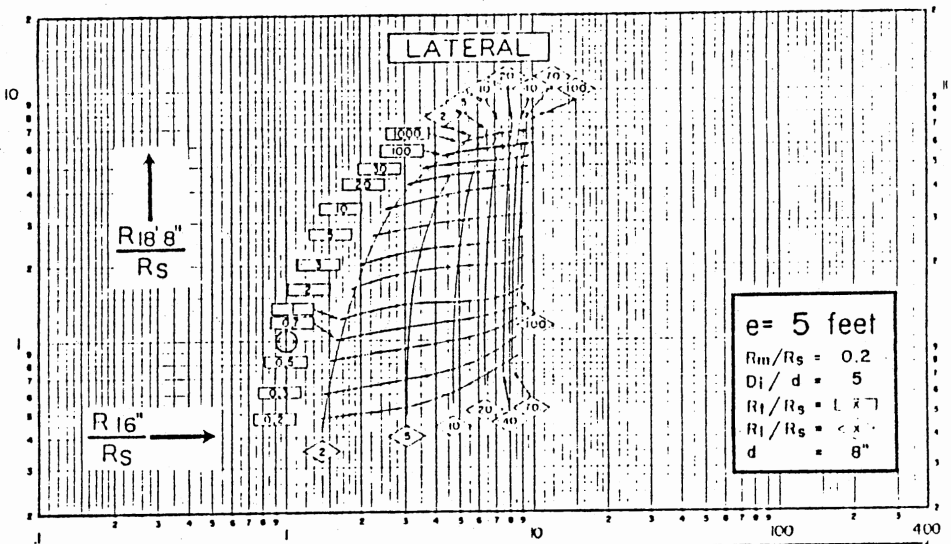
INVASION ANALYSIS CHARTS

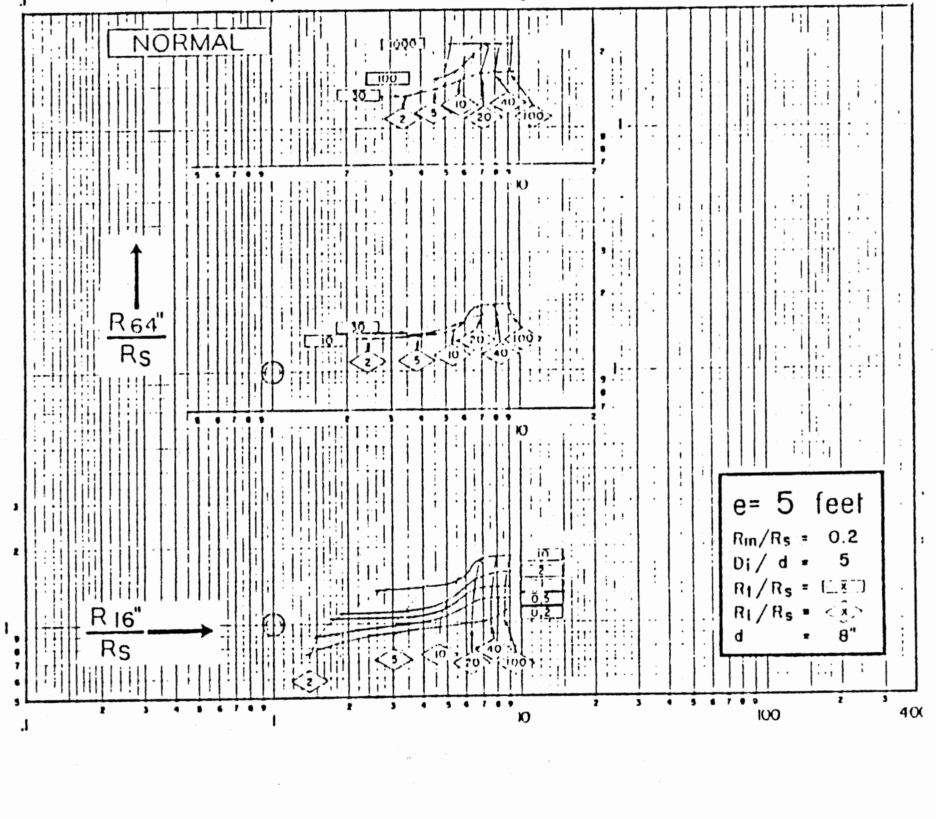


INVASION ANALYSIS CHARTS

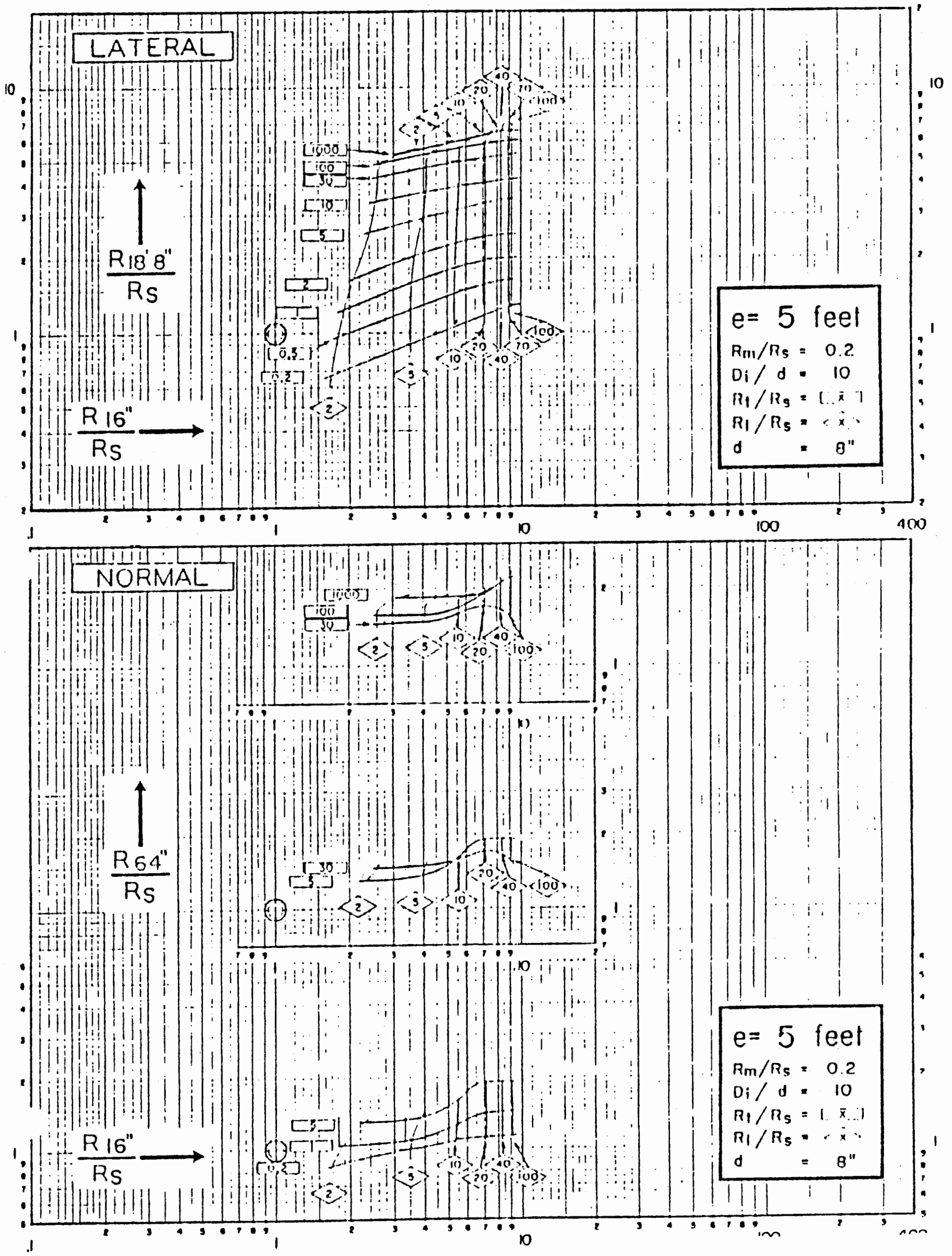


INVASION ANALYSIS CHARTS

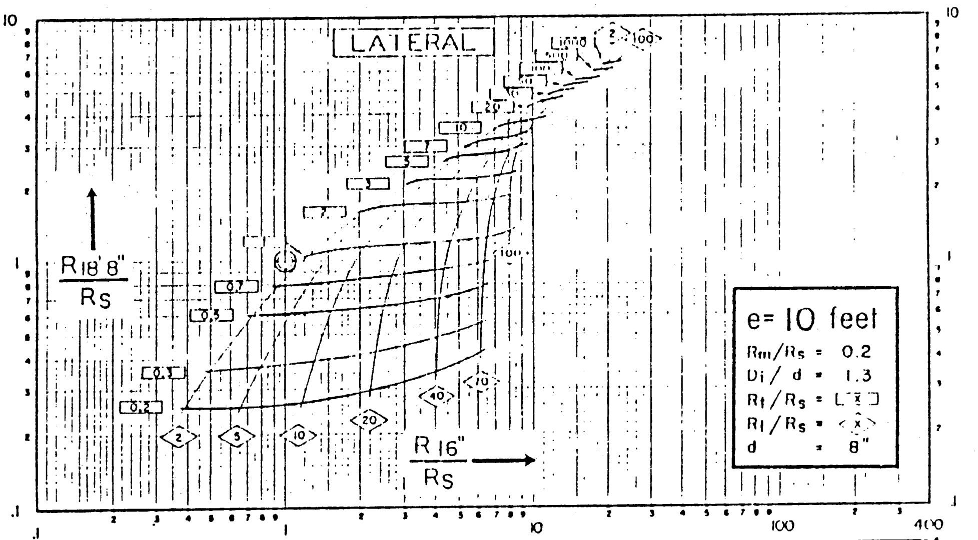


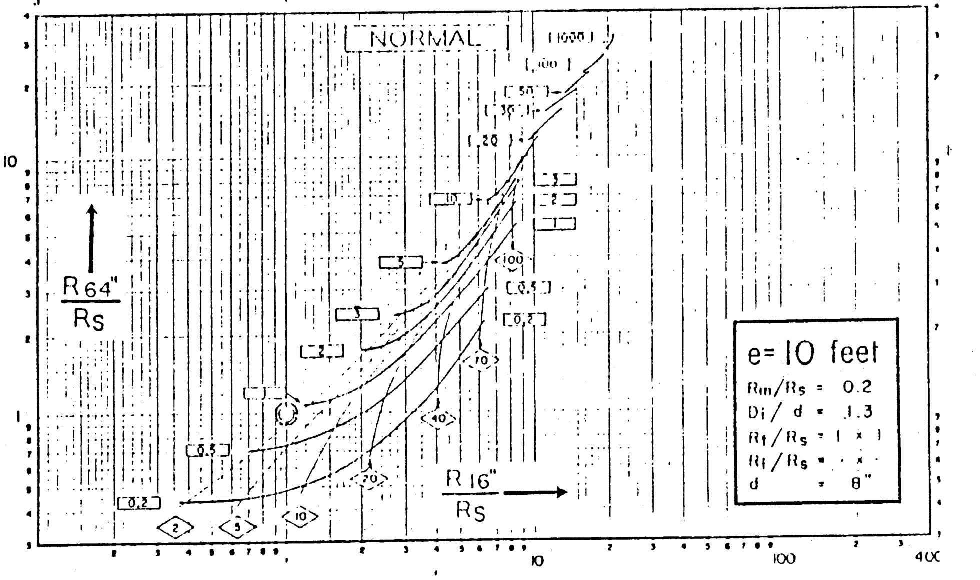


INVASION ANALYSIS CHARTS

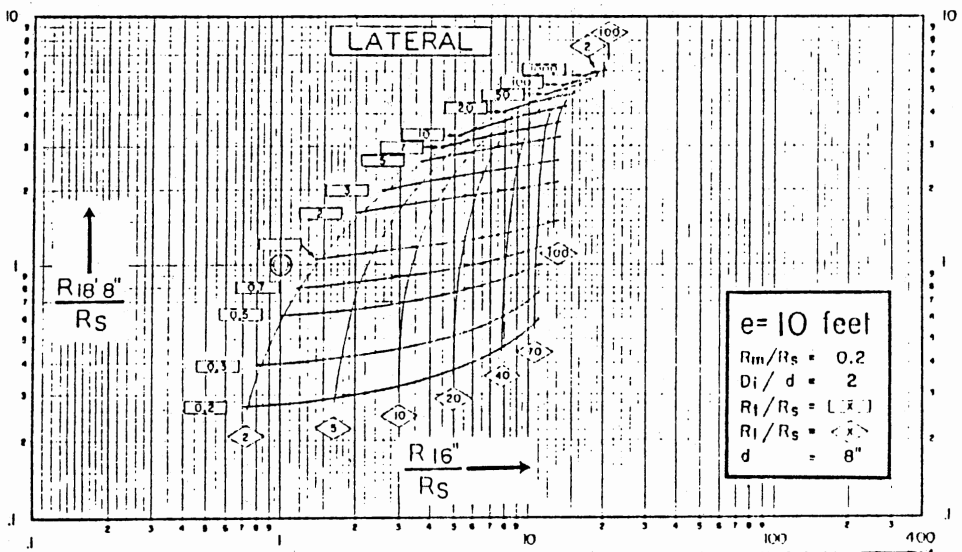


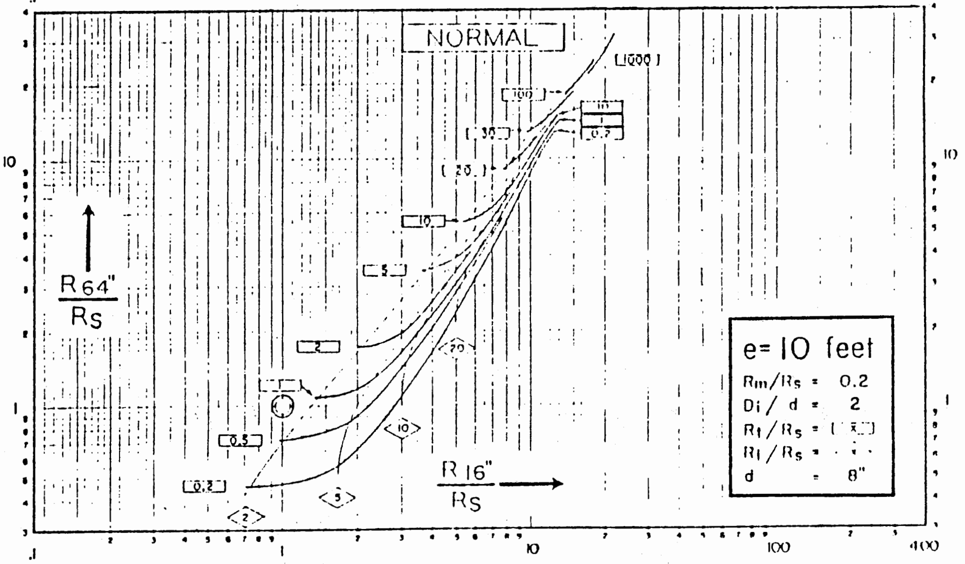
INVASION ANALYSIS CHARTS



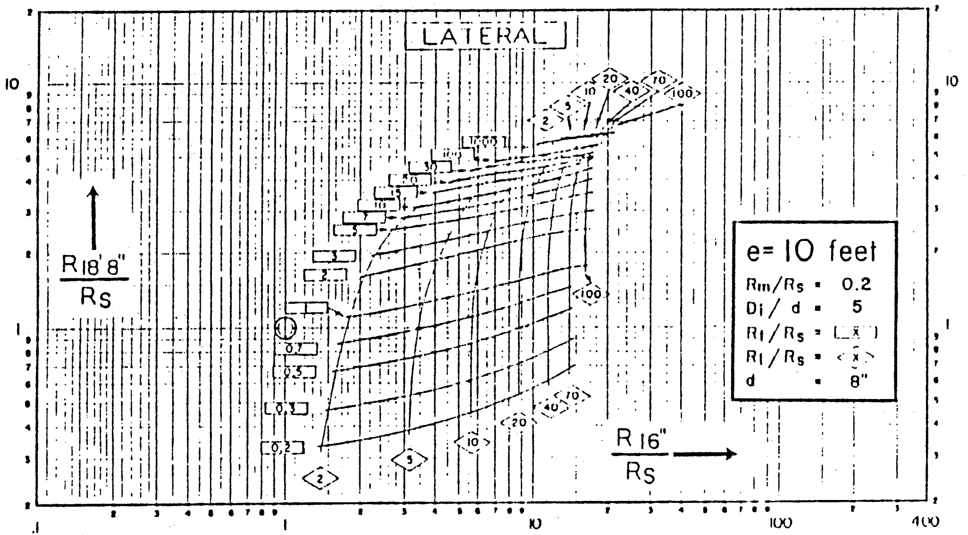


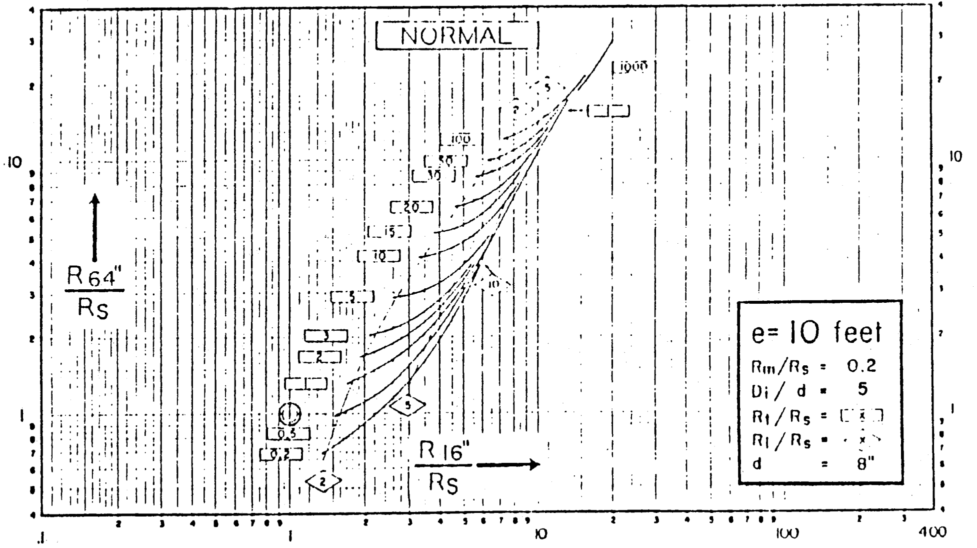
INVASION ANALYSIS CHARTS



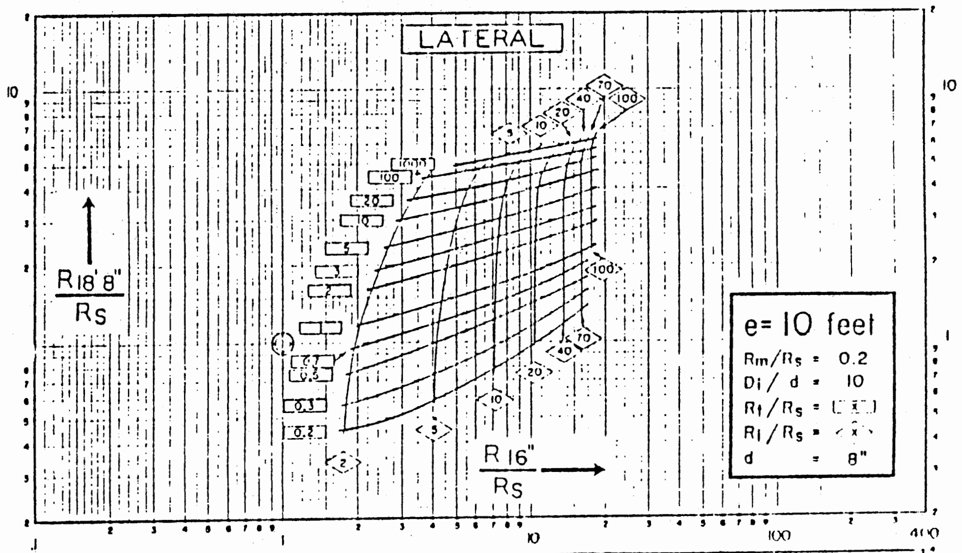


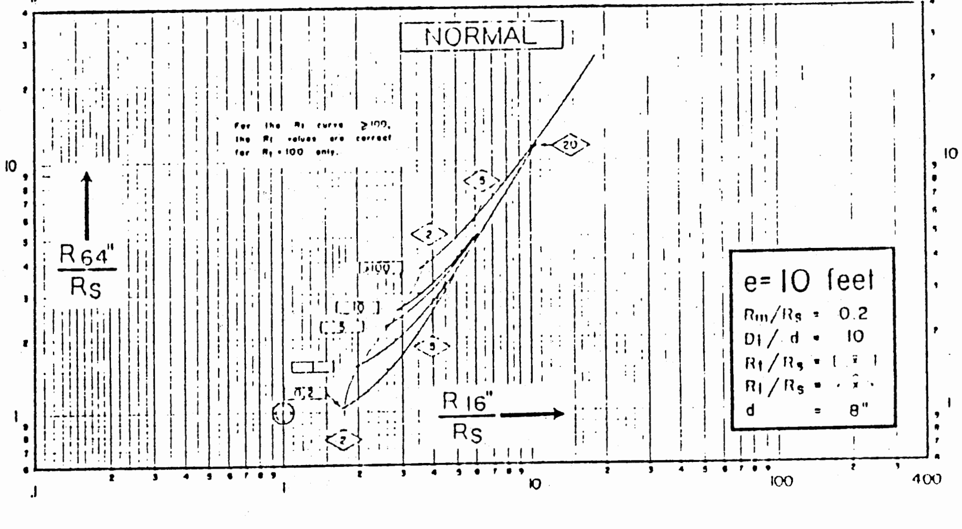
INVASION ANALYSIS CHARTS



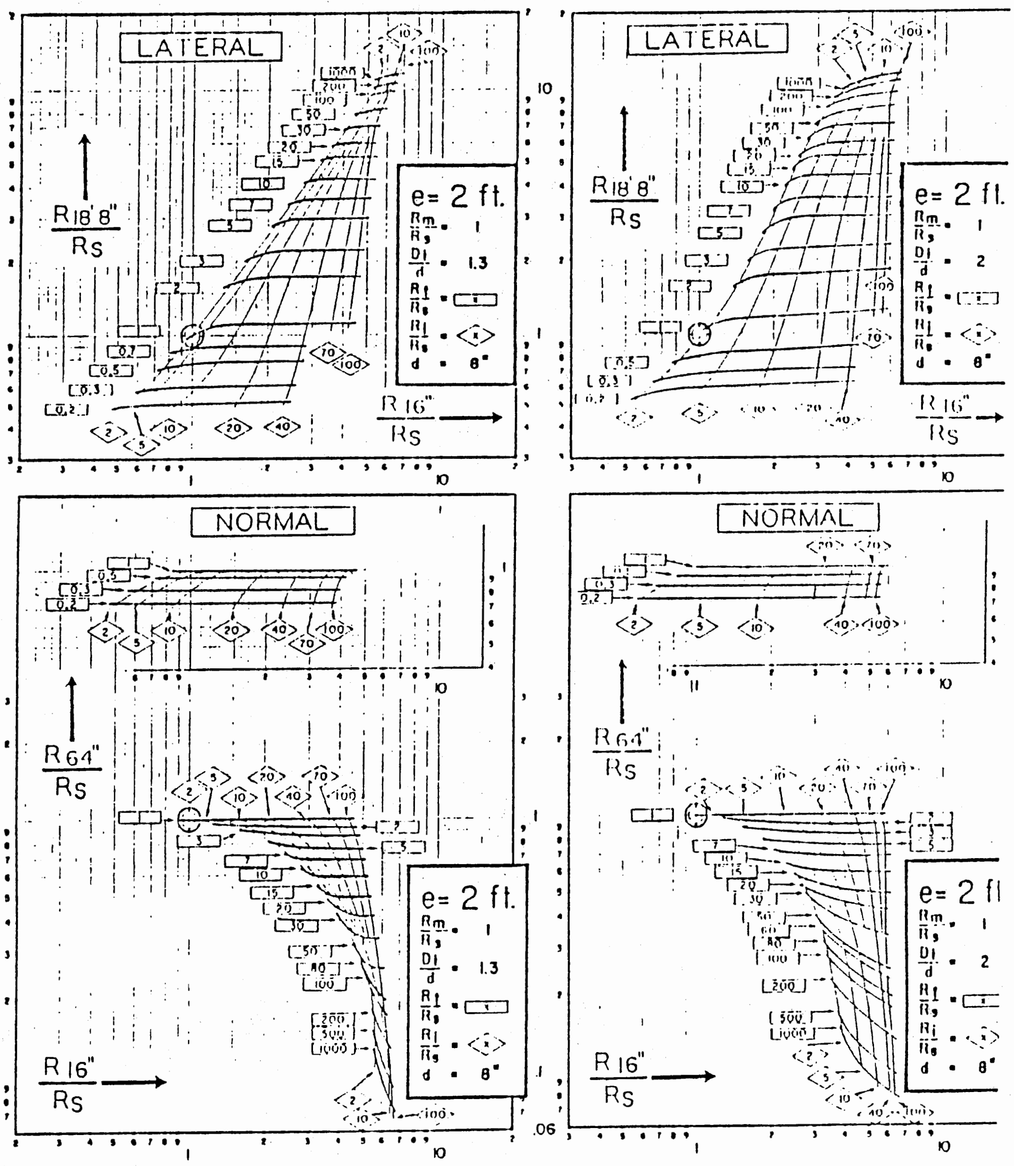


INVASION ANALYSIS CHARTS

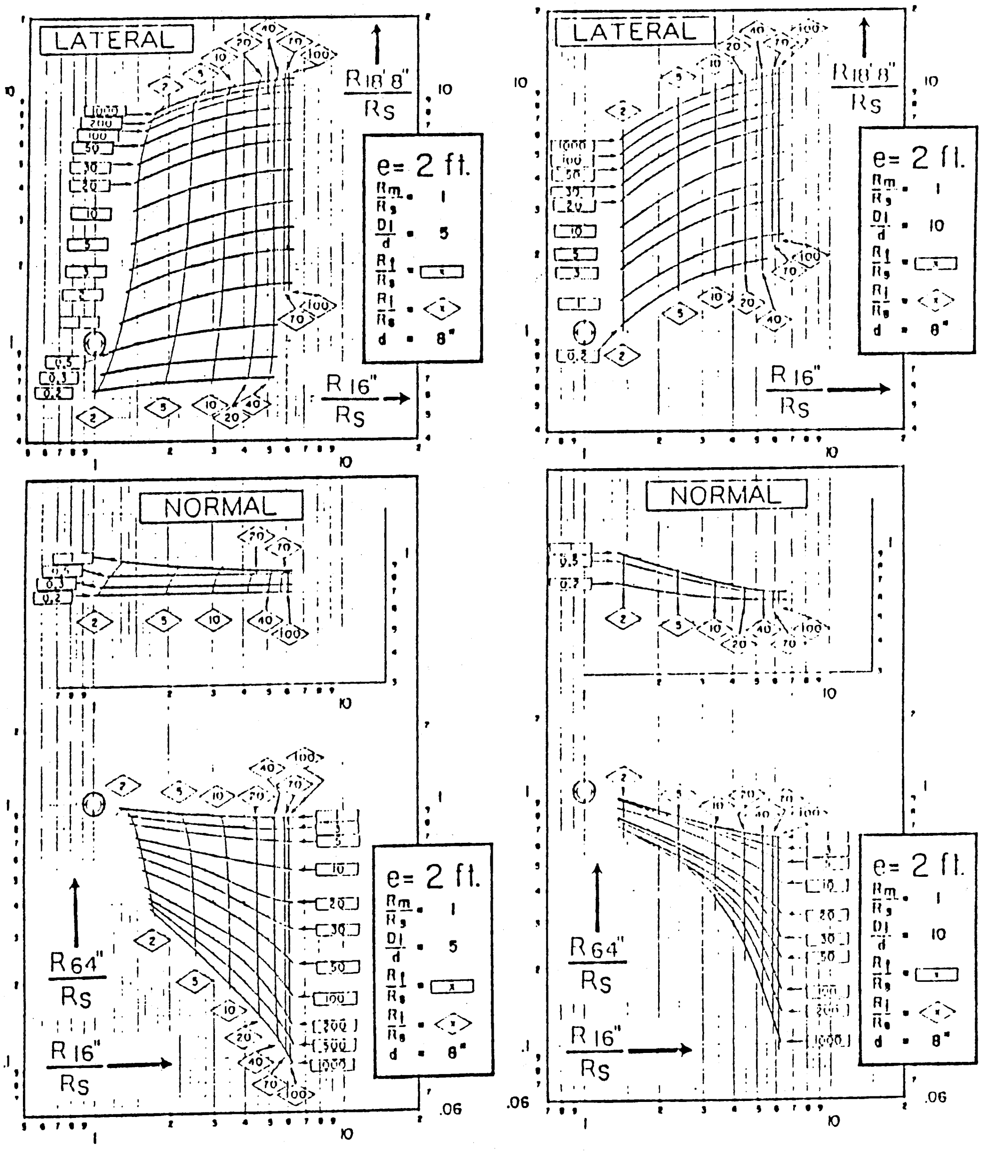



For the Rt curve ≥100, the Rt values are correct for Rt = 100 only.

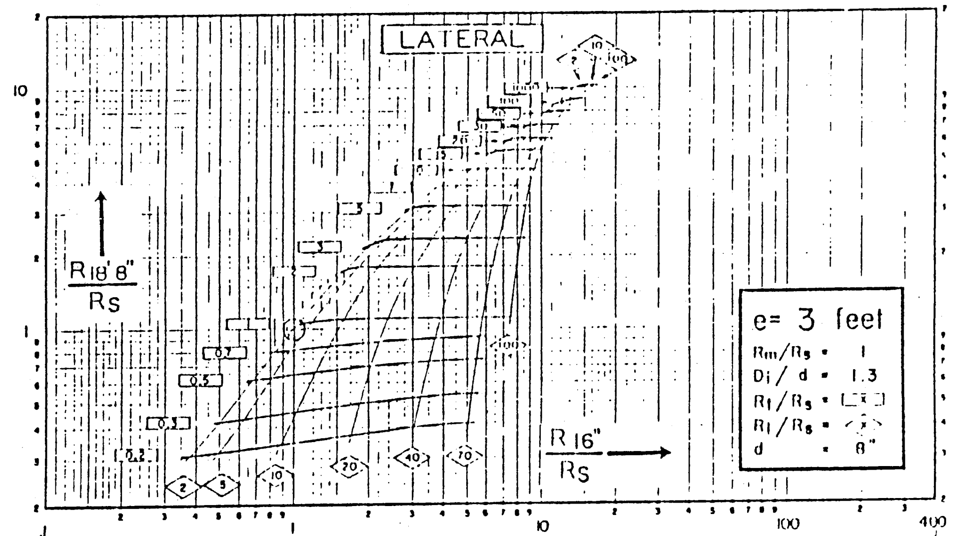
INVASION ANALYSIS CHARTS

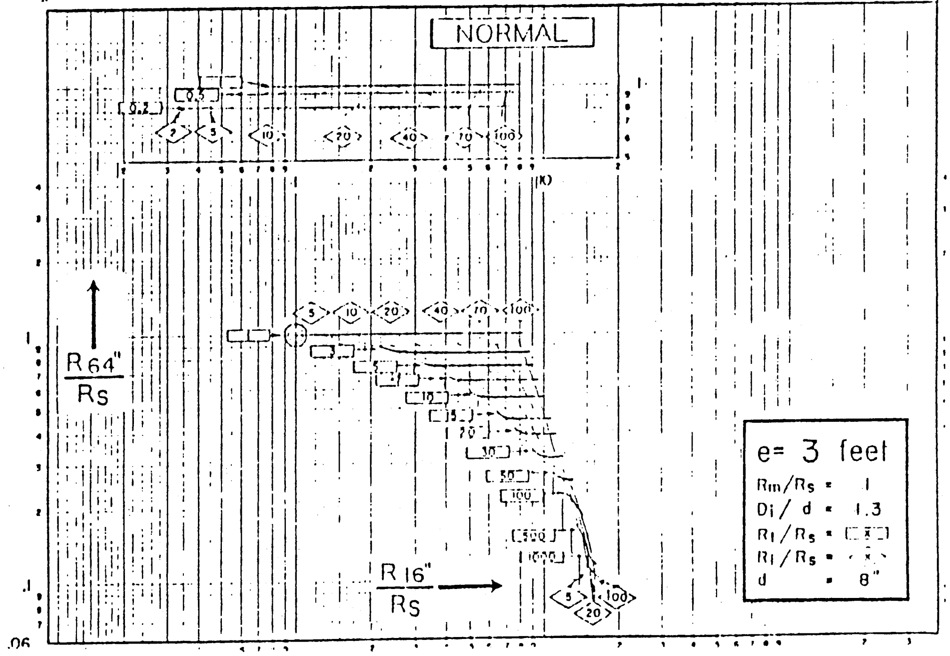


INVASION ANALYSIS CHARTS

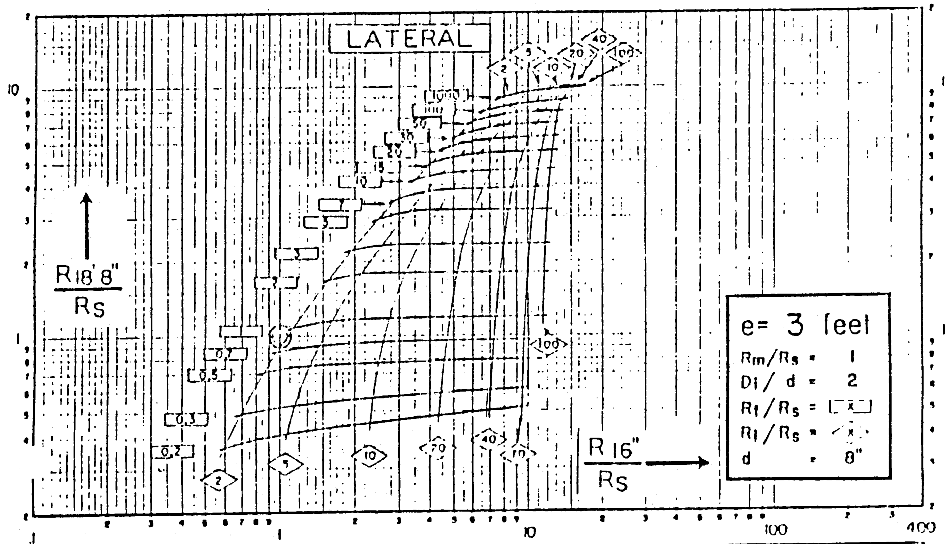


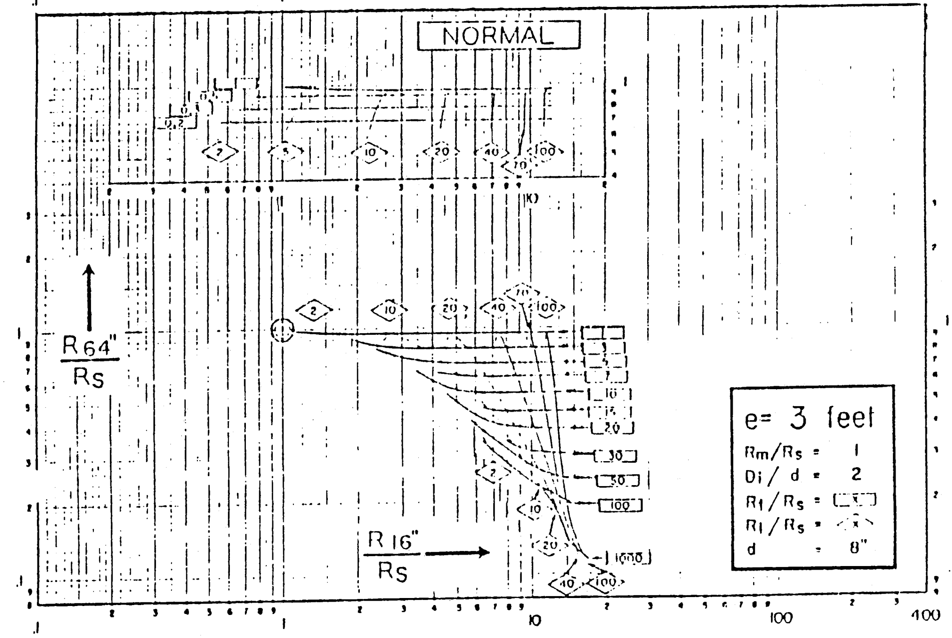
INVASION ANALYSIS CHARTS



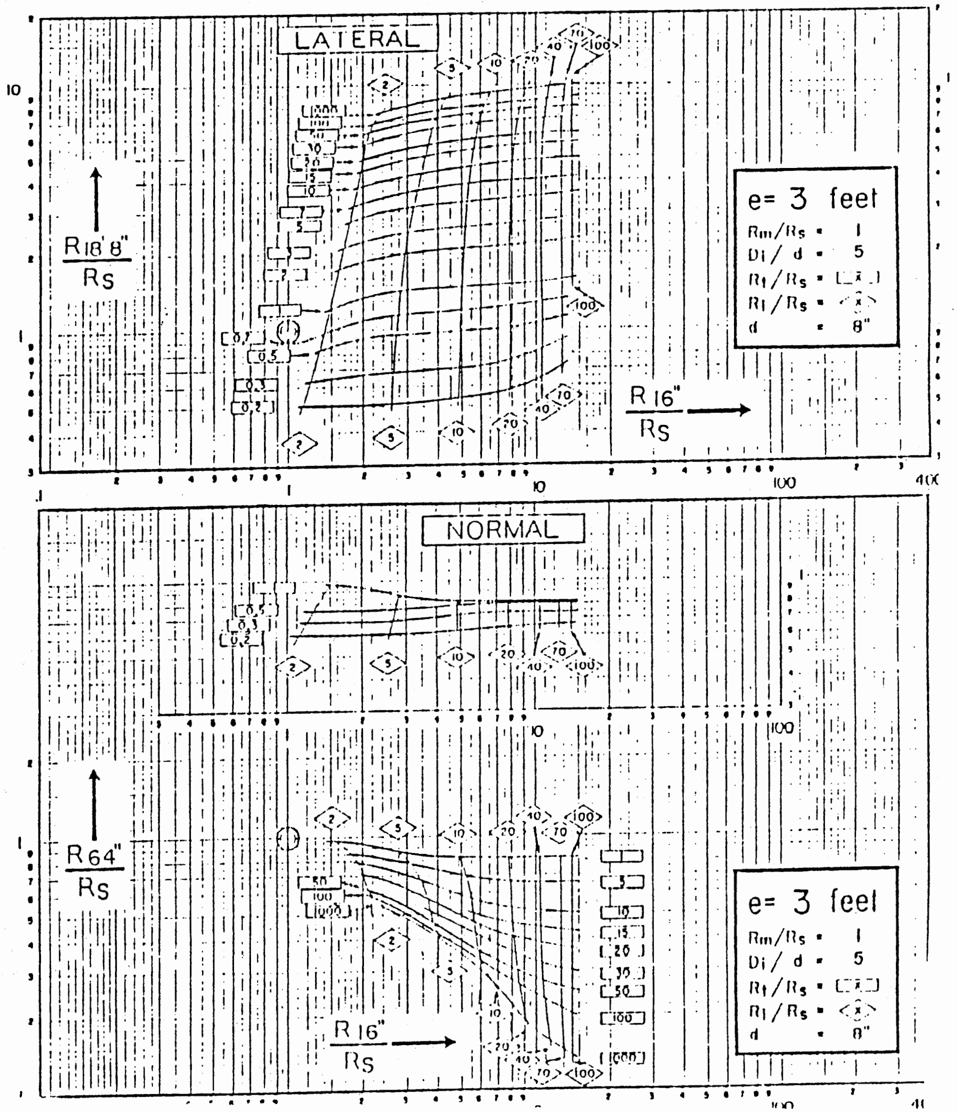


INVASION ANALYSIS CHARTS

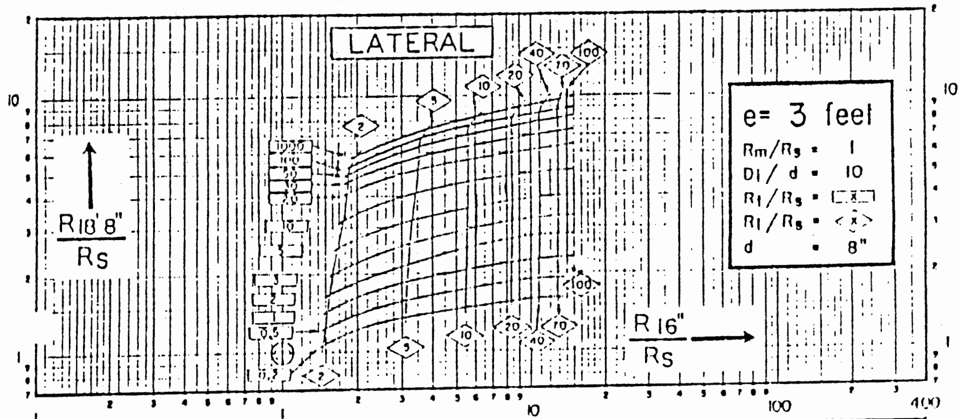


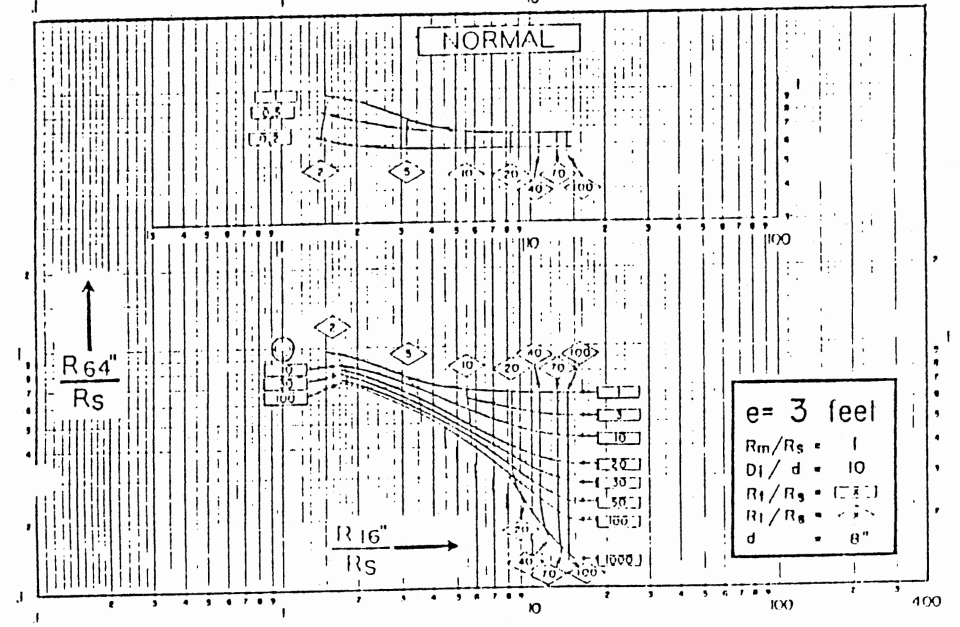


INVASION ANALYSIS CHARTS

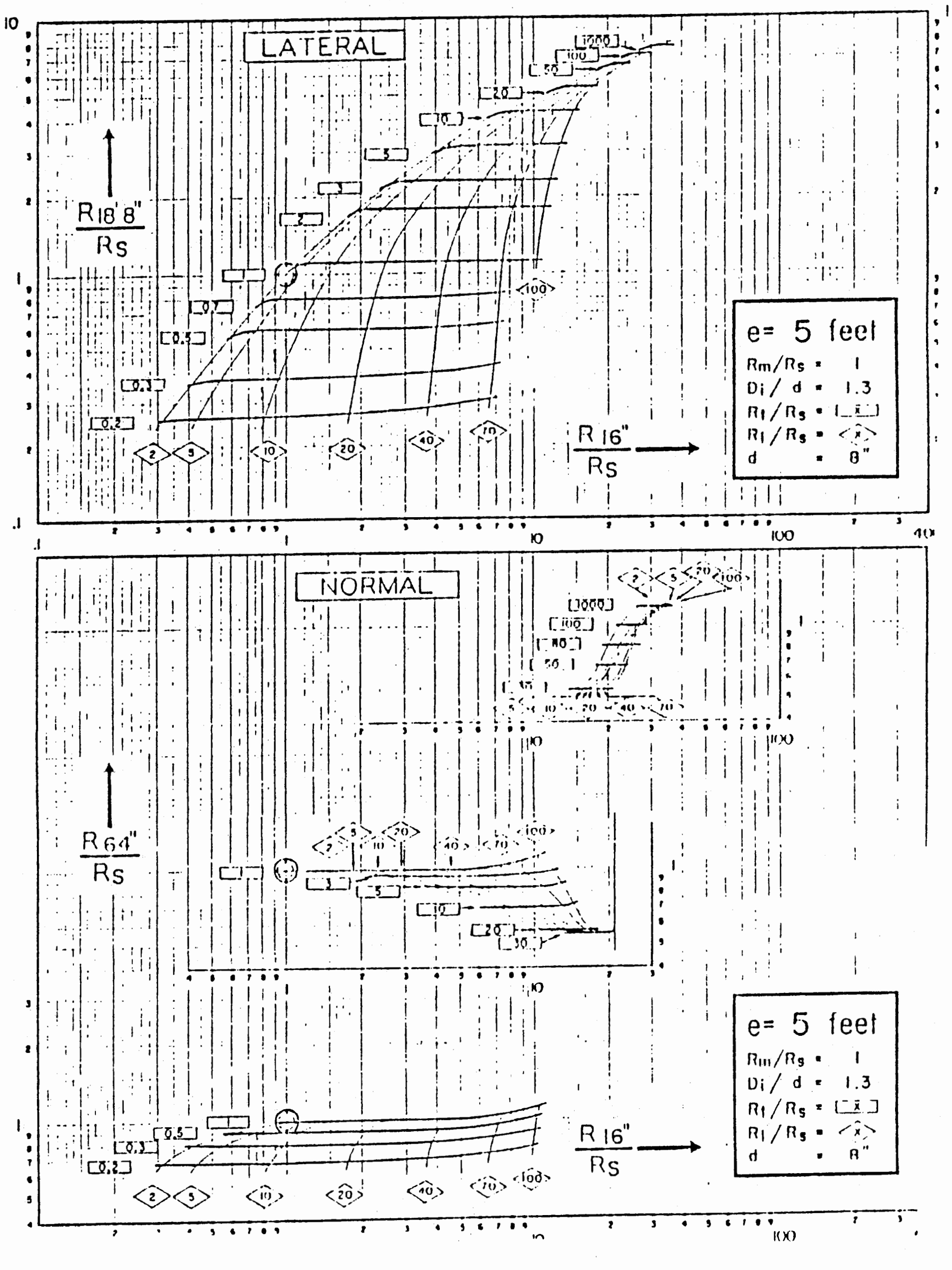


INVASION ANALYSIS CHARTS

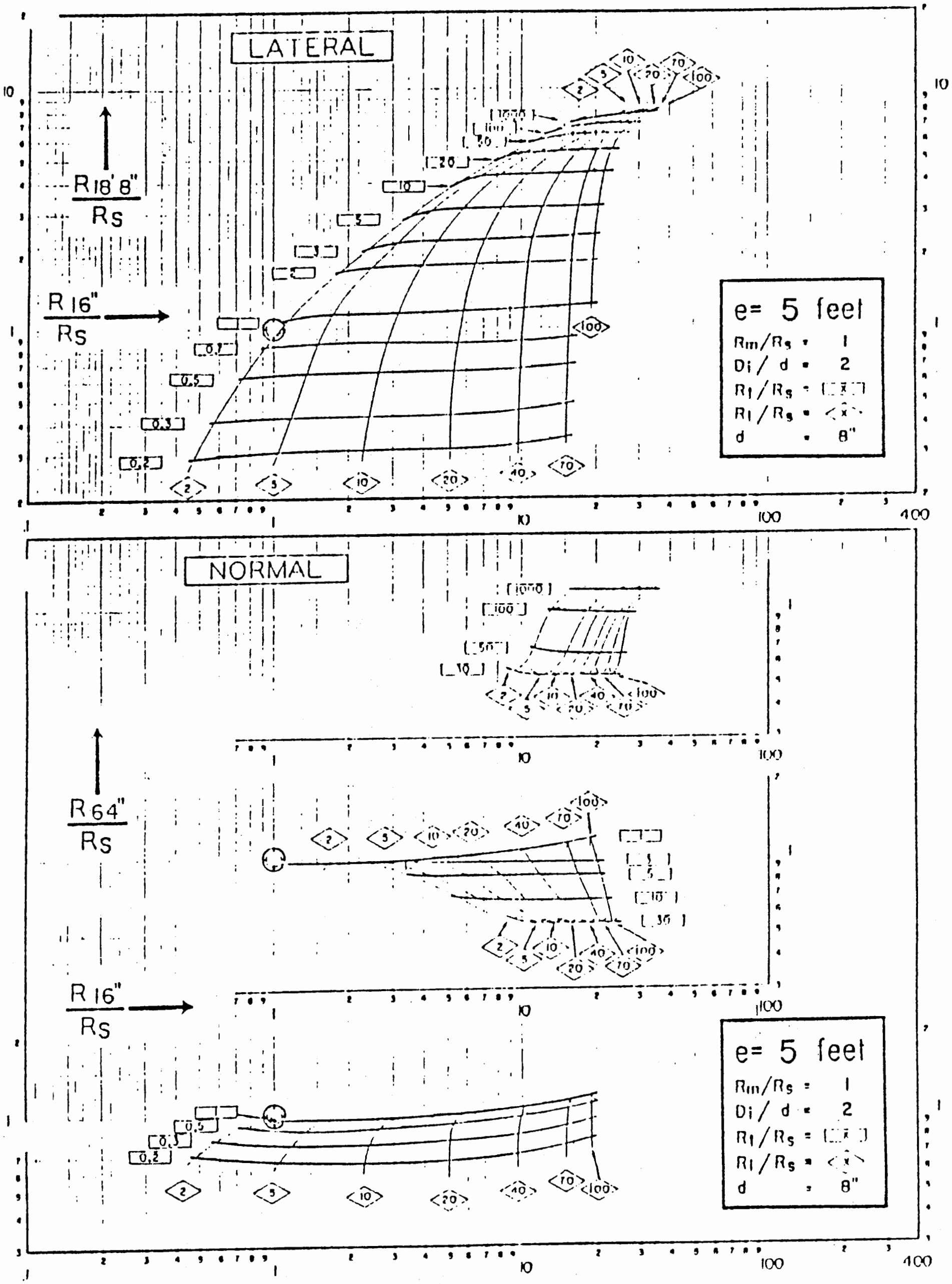




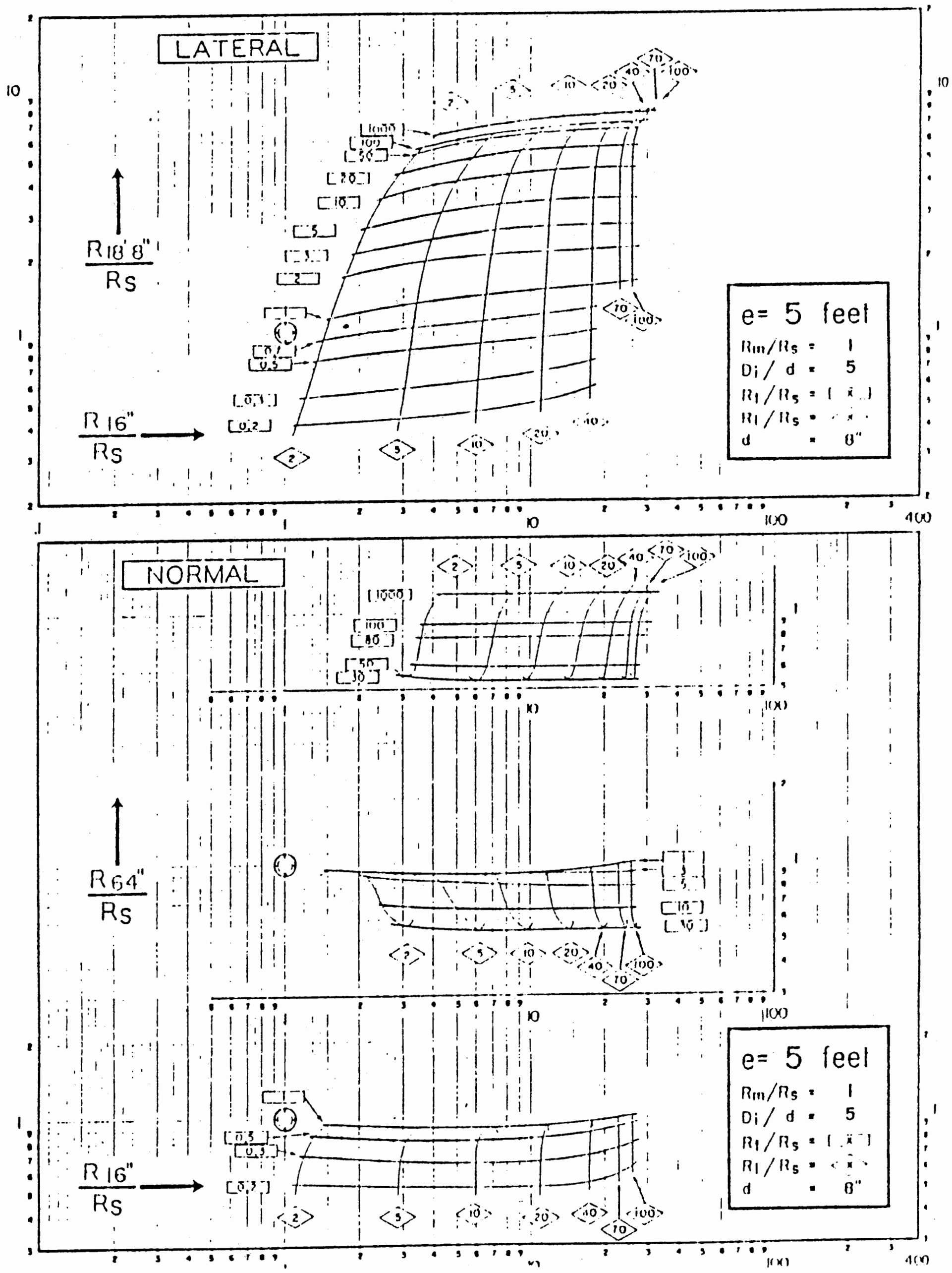
INVASION ANALYSIS CHARTS



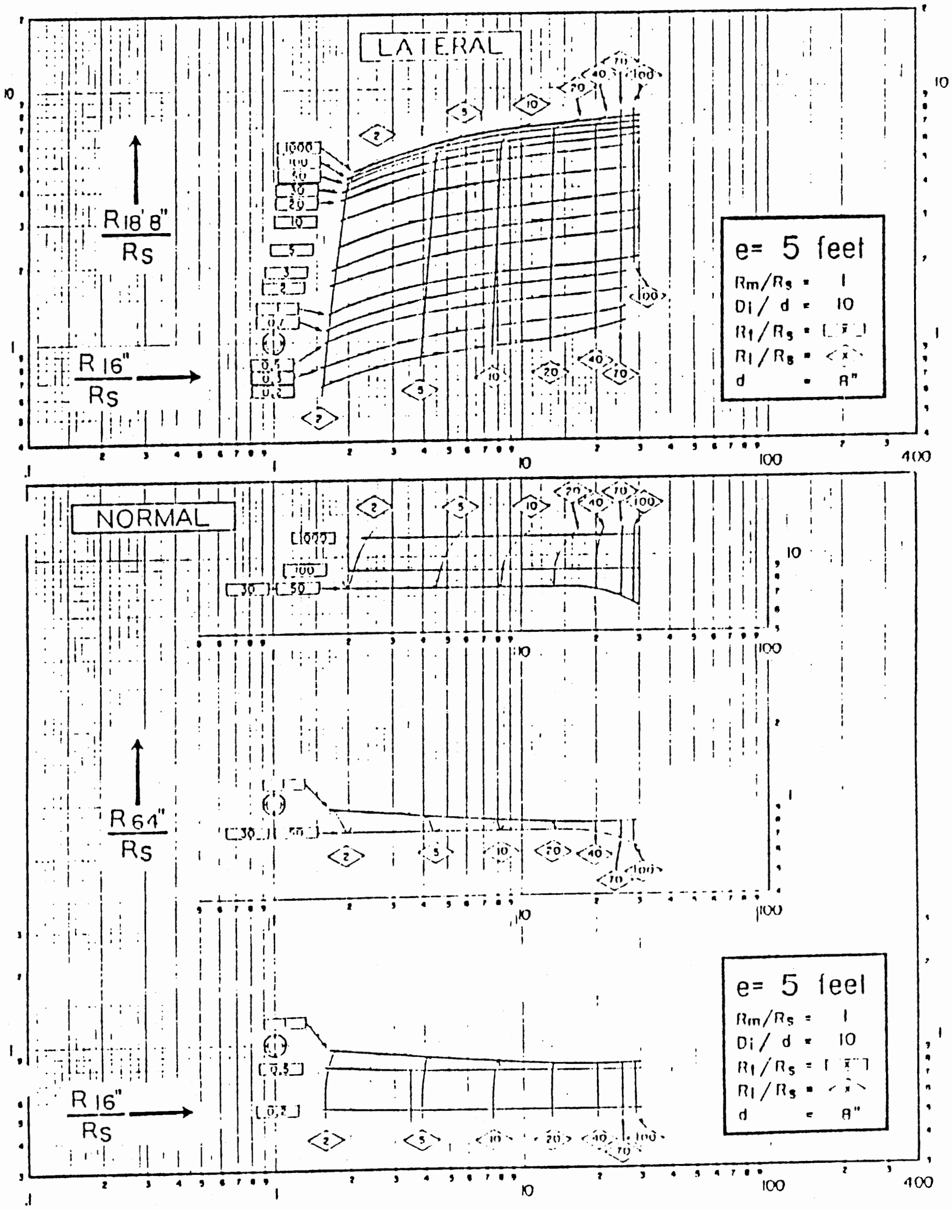
INVASION ANALYSIS CHARTS



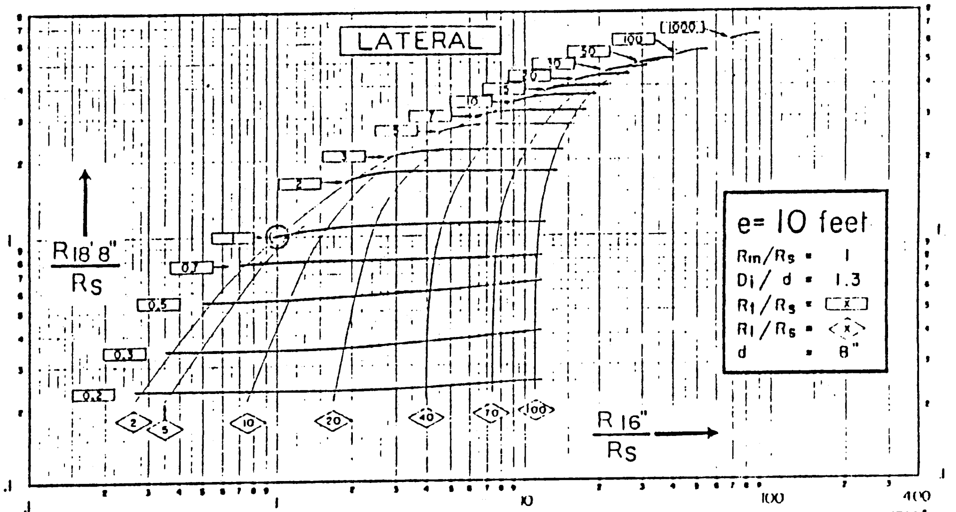
INVASION ANALYSIS CHARTS

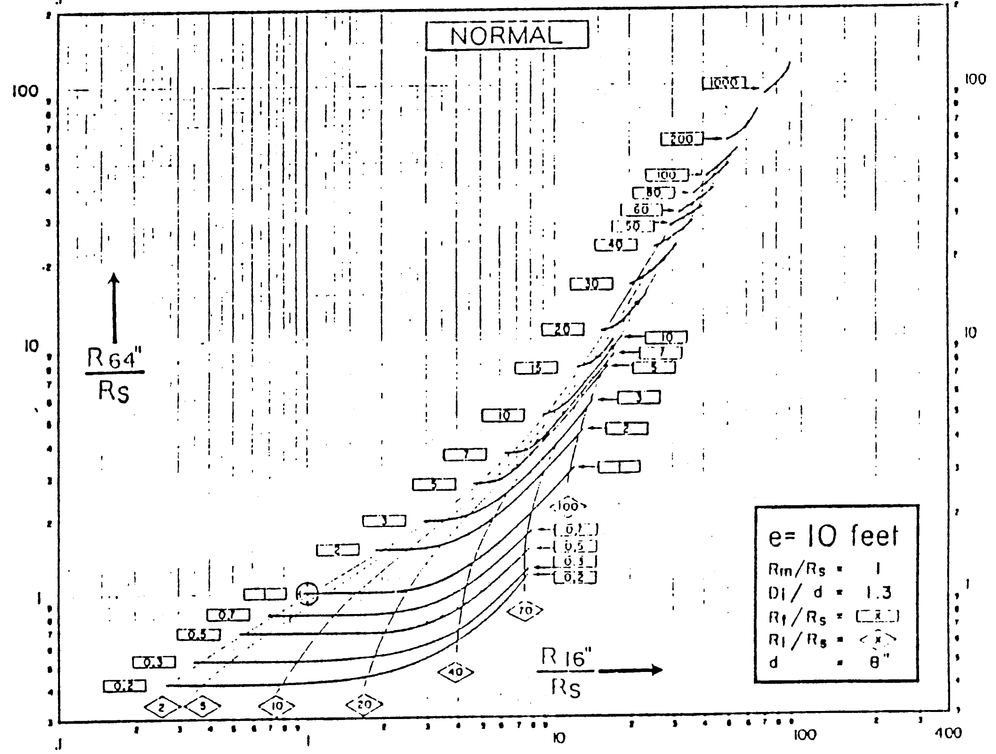


INVASION ANALYSIS CHARTS

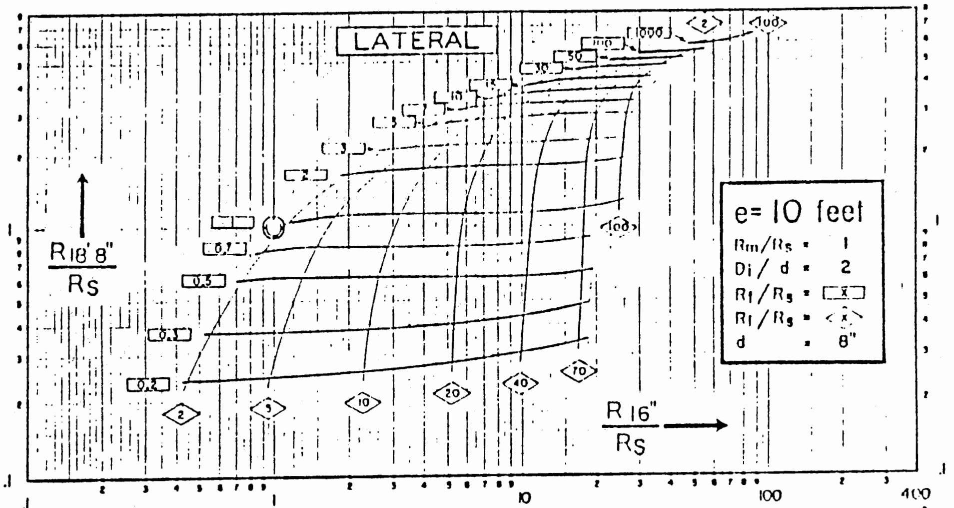


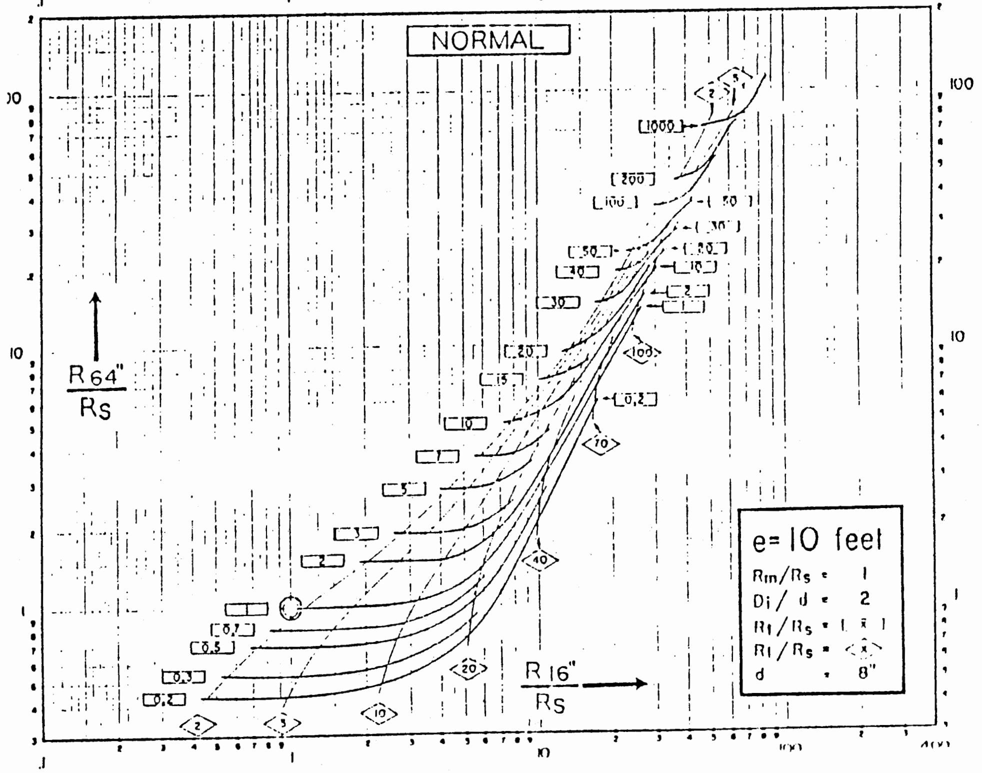
INVASION ANALYSIS CHARTS



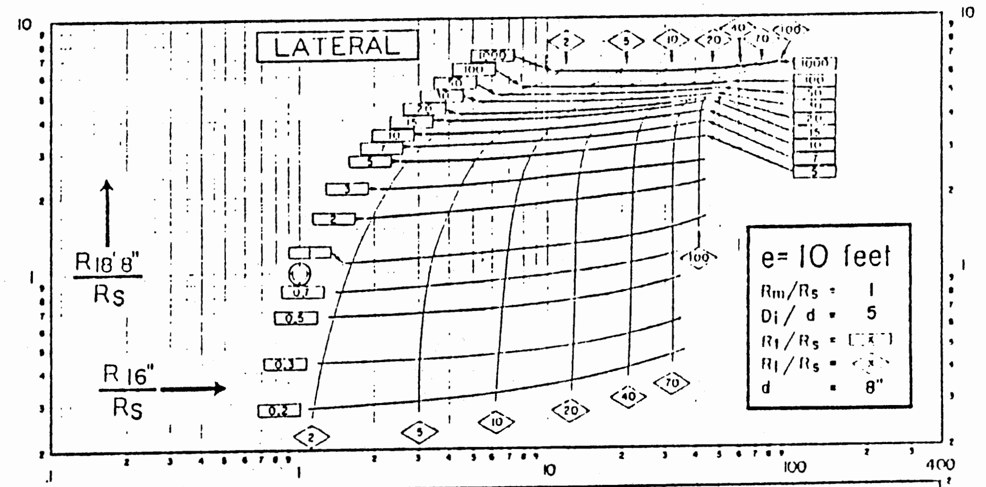


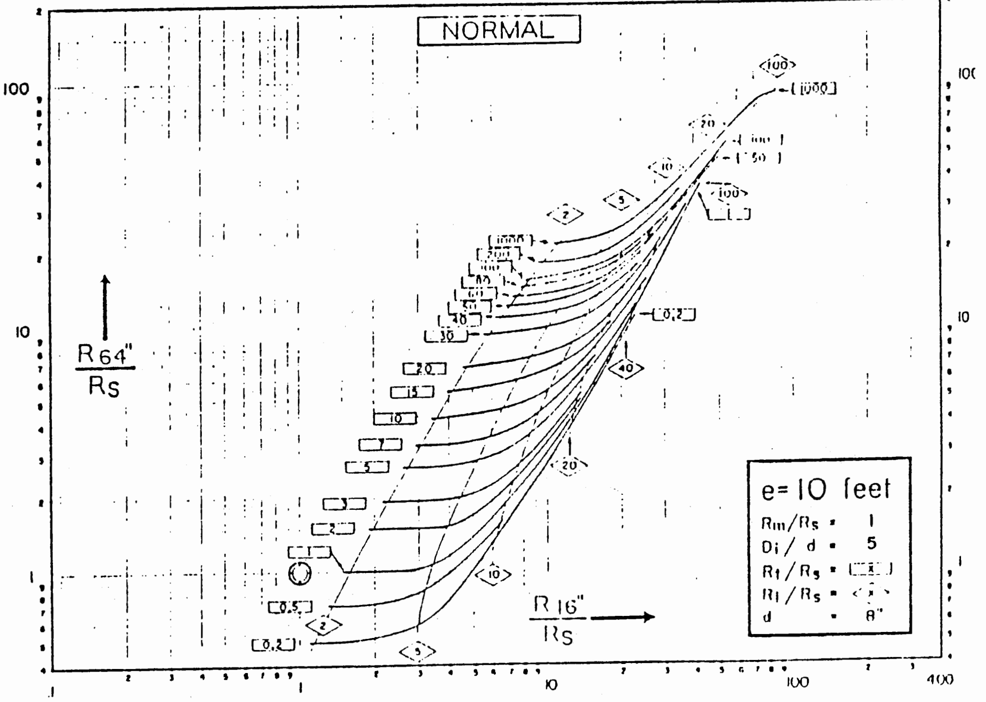
INVASION ANALYSIS CHARTS



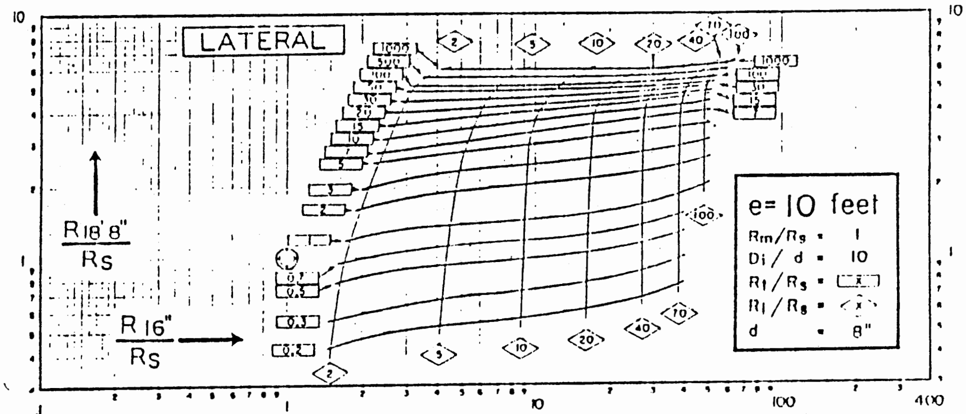


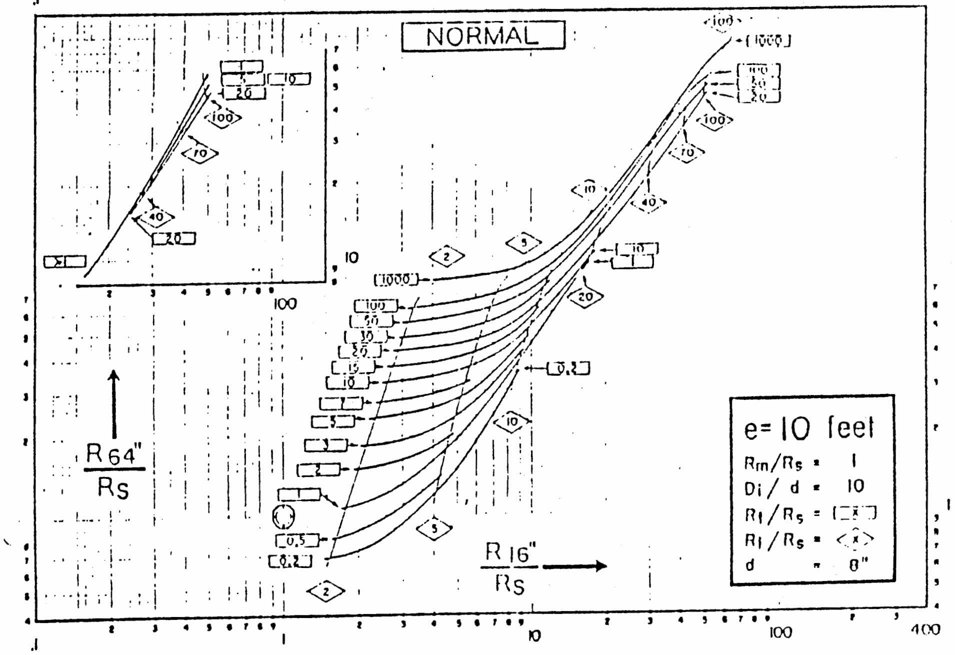
INVASION ANALYSIS CHARTS





INVASION ANALYSIS CHARTS





APPENDIX D

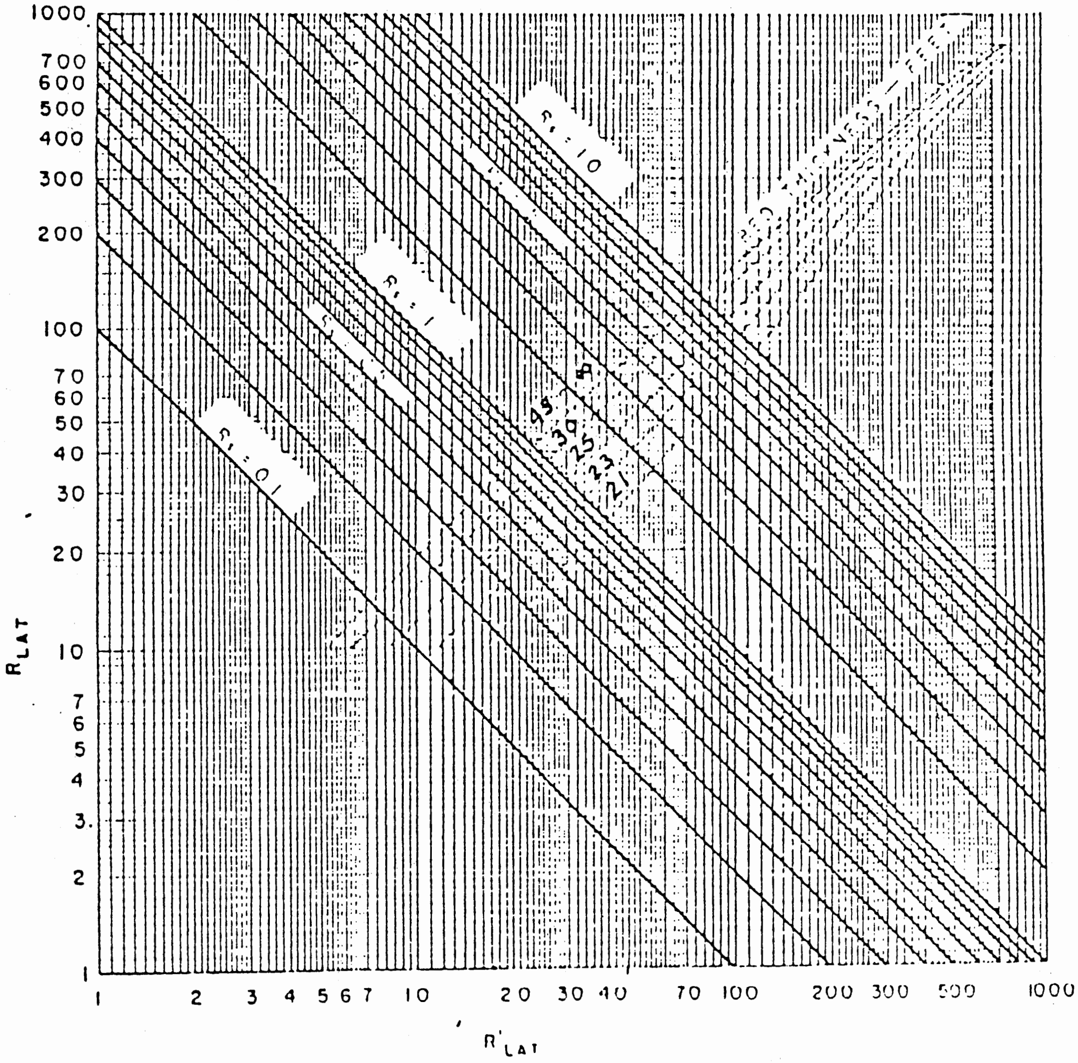
Ri-Rt CONVERSION CHARTS (LANE WELLS, 1956)

LANE-WELLS

RESISTIVITY DEPARTURE CURVES

(LATERAL)

May 1956

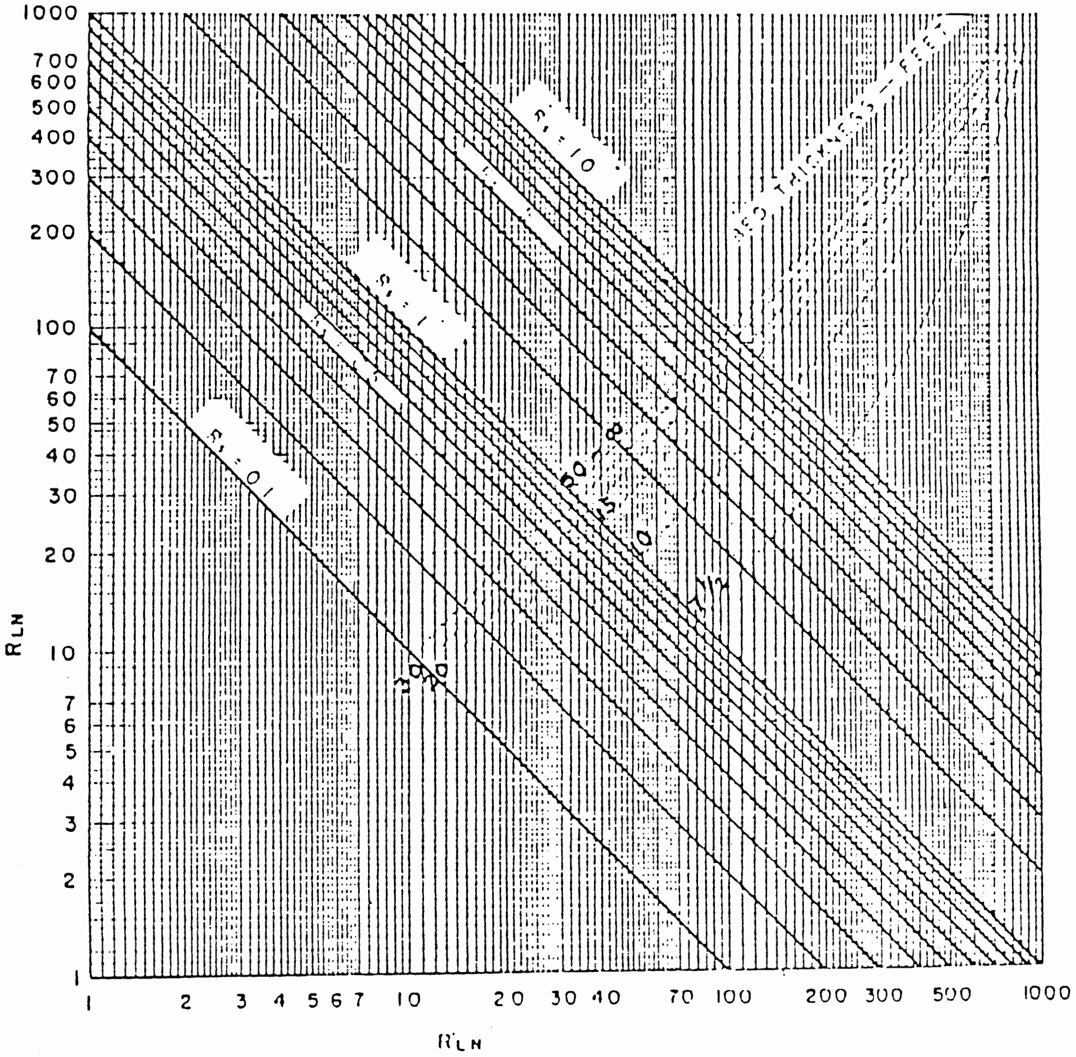


LANE-WELLS

RESISTIVITY DEPARTURE CURVES

(LONG NORMAL)

May 1956

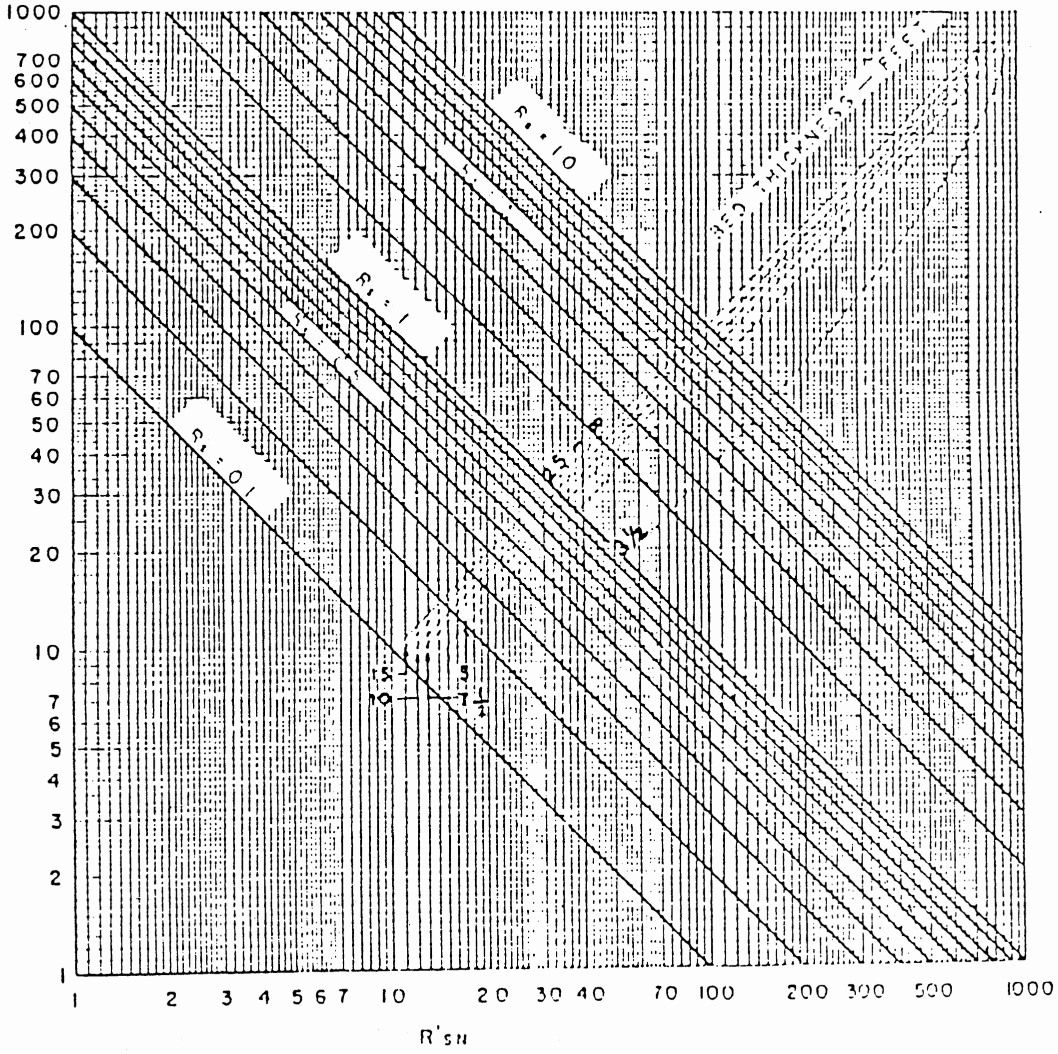


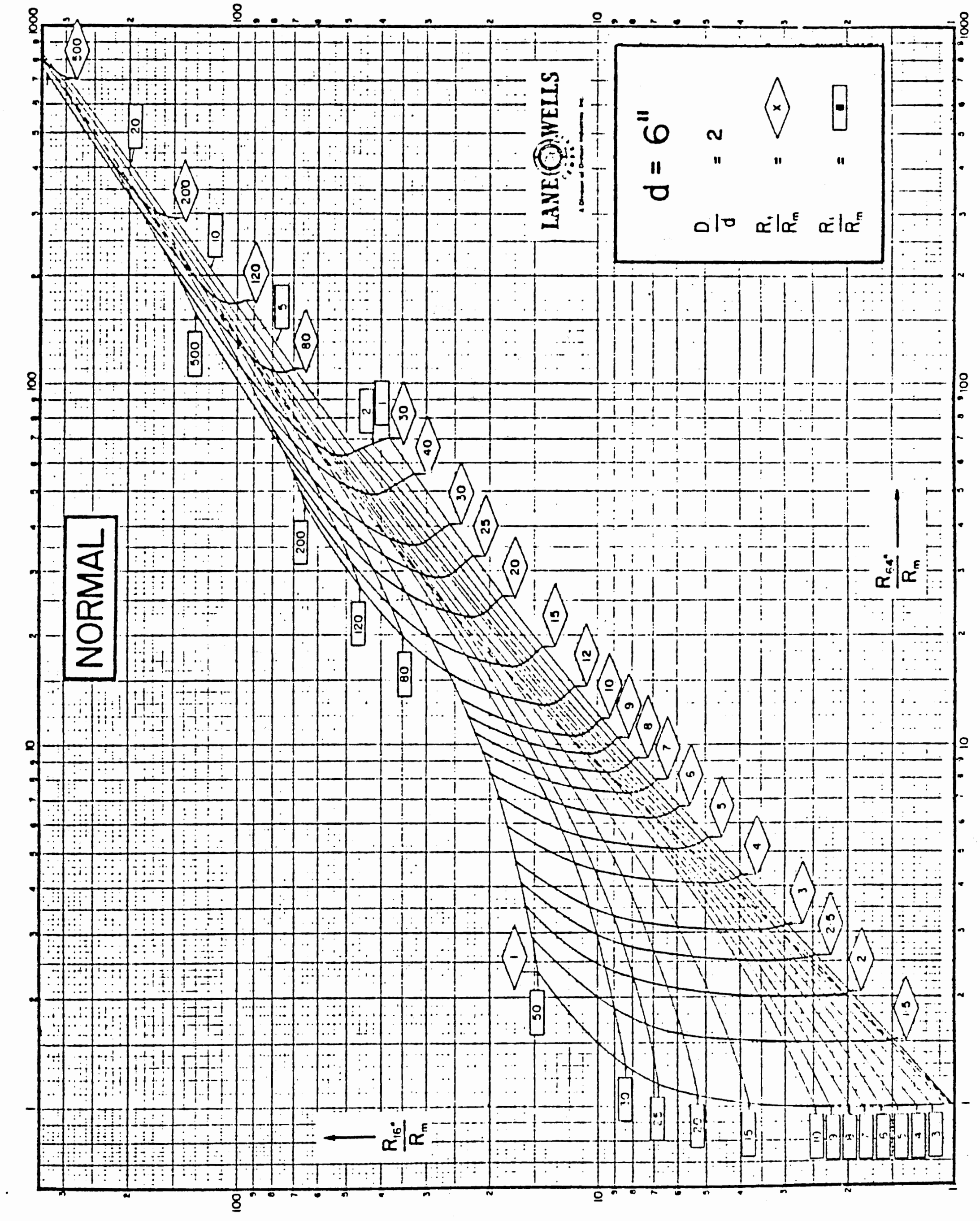
LANE-WELLS

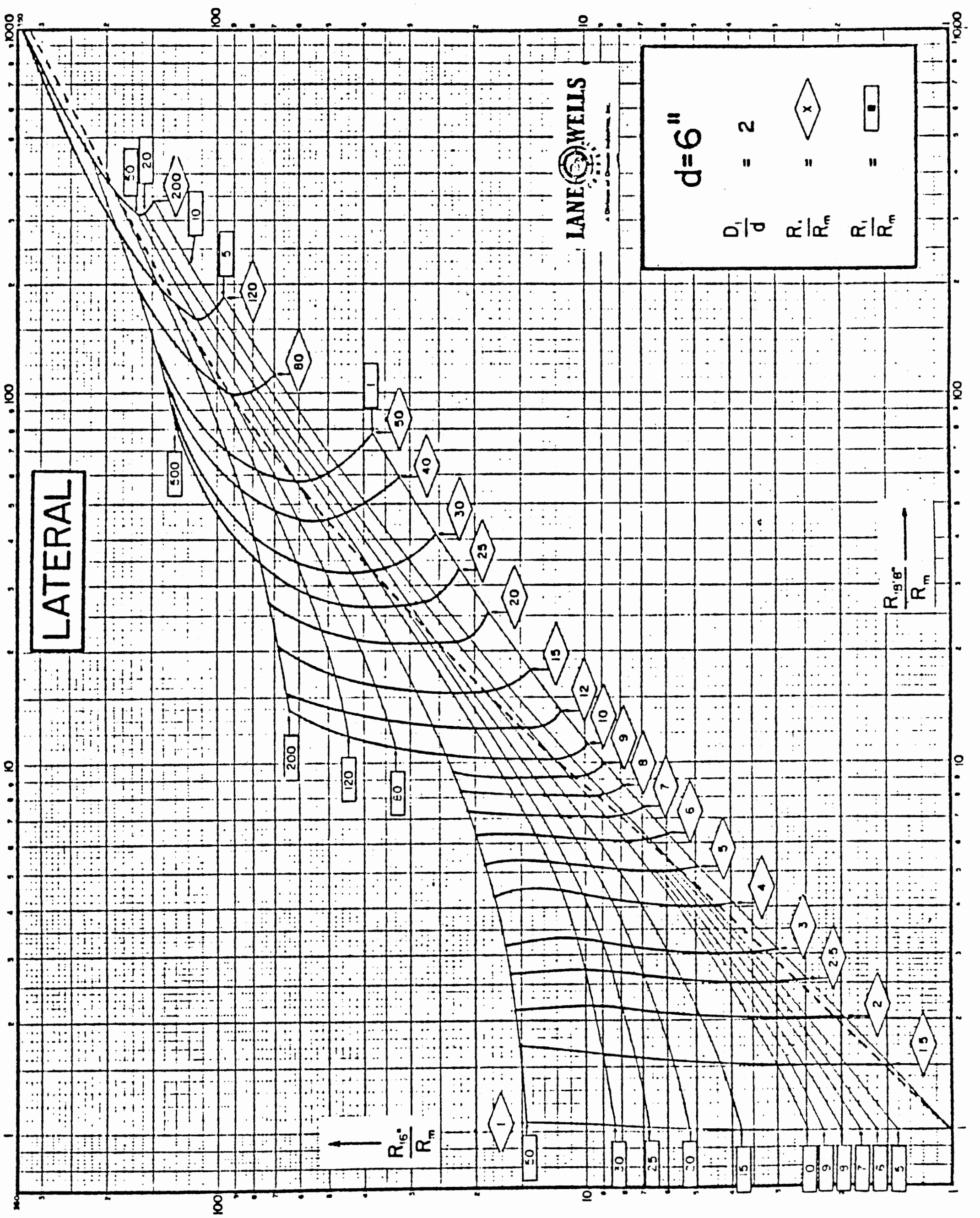
RESISTIVITY DEPARTURE CURVES

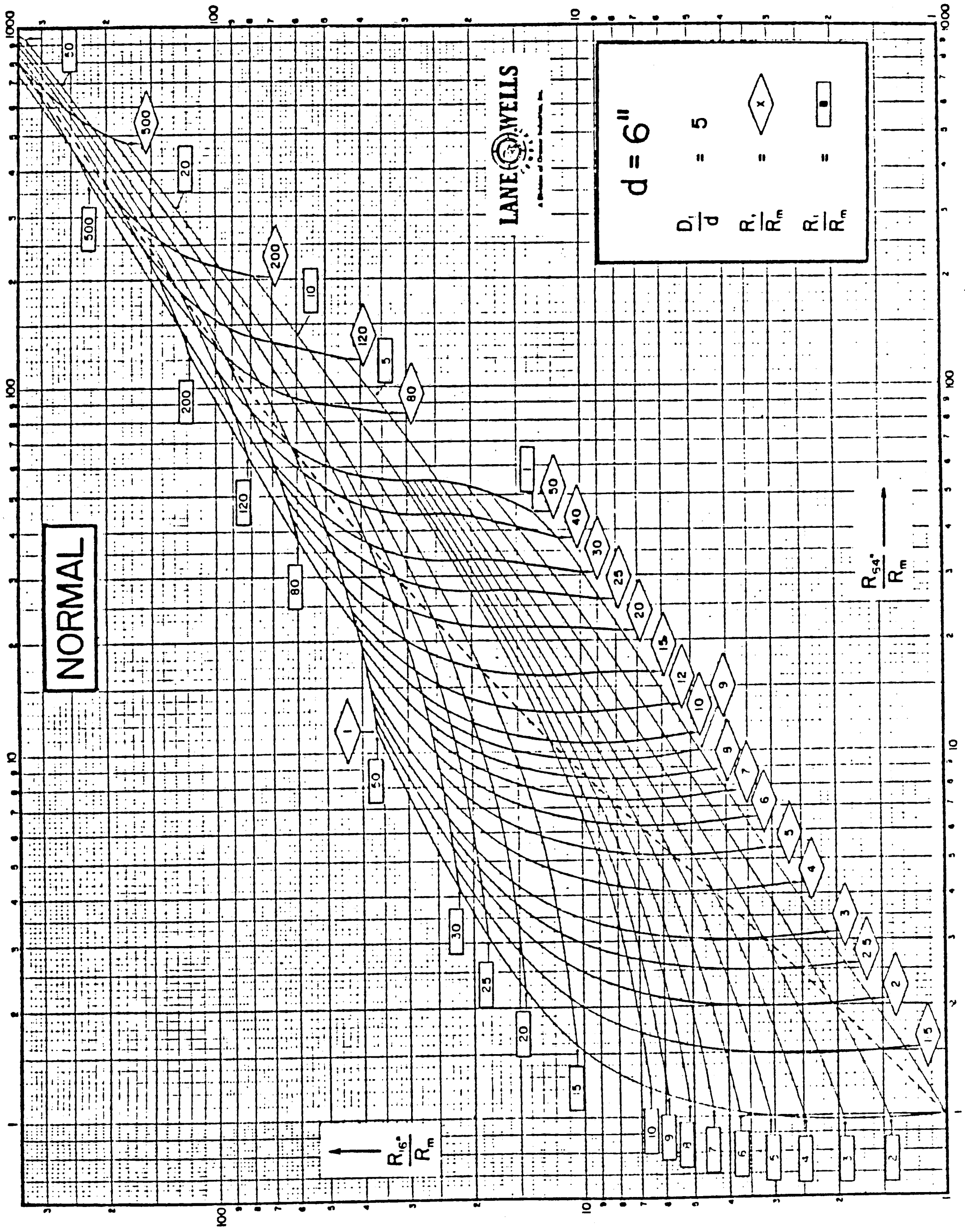
(SHORT NORMAL)

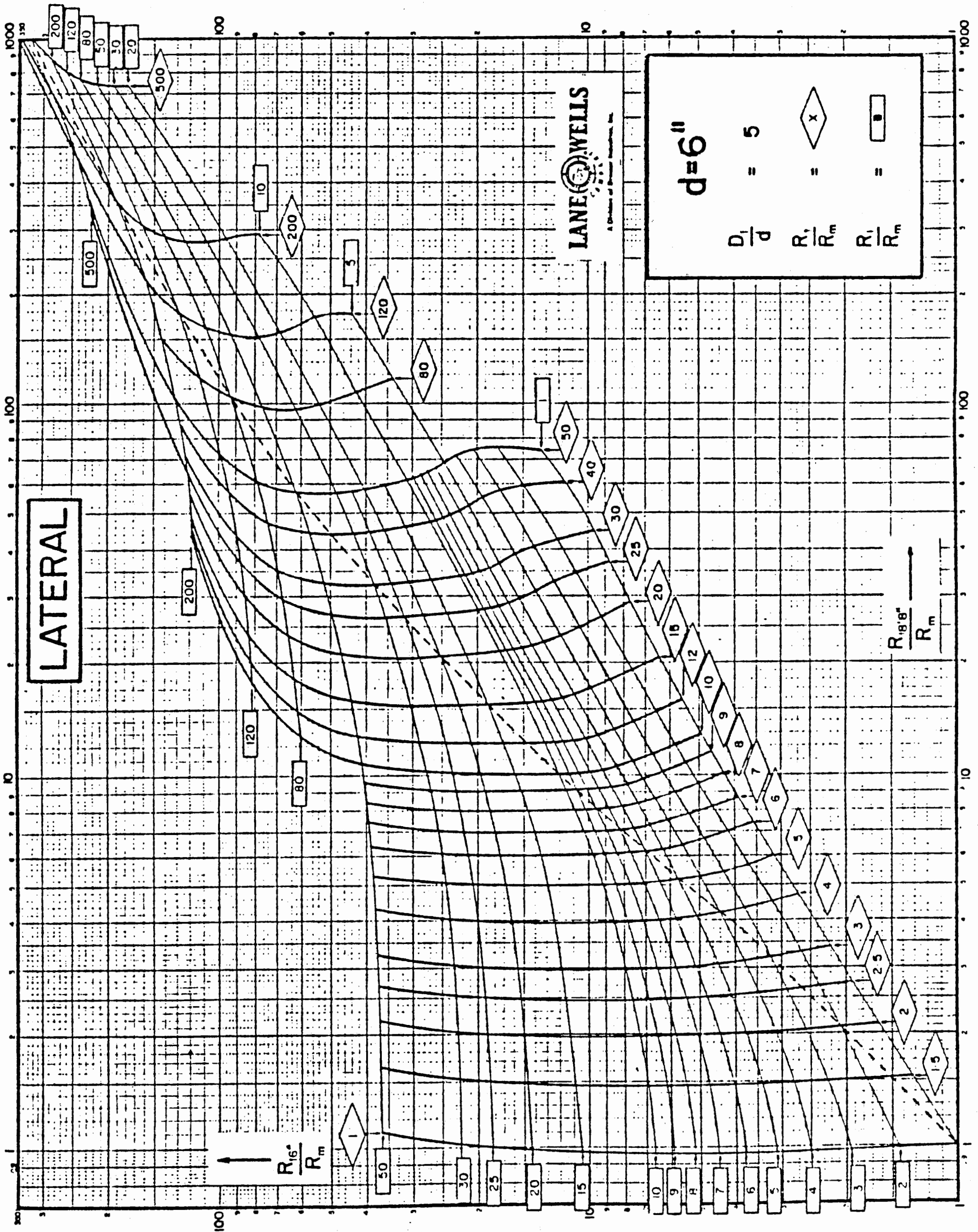
May 1956

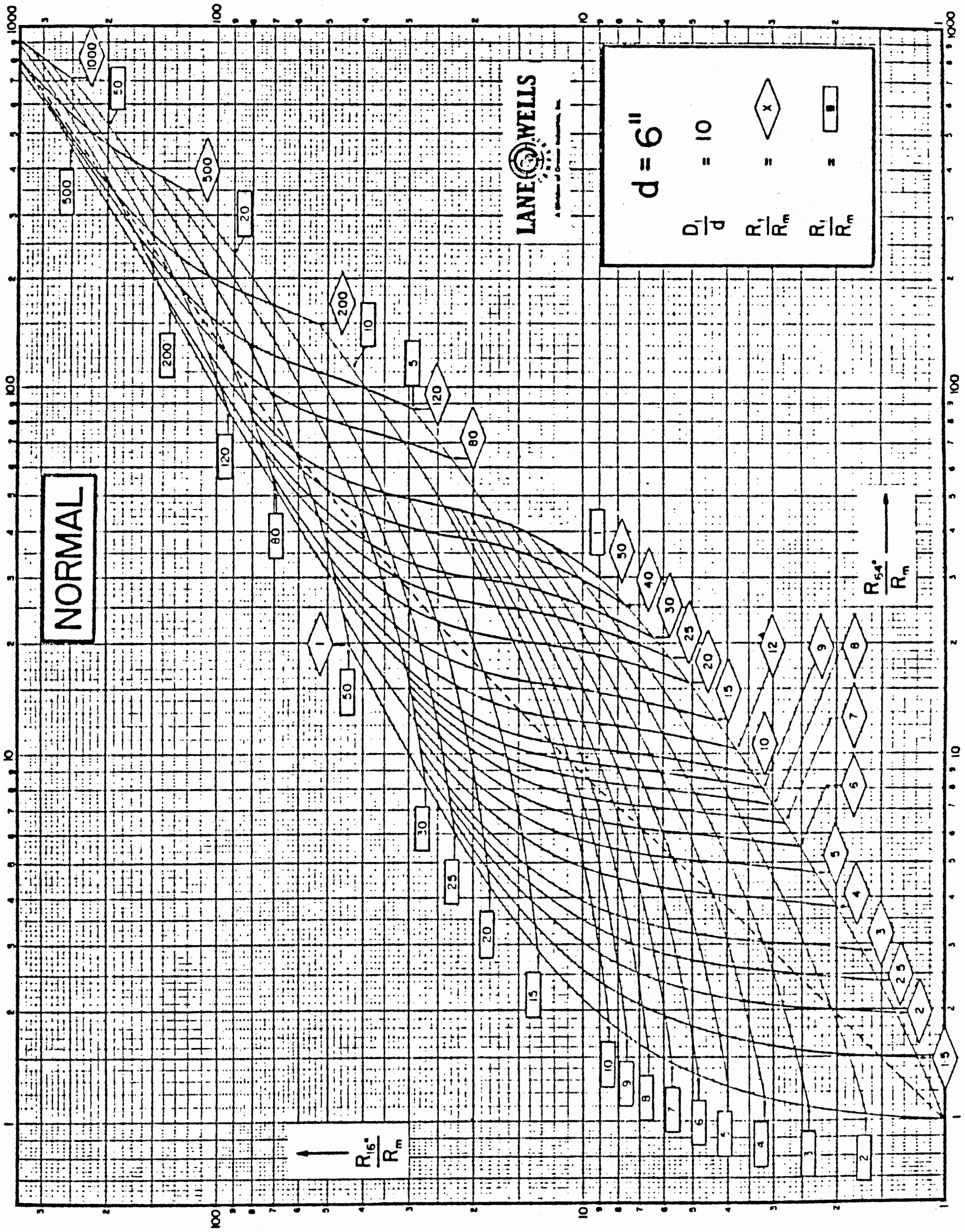


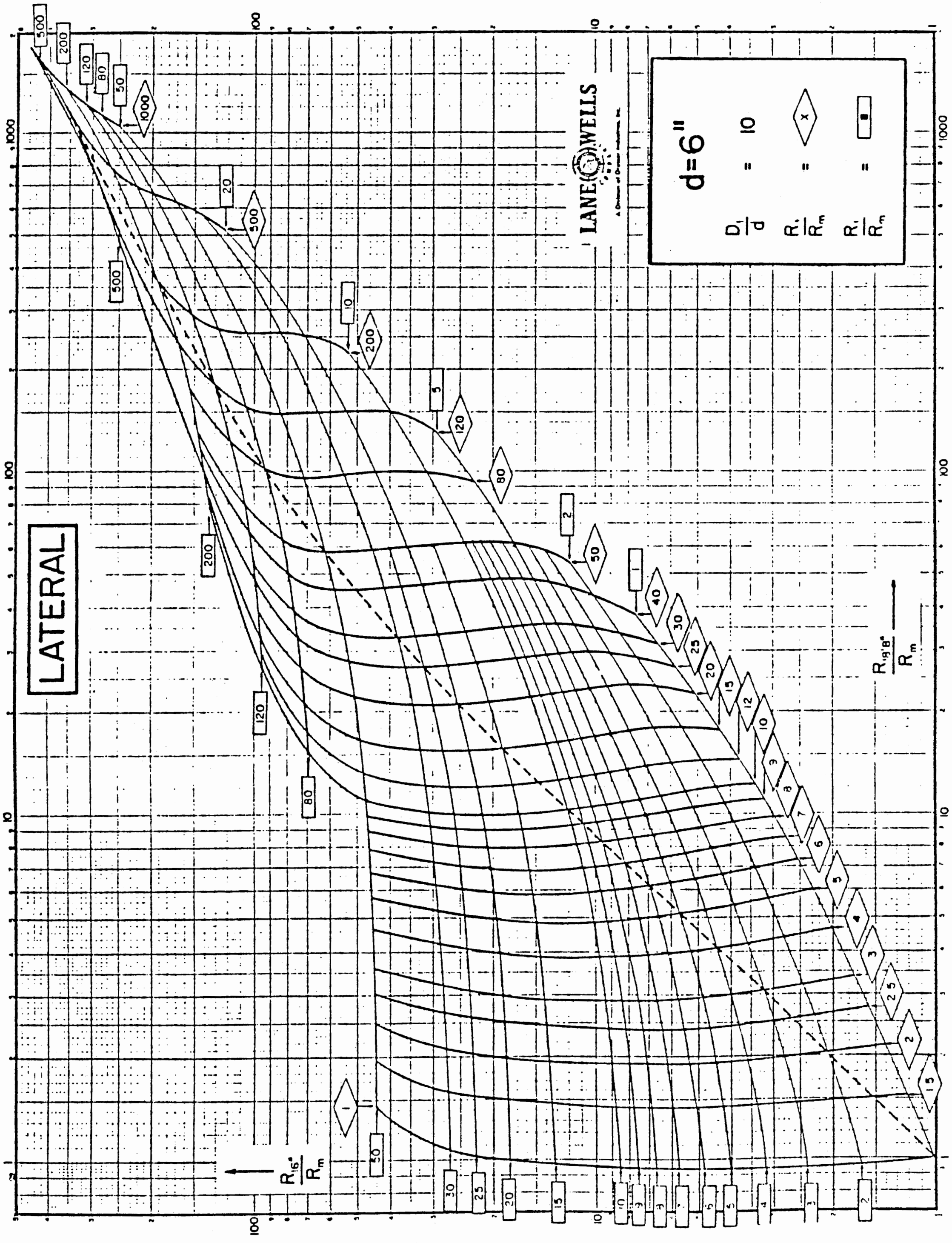

NORMAL
LANE-WELLS
d = 6"
D/d = 2
R_t/R_m = x
R_t/R_m = ■
$R_{16"}/R_m$
$R_{64"}/R_m$
1
10
100
1000
500
200
120
80
30
40
30
25
20
15
12
10
9
8
7
6
5
4
3
2.5
2
1.5
1
20
10
5
2
1
500
200
120
80
50
30
25
20
15
10
9
8
7
6
5
4
3

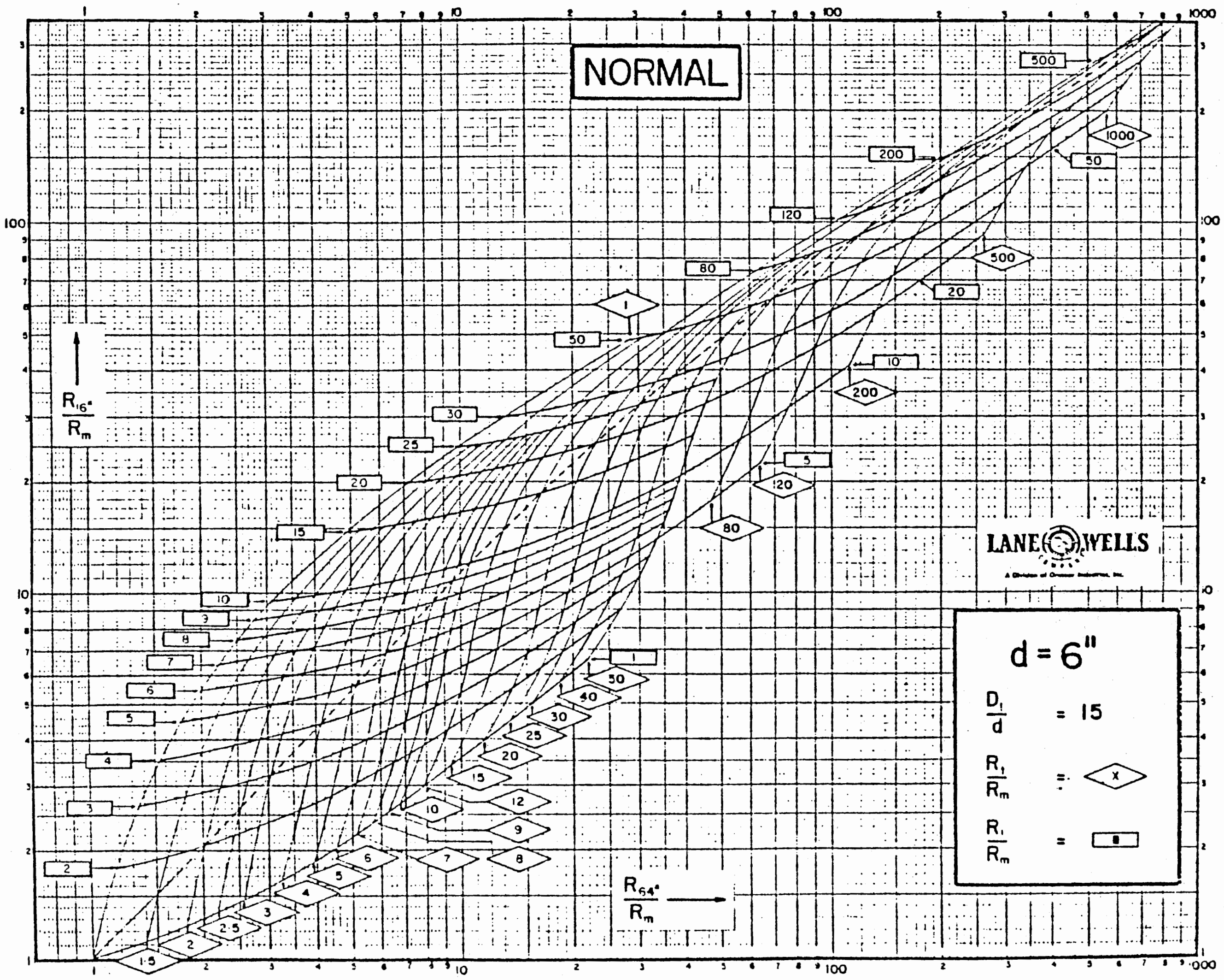

LATERAL
LANE WELLS
d=6"
$\frac{D_i}{d}$ = 2
$\frac{R_i}{R_m}$ = x
$\frac{R_t}{R_m}$ =
$\frac{R_{16"}}{R_m}$
$\frac{R_{18'8"}}{R_m}$
1
10
100
1000
50
20
200
10
5
120
80
1
50
40
30
25
20
15
12
10
9
8
7
6
5
4
3
2.5
2
1.5
1
500
200
120
80
50
30
25
20
15
10
9
7
6
5

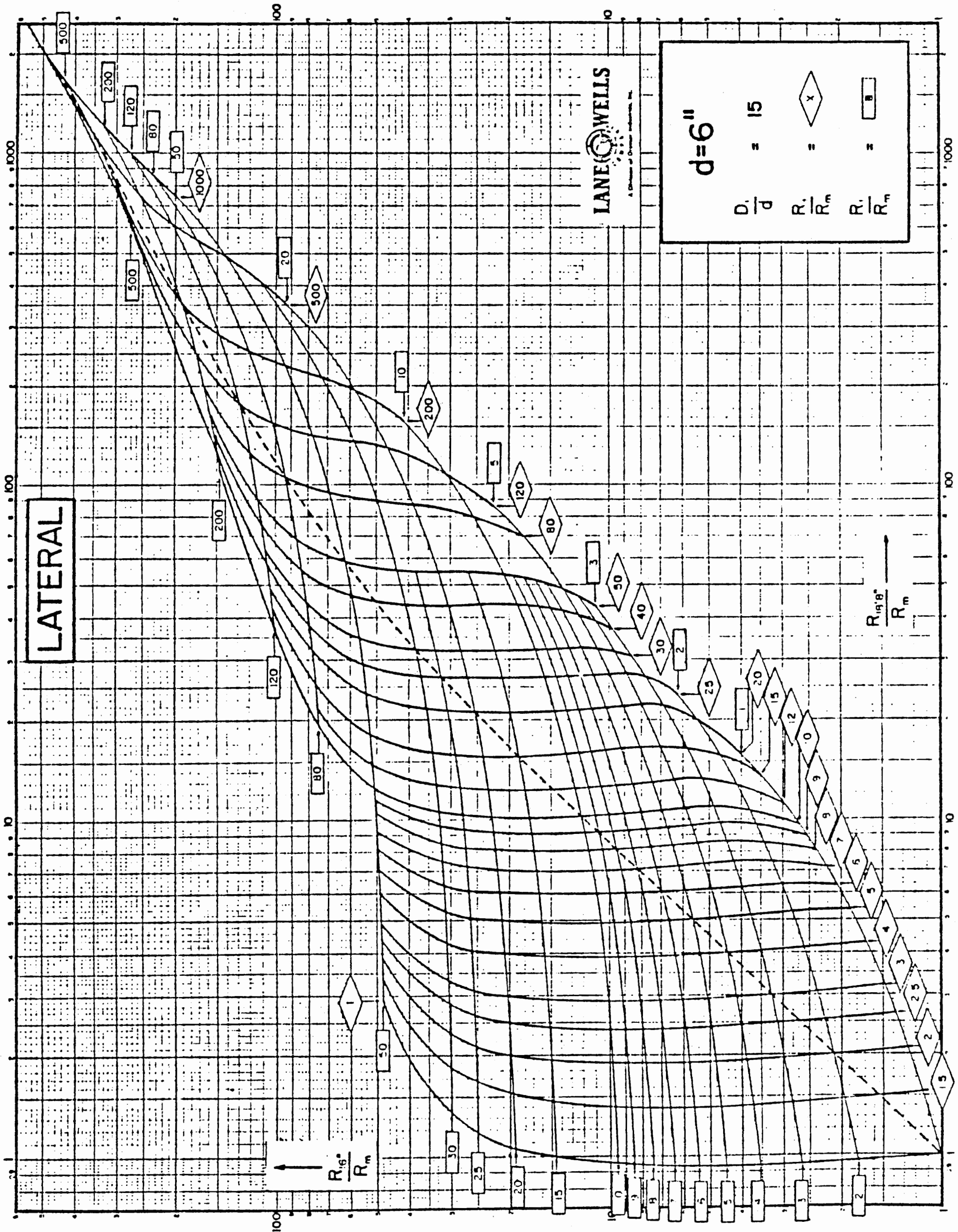

NORMAL
LANE-WELLS
d = 6"
$\frac{D_i}{d}$ = 5
$\frac{R_i}{R_m}$ = ◇
$\frac{R_i}{R_m}$ = ▪
$\frac{R_{16"}}{R_m}$
$\frac{R_{54"}}{R_m}$
1
10
100
1000
500
200
120
80
50
40
30
25
20
15
12
10
9
8
7
6
5
4
3
2.5
2
1.5
1

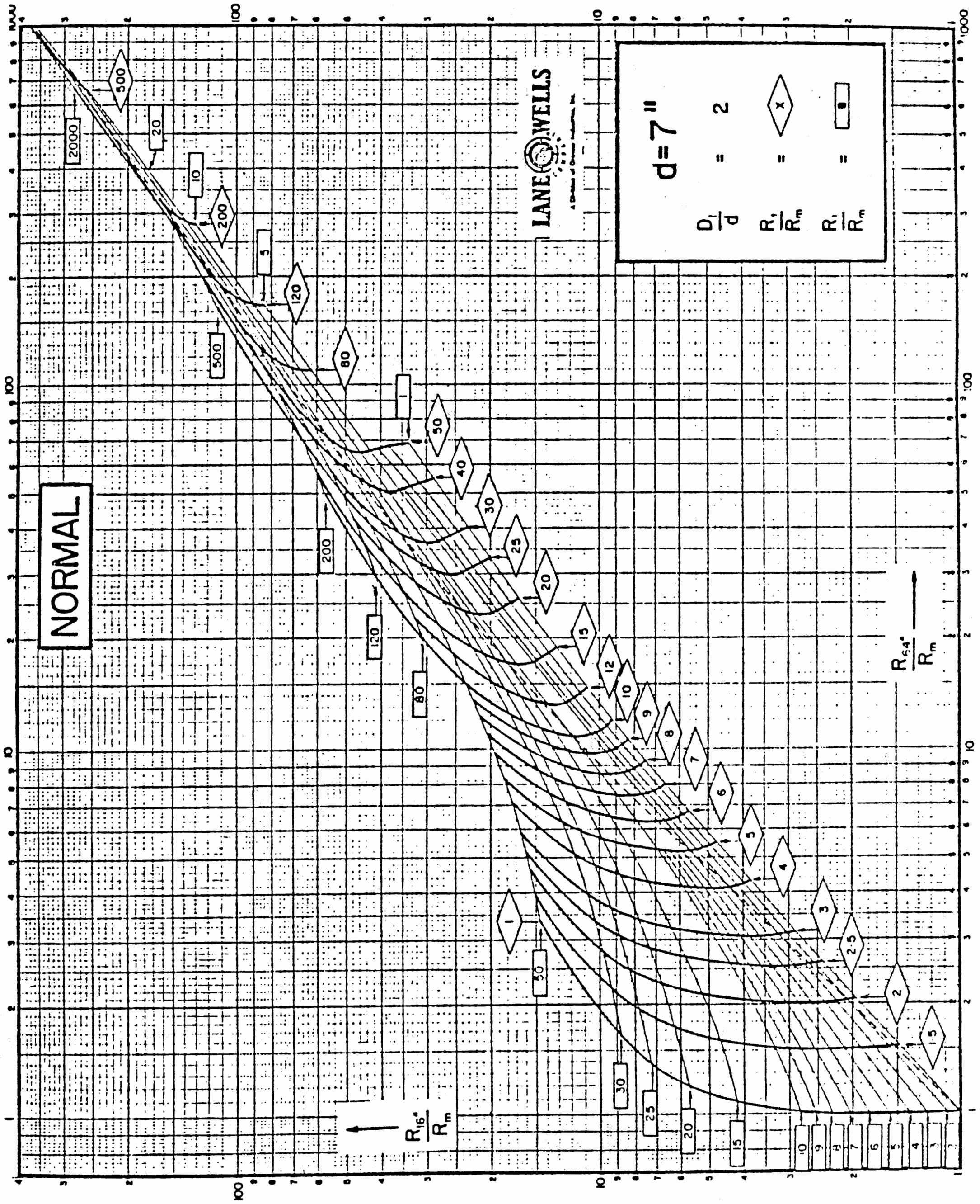

LATERAL
LANE WELLS
d=6"
D_i/d = 5
R_i/R_m = ◇
R_i/R_m = ▭
R_16"/R_m
R_18'8"/R_m
1000
100
10
1
200
120
80
50
30
20
500
10
200
5
120
80
1
50
40
30
25
20
15
12
10
9
8
7
6
5
4
3
2.5
2
1.5
500
200
120
80
50
30
25
20
15
10
9
8
7
6
5
4
3
2

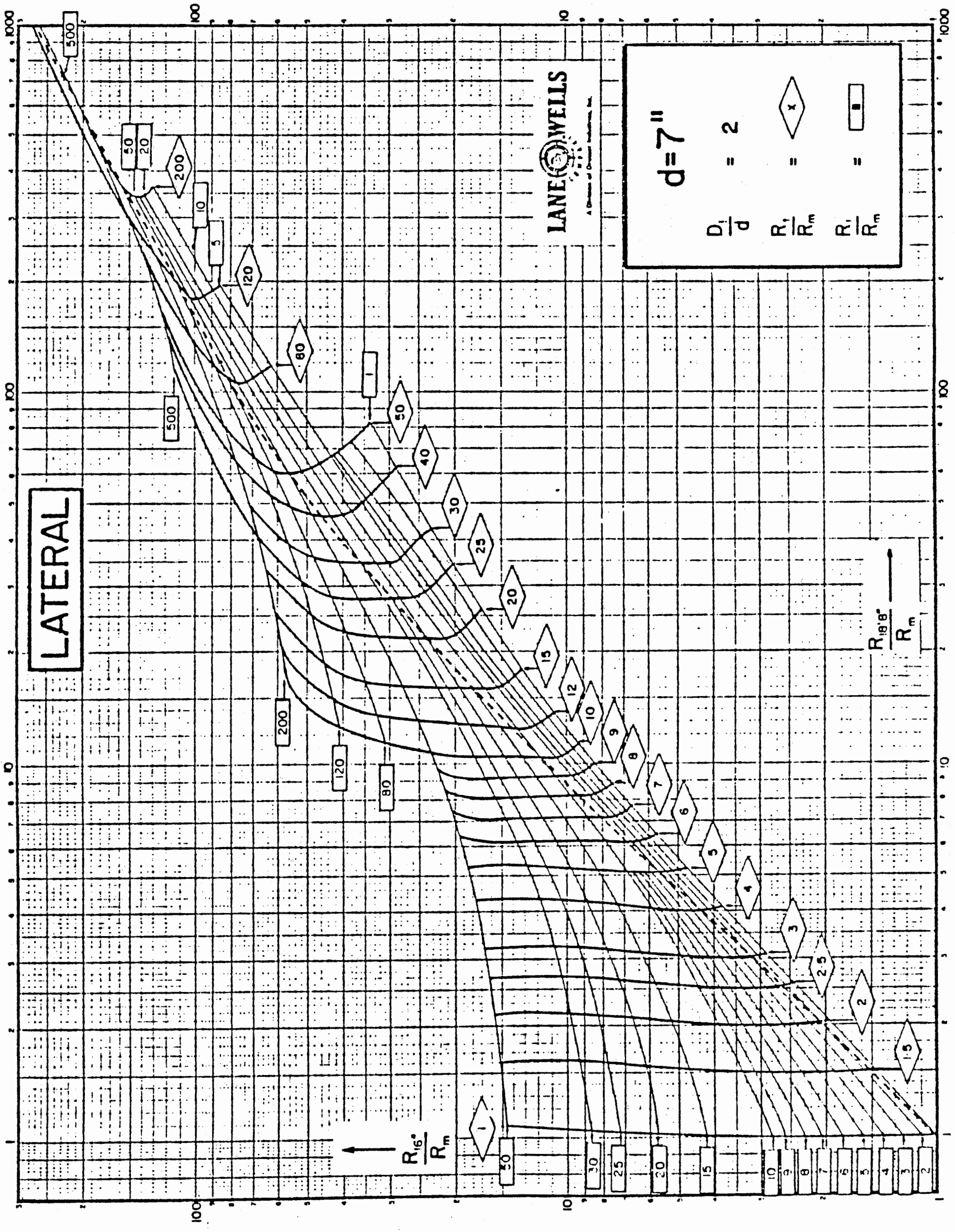

NORMAL
LANE-WELLS
d = 6"
$\frac{D_i}{d}$ = 10
$\frac{R_t}{R_m}$ = ◇
$\frac{R_i}{R_m}$ = ▭
$\frac{R_{16"}}{R_m}$
$\frac{R_{64"}}{R_m}$
1
10
100
1000
1000
500
200
120
80
50
40
30
25
20
15
12
10
9
8
7
6
5
4
3
2.5
2
1.5
1
50
20
10
5
1
500
200
120
80
50
30
25
20
15
10
9
8
7
6
5
4
3
2

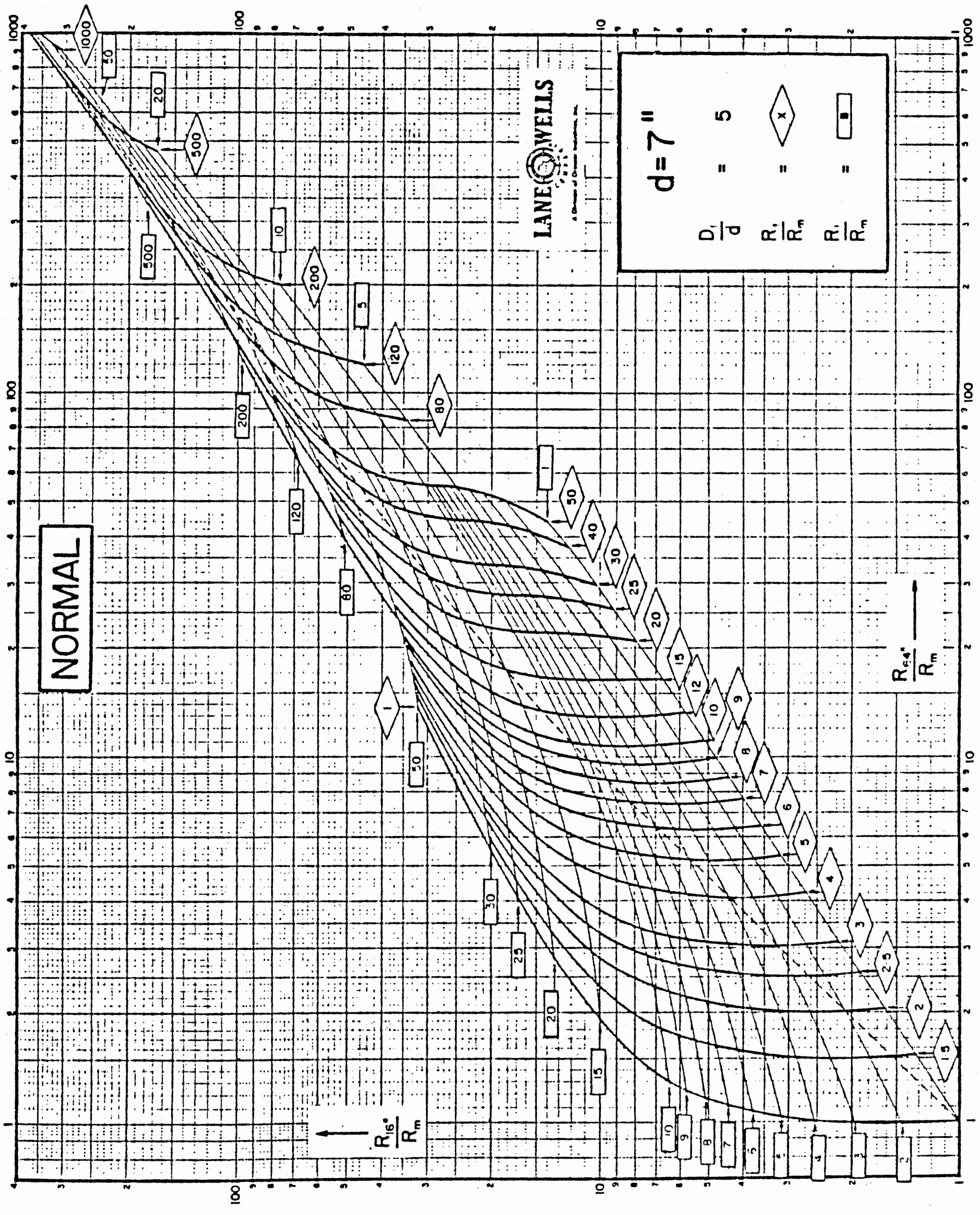

LATERAL
LANE-WELLS
d=6"
D_i/d = 10
R_i/R_m = ◇x
R_t/R_m = ■
$R_{16"}/R_m$
$R_{18'8"}/R_m$
1
10
100
1000
500
200
120
80
50
1000
20
10
5
2
1
40
30
25
15
12
9
8
7
6
4
3
2.5
1.5

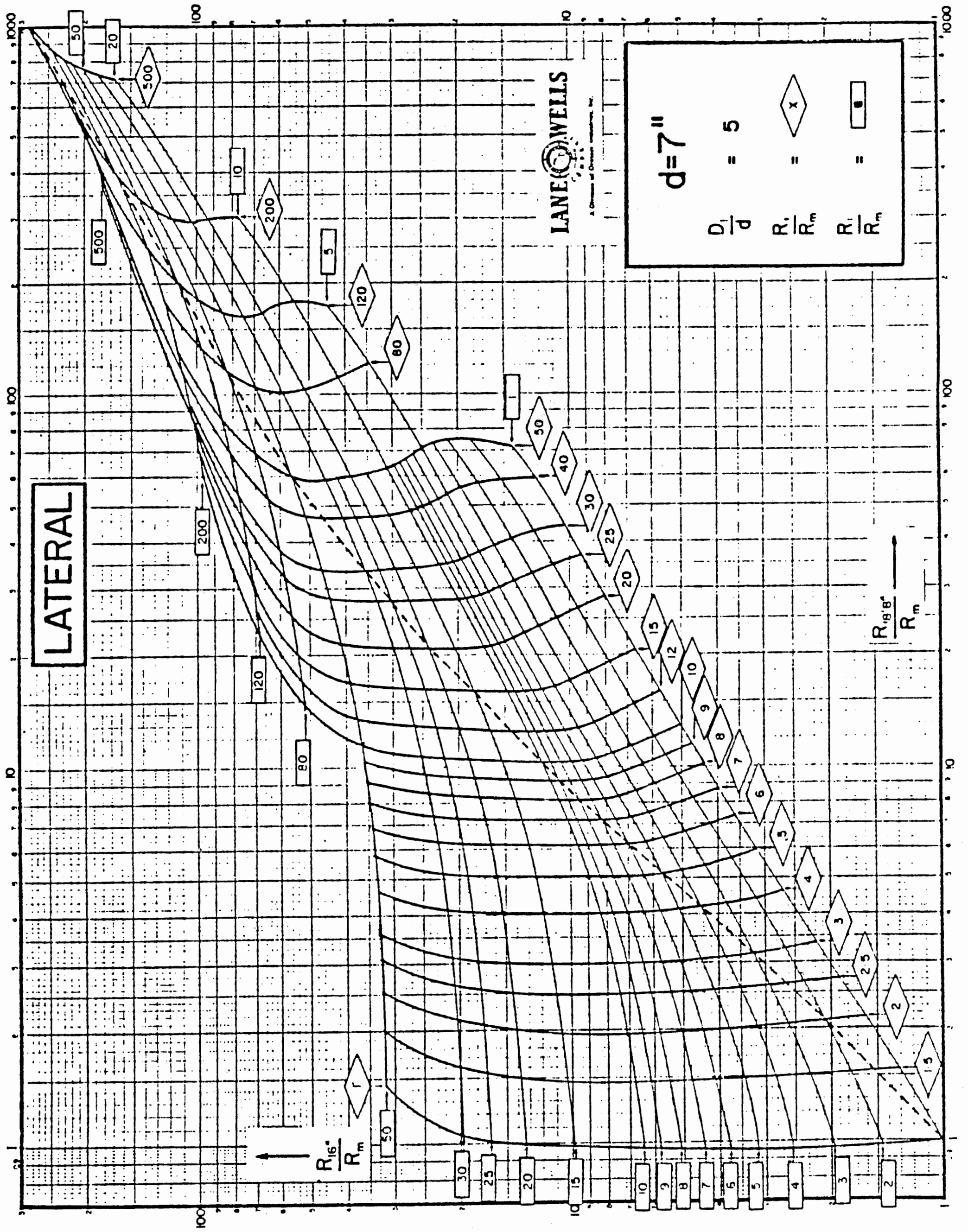

NORMAL
d = 6"
$\frac{D_i}{d}$ = 15
$\frac{R_t}{R_m}$ = X
$\frac{R_i}{R_m}$ =
LANE WELLS
$\frac{R_{16"}}{R_m}$
$\frac{R_{64"}}{R_m}$
500
200
120
80
50
30
25
20
15
10
9
8
7
6
5
4
3
2
1000
500
200
120
80
50
40
30
25
20
15
12
10
9
8
7
6
5
4
3
2.5
2
1.5
1
1
10
100
1000

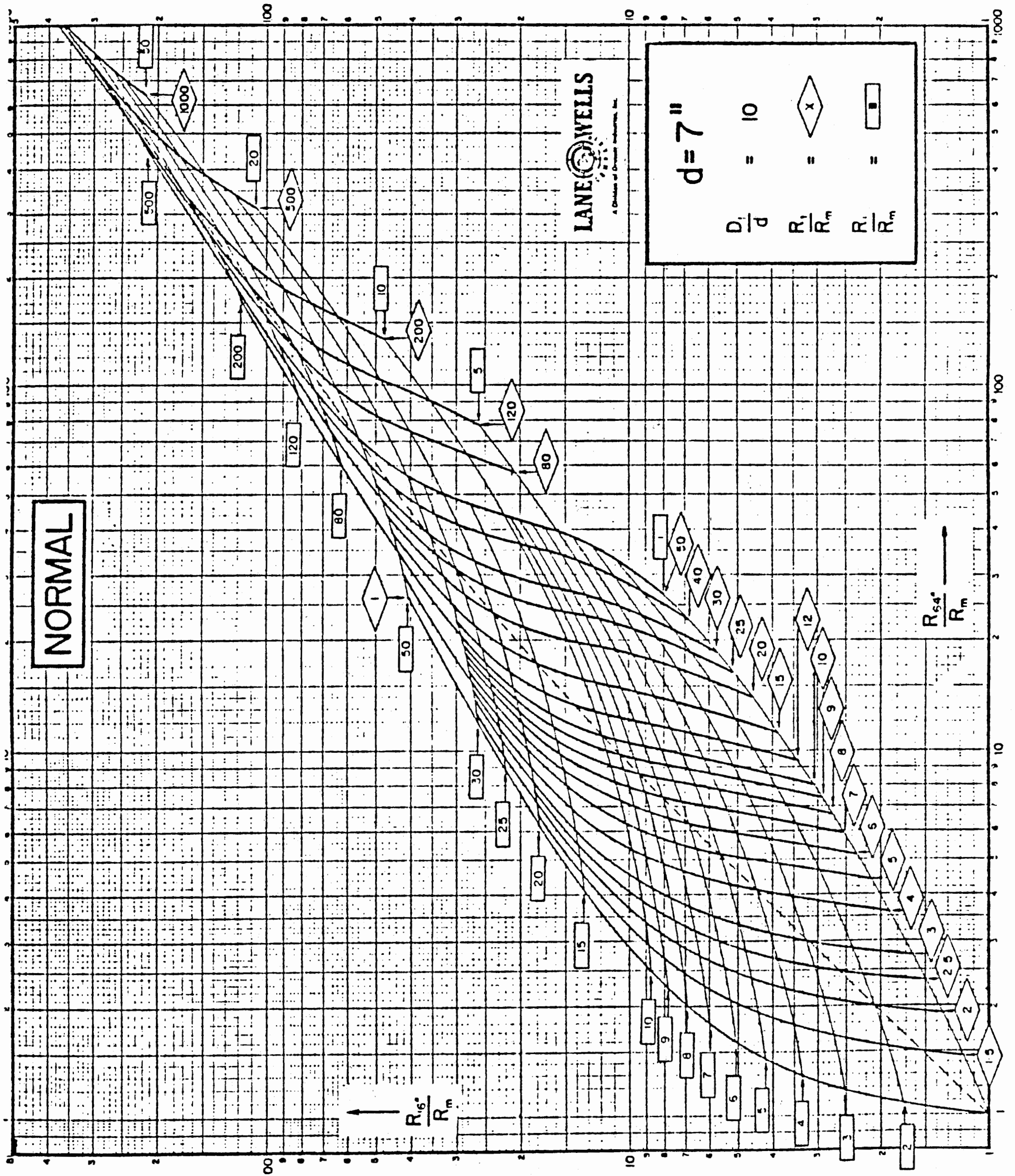

LATERAL
LANE-WELLS
d=6"
D_i/d = 15
R_i/R_m = ◇x
R_i/R_m = ▭B
R_16"/R_m
R_18'8"/R_m
1000
100
10
1

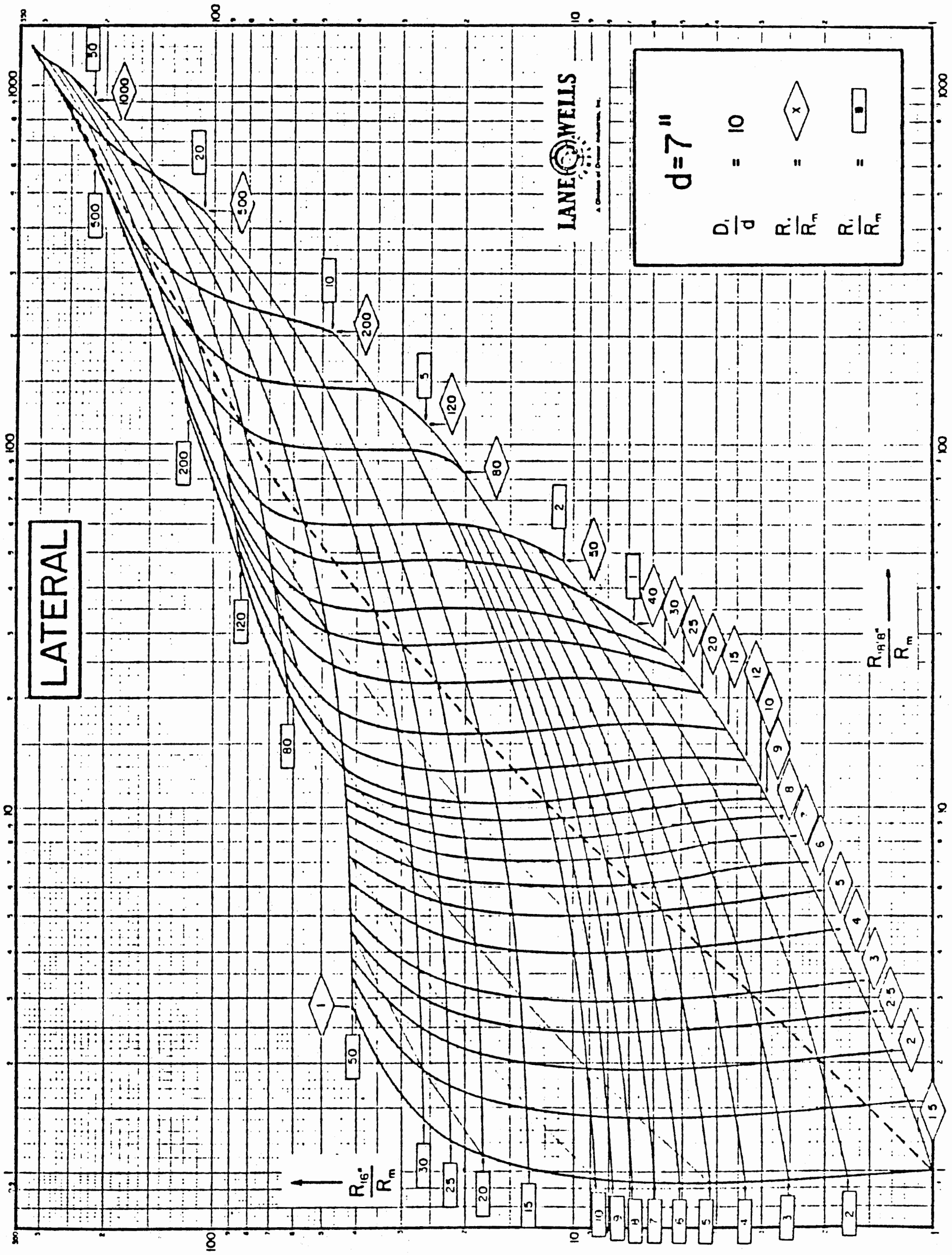

NORMAL
LANE WELLS
d=7"
$\frac{D_i}{d}$ = 2
$\frac{R_i}{R_m}$ = ◇x
$\frac{R_i}{R_m}$ = ▭
$\frac{R_{16"}}{R_m}$
$\frac{R_{64"}}{R_m}$
1
10
100
1000
500
200
120
80
50
40
30
25
20
15
12
10
9
8
7
6
5
4
3
2.5
2
1.5
2000
500
200
120
80
50
30
25
20
15
10
5
1

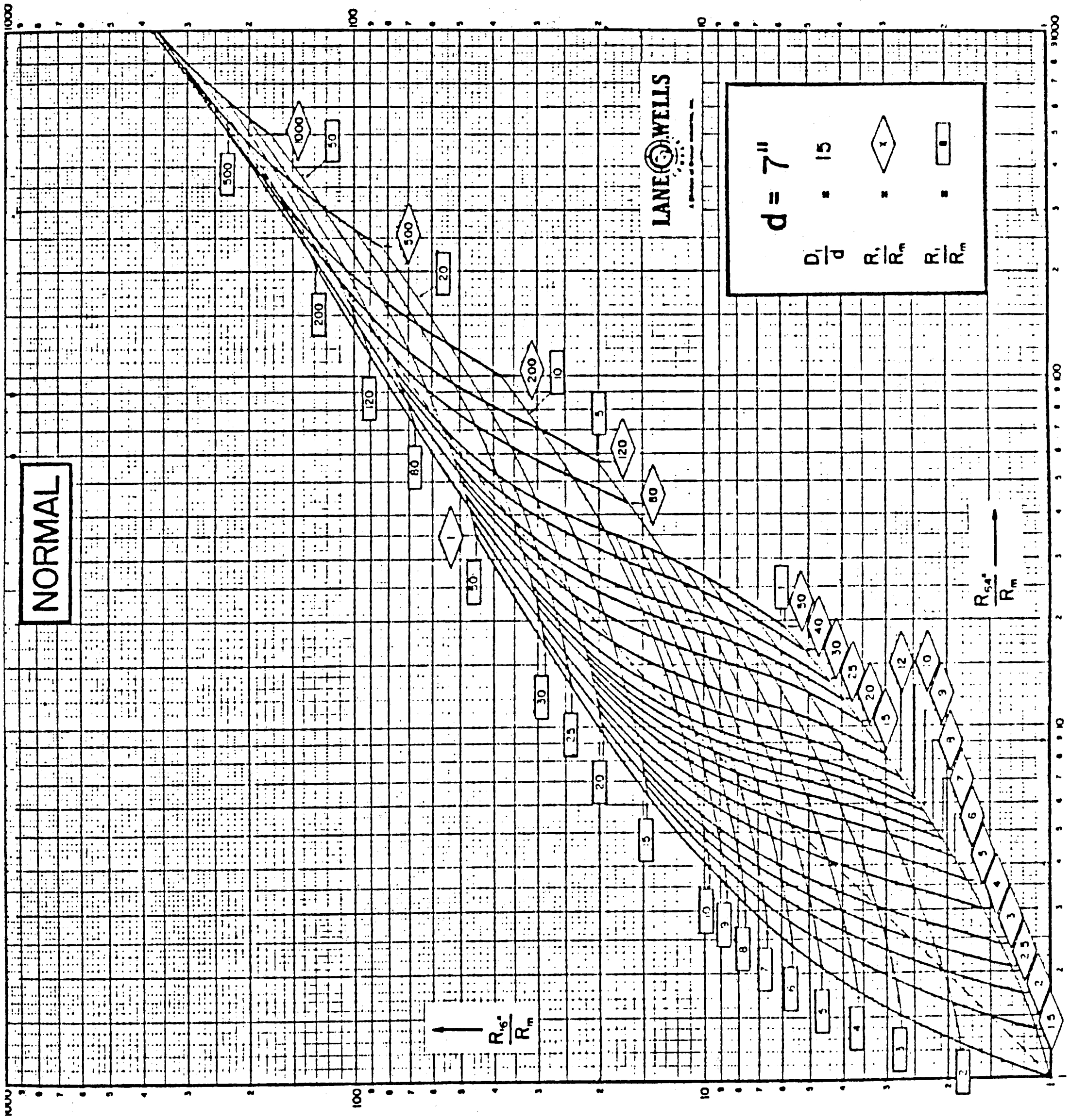

LATERAL
LANE WELLS
A Division of Dresser Industries, Inc.
d=7"
$\frac{D_i}{d}$ = 2
$\frac{R_t}{R_m}$ = ◇
$\frac{R_i}{R_m}$ = ▭
$\frac{R_{16"}}{R_m}$
$\frac{R_{18'8"}}{R_m}$
500
50
20
200
10
5
120
80
1
50
40
30
25
20
15
12
10
9
8
7
6
5
4
3
2.5
2
1.5
1
500
200
120
80
50
30
25
20
15
10
9
8
7
6
5
4
3
2
1
10
100
1000

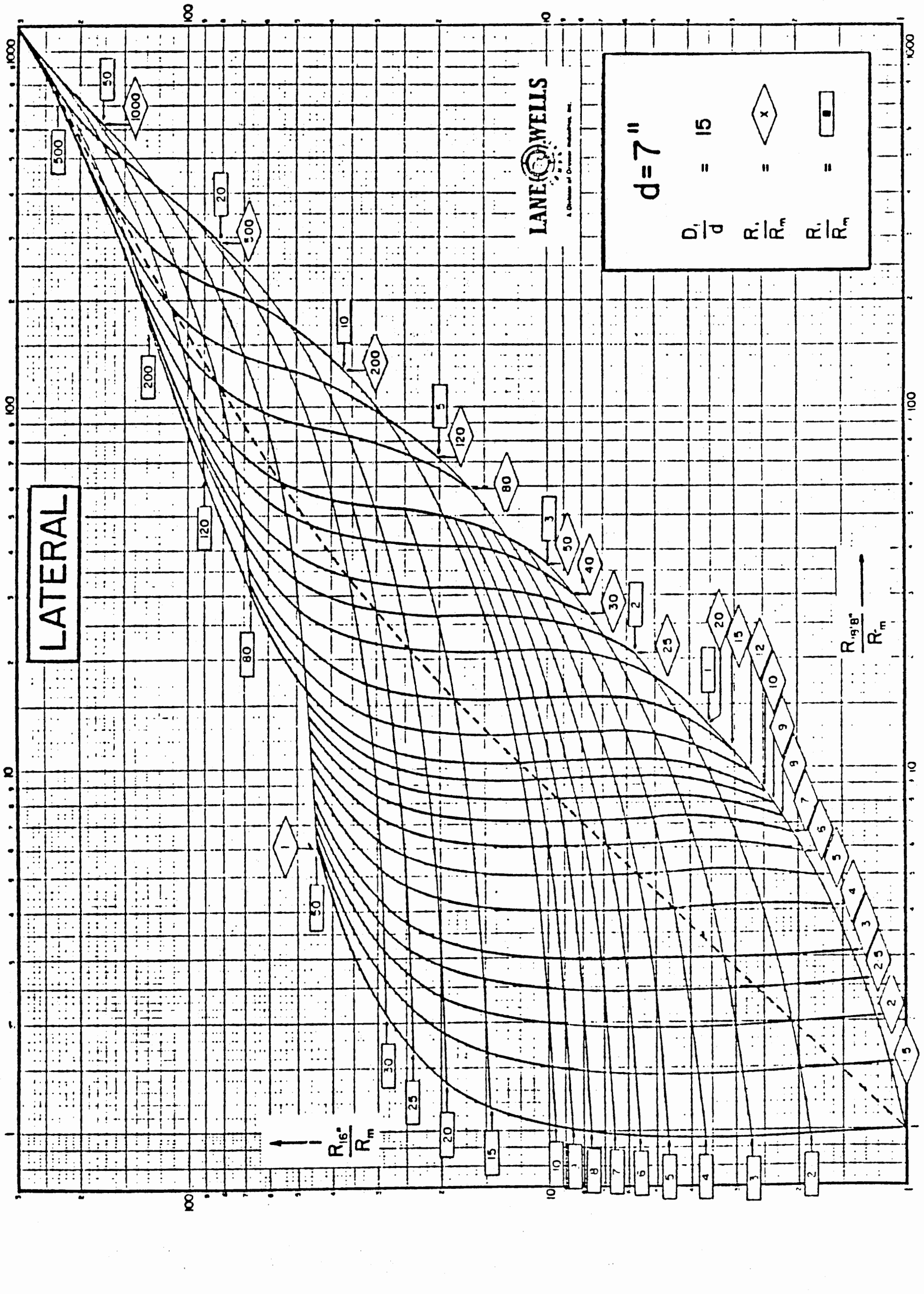

NORMAL
LANE-WELLS
d = 7"
D_i/d = 5
R_i/R_m = ◇
R_t/R_m = ▭
R16"/Rm
R64"/Rm
1000
100
10
1
1000
50
20
500
500
10
200
5
120
200
80
1
120
50
40
30
80
25
20
15
12
1
9
10
50
8
7
6
5
4
3
2.5
2
1.5
30
25
20
15
10
9
8
7
5
4
3
2

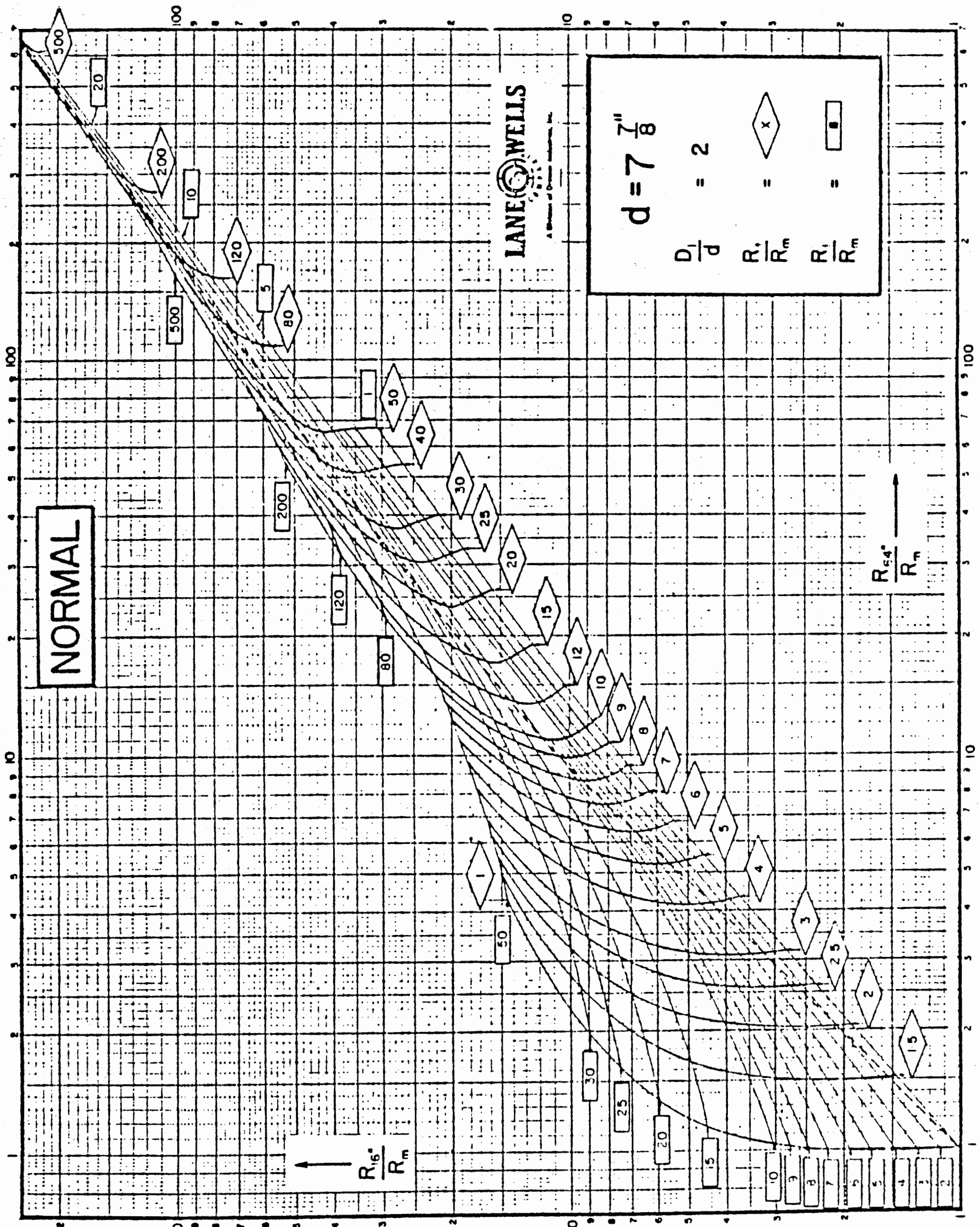

LATERAL
LANE WELLS
d=7"
$\frac{D_i}{d}$ = 5
$\frac{R_i}{R_m}$ = x
$\frac{R_i}{R_m}$ = ■
$\frac{R_{16"}}{R_m}$
$\frac{R_{18'8"}}{R_m}$
1
10
100
1000
500
200
120
80
50
40
30
25
20
15
12
10
9
8
7
6
5
4
3
2.5
2
1.5
r

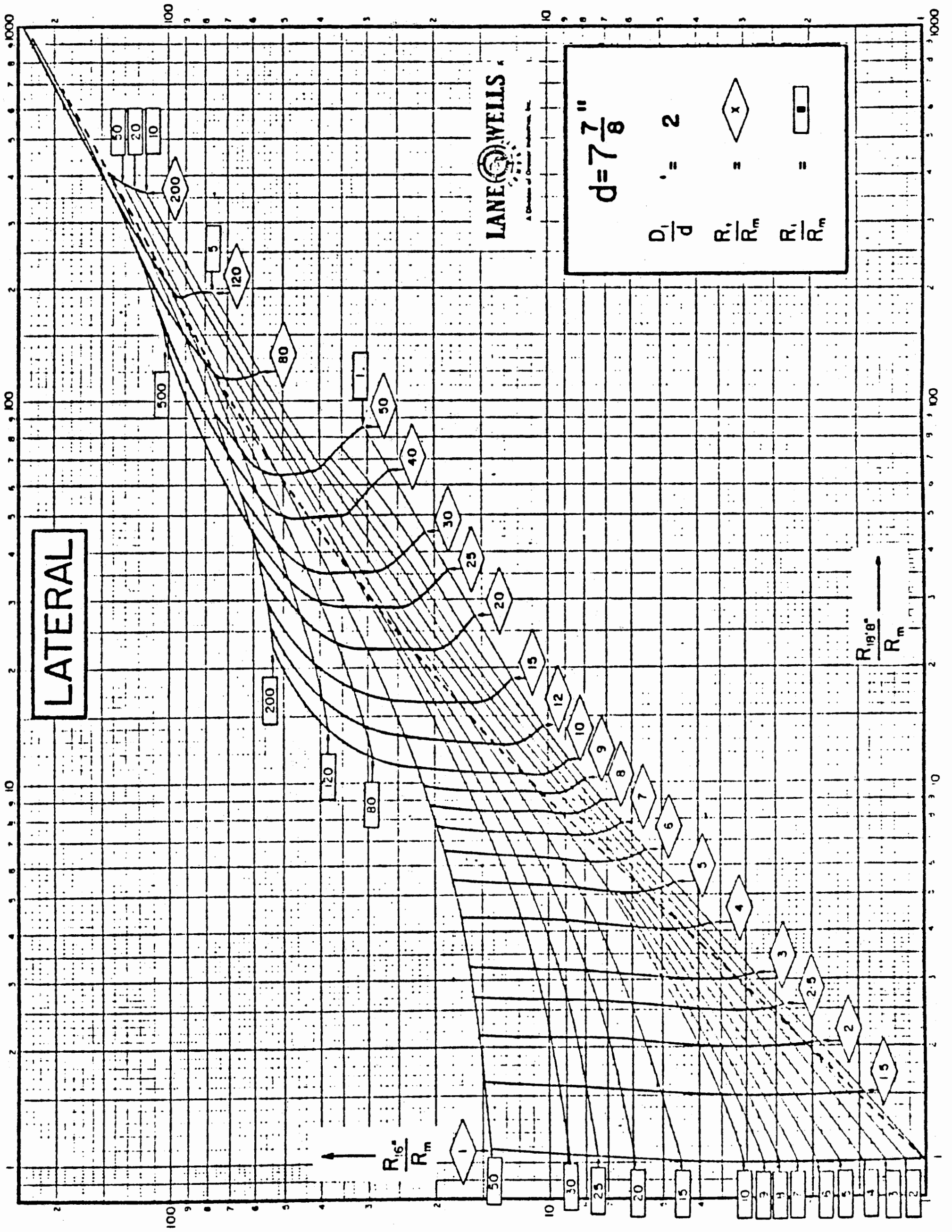

NORMAL
LANE-WELLS
A Division of Dresser Industries, Inc.
d = 7"
D_i/d = 10
R_t/R_m = ◇
R_i/R_m = ▭
$R_{16"}/R_m$
$R_{64"}/R_m$
1000
500
200
120
80
50
40
30
25
20
15
12
10
9
8
7
6
5
4
3
2.5
2
1.5
1
100
10

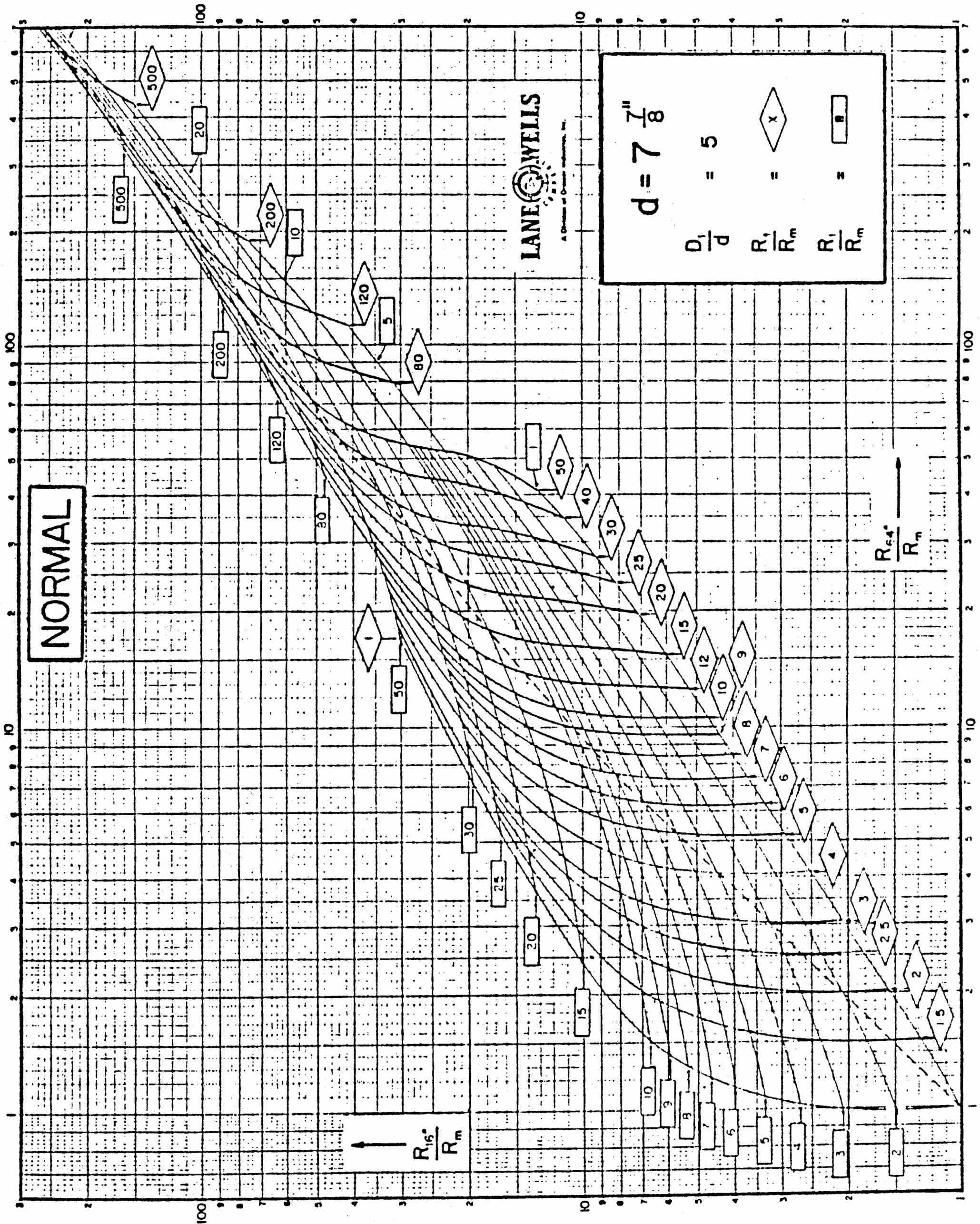

LATERAL
LANE WELLS
d=7"
$\frac{D_i}{d}$ = 10
$\frac{R_i}{R_m}$ =
$\frac{R_t}{R_m}$ =
$\frac{R_{16"}}{R_m}$
$\frac{R_{18'8"}}{R_m}$
1000
100
10
1
1000
500
200
120
80
50
40
30
25
20
15
12
10
9
8
7
6
5
4
3
2.5
2
1.5
1

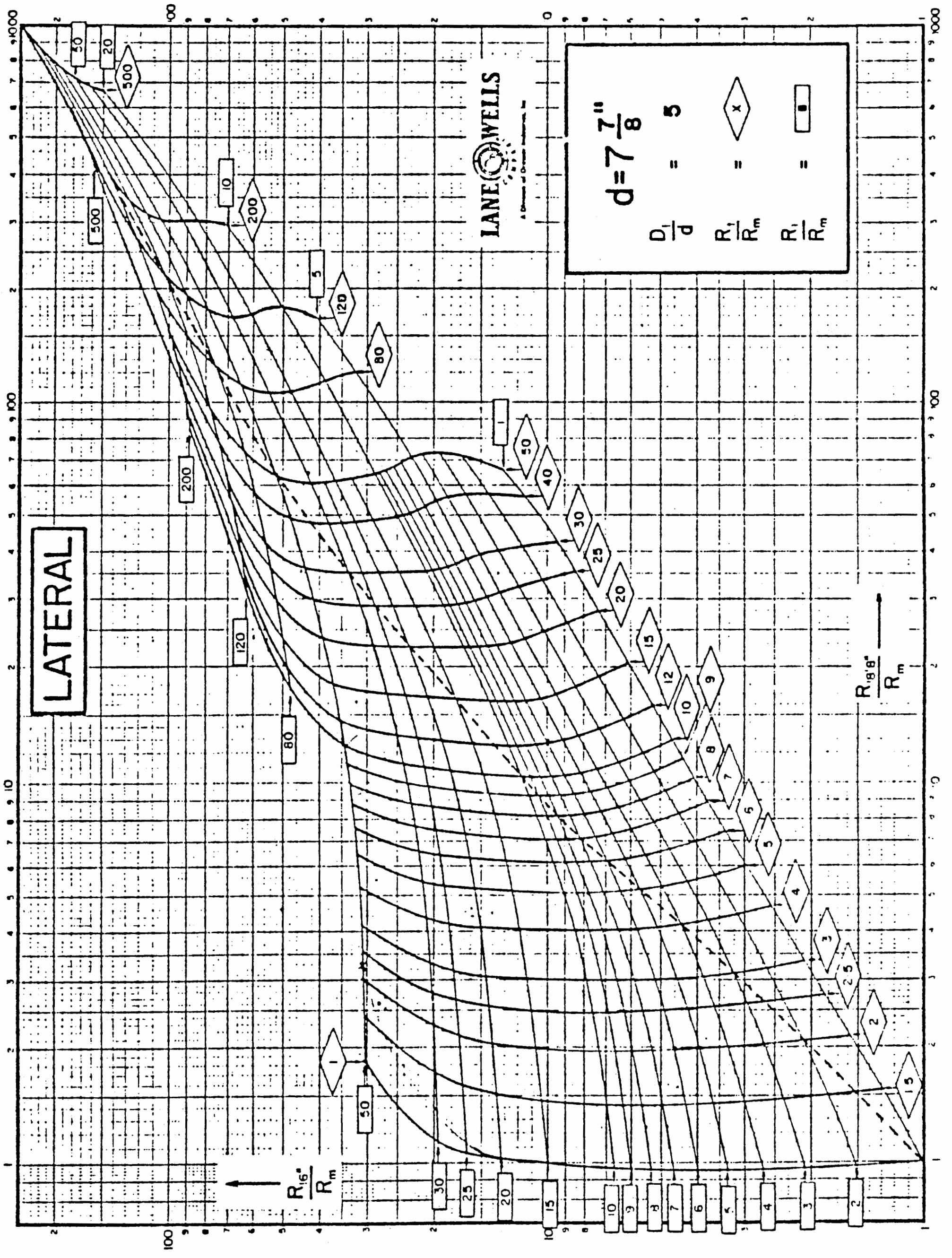

NORMAL
LANE-WELLS
d = 7"
$\frac{D_i}{d}$ = 15
$\frac{R_i}{R_m}$ = ◇
$\frac{R_t}{R_m}$ = ▭
$\frac{R_{16''}}{R_m}$
$\frac{R_{64''}}{R_m}$
1000
500
200
120
80
50
40
30
25
20
15
12
10
9
8
7
6
5
4
3
2.5
2
1.5
1
1
2
3
4
5
6
7
8
9
10
100
1000

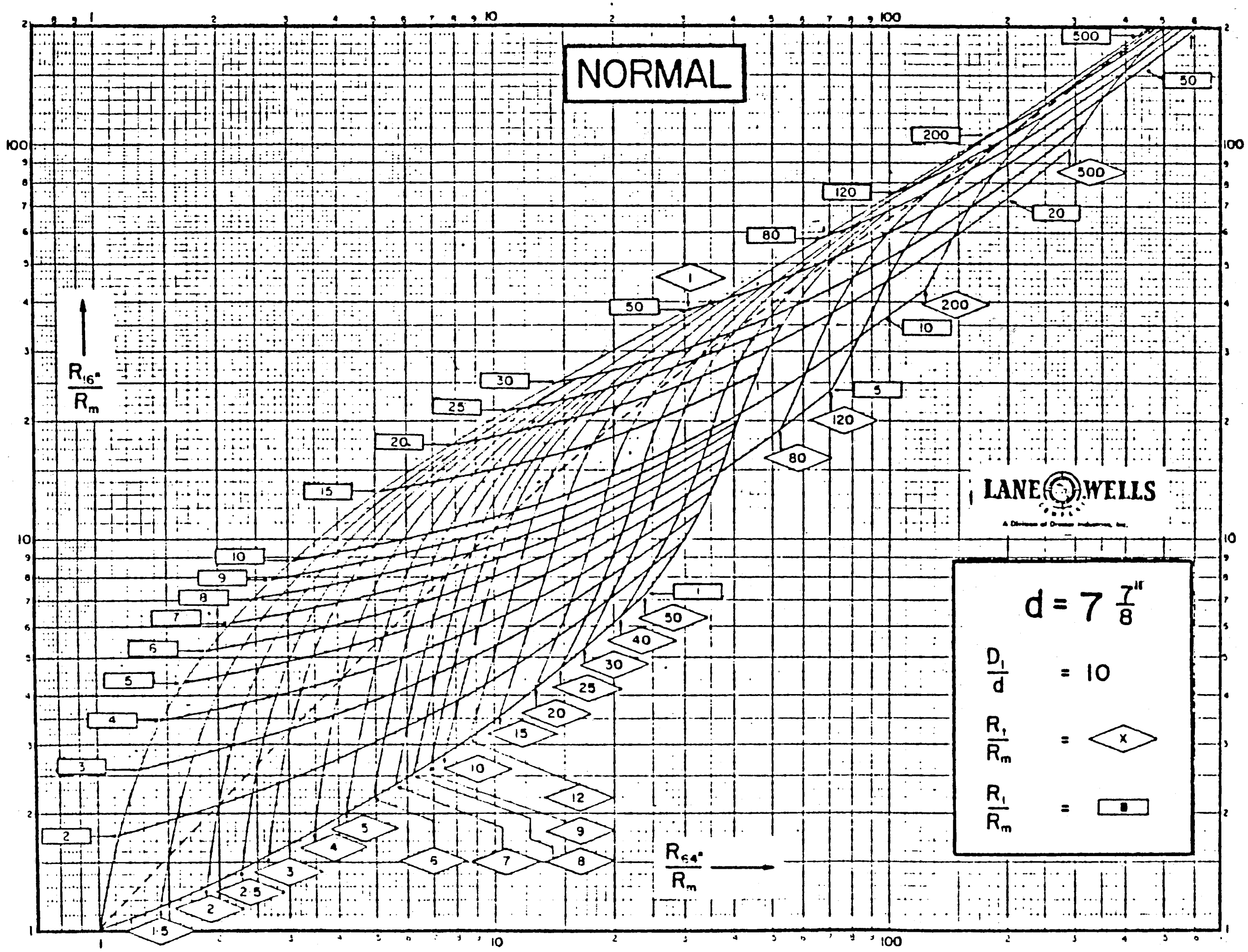

LATERAL
LANE-WELLS
d=7"
$\frac{D_i}{d}$ = 15
$\frac{R_i}{R_m}$ = ◇
$\frac{R_i}{R_m}$ = ▭
$\frac{R_{16"}}{R_m}$
$\frac{R_{18'8"}}{R_m}$
1
10
100
1000
1000
500
200
120
80
50
30
25
20
15
10
8
7
6
5
4
3
2
1.5
12
9
40
1

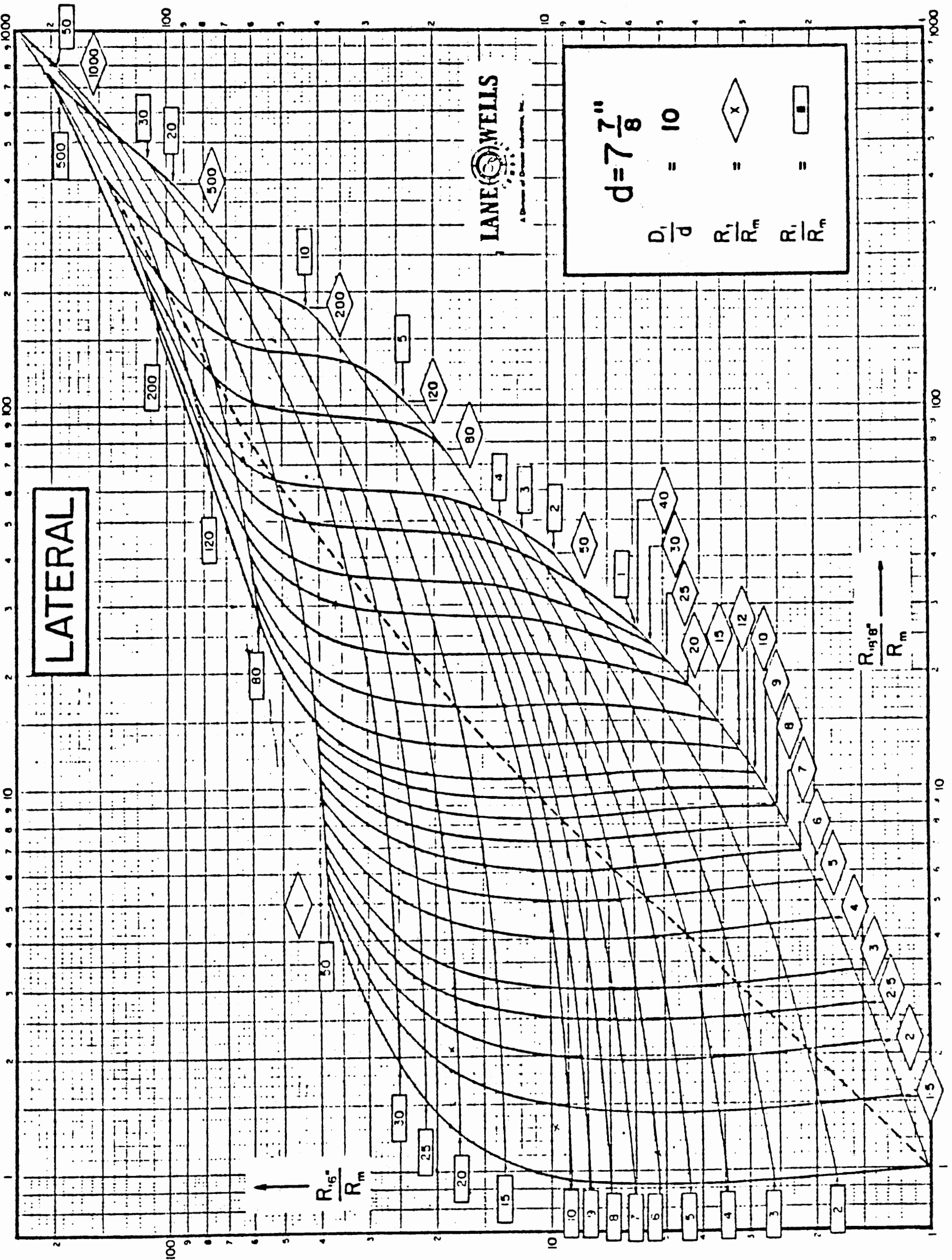

NORMAL
LANE-WELLS
d = 7 7/8"
D_i/d = 2
R_i/R_m = ◇x
R_i/R_m = ▭
R_16"/R_m
R_64"/R_m
500
200
120
80
50
40
30
25
20
15
12
10
9
8
7
6
5
4
3
2.5
2
1.5
1
500
200
120
80
50
30
25
20
15
10
5
1
100
10
1

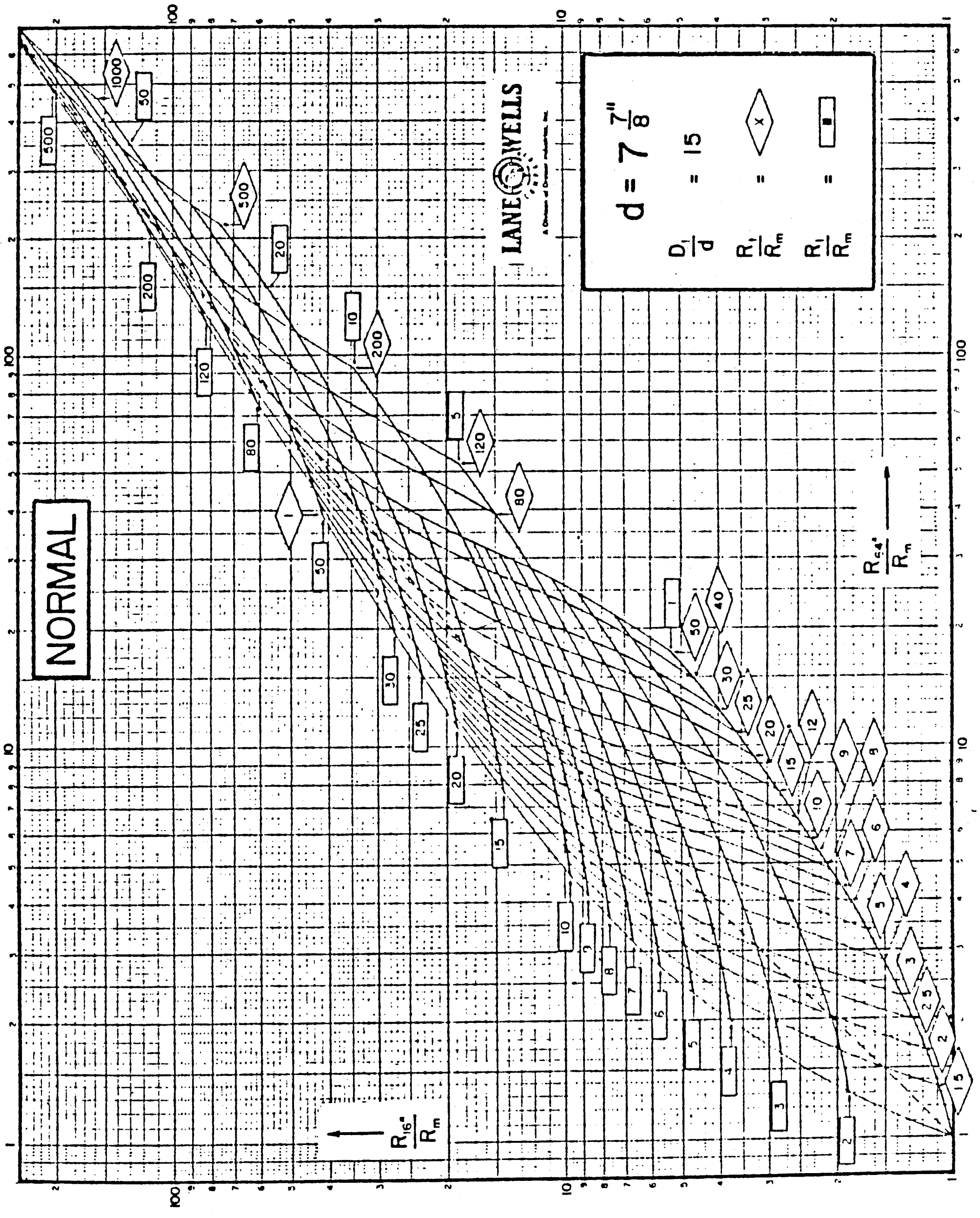

LATERAL
LANE-WELLS
A Division of Dresser Industries, Inc.
d=7 7/8"
D_i/d = 2
R_i/R_m = ◇
R_i/R_m = ▪
R_16"/R_m
R_19'8"/R_m
1
1.5
2
2.5
3
4
5
6
7
8
9
10
12
15
20
25
30
40
50
80
120
200
500
10
20
50
5
1
2
3
4
5
7
8
9
10
15
20
25
30
50
80
120
200
10
100
1000

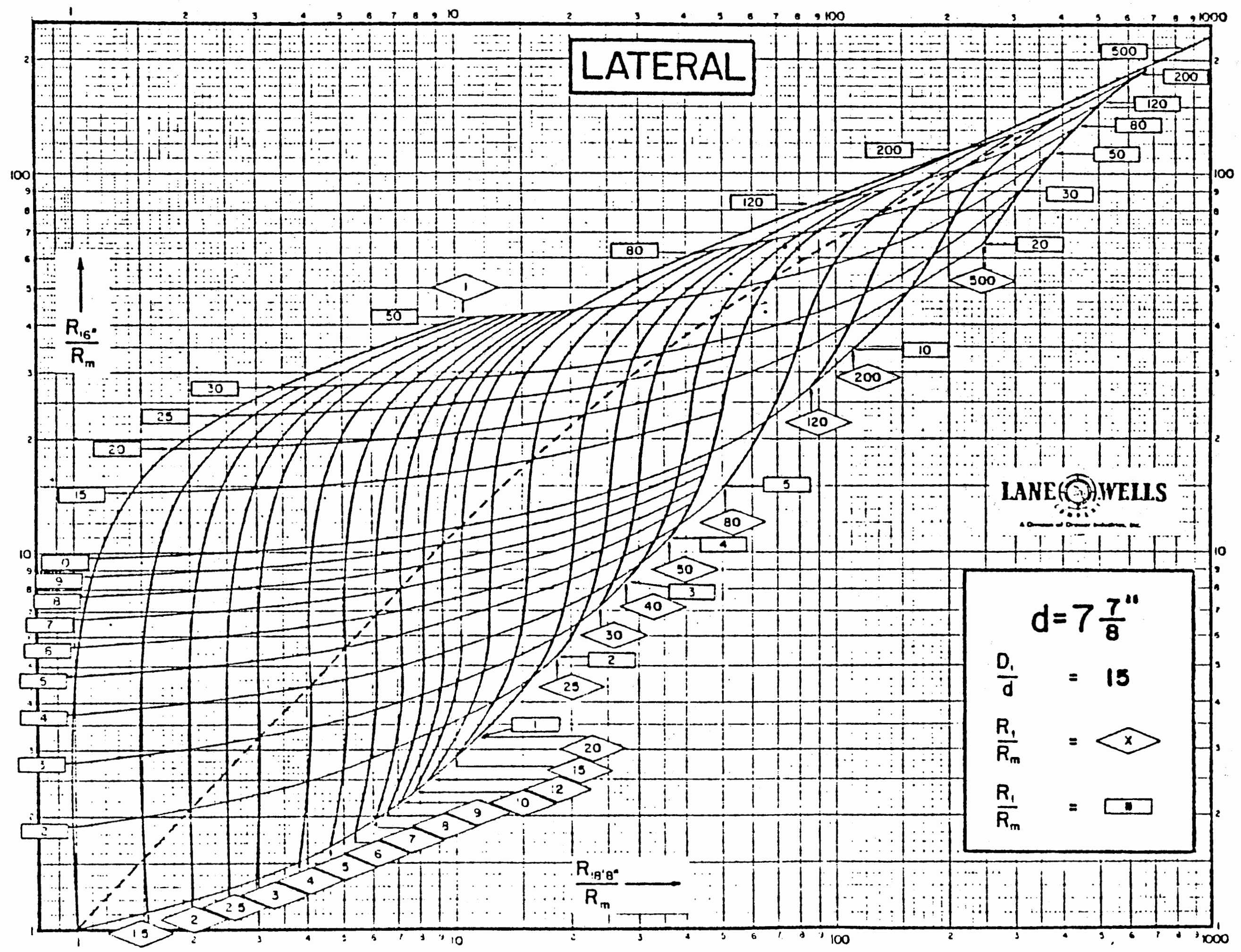

NORMAL
LANE WELLS
d = 7 7/8"
D_i/d = 5
R_i/R_m = ◇ x
R_i/R_m = ▭ ■
$R_{16"}/R_m$
$R_{64"}/R_m$
500
200
120
80
50
40
30
25
20
15
12
10
9
8
7
6
5
4
3
2.5
2
1.5
1
100
10

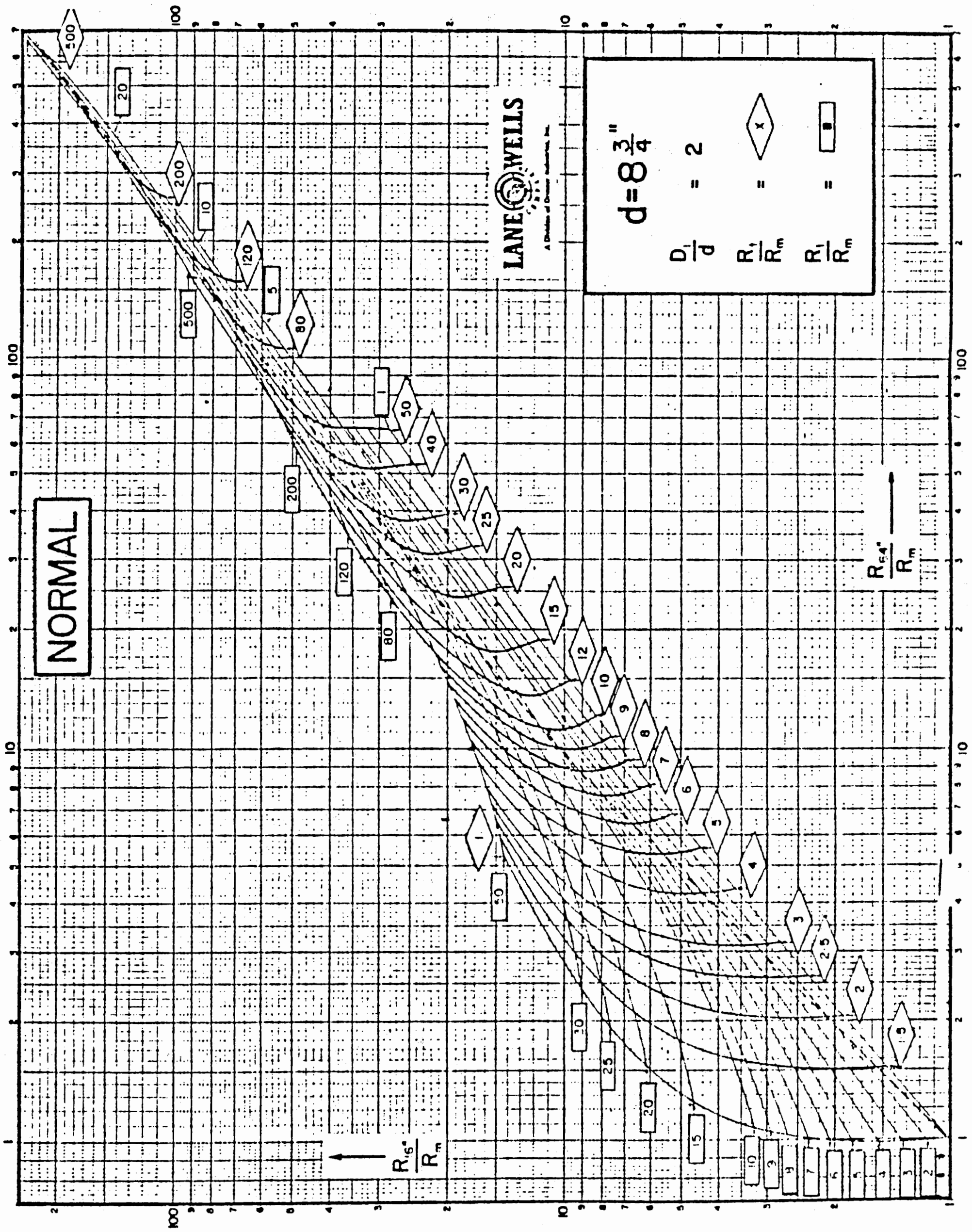

LATERAL
LANE-WELLS
A Division of Dresser Industries, Inc.
d=7 7/8"
$\frac{D_1}{d}$ = 5
$\frac{R_1}{R_m}$ = ◇
$\frac{R_1}{R_m}$ = ▭
$\frac{R_{18'8"}}{R_m}$
$\frac{R_{16"}}{R_m}$
1
10
100
1000
500
200
120
80
50
40
30
25
20
15
12
10
9
8
7
6
5
4
3
2.5
2
1.5
1

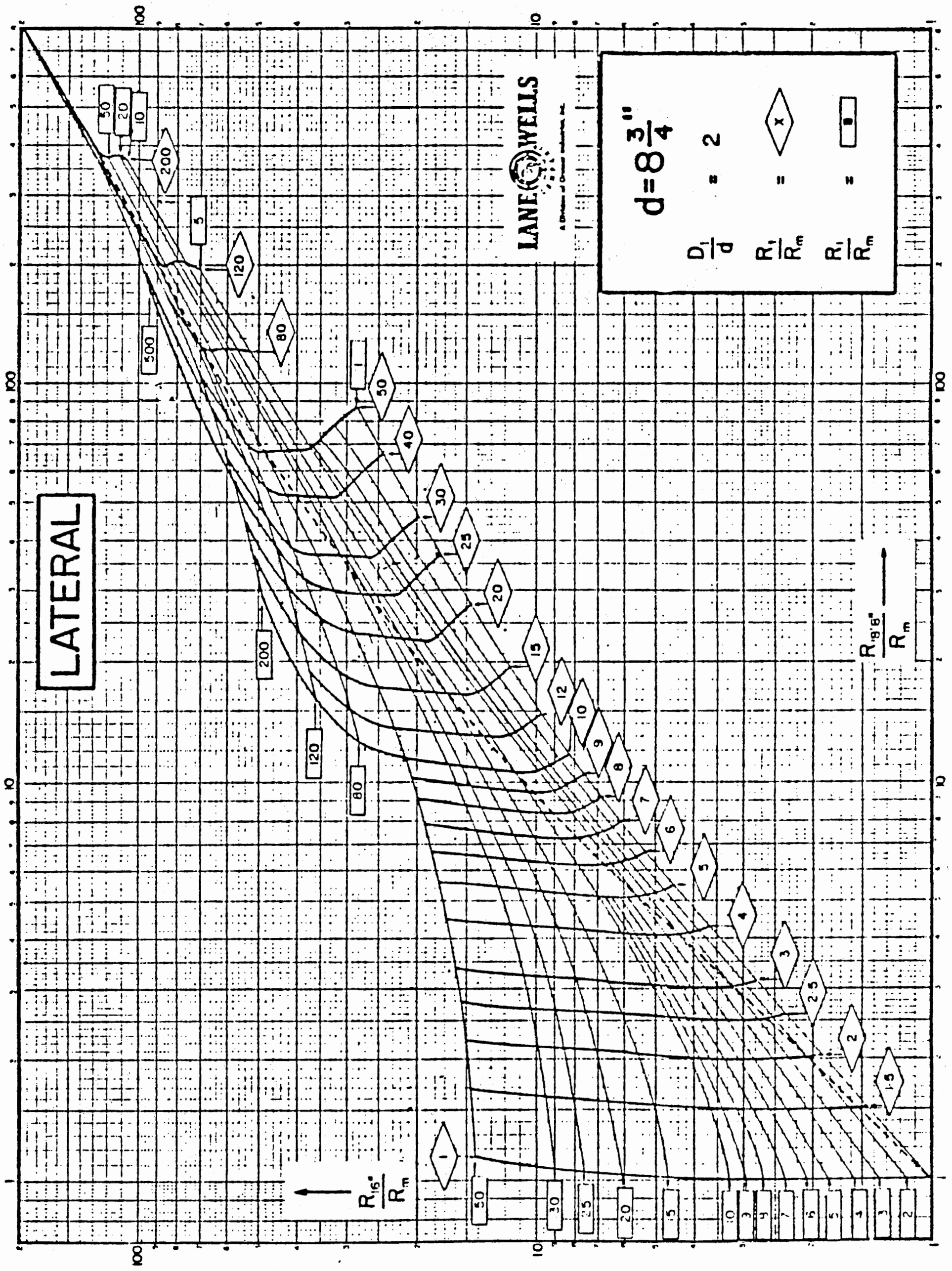

NORMAL
LANE-WELLS
A Division of Dresser Industries, Inc.
$d = 7\frac{7}{8}''$
$\frac{D_i}{d} = 10$
$\frac{R_t}{R_m} = \diamond\, x$
$\frac{R_i}{R_m} = \square$
$\frac{R_{16''}}{R_m}$
$\frac{R_{64''}}{R_m}$
1
2
3
4
5
6
7
8
9
10
100
500
50
200
120
80
1
30
25
20
15
10
9
8
7
6
5
4
3
2
500
20
200
10
5
120
80
1
50
40
30
25
20
15
10
12
9
8
7
6
5
4
3
2.5
2
1.5

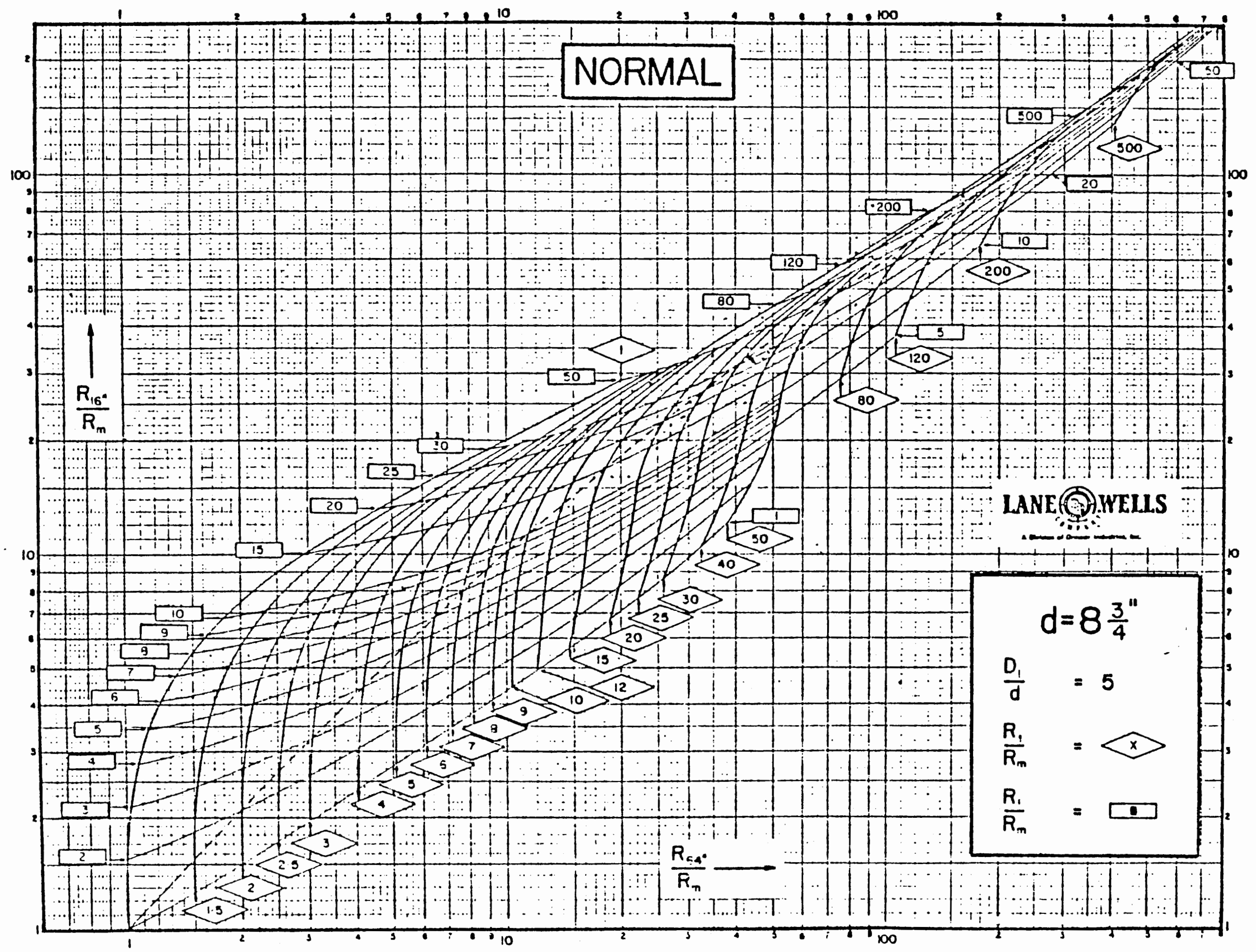

LATERAL
LANE-WELLS
A Division of Dresser Industries, Inc.
d=7 7/8"
D_i/d = 10
R_i/R_m = ◇x
R_i/R_m = ▭
R_16"/R_m
R_19'8"/R_m
1
10
100
1000
1000
500
200
120
80
50
30
25
20
15
12
10
9
8
7
6
5
4
3
2.5
2
1.5
500
200
120
80
50
30
20
10
5
4
3
2
1
50
30
25
20
15
10
9
8
7
6
5
4
3
2

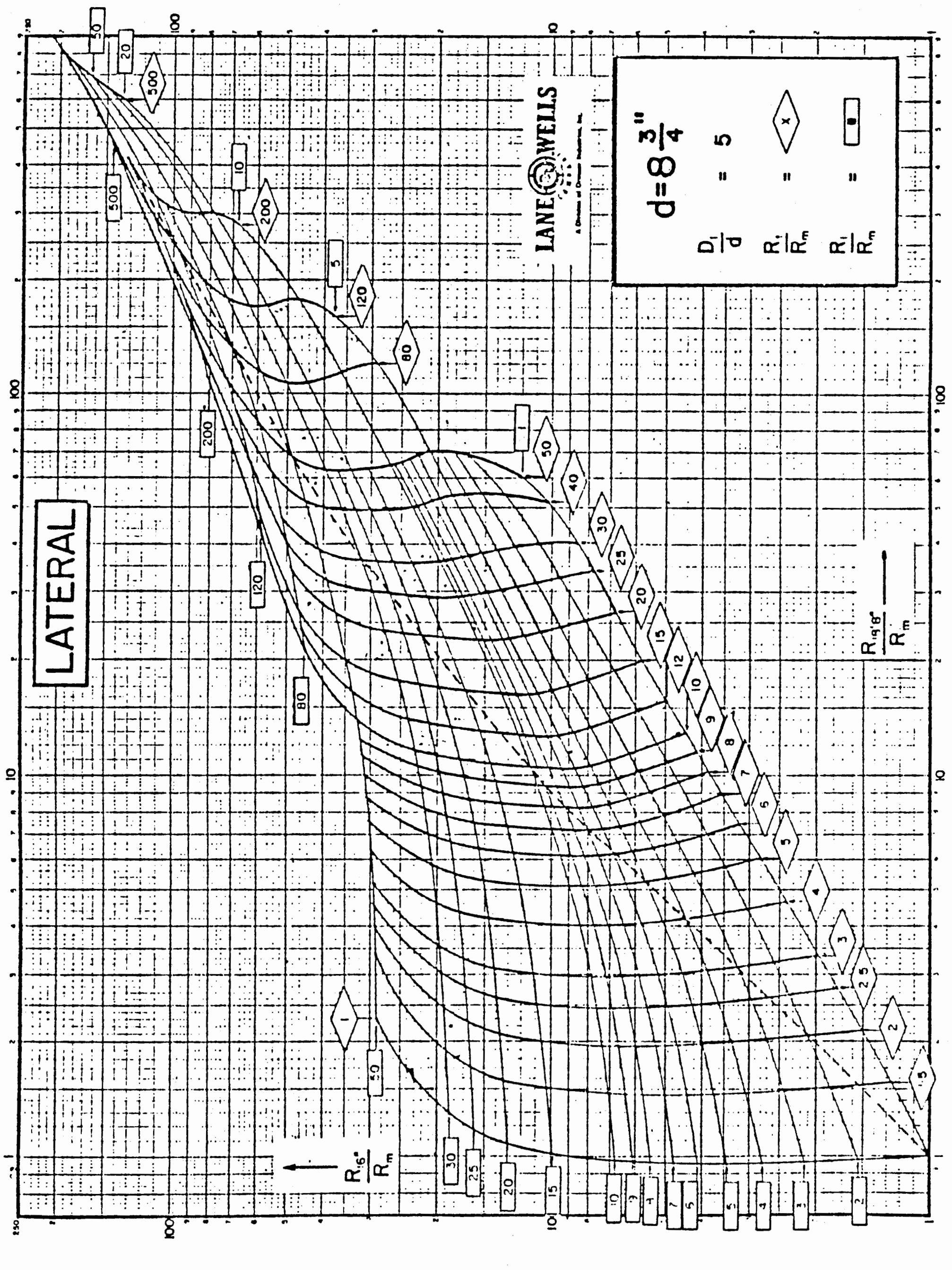

NORMAL
LANE-WELLS
d = 7 7/8"
$\frac{D_i}{d}$ = 15
$\frac{R_i}{R_m}$ = ◇
$\frac{R_i}{R_m}$ = ▭
$\frac{R_{16"}}{R_m}$
$\frac{R_{64"}}{R_m}$
1000
500
200
120
80
50
30
25
20
15
10
9
8
7
6
5
4
3
2
1.5
1
100
10

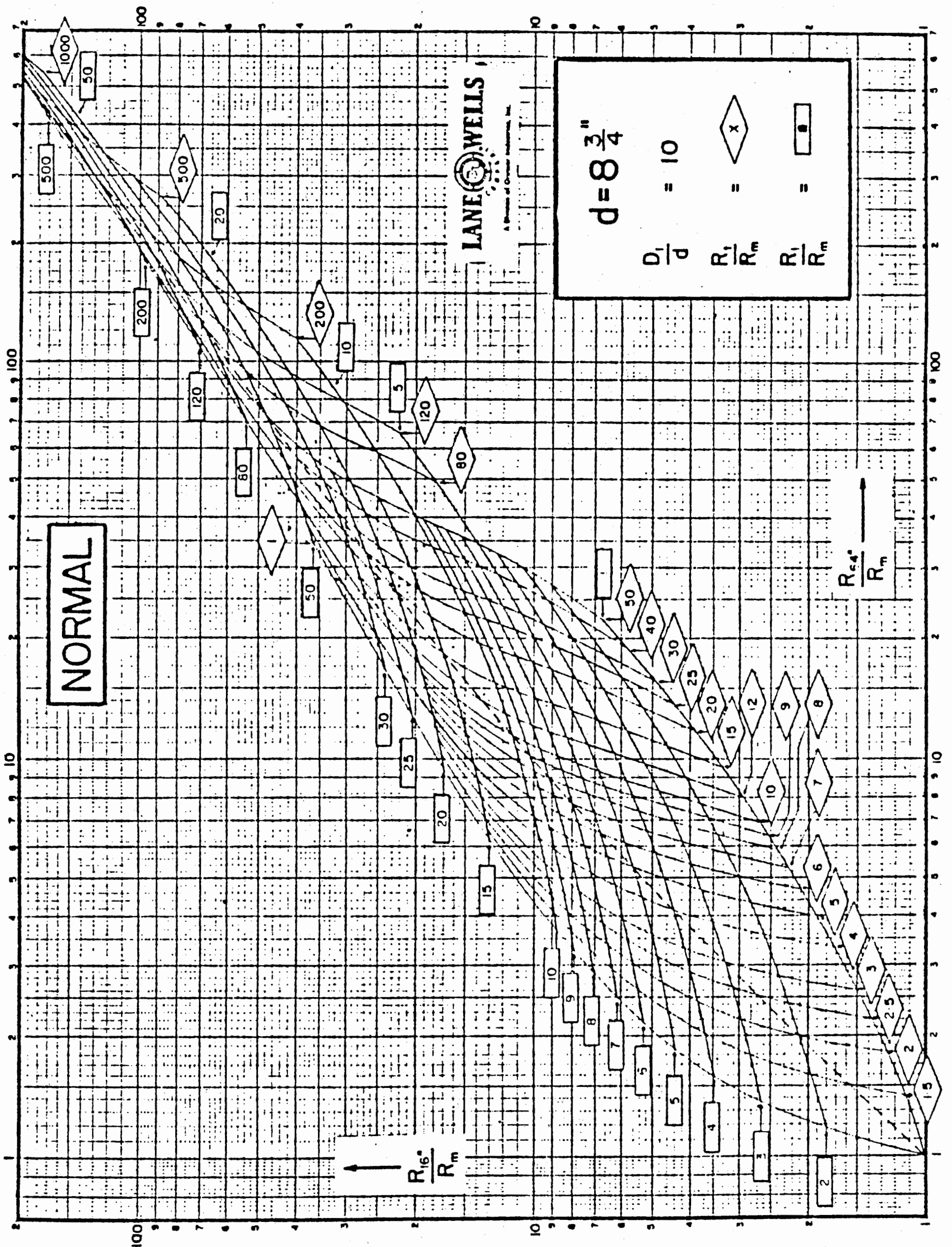

LATERAL
LANE WELLS
A Division of Dresser Industries, Inc.
d = 7 7/8"
D₁/d = 15
R₁/Rm = ◇
R₁/Rm = ▭
R16"/Rm
R18'8"/Rm
1
10
100
1000
500
200
120
80
50
30
25
20
15
10
9
8
7
6
5
4
3
2
1
40
12
2.5
1.5

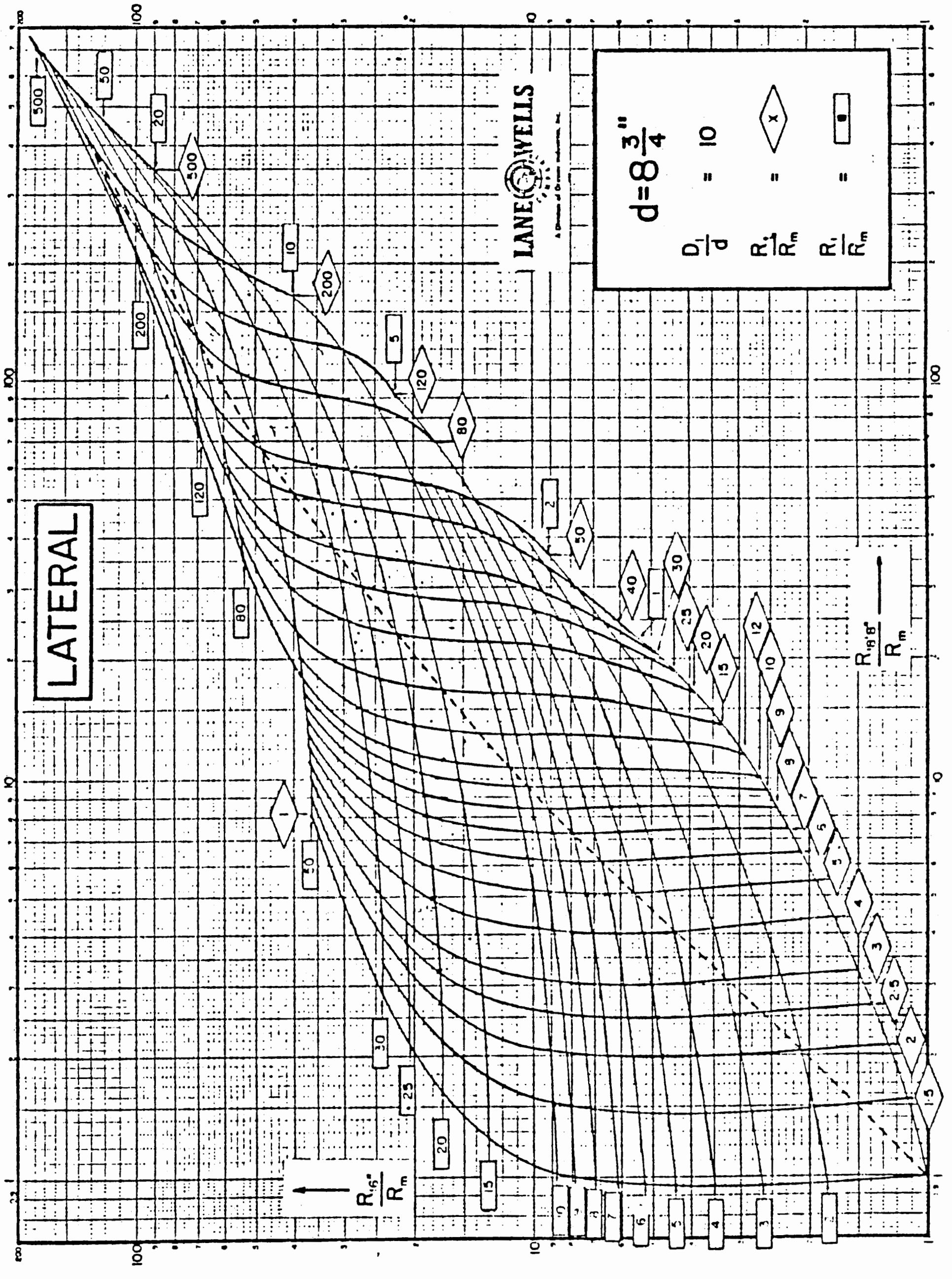

NORMAL
LANE-WELLS
A Division of Dresser Industries, Inc.
d=8 3/4"
$\frac{D_i}{d}$ = 2
$\frac{R_i}{R_m}$ = ◇
$\frac{R_i}{R_m}$ = ▭
$\frac{R_{16"}}{R_m}$
$\frac{R_{64"}}{R_m}$
500
200
120
80
50
40
30
25
20
15
12
10
9
8
7
6
5
4
3
2.5
2
1.5
1
20
10
5
1
500
200
120
80
50
30
25
20
15
10
9
8
7
6
5
4
3
2
1
10
100

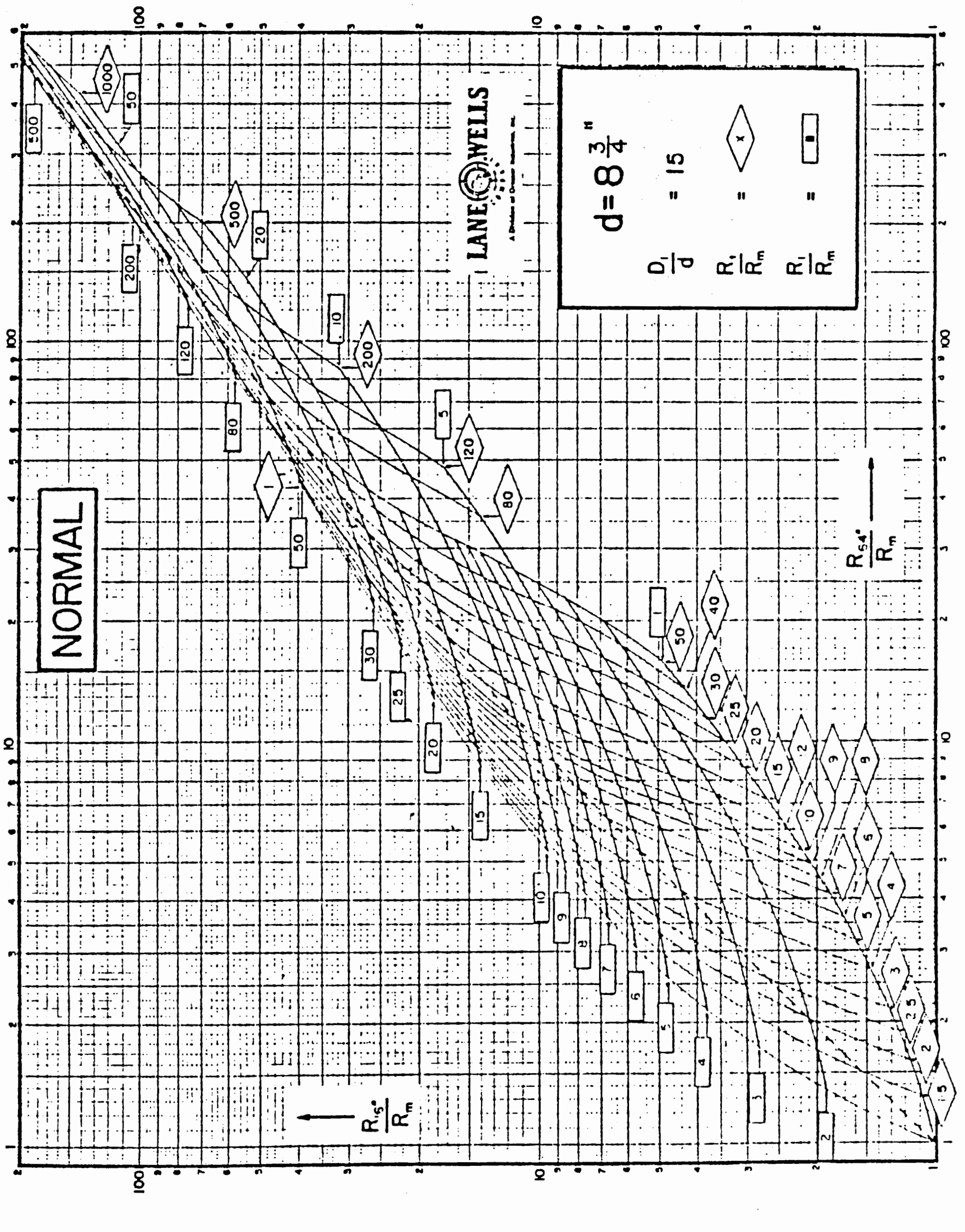

LATERAL
LANE WELLS
A Division of Dresser Industries, Inc.
d=8 3/4"
D_i/d = 2
R_i/R_m = ◇
R_i/R_m = ▭
R_16"/R_m
R_18'8"/R_m
1
10
100
1000
1
1.5
2
2.5
3
4
5
6
7
8
9
10
12
15
20
25
30
40
50
80
120
200
50
20
10
5
500
200
120
80
1
50
30
25
20
15
10
9
8
7
6
5
4
3
2

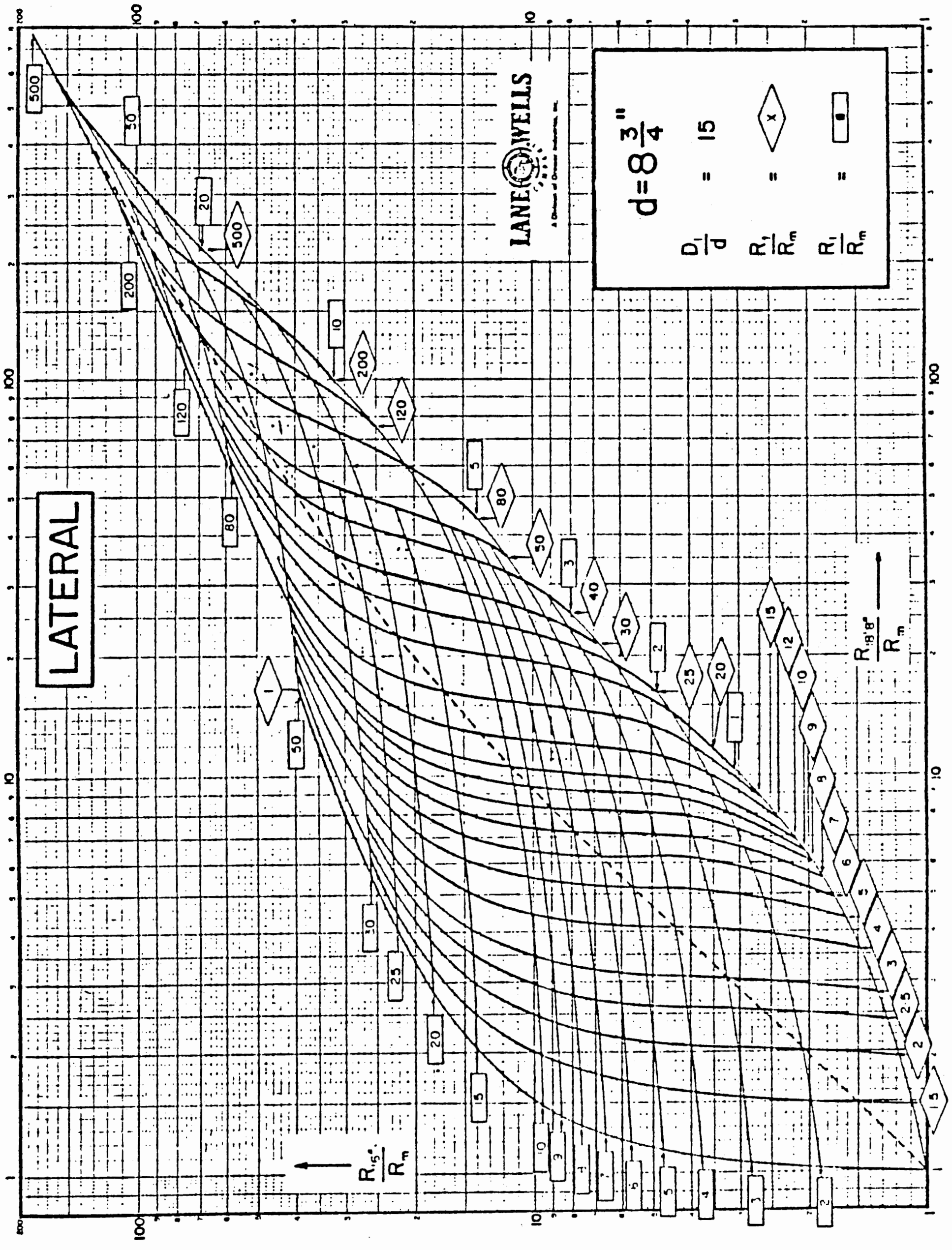

NORMAL
$\frac{R_{16"}}{R_m}$
$\frac{R_{64"}}{R_m}$
LANE WELLS
A Division of Dresser Industries, Inc.
$d = 8\frac{3}{4}"$
$\frac{D_i}{d} = 5$
$\frac{R_i}{R_m}$ = x
$\frac{R_i}{R_m}$ = ▭
50
500
500
20
200
10
200
120
80
5
120
80
1
50
30
25
20
15
10
9
8
7
6
5
4
3
2
1
50
40
30
25
20
15
12
10
9
8
7
6
5
4
3
2.5
2
1.5
1
10
100

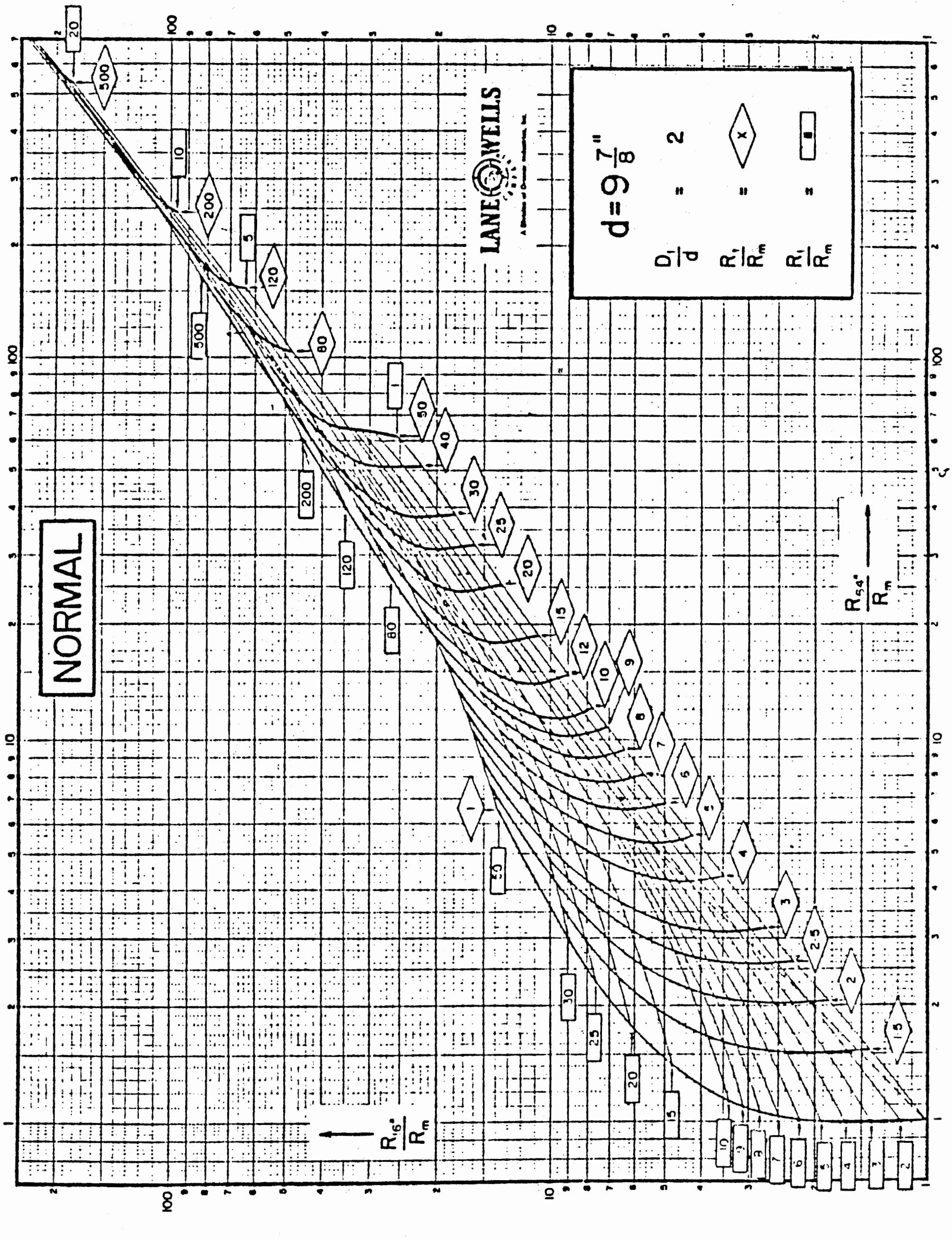

LATERAL
LANE-WELLS
d=8 3/4"
D_i/d = 5
R_t/R_m = ◇
R_i/R_m = ▭
R_16"/R_m
R_18'8"/R_m
500
200
120
80
50
40
30
25
20
15
12
10
9
8
7
6
5
4
3
2.5
2
1.5
1
50
20
10
5
1
500
200
120
80
50
30
25
20
15
10
9
8
7
6
5
4
3
2
100
10
1

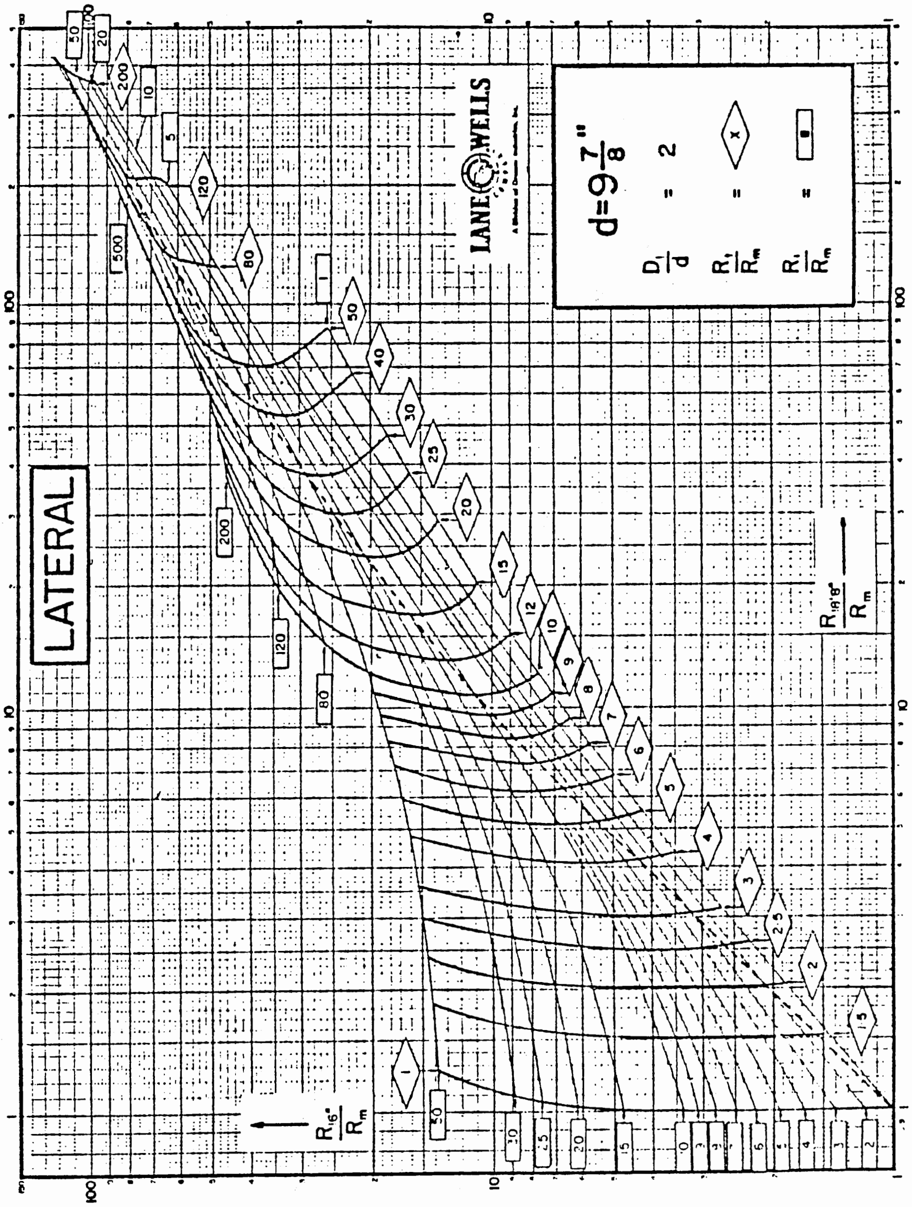

NORMAL
LANE-WELLS
d=8 3/4"
D_i/d = 10
R_i/R_m = x
R_t/R_m = ■
R_16"/R_m
R_64"/R_m
1000
500
200
120
80
50
40
30
25
20
15
12
10
9
8
7
6
5
4
3
2.5
2
1.5
1
100
10
1

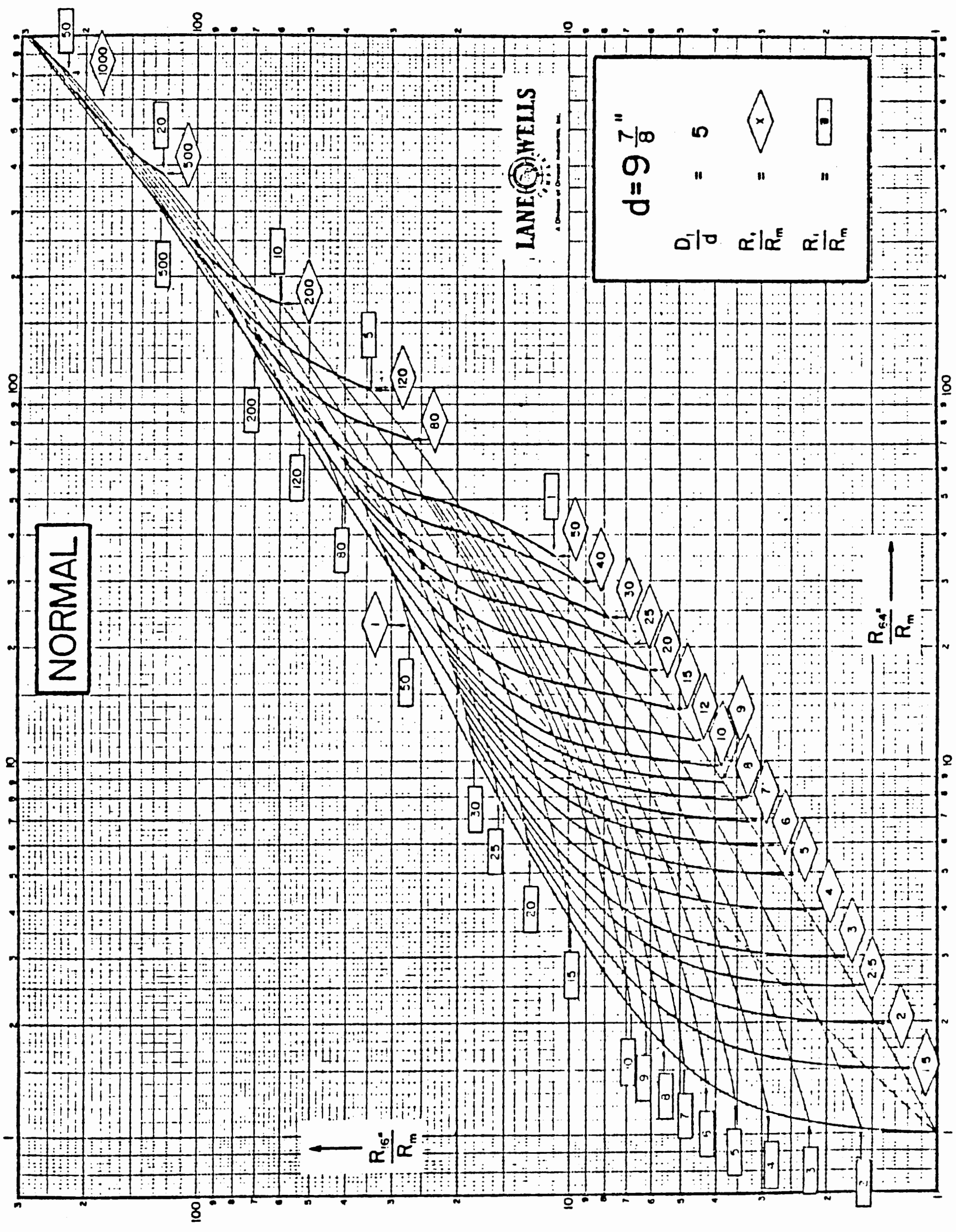

LATERAL
LANE-WELLS
d=8 3/4"
$\frac{D_i}{d}$ = 10
$\frac{R_i}{R_m}$ = ◇ x
$\frac{R_t}{R_m}$ = ▭
$\frac{R_{16"}}{R_m}$
$\frac{R_{18'8"}}{R_m}$
500
200
120
80
50
30
25
20
15
10
5
2
1
1.5
2
2.5
3
4
5
6
7
8
9
10
12
15
20
25
30
40
50
80
120
200
500
100
10
1

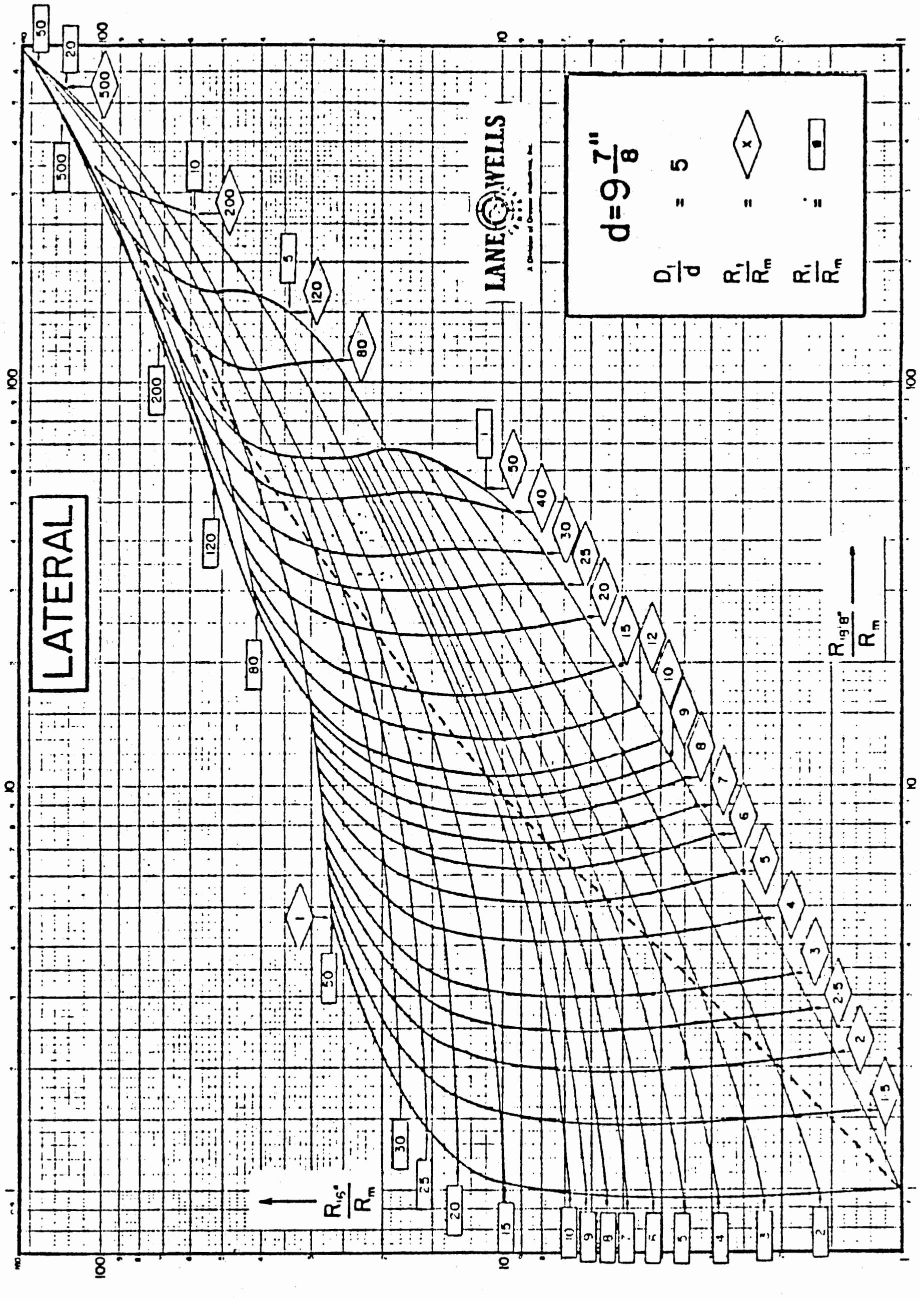

NORMAL
LANE-WELLS
d= 8 3/4"
D_i/d = 15
R_i/R_m = ◇ x
R_i/R_m = ▭
R_15"/R_m
R_64"/R_m
1000
500
200
120
80
50
40
30
25
20
15
10
9
8
7
6
5
4
3
2.5
2
1.5
1

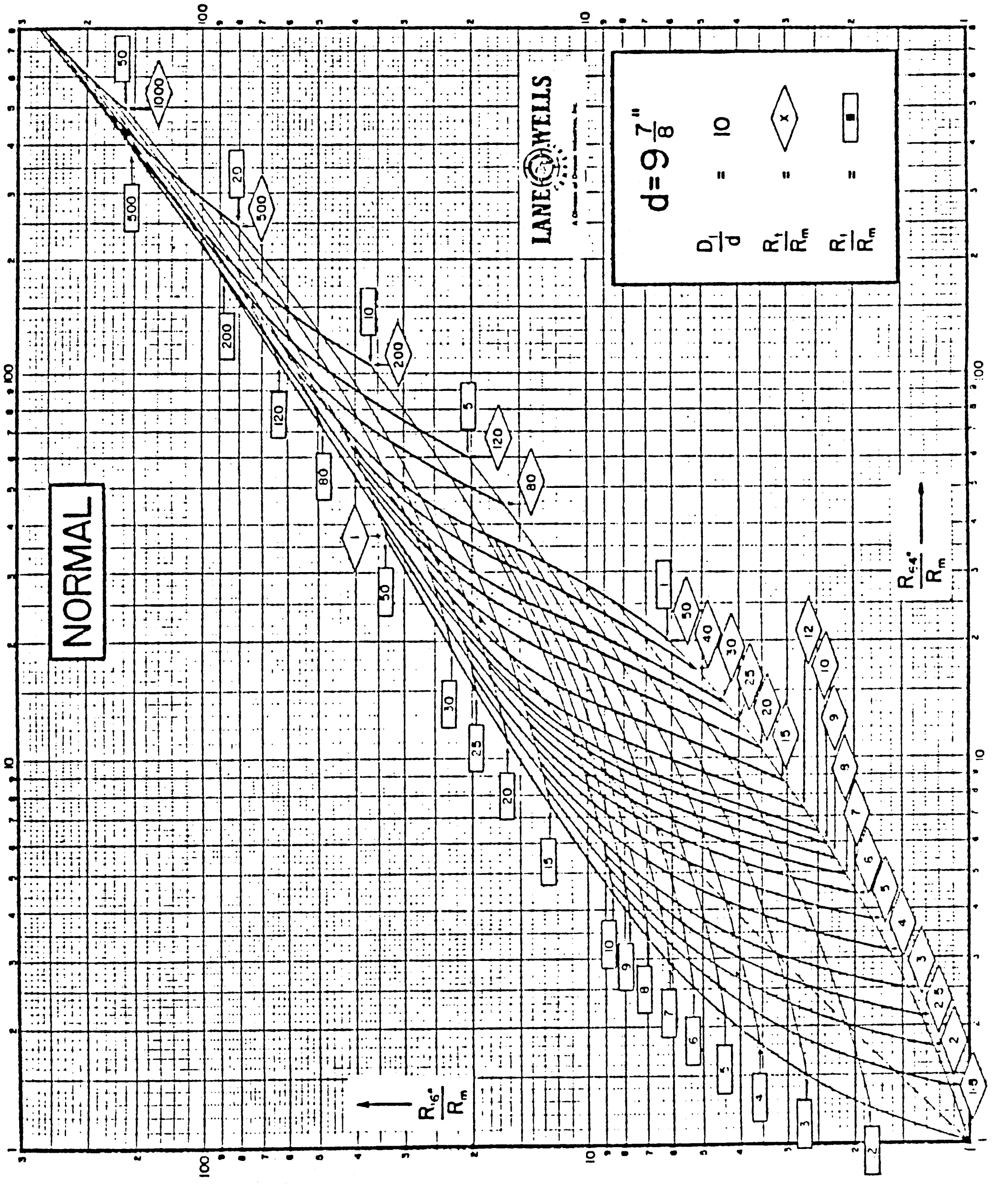

LATERAL
LANE-WELLS
d=8 3/4"
$\frac{D_i}{d}$ = 15
$\frac{R_t}{R_m}$ = ◇
$\frac{R_i}{R_m}$ = ▭
$\frac{R_{15'6"}}{R_m}$
$\frac{R_{18'8"}}{R_m}$
1
10
100
1000
500
50
20
200
10
120
80
5
3
2
1
50
30
25
20
15
10
9
8
7
6
5
4
3
2
500
200
120
80
50
40
30
25
20
15
12
10
9
8
7
6
5
4
3
2.5
2
1.5
1

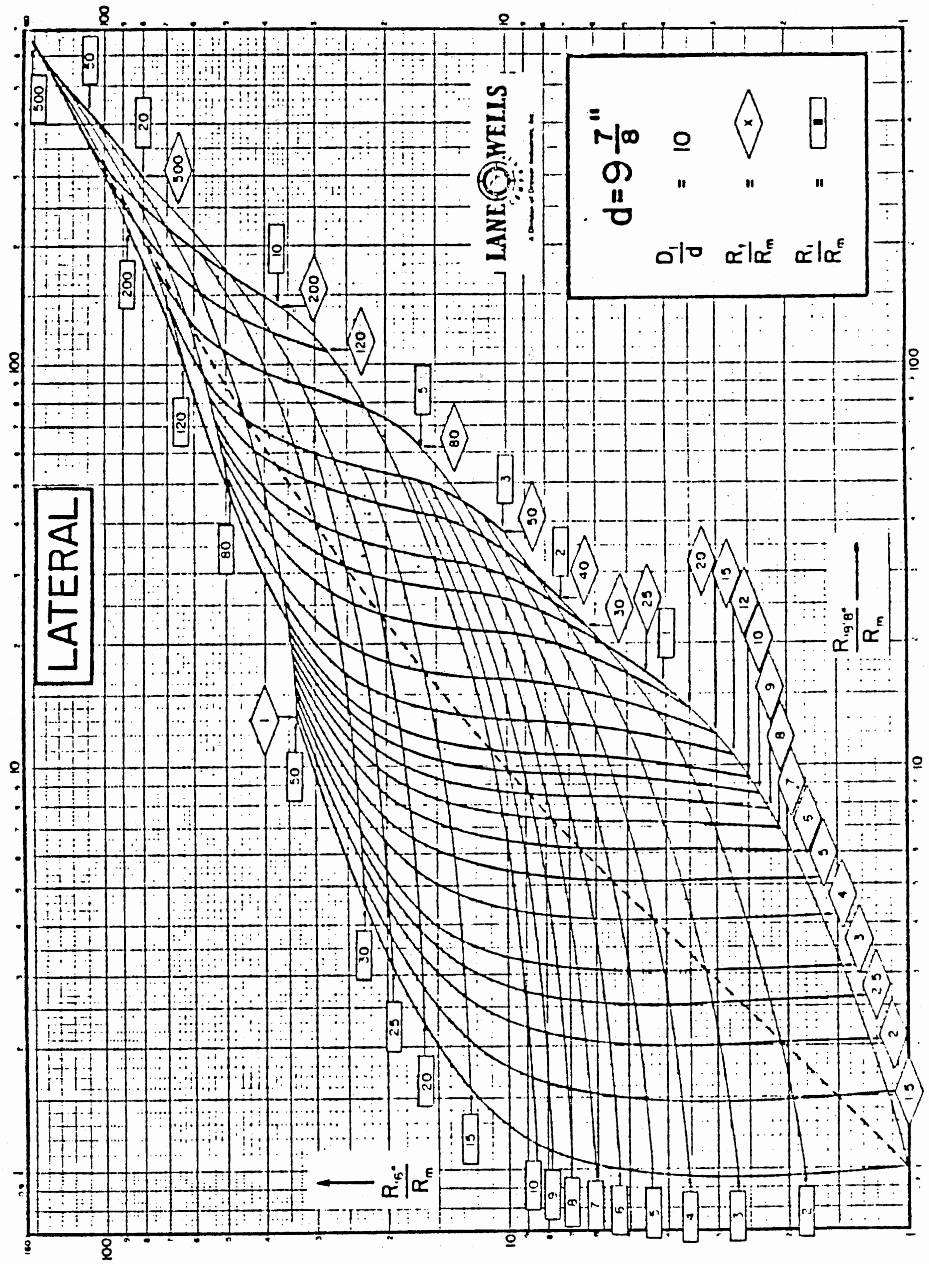

NORMAL
LANE-WELLS
d=9 7/8"
D_i/d = 2
R_i/R_m = ◇x
R_i/R_m = ▭
R_16"/R_m
R_64"/R_m
500
200
120
80
50
40
30
25
20
15
12
10
9
8
7
6
5
4
3
2.5
2
1.5
1
100
10
2
3
4
5
6
7
8
9

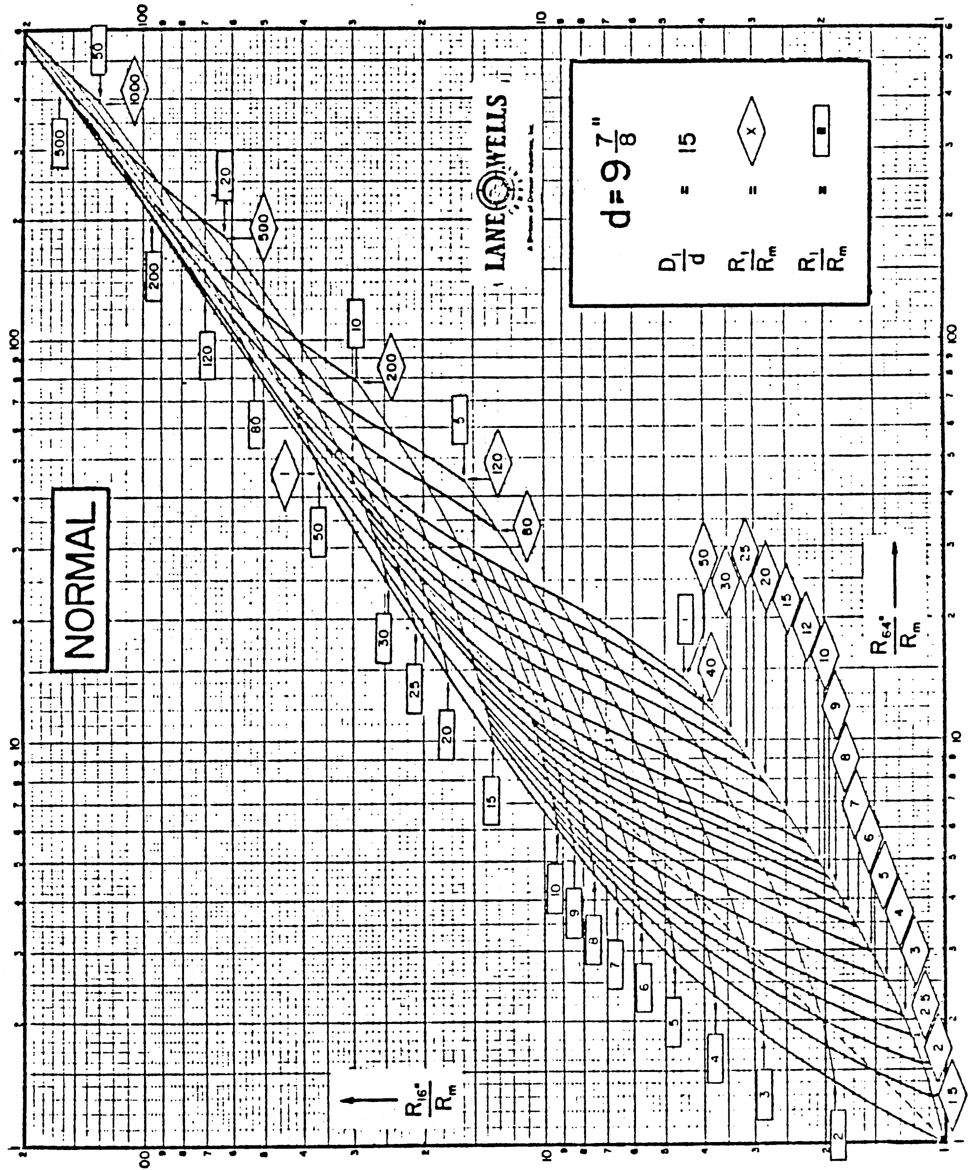

LATERAL
LANE-WELLS
A Division of Dresser Industries, Inc.
d=9 7/8"
D/d = 2
R_i/R_m = ◇x
R_i/R_m = ▭
R_16"/R_m
R_18'8"/R_m
1
10
100
500
200
120
80
50
20
10
5
1
200
120
80
50
40
30
25
20
15
12
10
9
8
7
6
5
4
3
2.5
2
1.5
1
50
30
25
20
15
10
5
4
3
2

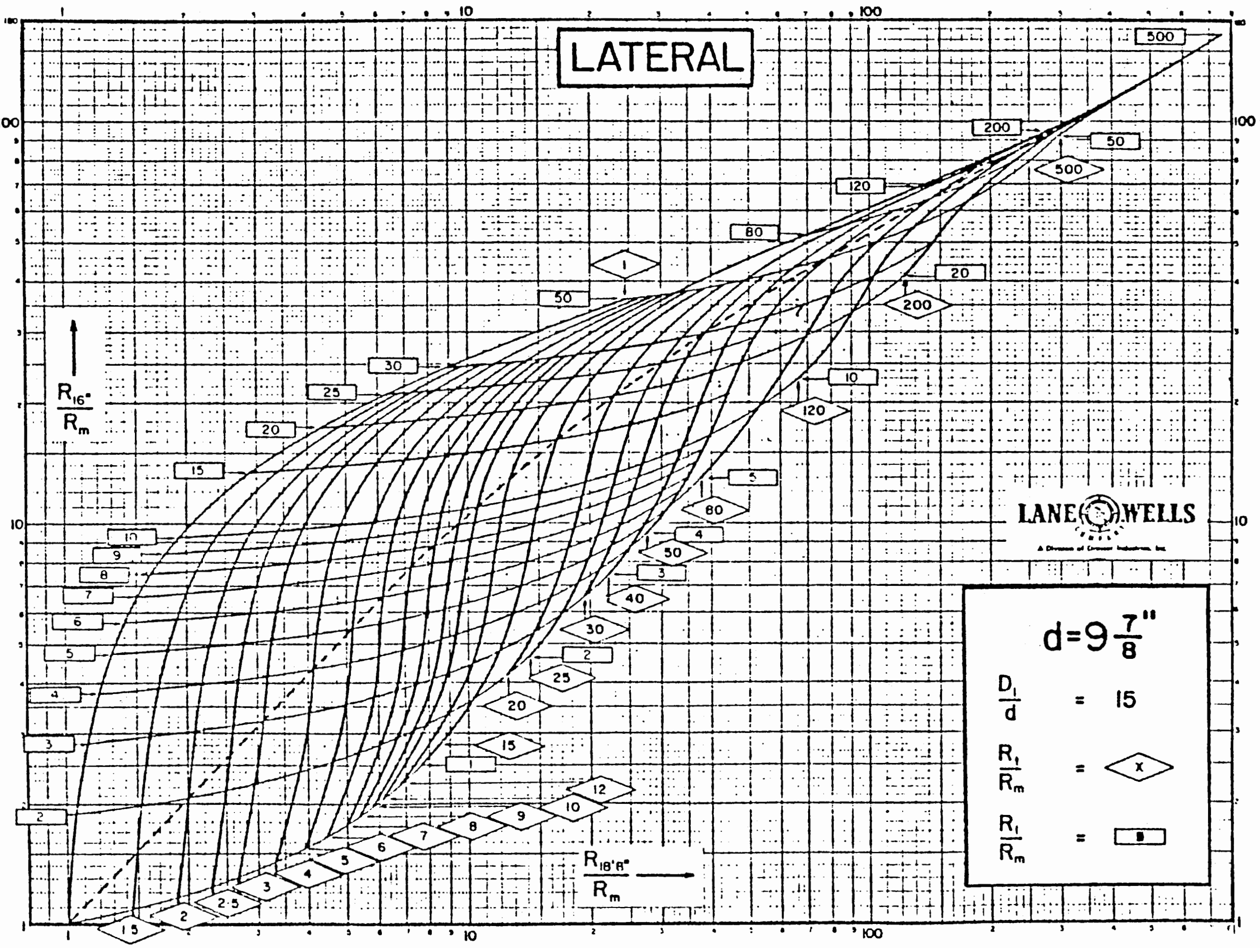

NORMAL
LANE-WELLS
$d = 9\frac{7}{8}''$
$\frac{D_i}{d} = 5$
$\frac{R_i}{R_m} = \Diamond$
$\frac{R_i}{R_m} = \square$
$\frac{R_{16''}}{R_m}$
$\frac{R_{64''}}{R_m}$
1000
500
200
120
80
50
40
30
25
20
15
12
10
9
8
7
6
5
4
3
2.5
2
1.5
1
100
10

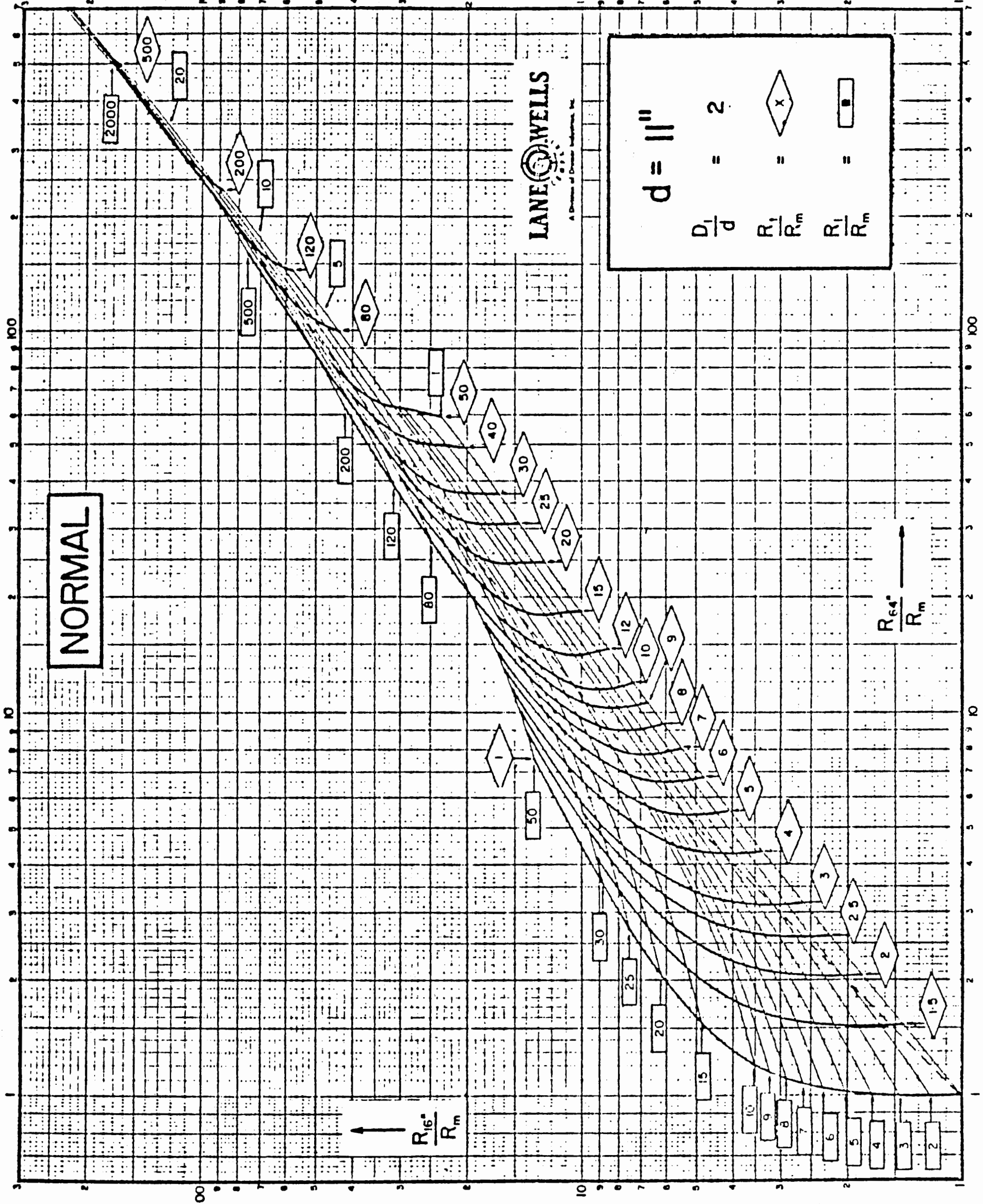

LATERAL
LANE WELLS
$d = 9\frac{7}{8}''$
$\frac{D_i}{d} = 5$
$\frac{R_i}{R_m} = ◇$
$\frac{R_i}{R_m} = ▭$
$\frac{R_{19'8''}}{R_m}$
$\frac{R_{16''}}{R_m}$
1
10
100
1000
500
200
120
80
50
40
30
25
20
15
12
10
9
8
7
6
5
4
3
2.5
2
1.5
1

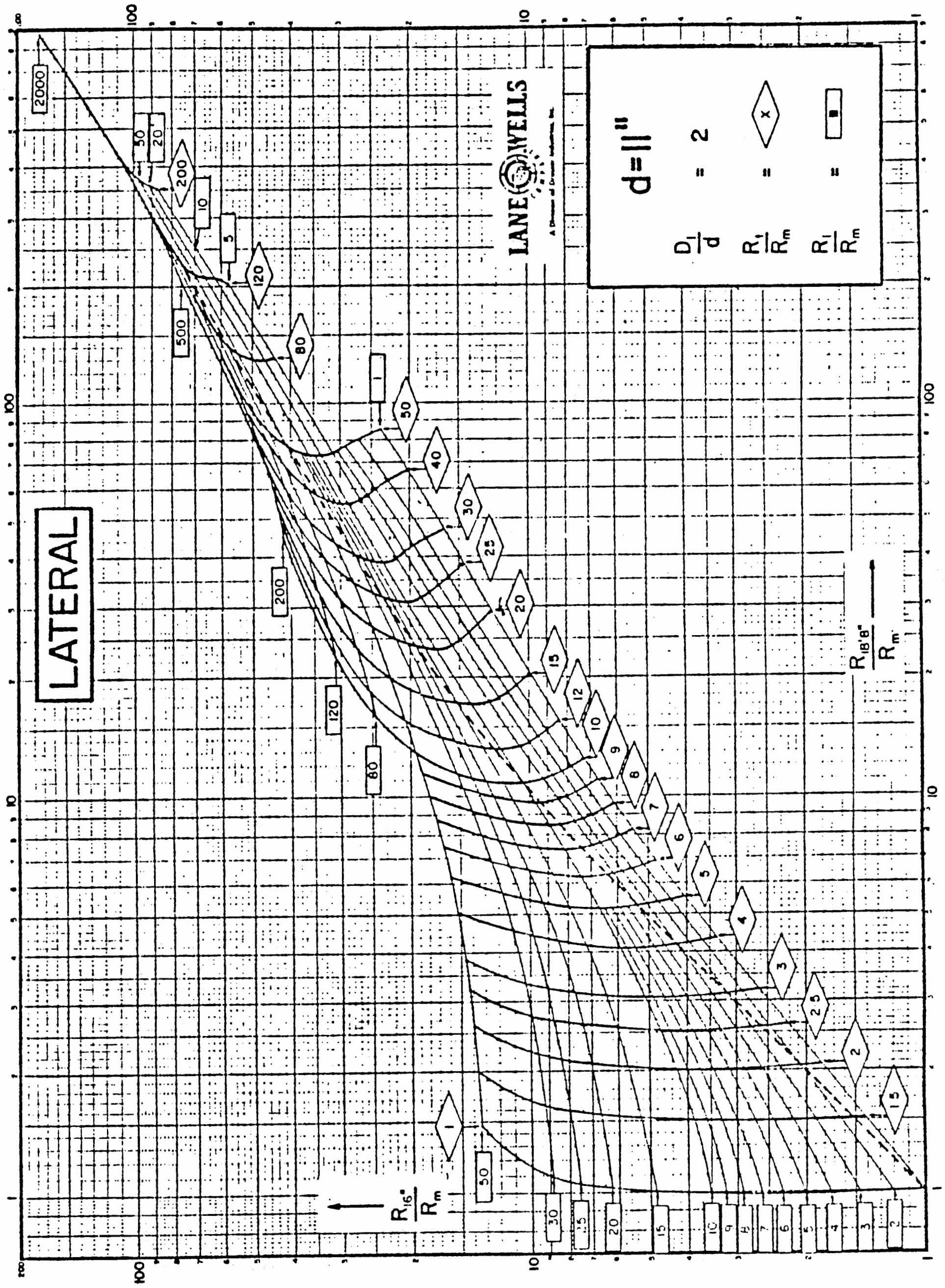

NORMAL
R16"/Rm
R64"/Rm
LANE-WELLS
d = 9 7/8"
Di/d = 10
Rt/Rm = ◇
Ri/Rm = ▭
1.5
2
2.5
3
4
5
6
7
8
9
10
12
15
20
25
30
40
50
80
120
200
500
1000
1
10
100

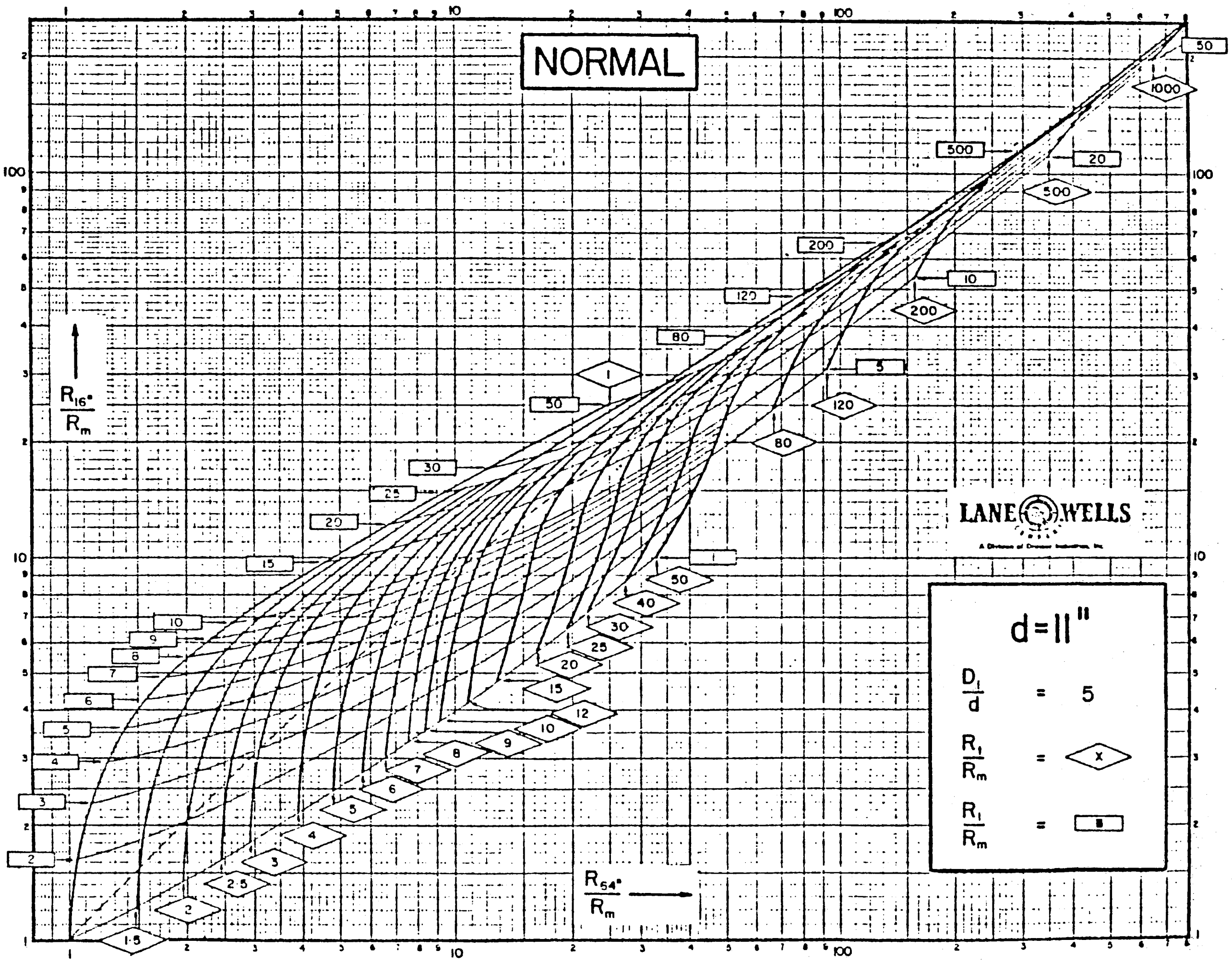

LATERAL
LANE WELLS
d=9 7/8"
D_i/d = 10
R_i/R_m = ◇
R_t/R_m = ▭
R_16"/R_m
R_19'8"/R_m
1
10
100
1000
500
200
120
80
50
40
30
25
20
15
12
10
9
8
7
6
5
4
3
2.5
2
1.5
1

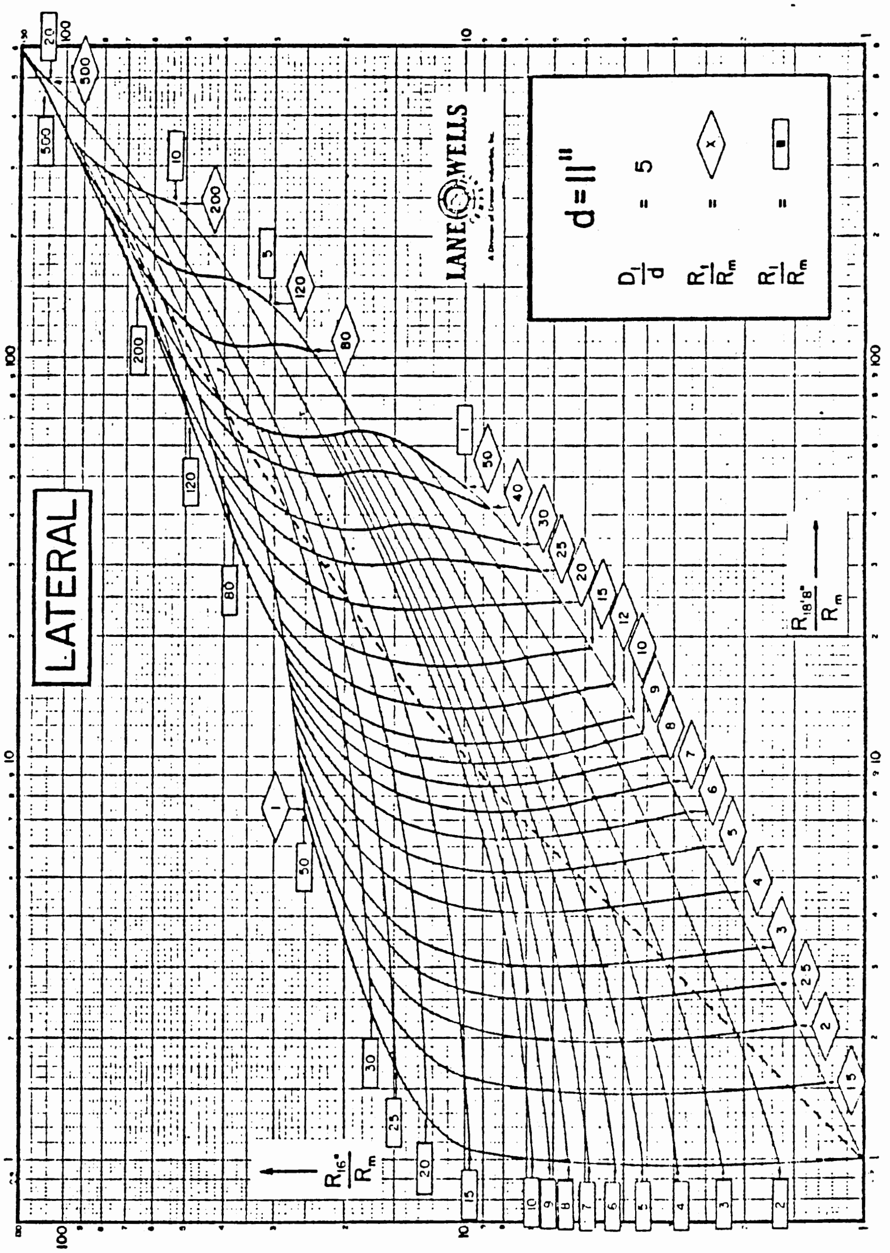

NORMAL
LANE WELLS
$d = 9\frac{7}{8}''$
$\frac{D_1}{d}$ = 15
$\frac{R_1}{R_m}$ = X
$\frac{R_1}{R_m}$ = ■
$\frac{R_{16''}}{R_m}$
$\frac{R_{64''}}{R_m}$
1
10
100
1000

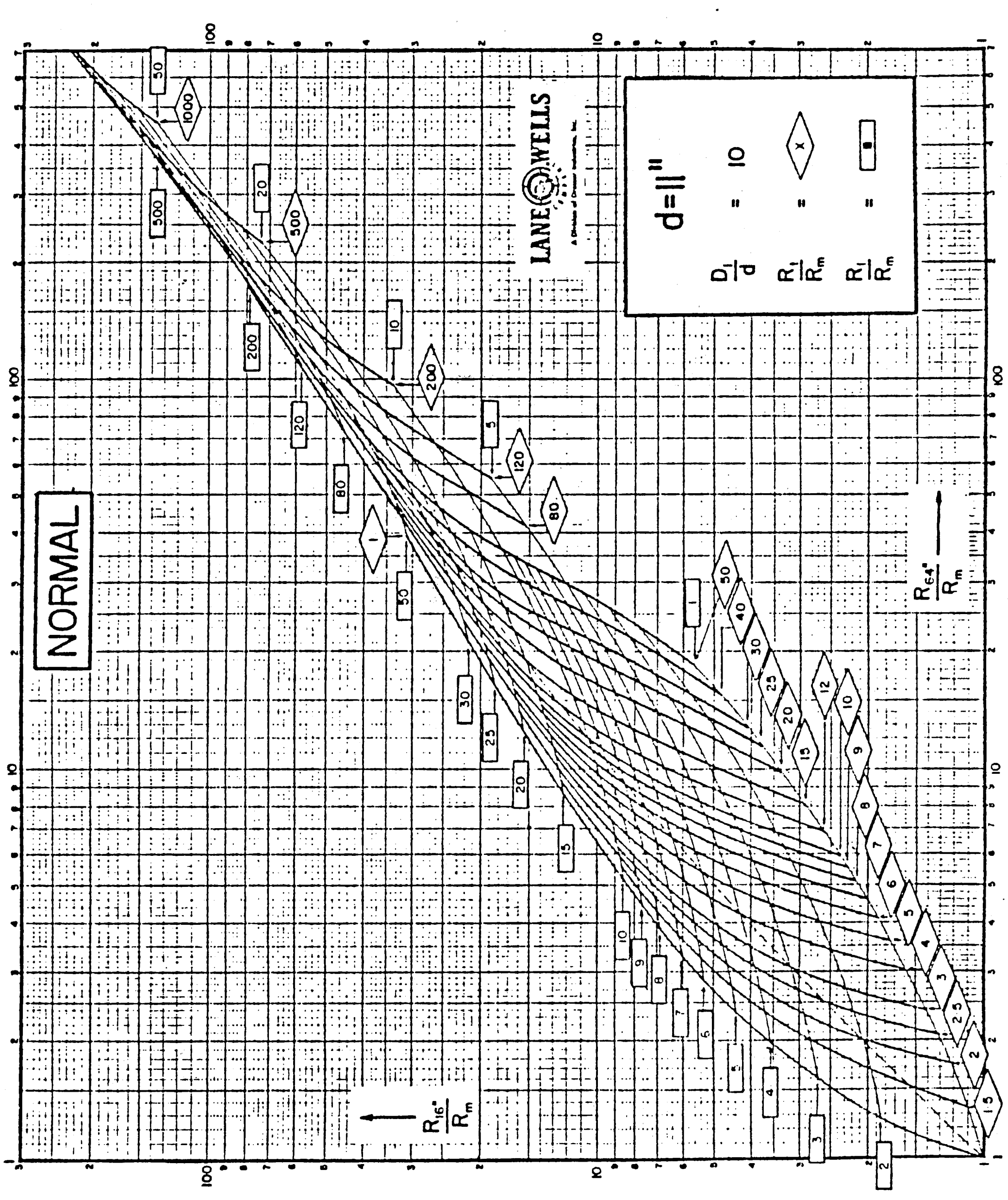

LATERAL
R16"/Rm
R18'8"/Rm
LANE-WELLS
A Division of Dresser Industries, Inc.
d=9 7/8"
Di/d = 15
Rt/Rm = ◇
Ri/Rm = ▭
1
10
100
500
200
50
120
80
20
1
50
30
25
20
15
10
9
8
7
6
5
4
3
2
1.5
2.5
12

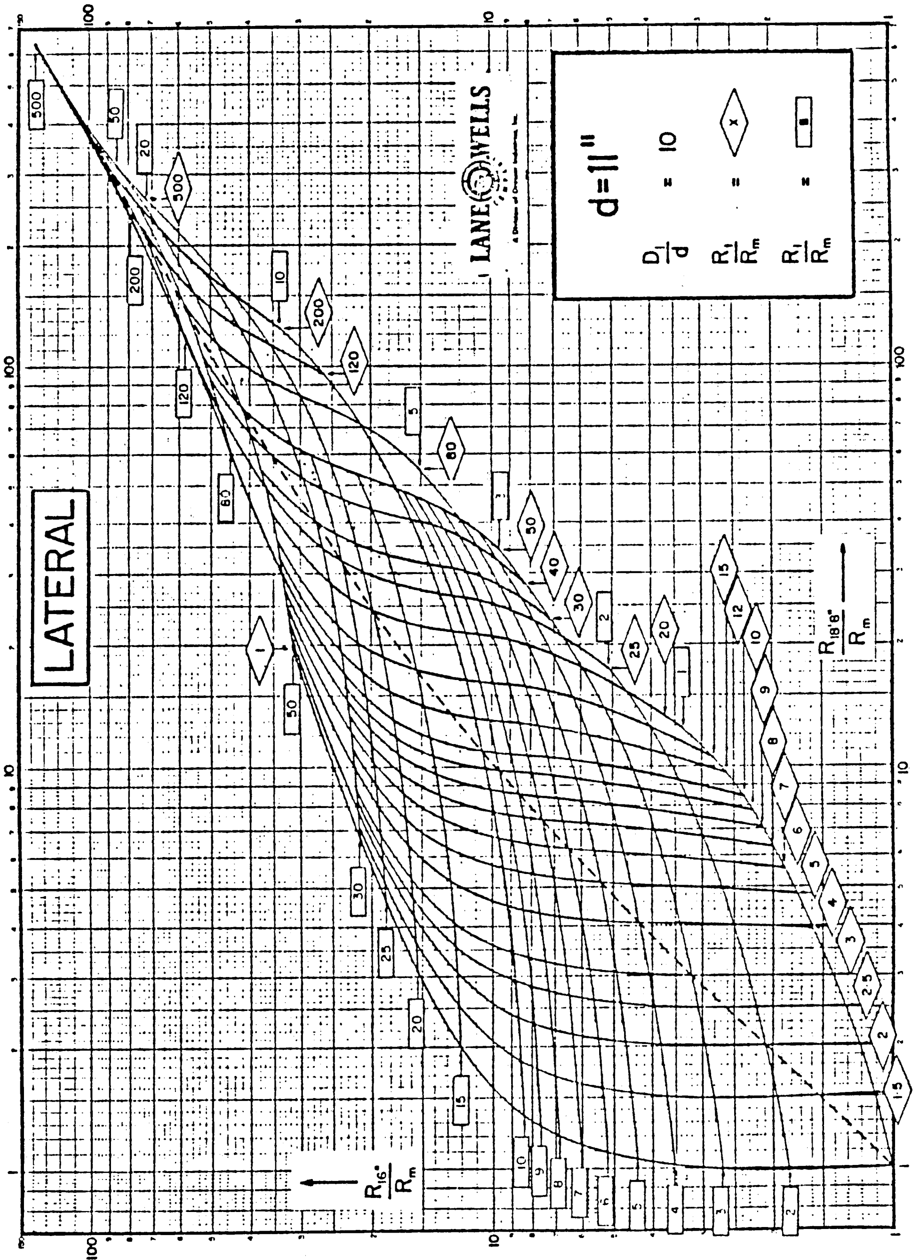

NORMAL
LANE-WELLS
A Division of Dresser Industries, Inc.
d = 11"
$\frac{D_i}{d}$ = 2
$\frac{R_t}{R_m}$ = ◇
$\frac{R_i}{R_m}$ = ▭
$\frac{R_{16''}}{R_m}$
$\frac{R_{64''}}{R_m}$
500
200
120
80
50
40
30
25
20
15
12
10
9
8
7
6
5
4
3
2.5
2
1.5
1
2000
20
10
500
5
1
200
120
80
50
30
25
20
15
10
9
8
7
6
5
4
3
2
1
10
100

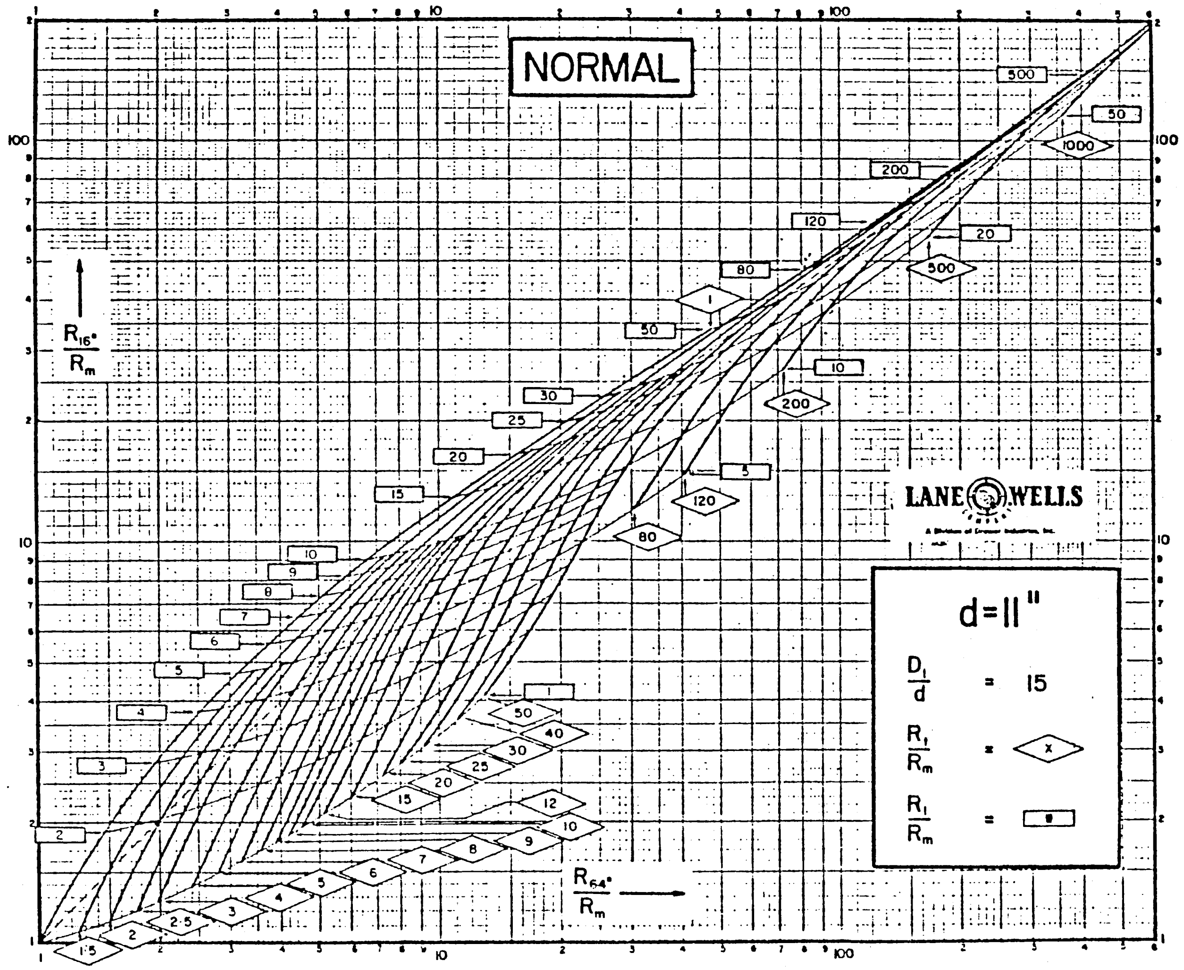

LATERAL
LANE-WELLS
A Division of Dresser Industries, Inc.
d=11"
$\frac{D_1}{d}$ = 2
$\frac{R_i}{R_m}$ = ◇x
$\frac{R_i}{R_m}$ = ■
$\frac{R_{16"}}{R_m}$
$\frac{R_{18'8"}}{R_m}$
2000
50
20
200
10
5
120
500
80
1
50
40
30
25
20
200
15
12
10
9
8
7
6
5
4
3
2.5
2
1.5
120
80
1
50
30
15
20
15
10
9
8
7
6
5
4
3
2
100
10
1

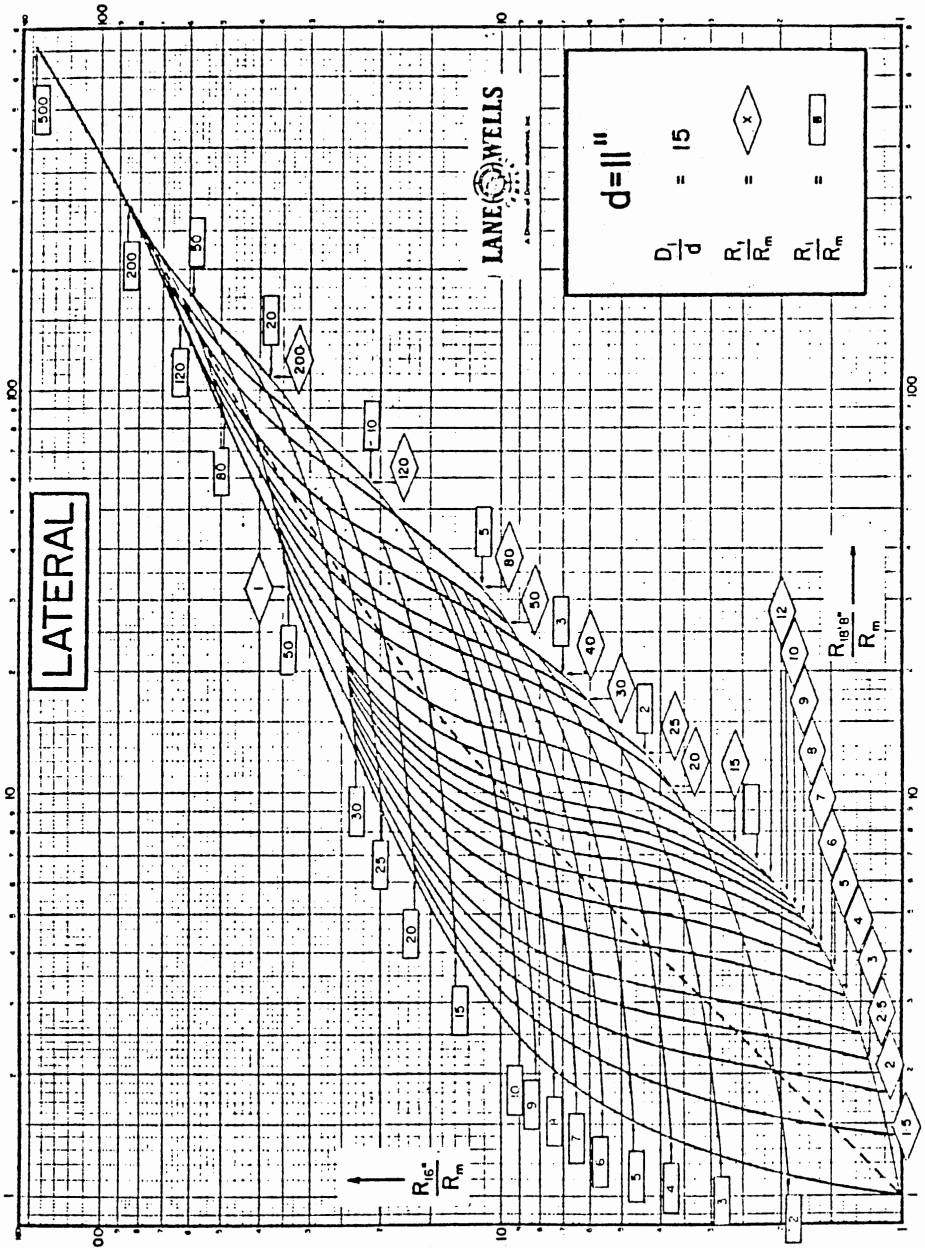

NORMAL
$\frac{R_{16"}}{R_m}$
$\frac{R_{64"}}{R_m}$
LANE-WELLS
A Division of Dresser Industries, Inc.
d=11"
$\frac{D_i}{d}$ = 5
$\frac{R_i}{R_m}$ = ◇
$\frac{R_i}{R_m}$ = ▭
50
1000
500
20
500
200
10
200
120
5
120
80
80
1
50
1
30
25
20
15
10
9
8
7
6
5
4
3
2
50
40
30
25
20
15
12
10
9
8
7
6
5
4
3
2.5
2
1.5
1
2
3
4
5
6
7
8
9
10
100

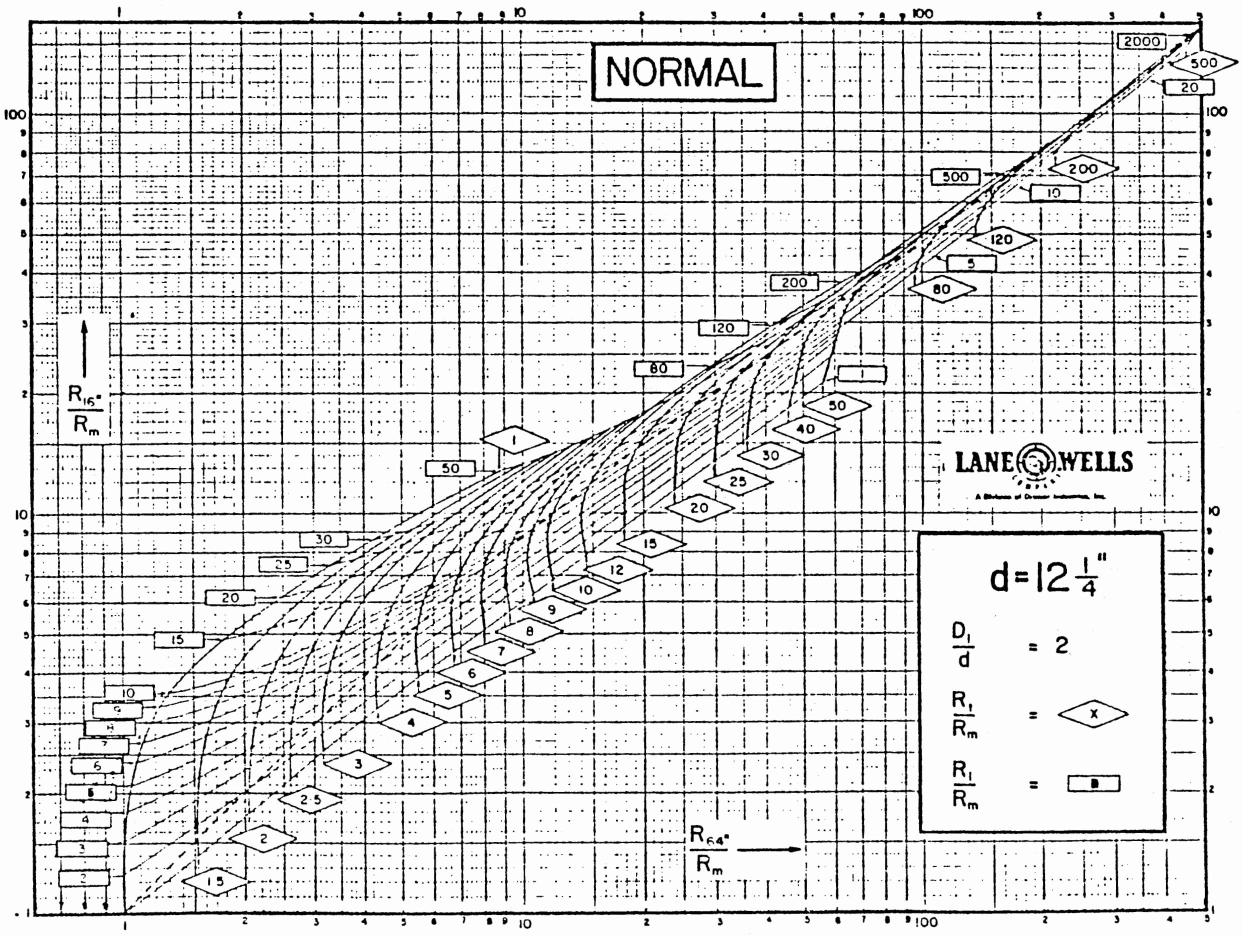

LATERAL
LANE-WELLS
A Division of Dresser Industries, Inc.
d = 11"
D_i/d = 5
R_i/R_m = ◇x
R_i/R_m = ■
R_16"/R_m
R_18'8"/R_m
500
200
120
80
50
30
25
20
15
10
9
8
7
6
5
4
3
2
1
40
12
2.5
1.5
100
10
1

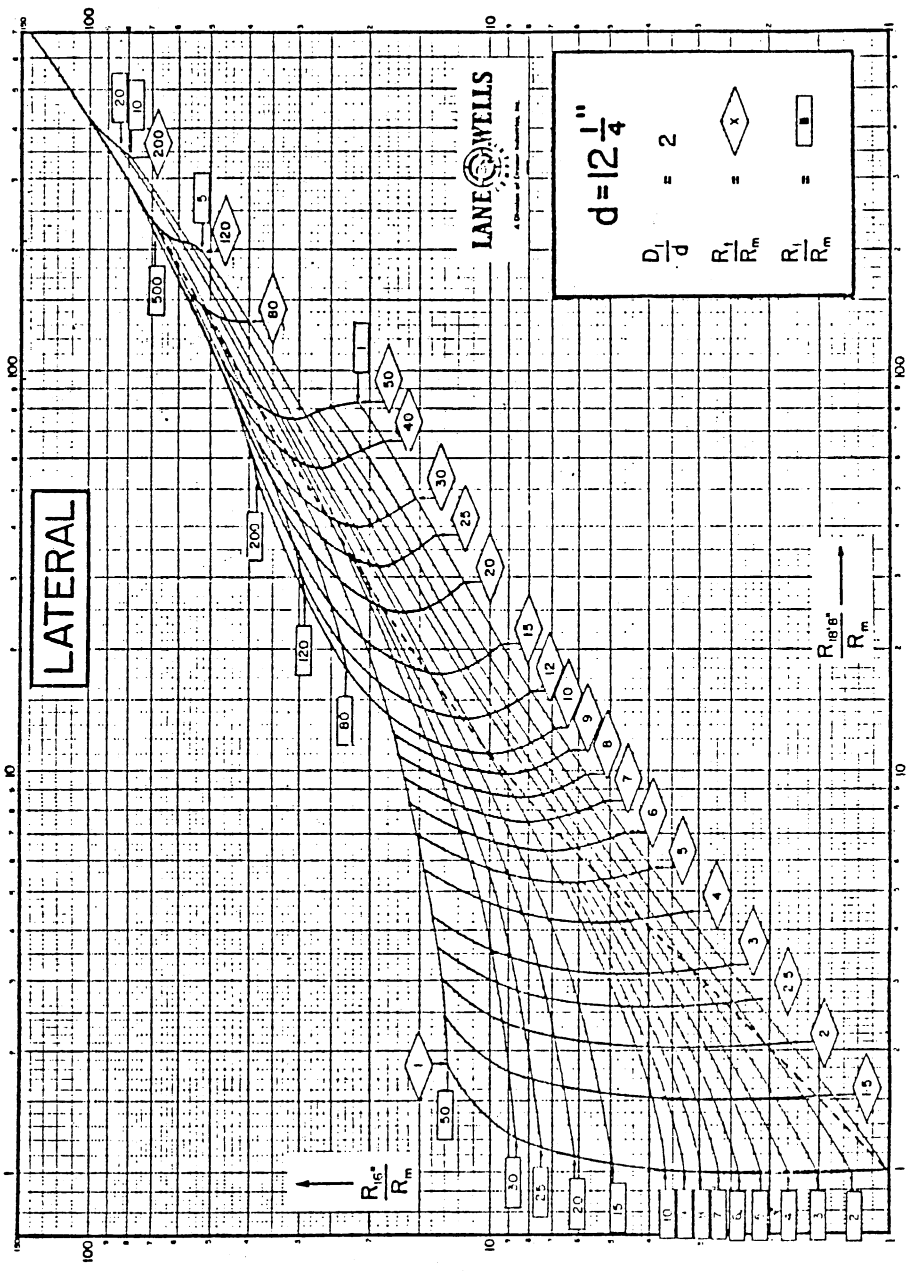

NORMAL
LANE-WELLS
d=11"
$\frac{D_i}{d}$ = 10
$\frac{R_i}{R_m}$ = ◇
$\frac{R_t}{R_m}$ = ▭
$\frac{R_{16"}}{R_m}$
$\frac{R_{64"}}{R_m}$

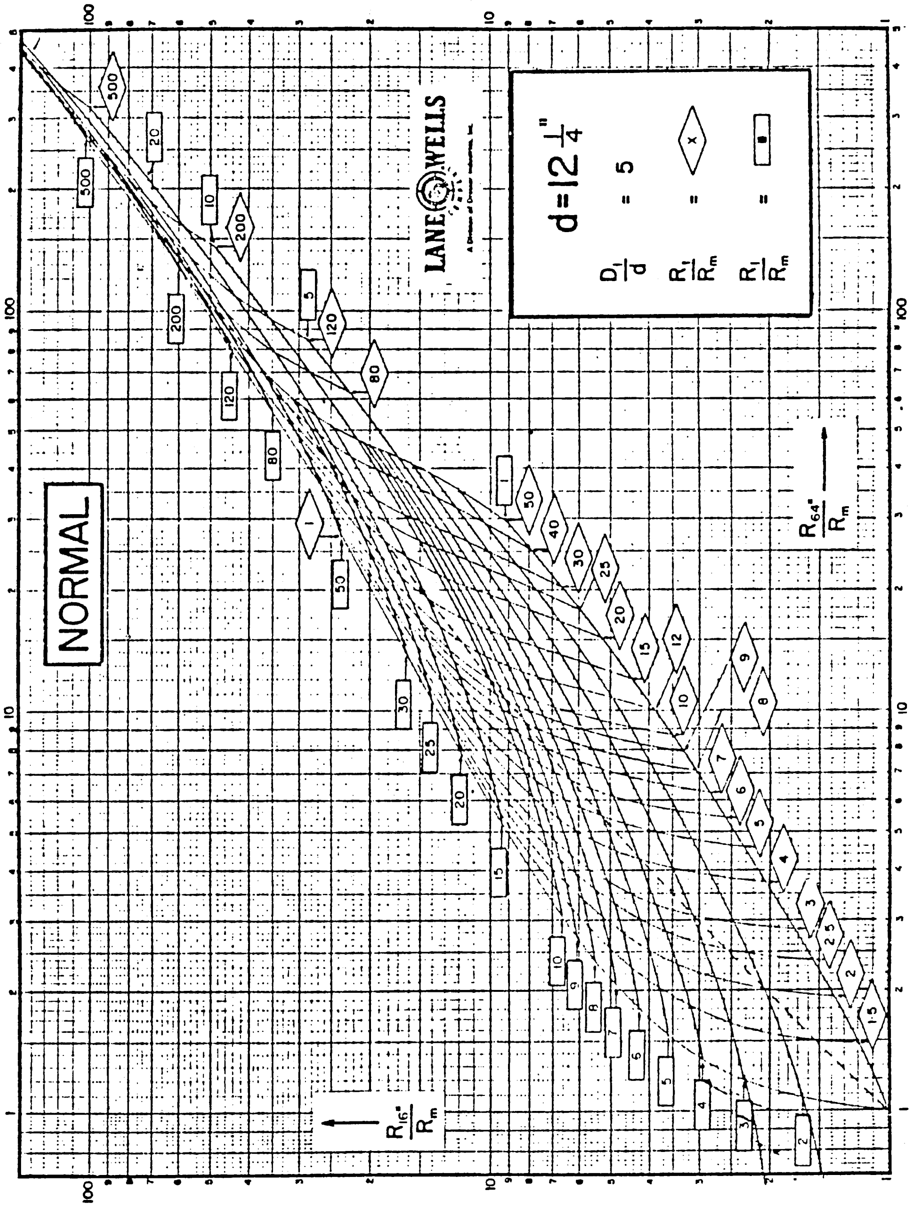

LATERAL
LANE WELLS
A Division of Dresser Industries, Inc.
d=11"
$\frac{D_1}{d}$ = 10
$\frac{R_1}{R_m}$ = x
$\frac{R_1}{R_m}$ = ▪
$\frac{R_{16"}}{R_m}$
$\frac{R_{18'8"}}{R_m}$
1
10
100
1000
500
200
120
80
50
40
30
25
20
15
12
10
9
8
7
6
5
4
3
2.5
2
1.5
1

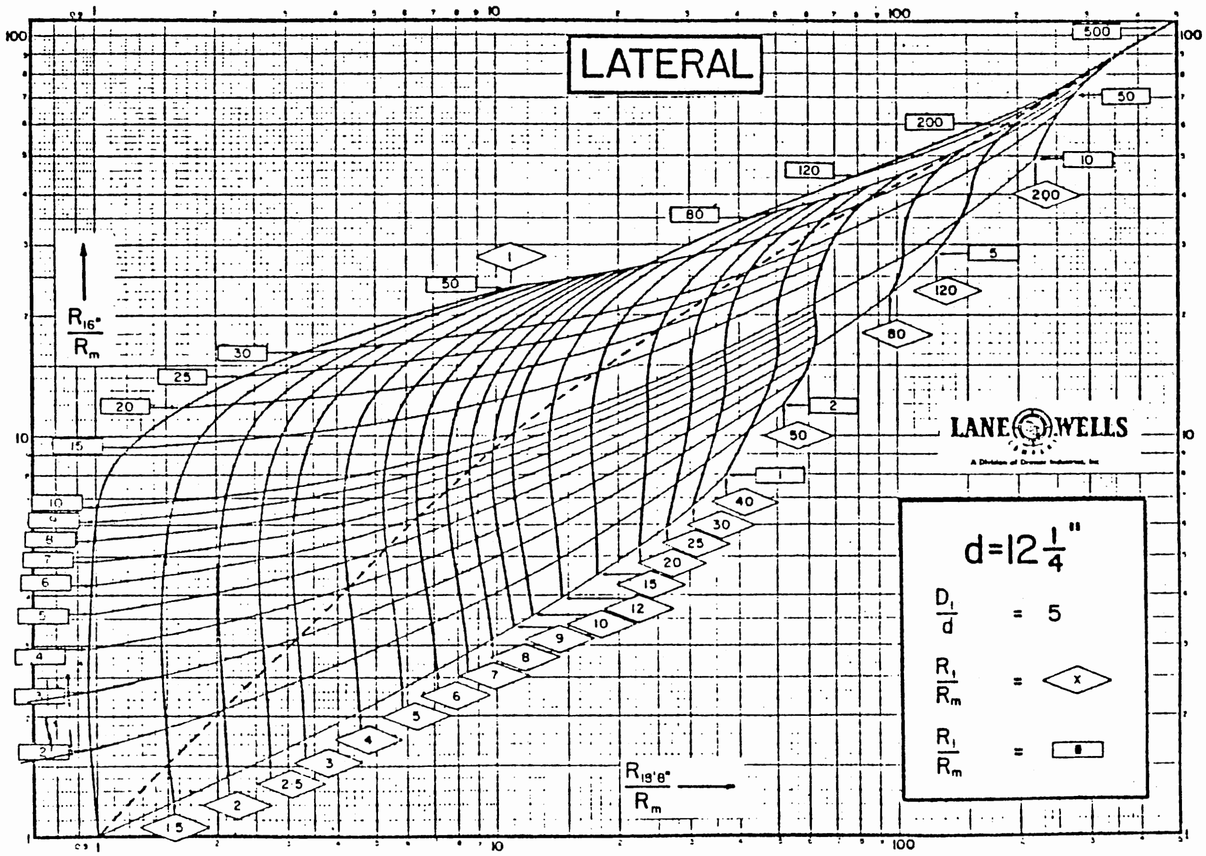

NORMAL
LANE WELLS
d=11"
$\frac{D_i}{d}$ = 15
$\frac{R_i}{R_m}$ = ◇
$\frac{R_t}{R_m}$ = ▭
$\frac{R_{16''}}{R_m}$
$\frac{R_{64''}}{R_m}$
1
10
100
1.5
2
2.5
3
4
5
6
7
8
9
10
12
15
20
25
30
40
50
80
120
200
500
1000

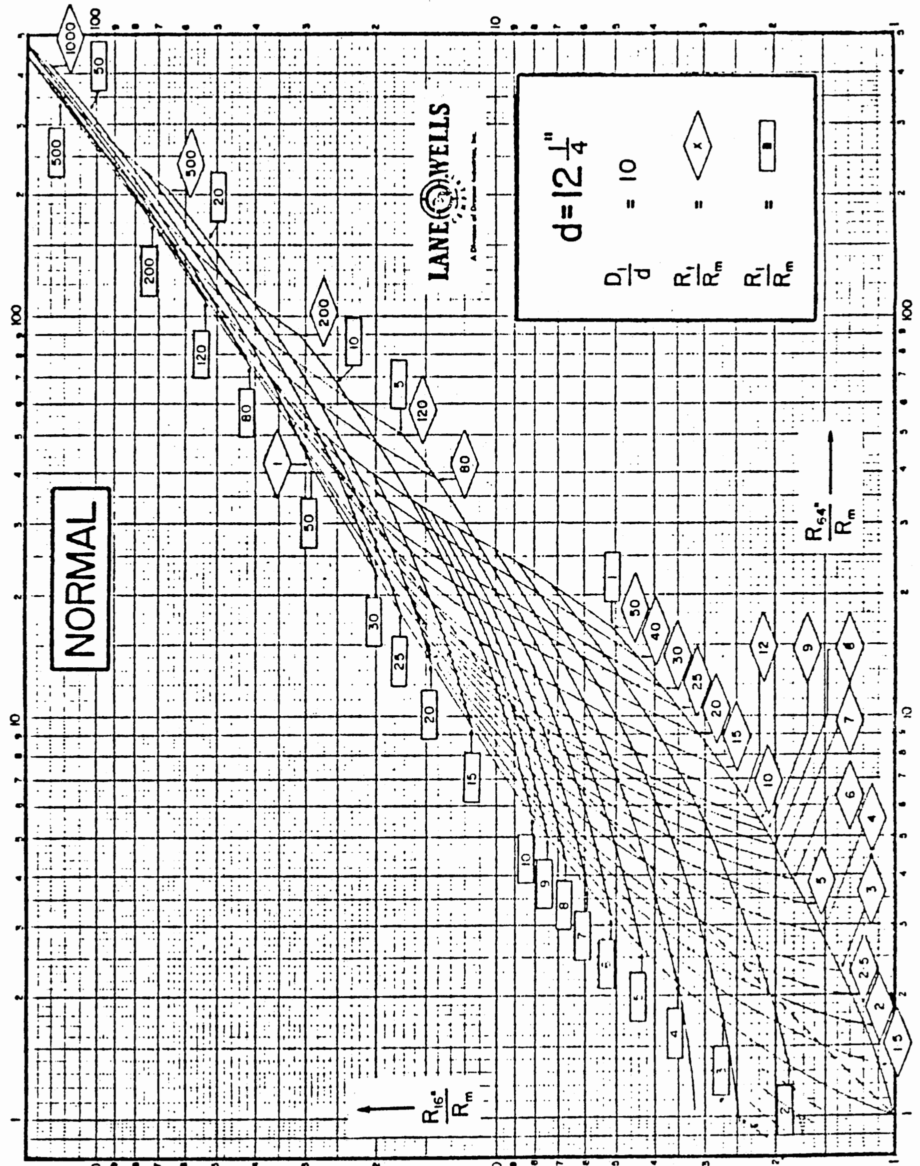

LATERAL
LANE WELLS
A Division of Dresser Industries, Inc.
d=11"
D1/d = 15
R1/Rm = ◇x
R1/Rm = ▭
R16"/Rm
R18'8"/Rm
1
10
100
1000
500
200
120
80
50
30
25
20
15
10
9
8
7
6
5
4
3
2
1.5
1
12
40

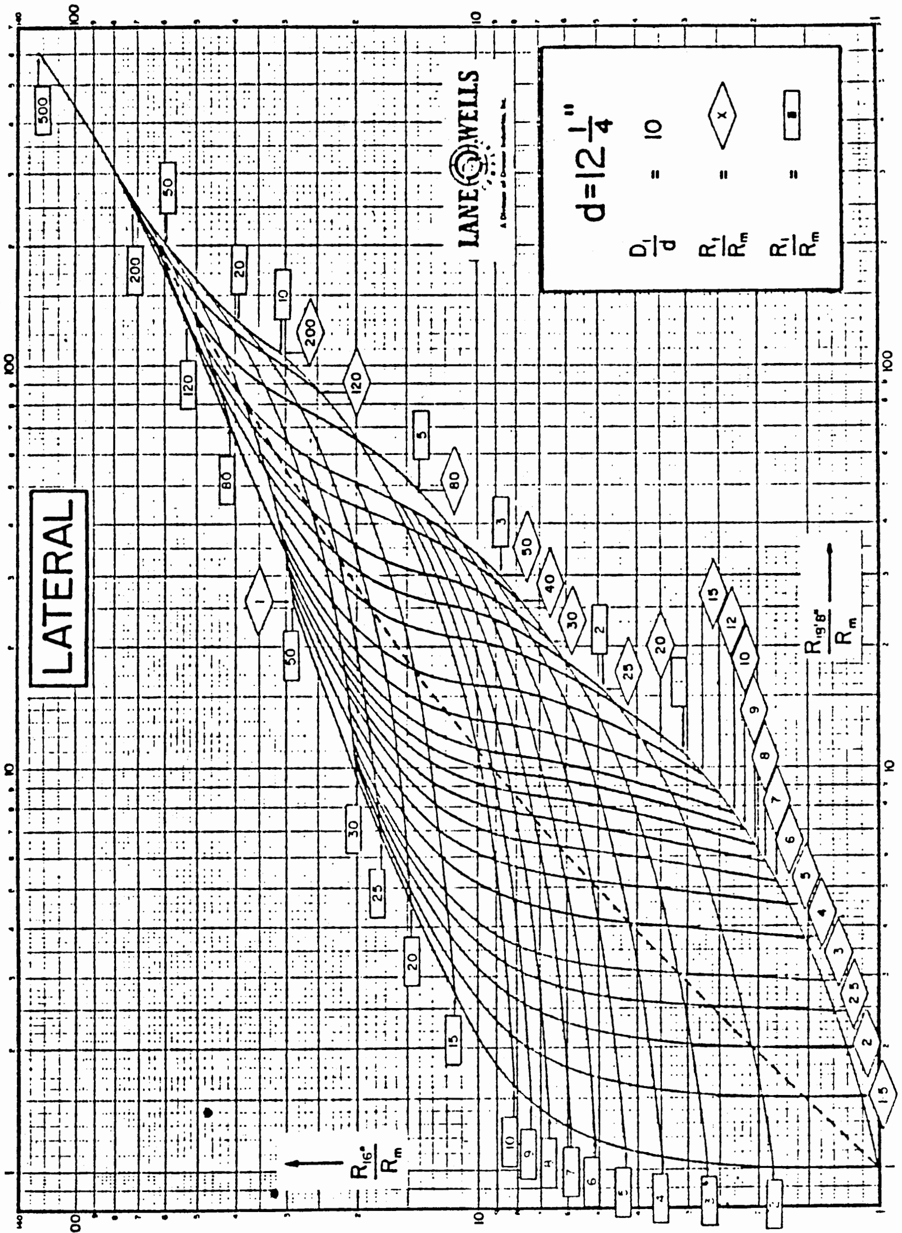

NORMAL
LANE WELLS
A Division of Dresser Industries, Inc.
d = 12 1/4"
D_1/d = 2
R_i/R_m = ◇ x
R_i/R_m = ▭
R_16"/R_m
R_64"/R_m
2000
500
20
200
10
500
120
5
200
80
120
80
1
50
40
30
25
20
15
12
10
9
8
7
6
5
4
3
2.5
2
1.5
1
50
30
25
20
15
10
9
8
7
6
5
4
3
2
1
10
100

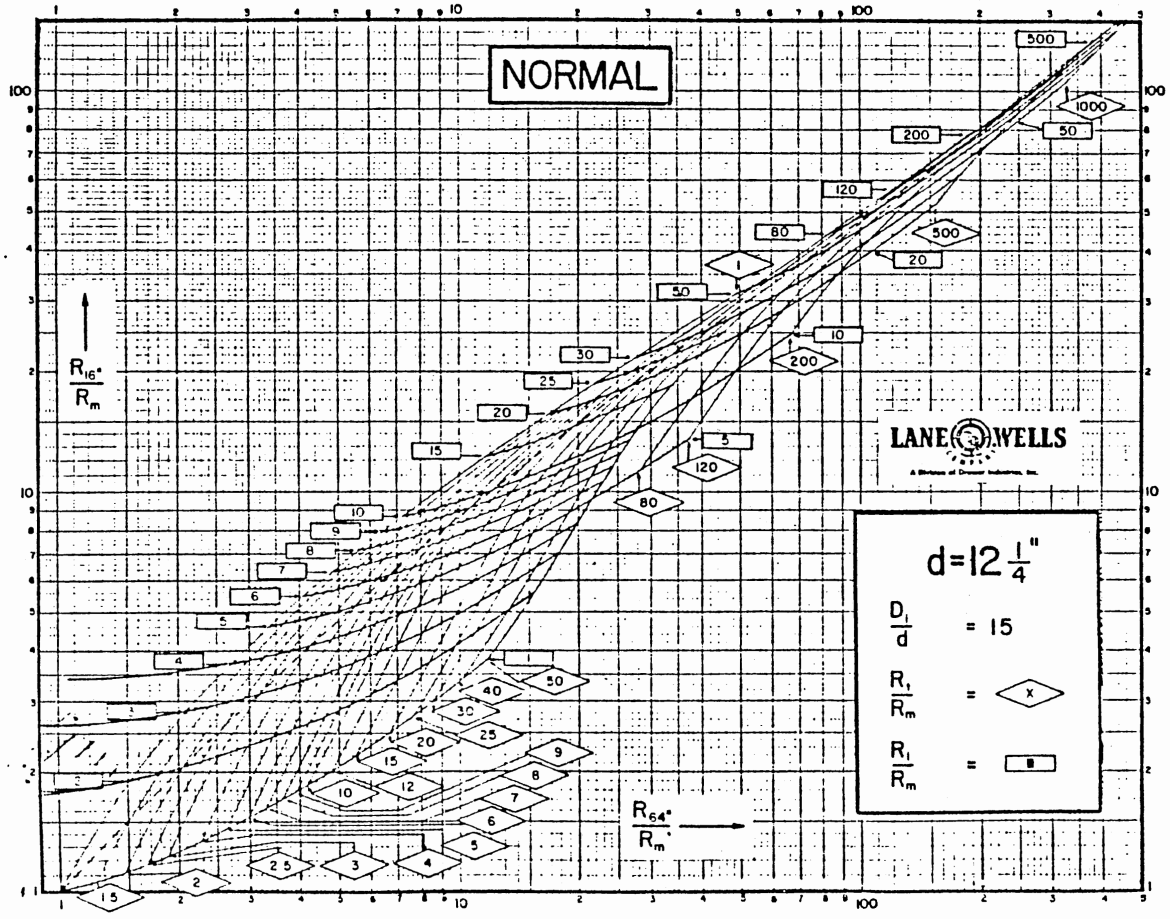

LATERAL
LANE-WELLS
d=12 1/4"
D_i/d = 2
R_i/R_m = ◇
R_t/R_m = ▭
R16"/Rm
R18'8"/Rm
1
10
100
1
1.5
2
2.5
3
4
5
6
7
8
9
10
12
15
20
25
30
40
50
80
120
200
2
3
4
5
6
7
8
10
15
20
25
30
50
80
120
200
500
1
5
10
20

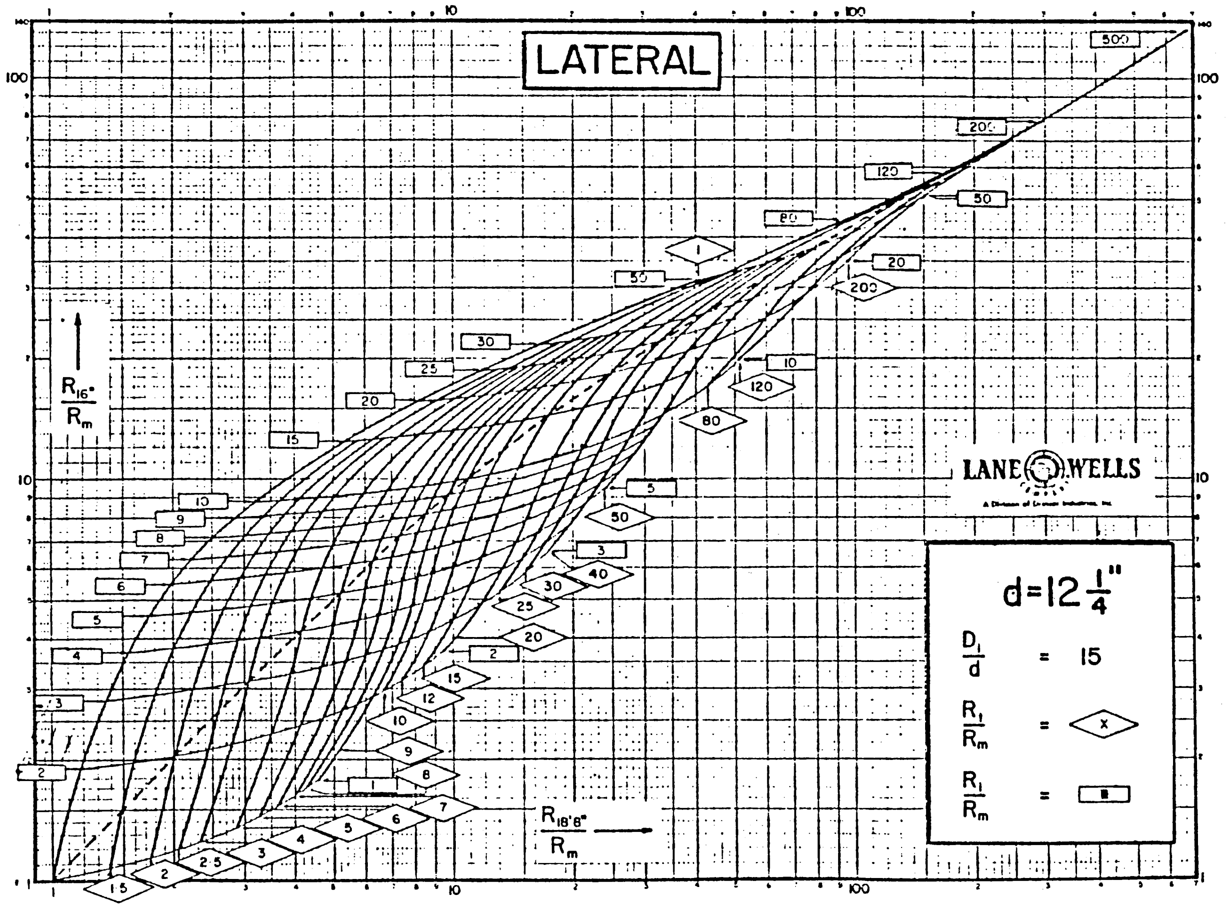

NORMAL
LANE-WELLS
d = 12 1/4"
D_i/d = 5
R_i/R_m = ◇
R_i/R_m = ▭
R16"/Rm
R64"/Rm
500
200
120
80
50
40
30
25
20
15
12
10
9
8
7
6
5
4
3
2.5
2
1.5
1
2
3
4
5
6
7
8
9
10
15
20
25
30
50
80
120
200
500
10
20
1
10
100


LATERAL
LANE WELLS
A Division of Dresser Industries, Inc.
d=12 1/4"
$\frac{D_1}{d}$ = 5
$\frac{R_1}{R_m}$ = ◇
$\frac{R_i}{R_m}$ = ▭
$\frac{R_{16"}}{R_m}$
$\frac{R_{19'8"}}{R_m}$
1
10
100
500
50
200
10
120
200
80
5
1
120
50
80
30
25
2
20
50
15
1
40
10
30
9
25
8
20
7
15
6
12
5
10
9
4
8
7
3
6
2
5
4
3
2.5
2
1.5


NORMAL
LANE-WELLS
A Division of Dresser Industries, Inc.
d=12 1/4"
D/d = 10
Ri/Rm = ◇
Ri/Rm = ▭
R16"/Rm
R64"/Rm


LATERAL
LANE WELLS
$d = 12\frac{1}{4}''$
$\frac{D_1}{d} = 10$
$\frac{R_1}{R_m}$ = ◇
$\frac{R_i}{R_m}$ = ▭
$\frac{R_{16''}}{R_m}$
$\frac{R_{19'8''}}{R_m}$
1
10
100
500
200
120
80
50
40
30
25
20
15
12
10
9
8
7
6
5
4
3
2.5
2
1.5
1


NORMAL
LANE-WELLS
d=12 1/4"
D_i/d = 15
R_i/R_m = ◇
R_i/R_m = ▭
R16"/R_m
R64"/R_m
1
10
100
500
1000
50
200
120
500
80
1
20
50
10
30
200
25
20
5
15
120
80
10
9
8
7
6
5
4
50
40
30
25
20
9
15
10
12
8
7
6
5
2.5
3
4
2
1.5


LATERAL
LANE-WELLS
A Division of Dresser Industries, Inc.
d=12 1/4"
D₁/d = 15
R₁/Rm = ◇ x
R₁/Rm = ▭
R16"/Rm
R18'8"/Rm
1
10
100
500
200
120
80
50
30
25
20
15
10
9
8
7
6
5
4
3
2
1
1.5
2
2.5
3
4
5
6
7
8
9
10
12
15
20
25
30
40
50
80
120
200

APPENDIX E

DATA SHEETS FROM ANALYSES OF OLD ELECTRIC LOGS IN "WET" RED FORK SANDSTONE, PAYNE COUNTY

COMPANY : W. H. MARTGAN

WELL : GOOM No. 1

FIELD : Wildcat

LOCATION : NE, NE, NE Sec. 30, T19N, R 3E ; Payne Co. Okla.

FORMATION : Red Fork Sandstone

FROM HEADER

Rm = 2.2 @ 66 degrees F.   Bit Size 7 7/8 inches

Rm = 1.2 @ 120 Degrees F. (B.H.T.)

Depth of Red Fork = 4070 ft.   Temp. of Fmt. 114 °F

Rm @ Fmt. Temp. = 1.3   Fmt. Thickness 30 ft.

Resistivity of Shale (Normals) = 8   PSP = −110 mv

Resistivity of Shale (Lateral) = 8   SSP = −110 mv

UNCORRECTED DATA	CORRECTED DATA	CHART No.
Rsn = 17	Rsn = 16	A-1
Rln = 4.5	Rln = 5.0	A-2
Rlat = 1.8	Rlat = 1.8	A-3

Rsn(corr.)/Rm = 12.3. Rln(corr.)/Rm = 3.8. Rlat(corr.)/Rm = 1.38.

LANE WELLS DEPARTURE CURVES DATA

	NORMALS			LATERAL		
Di/d	Rt/Rm	Ri/Rm	Ri/Rt	Rt/Rm	Ri/Rm	Ri/Rt
2	1.0	50	50	1.4	48	34.5
5	1.0	21	21	1.5	21	14
10	< 1.0	16	—	1.4	16	11.5
15	<< 1.0	15	—	1.1	15	13.6

Rt/Rm = ≃1.2   Ri/Rm = ≃21   Ri/Rt = ≃17   Rt = 1.6

******** NOTE: All resistivities reported in Ohm-m **********

COMPANY : W.C. ALLEN
WELL : CALDWELL No. 1
FIELD : Wildcat
LOCATION : SE, SE, NW Sec. 25, T 18N, R 2E ; Payne Co. Okla.
FORMATION : Red Fork Sandstone

FROM HEADER

Rm = 1.7 @ 84 degrees F.　Bit Size 9 inches
Rm = 1.3 @ 112 Degrees F. (B.H.T.)
Depth of Red Fork = 4214 ft.　Temp. of Fmt. 108.6 °F
Rm @ Fmt. Temp. = 1.35　Fmt. Thickness 20 ft.
Resistivity of Shale (Normals) = 7　PSP = -95 mv
Resistivity of Shale (Lateral) = 7　SSP = -100 mv

UNCORRECTED DATA	CORRECTED DATA	CHART No.
Rsn = 19	Rsn = 20	A-1
Rln = 7.5	Rln = 7.5	A-2
Rlat = 2.0	Rlat = —	A-3

Rsn(corr.)/Rm = 14.8.　Rln(corr.)/Rm = 5.6.　Rlat(corr.)/Rm = —.

LANE WELLS DEPARTURE CURVES DATA

	NORMALS			LATERAL		
Di/d	Rt/Rm	Ri/Rm	Ri/Rt	Rt/Rm	Ri/Rm	Ri/Rt
2	1.25	51	40.8			
5	1	22.5	22.5			
10	< 1	17	—			
15	< 1	15.2	—			

Rt/Rm = 1　Ri/Rm = 22.5　Ri/Rt = 22.5　Rt = 1.35

******* NOTE: All resistivities reported in Ohm-m **********

COMPANY : Wilcox Oil Company
WELL : W.B. DAVIS No 1
FIELD : Wildcat
LOCATION : Sw, Sw, NE Sec. 2, T 18N, R 3E ; Payne Co. Okla.
FORMATION : Red Fork Sandstone

FROM HEADER

Rm = 2.0 @ 70 degrees F. Bit Size 9 inches
Rm = 1.2 @ 121 Degrees F. (B.H.T.)
Depth of Red Fork = 3890 ft. Temp. of Fmt. 118.7 °F
Rm @ Fmt. Temp. = 1.24 Fmt. Thickness 45 ft.
Resistivity of Shale (Normals) = 10 PSP = -120 mv
Resistivity of Shale (Lateral) = 7 SSP = -120 mv

UNCORRECTED DATA	CORRECTED DATA	CHART No.
Rsn = 9	Rsn = 9	A-1
Rln = 2	Rln = 1.7	A-2
Rlat = 1.8	Rlat = 1.8	A-3

Rsn(corr.)/Rm = 7.3. Rln(corr.)/Rm = 1.4. Rlat(corr.)/Rm = 1.45.

LANE WELLS DEPARTURE CURVES DATA

	NORMALS			LATERAL		
Di/d	Rt/Rm	Ri/Rm	Ri/Rt	Rt/Rm	Ri/Rm	Ri/Rt
2	≥0.8	24	—	1.38	22.5	16.3
5	< 1	11	—	1.5	10.3	6.9
10	< 1	8.2	—	1.45	8.3	5.7
15	< 1	7.5	—	1.2	7.6	6.3

Rt/Rm = 1.2 Ri/Rm = 23 Ri/Rt = 19.2 Rt = 1.5

******** NOTE: All resistivities reported in Ohm-m **********

COMPANY : Gulf Oil Company

WELL : Hathe OFFIELD No. 1

FIELD : Wildcat

LOCATION : SW, SW, NE Sec. 31, T 18N, R 3E ; Payne Co. Okla.

FORMATION : Red Fork Sandstone

FROM HEADER

Rm = 1.7 @ 80 degrees F. Bit Size 9 inches

Rm = 1.0 @ 120 Degrees F. (B.H.T.)

Depth of Red Fork = 4195 ft. Temp. of Fmt. 115.2 °F

Rm @ Fmt. Temp. = 1.08 Fmt. Thickness 26 ft.

Resistivity of Shale (Normals) = 10 PSP = -110 mv

Resistivity of Shale (Lateral) = 5 SSP = -110 mv

UNCORRECTED DATA	CORRECTED DATA	CHART No.
Rsn = 15.5	Rsn = 15	A-1
Rln = 5	Rln = 5	A-2
Rlat = 1.4	Rlat = 1.4	A-3

Rsn(corr.)/Rm = 13.9. Rln(corr.)/Rm = 4.6. Rlat(corr.)/Rm = 1.3.

LANE WELLS DEPARTURE CURVES DATA

	NORMALS			LATERAL		
Di/d	Rt/Rm	Ri/Rm	Ri/Rt	Rt/Rm	Ri/Rm	Ri/Rt
2	< 1	50	—	1.2	48	40
5	< 1	20.5	—	1.2	21	17.5
10	< 1	15.3	—	1.0	16	16
15	< 1	14.6	—	< 1	15.1	—

Rt/Rm = 1.2 Ri/Rm = 20.75 Ri/Rt = 17.3 Rt = 1.3

******** NOTE: All resistivities reported in Ohm-m **********

COMPANY : W.H. MARTEAN
WELL : Schreeder No. 1
FIELD : Wildcat
LOCATION : SW.NE,NW Sec. 34, T 19N, R 3E ; Payne Co. Okla.
FORMATION : Red Fork Sandstone

FROM HEADER

Rm = .2 @ 68 degrees F. Bit Size 7 7/8 inches
Rm = 1.2 @ 113 Degrees F. (B.H.T.)
Depth of Red Fork = 3906 ft. Temp. of Fmt. 112 °F
Rm @ Fmt. Temp. = 1.22 Fmt. Thickness 22 ft.
Resistivity of Shale (Normals) = 5 PSP = -100 mv
Resistivity of Shale (Lateral) = 5 SSP = -100 mv

UNCORRECTED DATA	CORRECTED DATA	CHART No.
Rsn = 8.5	Rsn = 8.2	A-1
Rln = 2.3	Rln = 2.0	A-2
Rlat = 1.5	Rlat = 1.5	A-3

Rsn(corr.)/Rm = 6.7. Rln(corr.)/Rm = 1.6. Rlat(corr.)/Rm = 1.2.

LANE WELLS DEPARTURE CURVES DATA

	NORMALS			LATERAL		
Di/d	Rt/Rm	Ri/Rm	Ri/Rt	Rt/Rm	Ri/Rm	Ri/Rt
2	1.15	22.5	19.6	1.2	22	18.3
5	1.07	10	9.3	1.25	4.9	7.9
10	< 1	7.5	—	1.28	7.7	6
15	< 1	6.7	—	1.18	7	5.4

Rt/Rm = 1.6 Ri/Rm = 22.25 Ri/Rt = 13.9 Rt = 1.95

******** NOTE: All resistivities reported in Ohm-m **********

COMPANY : TEXAS PACIFIC COAL & Oil Company

WELL : STOKY No. 3

FIELD : N. Cothegham

LOCATION : NW, NE, NW Sec. 1, T 17N, R 3E ; Payne Co. Okla.

FORMATION : Red Fork Sandstone

FROM HEADER

Rm = 1.1 @ 95 degrees F. Bit Size 8 3/4 inches

Rm = 0.89 @ 115 Degrees F. (B.H.T.)

Depth of Red Fork = 3864 ft. Temp. of Fmt. 112.5 °F

Rm @ Fmt. Temp. = 0.92 Fmt. Thickness 50 ft.

Resistivity of Shale (Normals) = 8 PSP = -105 mv

Resistivity of Shale (Lateral) = 8 SSP = -105 mv

UNCORRECTED DATA	CORRECTED DATA	CHART No.
Rsn = 15	Rsn = 16	A-1
Rln = 6	Rln = 5.4	A-2
Rlat = 1.5	Rlat = 1.5	A-3

Rsn(corr.)/Rm = 17.4. Rln(corr.)/Rm = 5.9. Rlat(corr.)/Rm = 1.6.

LANE WELLS DEPARTURE CURVES DATA

	NORMALS			LATERAL		
Di/d	Rt/Rm	Ri/Rm	Ri/Rt	Rt/Rm	Ri/Rm	Ri/Rt
2	< 1	55	—	≃ 1.4	57	40.7
5	< 1	26	—	1.38	27	19.6
10	< 1	20	—	1.0	20	20
15	< 1	19	—	< 1	19	—

Rt/Rm = 1.38 Ri/Rm = 27 Ri/Rt = 19.6 Rt = 1.3

******** NOTE: All resistivities reported in Ohm-m **********

COMPANY : Home Gas Company of Cushing

WELL : Lovell Bros. No. 1

FIELD : Semi-wildcat

LOCATION : SW, SE, NW Sec. 35, T 18N, R 3E ; Payne Co. Okla.

FORMATION : Red Fork Sandstone

FROM HEADER

Rm = 3.0 @ 62 degrees F. Bit Size 8 3/4 inches

Rm = 1.6 @ 112 Degrees F. (B.H.T.)

Depth of Red Fork = 3955 ft. Temp. of Fmt. 106.7 °F

Rm @ Fmt. Temp. = 1.75 Fmt. Thickness 30 ft.

Resistivity of Shale (Normals) = 10 PSP = -112 mv

Resistivity of Shale (Lateral) = 10 SSP = -112 mv

UNCORRECTED DATA	CORRECTED DATA	CHART No.
Rsn = 23	Rsn = 23	A-1
Rln = 7.2	Rln = 7.2	A-2
Rlat = 1.8	Rlat = 1.8	A-3

Rsn(corr.)/Rm = 13.1. Rln(corr.)/Rm = 4.1. Rlat(corr.)/Rm = 1.03.

LANE WELLS DEPARTURE CURVES DATA

	NORMALS			LATERAL		
Di/d	Rt/Rm	Ri/Rm	Ri/Rt	Rt/Rm	Ri/Rm	Ri/Rt
2	< 1	45	—	< 1	48	—
5	< 1	20	—	1	20	20
10	<< 1	17	—	< 1	16	—
15	<< 1	16	—	<< 1	13	—

Rt/Rm = 1 Ri/Rm = 20 Ri/Rt = 20 Rt = 1.75

******** NOTE: All resistivities reported in Ohm-m **********

COMPANY : Russell McGuire

WELL : Testerman No. 2

FIELD : W. MEHAN

LOCATION : NW, SE, SE Sec. 10, T 18N, R 3E ; Payne Co. Okla.

FORMATION : Red Fork Sandstone

FROM HEADER

Rm = 3.6 @ 44 degrees F. Bit Size 9 inches

Rm = 1.4 @ 110 Degrees F. (B.H.T.)

Depth of Red Fork = 3820 ft. Temp. of Fmt. 108 °F

Rm @ Fmt. Temp. = 1.45 Fmt. Thickness 25 ft.

Resistivity of Shale (Normals) = 8 PSP = -100 mv

Resistivity of Shale (Lateral) = 8 SSP = -100 mv

UNCORRECTED DATA	CORRECTED DATA	CHART No.
Rsn = 8	Rsn = 7.5	A-1
Rln = 1.8	Rln = 1.6	A-2
Rlat = 1.6	Rlat = 1.6	A-3

Rsn(corr.)/Rm = 5.2. Rln(corr.)/Rm = 1.1. Rlat(corr.)/Rm = 1.1.

LANE WELLS DEPARTURE CURVES DATA

	NORMALS			LATERAL		
Di/d	Rt/Rm	Ri/Rm	Ri/Rt	Rt/Rm	Ri/Rm	Ri/Rt
2	< 1	16.5	—	1.08	16.5	15.3
5	< 1	7.4	—	1.15	7.4	6.4
10	<< 1	5.9	—	1.15	5.9	5.1
15	<< 1	5.3	—	< 1	5.3	—

Rt/Rm = 1.08 Ri/Rm = 16.5 Ri/Rt = 15.3 Rt = 1.6

******** NOTE: All resistivities reported in Ohm-m **********

APPENDIX F

POSITIONING AND SLOPE OF AN Ro LINE ON A SATURATION CHART

Positioning of Ro Line on Saturation Chart

The following information is intended to calrify how the position and slope of an Ro line have been established. Reference to calculated Rxo/Rt values, temperature, and SP is illustrated in the accompanying saturation chart.

(A) ASSUME: Drilling mud and formation water contain Similar salts, primarily sodium chloride.

GIVEN: 1) $SP = -K * Log(Rmf/Rw)$ (Guyod, 1974, p. 4-7; Dresser Atlas, 1982, p. 75).

2) $K = (60 + 0.138 * Tf)$, where Tf = temperature of formation (After Dresser Atlas Division, 1975, Chart 4, constant 0.138 midified from 0.133 in the instance of this saturation chart).

(B) ASSUME: $Sw = 1$ and $Sxo = 1$

Therefore: 3) $Sw = 1 = F * Rw/Rt$ and $Rw = Rt/F$

4) $Sxo = 1 = F * Rmf/Rxo$ and $Rmf = Rxo/F$

5) Rmf/Rw (equation 1) $= (Rxo/F)/(Rt/F) = Rxo/Rt$

6) $SP = -K * Log(Rxo/Rt)$

(C) ASSUME: $Tf = 100$ degrees F.

Therefore: 7) $K = (60 + 0.138 * Tf) = -73.8$

(D) ASSUME: $SP = -10$

Therefore: 8) $-10 = -73.8 * Log(Rxo/Rt)$

9) $Log(Rxo/Rt) = -10/-73.8$

10) Rxo/Rt = 1.367 (point A)

(E) ASSUME: SP = -100

Therefore: 11) -100 = -73.8 * Log(Rxo/Rt)

12) Log(Rxo/Rt) = -100/-73.8

13) Rxo/Rt = 22.65 (point B)

Therefore: 14) -SP = -K * Log(Rxo/Rt)

15) Log(Rxo/Rt) = -SP/-K

16) Log(Rxo/Rt) = SP * 1/K

17) Log(Rxo/Rt) = 0.013550136 * SP

Therefore: Slope of Ro line = 0.0136

(F) ASSUME: Tf = 150 degrees F.

Therefore: 18) K = (60 + 0.138 * 150) = -80.7

(G) ASSUME: SP = -10

Therefore: 19) -10 = -80.7 * Log(Rxo/Rt)

20) Log(Rxo/Rt) = -10/-80.7

21) Rxo/Rt = 1.33 (point C)

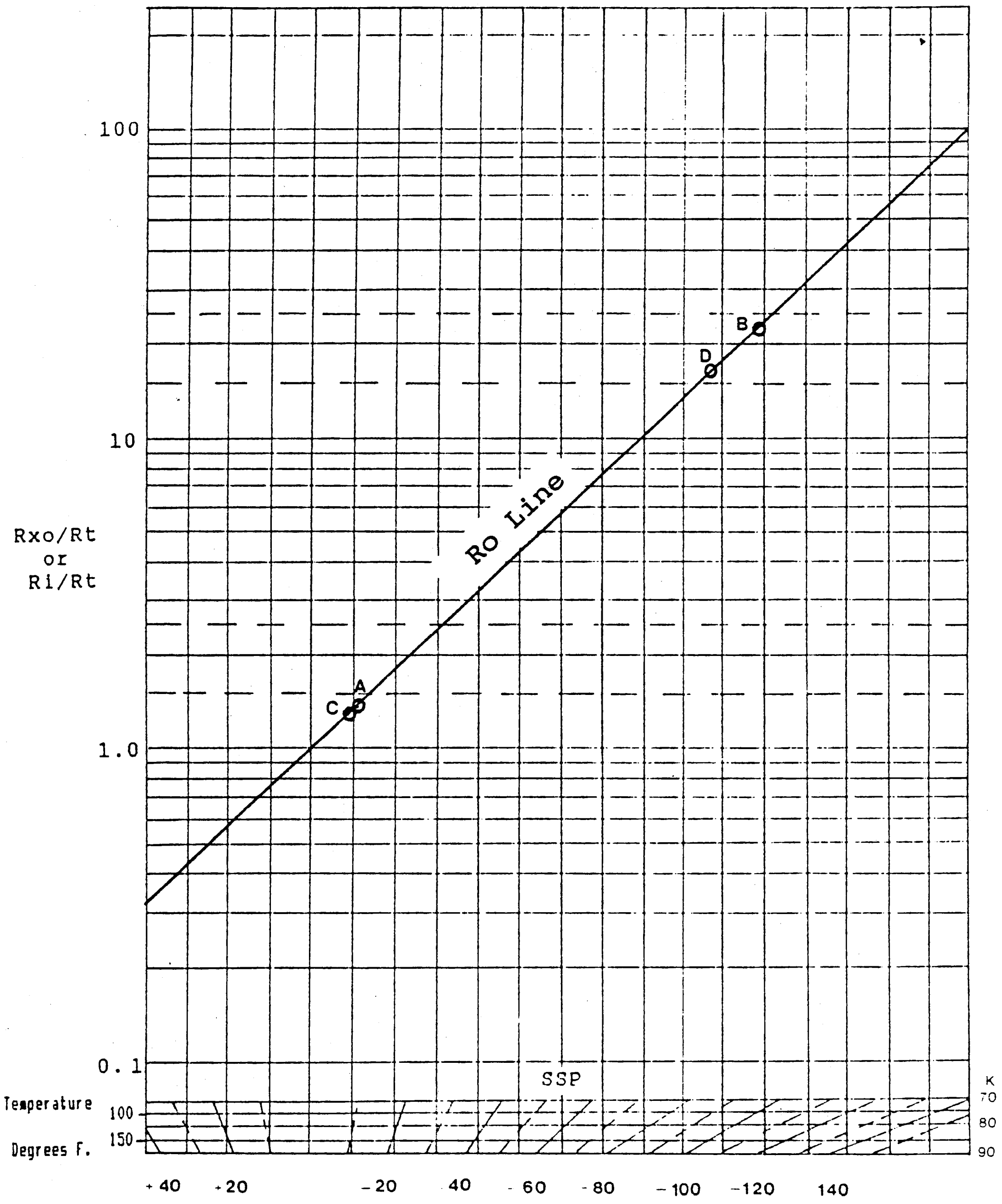
(H) ASSUME: SP = -100

Therefore: 22) -100 = -80.7 * Log(Rxo/Rt)

23) Log(Rxo/Rt) = -100/-80.7

24) Rxo/Rt = 17.344 (point D)

SATURATION CHART



APPENDIX G

DATA SHEETS FROM ANALYSES OF MODERN INDUCTION LOGS IN "WET" RED FORK SANDSTONE, PAYNE COUNTY

COMPANY : EARTH ENERGY RESOURCES

WELL : C.E. WALL No. 1

FIELD : W. VINCO

LOCATION : C, SW, SE Sec. 10, T 17N, R 2E,
Payne County, Oklahoma

FORMATION : Red Fork Sandstone

FROM HEADER

Rm = 1.15 @ 84 degrees F.

Rm = 0.8 @ 118 degrees F. (B.H.T)

Depth of Red Fork = 4280 Ft.

Temp. of Fmt. 113.6 degrees F.

Rm @ Fmt. Temp. = 0.85

Fmt. Thickness 70 Ft. Bit Size 7 7/8 inches

FROM LOG

DEPTH	SP	R(LL)	R(ILM)	R(ILD)	Rxo/Rt
4235	-80	20	5.7	4.0	9.0
4265	-80	10.5	1.9	1.4	13.0
4280	-80	9.0	1.95	1.45	11.0
4315	-80	9.5	1.9	1.5	12.2

***** NOTE: All Resistivities Reported in Ohm-m *****

COMPANY : BERRY OPERATING Co.

WELL : R. WALL No. 5-A

FIELD : W. VINCO

LOCATION : C-S/2,NE,SW,SW Sec. 10, T 17N, R 2E,
Payne County, Oklahoma

FORMATION : Red Fork Sandstone

FROM HEADER

Rm = 1.9 @ 70 degrees F.

Rm = 1.1 @ 115 degrees F. (B.H.T)

Depth of Red Fork = 4270 Ft.

Temp. of Fmt. 114.6 degrees F.

Rm @ Fmt. Temp. = 1.1

Fmt. Thickness 14 Ft. Bit Size 7 $\frac{7}{8}$ inches

FROM LOG

DEPTH	SP	R(LL)	R(ILM)	R(ILD)	Rxo/Rt
4206	-92	8.2	1.9	1.8	11.0
4268	-80	6.0	1.6	1.4	9.0
4288	-80	5.0	1.3	1.2	9.8

***** NOTE: All Resistivities Reported in Ohm-m *****

COMPANY : EARTH ENERGY RESOURCES

WELL : ROBERT TUCKER No 3-A

FIELD : MEHAN

LOCATION : C,NE,SE,SW Sec. 12, T 18N, R 3E,
Payne County, Oklahoma

FORMATION : Red Fork Sandstone

FROM HEADER

Rm = 1.2 @ 68 degrees F.

Rm = 0.69 @ 123 degrees F. (B.H.T)

Depth of Red Fork = 3730 Ft.

Temp. of Fmt. 115.8 degrees F.

Rm @ Fmt. Temp. = 0.76

Fmt. Thickness 47 Ft. Bit Size 7 7/8 inches

FROM LOG

DEPTH	SP	R(LL)	R(ILM)	R(ILD)	Rxo/Rt
3305	-60	7.2	2.0	1.3	9.4
3315	-60	8.0	2.05	1.4	9.6
3717	-55	14	4.0	3.1	8.3
3734	-55	20	5.8	3.8	10.0
3747	-58	16	3.8	2.8	10.0

***** NOTE: All Resistivities Reported in Ohm-m *****

COMPANY : BERRY OPERATING Company

WELL : R. Wall No. 1-A

FIELD : W. VINCO

LOCATION : 150' N of SE, SW Sec. 10, T 17N, R 2E,
Payne County, Oklahoma

FORMATION : Red Fork Sandstone

FROM HEADER

Rm = 0.95 @ 80 degrees F.

Rm = 0.65 @ 117 degrees F. (B.H.T)

Depth of Red Fork = 4275 Ft.

Temp. of Fmt. 116.3 degrees F.

Rm @ Fmt. Temp. = 0.66

Fmt. Thickness 54 Ft. Bit Size 7 7/8 inches

FROM LOG

DEPTH	SP	R(LL)	R(ILM)	R(ILD)	Rxo/Rt
4243	-82	11.5	3.0	2.85	10.0
4263	-82	6.0	1.6	1.4	8.8
4277	-82	5.8	1.5	1.35	9.0
4288	-82	6.5	1.5	1.4	11.0

***** NOTE: All Resistivities Reported in Ohm-m *****

COMPANY : WALTER A. KELLY Jr. Oil Producing Co.

WELL : C.E. WALL No. 3

FIELD : WEST VINCO

LOCATION : C, SE, NW, SE Sec. 10, T 17N, R 2E,
Payne County, Oklahoma

FORMATION : Red Fork Sandstone

FROM HEADER

Rm = 1.0 @ 76 degrees F.

Rm = 0.66 @ 115 degrees F. (B.H.T)

Depth of Red Fork = 4250 Ft.

Temp. of Fmt. 112.2 degrees F.

Rm @ Fmt. Temp. = 0.68

Fmt. Thickness 41 Ft. Bit Size 7 7/8 inches

FROM LOG

DEPTH	SP	R(LL)	R(ILM)	R(ILD)	Rxo/Rt
4197	-60	13.5	7.0	6.8	5.0
4242	-68	12	3.2	2.6	8.8
4262	-72	7.2	1.8	1.4	7.0
4304	-70	8.2	1.9	1.5	9.8
4329	-72	7.2	1.5	1.2	11.0

***** NOTE: All Resistivities Reported in Ohm-m *****

COMPANY : BERRY OPERATING COMPANY

WELL : R. WALL No. 3-A

FIELD : W. VINCO

LOCATION : C, S/2, SE, NW Sec. 10, T 17N, R 2E,
Payne County, Oklahoma

FORMATION : Red Fork Sandstone

FROM HEADER

Rm = 2.01 @ 77.8 degrees F.

Rm = 1.36 @ 115 degrees F. (B.H.T)

Depth of Red Fork = 4230 Ft.

Temp. of Fmt. 114.5 degrees F.

Rm @ Fmt. Temp. = 1.37

Fmt. Thickness 70 Ft. Bit Size 7 7/8 inches

FROM LOG

DEPTH	SP	R(LL)	R(ILM)	R(ILD)	Rxo/Rt
4197	-93	5.0	1.35	1.15	9.0
4206	-93	6.0	1.7	1.4	7.8
4220	-93	5.3	1.6	1.35	7.0

***** NOTE: All Resistivities Reported in Ohm-m *****

COMPANY : EARTH ENERGY RESOURCES

WELL : Coe- BAILEY No. 1

FIELD : W. VINCO

LOCATION : 2310' FSL - 255' FWL Sec. 11, T 17N, R 2E,
Payne County, Oklahoma

FORMATION : Red Fork Sandstone

FROM HEADER

Rm = 0.9 @ 81 degrees F.

Rm = 0.62 @ 117 degrees F. (B.H.T)

Depth of Red Fork = 4194 Ft.

Temp. of Fmt. 112.2 degrees F.

Rm @ Fmt. Temp. = 0.66

Fmt. Thickness 100 Ft. Bit Size 7 7/8 inches

FROM LOG

DEPTH	SP	R(LL)	R(ILM)	R(ILD)	Rxo/Rt
4230	-70	13.5	3.6	2.25	10.5
4244	-72	12.0	2.95	1.95	10.8
4280	-72	9.0	2.0	1.5	10.8
4290	-72	7.8	1.8	1.35	10.2

***** NOTE: All Resistivities Reported in Ohm-m *****

COMPANY : EARTH ENERGY RESOURCES

WELL : O'HERN No. 2

FIELD : E. SPORN

LOCATION : NW, NW, NW Sec. 26, T 17N, R 3E,
Payne County, Oklahoma

FORMATION : Red Fork Sandstone

FROM HEADER

Rm = 2.8 @ 50 degrees F.

Rm = 1.6 @ 126 degrees F. (B.H.T)

Depth of Red Fork = 4080 Ft.

Temp. of Fmt. 117 degrees F.

Rm @ Fmt. Temp. = 1.74

Fmt. Thickness 90 Ft. Bit Size 7 7/8 inches

FROM LOG

DEPTH	SP	R(LL)	R(ILM)	R(ILD)	Rxo/Rt
3855	-88	5.5	2.3	2.3	20
4020	-72	27	7.0	5.2	9.0
4027	-72	26	5.0	4.3	12.5
4055	-80	36	6.0	3.25	20.0
4073	-90	22	2.85	1.8	22.5
4085	-90	21	2.35	1.55	24

***** NOTE: All Resistivities Reported in Ohm-m *****

COMPANY : EARTH ENERGY RESOURCES

WELL : Tucker No. 4

FIELD : North Mehan

LOCATION : SW, SW, SE Sec. 12 , T 18N , R 3E ,
Payne County, Oklahoma

FORMATION : Red Fork Sandstone

FROM HEADER

Rm = 1.5 @ 78 degrees F.

Rm = 1.17 @ 100 degrees F. (B.H.T)

Depth of Red Fork = 3735 Ft.

Temp. of Fmt. 97.8 degrees F.

Rm @ Fmt. Temp. = 1.20

Fmt. Thickness 55 Ft. Bit Size 7 7/8 inches

FROM LOG

DEPTH	SP	R(LL)	R(ILM)	R(ILD)	Rxo/Rt
3713	-90	23	4.0	2.9	14.5
3726	-90	23	4.2	2.4	18.0
3735	-80	29	4.8	3.1	16.8
3760	-65	26	4.6	2.8	17.0

***** NOTE: All Resistivities Reported in Ohm-m *****

COMPANY : EARTH ENERGY RESOURCES

WELL : McKENZIE No. 10

FIELD : South Mehan

LOCATION : C, NW, SW, SE Sec. 13, T 18N, R 3E,
Payne County, Oklahoma

FORMATION : Red Fork Sandstone

FROM HEADER

Rm = 2.4 @ 58 degrees F.

Rm = 1.33 @ 110 degrees F. (B.H.T)

Depth of Red Fork = 3720 Ft.

Temp. of Fmt. 103.5 degrees F.

Rm @ Fmt. Temp. = 1.5

Fmt. Thickness 10 Ft. Bit Size 7 7/8 inches

FROM LOG

DEPTH	SP	R(LL)	R(ILM)	R(ILD)	Rxo/Rt
3730	-90	26	4.1	2.8	17

***** NOTE: All Resistivities Reported in Ohm-m *****

COMPANY : THOMAS N. BERRY

WELL : BERRY FEE No. 8

FIELD : MEHAN

LOCATION : NE, SW, SW Sec. 13, T18N, R3E,
Payne County, Oklahoma

FORMATION : Red Fork Sandstone

FROM HEADER

Rm = 2.6 @ 78 degrees F.

Rm = 1.76 @ 115 degrees F. (B.H.T)

Depth of Red Fork = 3764 Ft.

Temp. of Fmt. 111 degrees F.

Rm @ Fmt. Temp. = 1.85

Fmt. Thickness 40 Ft. Bit Size 7 7/8 inches

FROM LOG

DEPTH	SP	R(LL)	R(ILM)	R(ILD)	Rxo/Rt
3750	-92	16	4.3	3.0	8.5
3766	-92	32	5.2	3.5	17.0
3775	-92	28	5.0	3.2	16.0

***** NOTE: All Resistivities Reported in Ohm-m *****

COMPANY : WALTER A. KELLY Jr.

WELL : C.E. WALL No. 4

FIELD : W. VINCO

LOCATION : C, NE, SE Sec. 10, T 17N, R 2E,
Payne County, Oklahoma

FORMATION : Red Fork Sandstone

FROM HEADER

Rm = 2.2 @ 48 degrees F.

Rm = 0.95 @ 119 degrees F. (B.H.T)

Depth of Red Fork = 4250 Ft.

Temp. of Fmt. 113.4 degrees F.

Rm @ Fmt. Temp. = 1.05

Fmt. Thickness 100 Ft. Bit Size 7 7/8 inches

FROM LOG

DEPTH	SP	R(LL)	R(ILM)	R(ILD)	Rxo/Rt
4246	-85	10.5	2.25	1.7	12.0
4264	-85	11.5	2.0	1.55	14.0
4304	-97	10.2	1.9	1.45	13.0

***** NOTE: All Resistivities Reported in Ohm-m *****

COMPANY : Southport Exploration

WELL : Shively No. 1

FIELD : Northwest Sooner Valley

LOCATION : 330'FNL, 990'FWL N/2, NW, NW Sec. 21, T 19N, R 3E,
Payne County, Oklahoma

FORMATION : Red Fork Sandstone

FROM HEADER

Rm = 3.15 @ 67.5 degrees F.

Rm = 1.81 @ 117 degrees F. (B.H.T)

Depth of Red Fork = 3971 Ft.

Temp. of Fmt. 112 degrees F.

Rm @ Fmt. Temp. = 1.95

Fmt. Thickness 47 Ft. Bit Size 7 7/8 inches

FROM LOG

DEPTH	SP	R(LL)	R(ILM)	R(ILD)	Rxo/Rt
3955	-95	19.5	3.0	2.5	16
3965	-95	29	3.0	2.0	26
3974	-95	27	2.6	1.8	27.5
3980	-95	20	2.05	1.6	25

***** NOTE: All Resistivities Reported in Ohm-m *****

COMPANY : EARTH ENERGY RESOURCES

WELL : TUCKER No. 2

FIELD : NORTHEAST MEHAN

LOCATION : C, NE, SE Sec. 12, T 18N, R 3E,
Payne County, Oklahoma

FORMATION : Red Fork Sandstone

FROM HEADER

Rm = 1.68 @ 65 degrees F.

Rm = 0.993 @ 115 degrees F. (B.H.T)

Depth of Red Fork = 3960 Ft.

Temp. of Fmt. 108.6 degrees F.

Rm @ Fmt. Temp. = 1.08

Fmt. Thickness 24.5 Ft. Bit Size 7 7/8 inches

FROM LOG

DEPTH	SP	R(LL)	R(ILM)	R(ILD)	Rxo/Rt
3695	-75	16	3.2	2.3	12.5

***** NOTE: All Resistivities Reported in Ohm-m *****

APPENDIX H

DATA SHEETS FROM ANALYSES OF OLD ELECTRIC LOGS IN "PRODUCTIVE" RED FORK SANDSTONE, PAYNE COUNTY

COMPANY : SKELLY OIL COMPANY

WELL : MARTHA BERRY No. 4

FIELD : NORTH INGALLS

LOCATION : NW, SW, SE Sec. 22, T 19N, R 4E ; Payne Co. Okla.

FORMATION : Red Fork Sandstone

FROM HEADER

Rm = 1.7 @ 85 degrees F. Bit Size 9 inches

Rm = 1.3 @ 110 Degrees F. (B.H.T.)

Depth of Red Fork = 3465 ft. Temp. of Fmt. 108 °F

Rm @ Fmt. Temp. = 1.34 Fmt. Thickness 62 ft.

Resistivity of Shale (Normals) = 8 PSP = -120 mv

Resistivity of Shale (Lateral) = 8 SSP = -120 mv

UNCORRECTED DATA	CORRECTED DATA	CHART No.
Rsn = 25	Rsn = 25	A-1
Rln = 23.5	Rln = 23	A-2
Rlat = 15	Rlat = 13	A-3

Rsn(corr.)/Rm = 18.7. Rln(corr.)/Rm = 17.2. Rlat(corr.)/Rm = 9.7.

LANE WELLS DEPARTURE CURVES DATA

	NORMALS			LATERAL		
Di/d	Rt/Rm	Ri/Rm	Ri/Rt	Rt/Rm	Ri/Rm	Ri/Rt
2	12.8	27.5	2.15	8.7	45	5.2
5	12.1	20.0	1.7	8.7	23.5	2.7
10	11.2	18.3	1.6	8.6	19.5	2.3
15	9.5	18	1.9	7.9	18.3	2.3

Rt/Rm = 8.6 Ri/Rm = 19.5 Ri/Rt = 2.3 Rt = 11.5

******** NOTE: All resistivities reported in Ohm-m **********

COMPANY : Midstates Oil Corporation

WELL : State-Penny No. 2

FIELD : Butcher

LOCATION : C N/2, N/2, S/2, SW Sec. 36, T 19N, R 4E ; Payne Co. Okla.

FORMATION : Red Fork Sandstone

FROM HEADER

Rm = 1.75 @ 62 degrees F. Bit Size 7 7/8 inches

Rm = 0.97 @ 108 Degrees F. (B.H.T.)

Depth of Red Fork = 3526 ft. Temp. of Fmt. 106.5 °F

Rm @ Fmt. Temp. = 0.99 Fmt. Thickness 11.5 ft.

Resistivity of Shale (Normals) = 8.5 PSP = -75 mv

Resistivity of Shale (Lateral) = _____ SSP = -80 mv.

UNCORRECTED DATA	CORRECTED DATA	CHART No.
Rsn = 15	Rsn = 16	A-1
Rln = 12.5	Rln = 18	A-2
Rlat = 15	Rlat = —	A-3

Rsn(corr.)/Rm = 16.2. Rln(corr.)/Rm = 18.2. Rlat(corr.)/Rm = ____.

LANE WELLS DEPARTURE CURVES DATA

	NORMALS			LATERAL		
Di/d	Rt/Rm	Ri/Rm	Ri/Rt	Rt/Rm	Ri/Rm	Ri/Rt
2	15.8	7.5	0.47			
5	16.5	12	0.73			
10	17	13	0.76			
15	18	13	0.72			

Rt/Rm = 17.5 Ri/Rm = 13 Ri/Rt = 0.74 Rt = 17.3

******** NOTE: All resistivities reported in Ohm-m **********

COMPANY : Simon Lebow

WELL : ORVIS No. 4

FIELD : INGALLS

LOCATION : SE, NE, SW Sec. 22, T 19N, R 4E ; Payne Co. Okla.

FORMATION : Red Fork Sandstone

FROM HEADER

Rm = 1.7 @ 96 degrees F. Bit Size 9 inches

Rm = 1.2 @ 128 Degrees F. (B.H.T.)

Depth of Red Fork = 3455 ft. Temp. of Fmt. 125 °F

Rm @ Fmt. Temp. = 1.25 Fmt. Thickness 10 ft.

Resistivity of Shale (Normals) = 10 PSP = -110 mv

Resistivity of Shale (Lateral) = 10 SSP = -110 mv

UNCORRECTED DATA	CORRECTED DATA	CHART No.
Rsn = 32.5	Rsn = 32.5	A-1
Rln = 24	Rln = 24	A-2
Rlat = 26.5	Rlat = 20.5	A-3

Rsn(corr.)/Rm = 26. Rln(corr.)/Rm = 19.2. Rlat(corr.)/Rm = 16.4.

LANE WELLS DEPARTURE CURVES DATA

	NORMALS			LATERAL		
Di/d	Rt/Rm	Ri/Rm	Ri/Rt	Rt/Rm	Ri/Rm	Ri/Rt
2	≃ 4	67	16.75	14	55	3.9
5	7	38	5.4	14.2	31	2.2
10	< 1	34	—	13.5	27.5	2.0
15	< 1	30	—	12	25.5	2.1

Rt/Rm = 13.5 Ri/Rm = 27.5 Ri/Rt = 2.0 Rt = 16.9

******** NOTE: All resistivities reported in Ohm-m **********

COMPANY : Mc Coluster & Rahal

WELL : Moore No. 4

FIELD : North Schlegel

LOCATION : NW, NW, SE Sec. 17, T 18N, R 6E ; Payne Co. Okla.

FORMATION : Red Fork Sandstone

FROM HEADER

Rm = 0.9 @ 80 degrees F. Bit Size 9 inches

Rm = 0.7 @ 105 Degrees F. (B.H.T.)

Depth of Red Fork = 3055 ft. Temp. of Fmt. 104.7 °F

Rm @ Fmt. Temp. = 0.7 Fmt. Thickness 13 ft.

Resistivity of Shale (Normals) = 7.0 PSP = -65 mv

Resistivity of Shale (Lateral) = 7.5 SSP = -71.5 mv

UNCORRECTED DATA	CORRECTED DATA	CHART No.
Rsn = 17.2	Rsn = 18	A-1
Rln = 14	Rln = 21.3	A-2
Rlat = 13.5	Rlat = —	A-3

Rsn(corr.)/Rm = 25.7. Rln(corr.)/Rm = 30.4. Rlat(corr.)/Rm = —.

LANE WELLS DEPARTURE CURVES DATA

	NORMALS			LATERAL		
Di/d	Rt/Rm	Ri/Rm	Ri/Rt	Rt/Rm	Ri/Rm	Ri/Rt
2	23.5	24	1.02			
5	24	23	0.96			
10	24	23.5	0.98			
15	24	23.5	0.98			

Rt/Rm = 24 Ri/Rm = 23.5 Ri/Rt = 0.98 Rt = 16.8

******* NOTE: All resistivities reported in Ohm-m **********

COMPANY : Harris & Suppes Drlg. Company

WELL : Vickery No. 4

FIELD : North Cushing

LOCATION : NW, SW, SW Sec.____, T____, R____ ; Payne Co. Okla.

FORMATION : Red Fork Sandstone

FROM HEADER

Rm = 1 @ 82 degrees F. Bit Size 9 inches

Rm = 0.86 @ 95 Degrees F. (B.H.T.)

Depth of Red Fork = 3134 ft. Temp. of Fmt. 95 °F

Rm @ Fmt. Temp. = 0.86 Fmt. Thickness 17 ft.

Resistivity of Shale (Normals) = 9 PSP = -55 mv

Resistivity of Shale (Lateral) = 9 SSP = -57.2 mv

UNCORRECTED DATA	CORRECTED DATA	CHART No.
Rsn = 13	Rsn = 13.5	A-1
Rln = 13.5	Rln = 16	A-2
Rlat = 14	Rlat = —	A-3

Rsn(corr.)/Rm = 15.7. Rln(corr.)/Rm = 18.6. Rlat(corr.)/Rm = —.

LANE WELLS DEPARTURE CURVES DATA

Di/d	NORMALS Rt/Rm	 Ri/Rm	 Ri/Rt	LATERAL Rt/Rm	 Ri/Rm	 Ri/Rt
2	16.5	9	0.55			
5	16	13	0.8			
10	17	13.5	0.79			
15	16.5	13.5	0.82			

Rt/Rm = 16.5 Ri/Rm = 13.5 Ri/Rt = 0.82 Rt = 14.2

******** NOTE: All resistivities reported in Ohm-m **********

COMPANY : McCalister & Rahal

WELL : Moore No. 3

FIELD : Schlegel

LOCATION : NE, NW, SE Sec. 17, T 18N, R 6E ; Payne Co. Okla.

FORMATION : Red Fork Sandstone

FROM HEADER

Rm = 1.9 @ 85 degrees F. Bit Size 9 inches

Rm = 1.6 @ 103 Degrees F. (B.H.T.)

Depth of Red Fork = 3045 ft. Temp. of Fmt. 102.7 °F

Rm @ Fmt. Temp. = 1.6 Fmt. Thickness 17 ft.

Resistivity of Shale (Normals) = 7.5 PSP = -70 mv

Resistivity of Shale (Lateral) = ____ SSP = -73 mv

UNCORRECTED DATA	CORRECTED DATA	CHART No.
Rsn = 22.5	Rsn = 24	A-1
Rln = 17	Rln = 24	A-2
Rlat = 16	Rlat = —	A-3

Rsn(corr.)/Rm = 15. Rln(corr.)/Rm = 15. Rlat(corr.)/Rm = —.

LANE WELLS DEPARTURE CURVES DATA

	NORMALS			LATERAL		
Di/d	Rt/Rm	Ri/Rm	Ri/Rt	Rt/Rm	Ri/Rm	Ri/Rt
2	12.8	15	1.17			
5	12.2	14.5	1.18			
10	12	14	1.16			
15	12	14	1.16			

Rt/Rm = 12 Ri/Rm = 14 Ri/Rt = 1.16 Rt = 19.2

******** NOTE: All resistivities reported in Ohm-m **********

COMPANY : TEXAS PACIFIC COAL & Oil Company

WELL : Story No. 3

FIELD : N. Cottingham

LOCATION : NW, NE, NW Sec. 1, T 17N, R 3E ; Payne Co. Okla.

FORMATION : Red Fork Sandstone

FROM HEADER

Rm = 1.1 @ 95 degrees F. Bit Size 8 3/4 inches

Rm = 0.89 @ 115 Degrees F. (B.H.T.)

Depth of Red Fork = 3840 ft. Temp. of Fmt. 112.5 °F

PAY ZONE = 10 ft.

Rm @ Fmt. Temp. = 0.92 Fmt. Thickness 30 ft.

Resistivity of Shale (Normals) = 10 PSP = -100 mv

Resistivity of Shale (Lateral) = 10 SSP = -100 mv

UNCORRECTED DATA	CORRECTED DATA	CHART No.
Rsn = 22	Rsn = 23.2	A-1
Rln = 14.5	Rln = 14.6	A-2
Rlat = 5.5	Rlat = —	A-3

Rsn(corr.)/Rm = 24.2. Rln(corr.)/Rm = 15.9. Rlat(corr.)/Rm = —.

LANE WELLS DEPARTURE CURVES DATA

	NORMALS			LATERAL		
Di/d	Rt/Rm	Ri/Rm	Ri/Rt	Rt/Rm	Ri/Rm	Ri/Rt
2	≃ 5	73	14.6			
5	4	42	10.5			
10	< 1	29.5	—			
15	< 1	29.5	—			

Rt/Rm = 4 Ri/Rm = 42 Ri/Rt = 10.5 Rt = 3.7

******** NOTE: All resistivities reported in Ohm-m **********

COMPANY : C.U. BAY - T.W. & J.H. LOFFLAND & R.A. Patton

WELL : BELLIS No. 1

FIELD : BROYLES

LOCATION : SE, SE, NE Sec. 27, T 18N, R 4E ; Payne Co. Okla.

FORMATION : Red Fork Sandstone

FROM HEADER

Rm = 2.6 @ 62 degrees F. Bit Size 9 inches

Rm = 1.5 @ 109 Degrees F. (B.H.T.)

Depth of Red Fork = 3524 ft. Temp. of Fmt. 107.4 °F

Rm @ Fmt. Temp. = 1.54 Fmt. Thickness 18 ft.

Resistivity of Shale (Normals) = 7.5 PSP = -50 mv

Resistivity of Shale (Lateral) = 8 SSP = -50 mv

UNCORRECTED DATA	CORRECTED DATA	CHART No.
Rsn = 13.5	Rsn = 14.5	A-1
Rln = 8.5	Rln = 9	A-2
Rlat = 7	Rlat = –	A-3

Rsn(corr.)/Rm = 9.8. Rln(corr.)/Rm = 5.5. Rlat(corr.)/Rm = –.

LANE WELLS DEPARTURE CURVES DATA

	NORMALS			LATERAL		
Di/d	Rt/Rm	Ri/Rm	Ri/Rt	Rt/Rm	Ri/Rm	Ri/Rt
2	4.6	18	3.9			
5	4.5	10	2.2			
10	3.5	9	2.6			
15	2.25	8.8	3.9			

Rt/Rm = 2.25 Ri/Rm = 8.8 Ri/Rt = 3.9 Rt = 3.5

******* NOTE: All resistivities reported in Ohm-m *********

COMPANY : Wilcox Oil Company

WELL : Sam No. 1

FIELD :

LOCATION : SW, NW, SW Sec. 3, T 18N, R 2E ; Payne Co. Okla.

FORMATION : Red Fork Sandstone

FROM HEADER

Rm = 2.0 @ 28 degrees F. Bit Size 8 3/4 inches

Rm = 1.0 @ 119 Degrees F. (B.H.T.)

Depth of Red Fork = 4330 ft. Temp. of Fmt. 115.6 °F

Rm @ Fmt. Temp. = 1.05 Fmt. Thickness 20 ft.

Resistivity of Shale (Normals) = 10 PSP = -60 mv

Resistivity of Shale (Lateral) = 10 SSP = -62 mv

UNCORRECTED DATA	CORRECTED DATA	CHART No.
Rsn = 20	Rsn = 20	A-1
Rln = 12	Rln = 12	A-2
Rlat = 13.5	Rlat = —	A-3

Rsn(corr.)/Rm = 19. Rln(corr.)/Rm = 11.4. Rlat(corr.)/Rm = ____.

LANE WELLS DEPARTURE CURVES DATA

	NORMALS			LATERAL		
Di/d	Rt/Rm	Ri/Rm	Ri/Rt	Rt/Rm	Ri/Rm	Ri/Rt
2	≃4.5	53	11.8			
5	5	26.5	5.3			
10	1	22.5	22.5			
15	< 1	20.5	—			

Rt/Rm = 5 Ri/Rm = 26.5 Ri/Rt = 5.3 Rt = 5.23

******** NOTE: All resistivities reported in Ohm-m **********

COMPANY : TW & J.M. Loffland Jr.

WELL : STANOLIND - AMERADA No. 2

FIELD : Cushing LAke

LOCATION : SW, SW, SW Sec. 27, T 18N, R 4E ; Payne Co. Okla.

FORMATION : Red Fork Sandstone

FROM HEADER

Rm = 2 @ 80 degrees F. Bit Size 9 inches

Rm = 1.4 @ 112 Degrees F. (B.H.T.)

Depth of Red Fork = 3570 ft. Temp. of Fmt. 108.2 °F

PAY ZONE = 12 FT.

Rm @ Fmt. Temp. = 1.47 Fmt. Thickness 54 ft.

Resistivity of Shale (Normals) = 10 PSP = -80 mv

Resistivity of Shale (Lateral) = 10 SSP = -80 mv

UNCORRECTED DATA	CORRECTED DATA	CHART No.
Rsn = 20	Rsn = 20	A-1
Rln = 12	Rln = 12	A-2
Rlat = 11	Rlat = 11	A-3

Rsn(corr.)/Rm = 13.6. Rln(corr.)/Rm = 8.2. Rlat(corr.)/Rm = ——.

LANE WELLS DEPARTURE CURVES DATA

	NORMALS			LATERAL		
Di/d	Rt/Rm	Ri/Rm	Ri/Rt	Rt/Rm	Ri/Rm	Ri/Rt
2	5.0	35	7			
5	5.0	17.5	3.5			
10	3.0	15	5			
15	<1	14.5	—			

Rt/Rm = 5.0 Ri/Rm = 17.5 Ri/Rt = 3.5 Rt = 7.4

******** NOTE: All resistivities reported in Ohm-m **********

COMPANY : FOSTER DRILLING COMPANY

WELL : GRIMM No. 1

FIELD : S. Rippley

LOCATION : NE,SE,SW Sec. 31, T 18N, R 4E ; Payne Co. Okla.

FORMATION : Red Fork Sandstone

FROM HEADER

Rm = 1 @ 78 degrees F. Bit Size 9 inches

Rm = 0.7 @ 113 Degrees F. (B.H.T.)

Depth of Red Fork = 3615 ft. Temp. of Fmt. 110.8 °F ≃ 24 ft. of PAY

Rm @ Fmt. Temp. = 0.72 Fmt. Thickness 75 ft.

Resistivity of Shale (Normals) = 10 PSP = -100 mv

Resistivity of Shale (Lateral) = 10 SSP = -100 mv

UNCORRECTED DATA	CORRECTED DATA	CHART No.
Rsn = 20	Rsn = 20.5	A-1
Rln = 15	Rln = 16	A-2
Rlat = 15	Rlat = 15	A-3

Rsn(corr.)/Rm = 28.5. Rln(corr.)/Rm = 22.2. Rlat(corr.)/Rm = 20.8.

LANE WELLS DEPARTURE CURVES DATA

	NORMALS			LATERAL		
Di/d	Rt/Rm	Ri/Rm	Ri/Rt	Rt/Rm	Ri/Rm	Ri/Rt
2	≃ 8	80	10	17.4	58	3.3
5	6	47	7.8	17.4	36	2.1
10	1	39	39	16.8	30	1.8
15	< 1	35	—	15.3	29	1.9

Rt/Rm = 17.4 Ri/Rm = 47 Ri/Rt = 2.7 Rt = 12.5

******** NOTE: All resistivities reported in Ohm-m **********

COMPANY : C.E. McCaughey et al

WELL : Stanolind et al No. 1

FIELD : Cushing Lake

LOCATION : NE, SE, SE Sec. 28, T18N, R4E ; Payne Co. Okla.

FORMATION : Red Fork Sandstone

FROM HEADER

Rm = 3.6 @ 53 degrees F. Bit Size 9 inches

Rm = 1.7 @ 110 Degrees F. (B.H.T.)

Depth of Red Fork = 3624 ft. Temp. of Fmt. 102.8 °F

Rm @ Fmt. Temp. = 1.94 Fmt. Thickness 22 ft.

Resistivity of Shale (Normals) = 10 PSP = -60 mv

Resistivity of Shale (Lateral) = 10 SSP = -60 mv

UNCORRECTED DATA	CORRECTED DATA	CHART No.
Rsn = 18	Rsn = 19	A-1
Rln = 17	Rln = 19.5	A-2
Rlat = 9	Rlat = ≃10	A-3

Rsn(corr.)/Rm = 9.8. Rln(corr.)/Rm = 10. Rlat(corr.)/Rm = ____.

LANE WELLS DEPARTURE CURVES DATA

	NORMALS			LATERAL		
Di/d	Rt/Rm	Ri/Rm	Ri/Rt	Rt/Rm	Ri/Rm	Ri/Rt
2	9.0	8.0	0.89	4.95	20.5	4.1
5	9.0	8.5	0.94	5.1	11.8	2.3
10	9.0	8.5	0.94	5.0	9.9	1.98
15	9.1	8.7	0.96	4.8	9.5	1.98

Rt/Rm = 5.1 Ri/Rm = 11.8 Ri/Rt = 2.3 Rt = 9.9

******** NOTE: All resistivities reported in Ohm-m **********

COMPANY : H. WAGGONER COMPANY

WELL : Wilson No. 1

FIELD : Semi-wildcat

LOCATION : NE, SE, SE Sec. 29, T 18N, R 4E ; Payne Co. Okla.

FORMATION : Red Fork Sandstone

FROM HEADER

Rm = 1.6 @ 94 degrees F. Bit Size 8 3/4 inches

Rm = 1.4 @ 108 Degrees F. (B.H.T.)

Depth of Red Fork = 3658 ft. Temp. of Fmt. 107.6 °F

Rm @ Fmt. Temp. = 1.4 Fmt. Thickness 24 ft.

Resistivity of Shale (Normals) = 8 PSP = -65 mv

Resistivity of Shale (Lateral) = 8 SSP = -65 mv

UNCORRECTED DATA	CORRECTED DATA	CHART No.
Rsn = 13.5	Rsn = 15.5	A-1
Rln = 5	Rln = 3.4	A-2
Rlat = ≈5	Rlat = 5.4	A-3

Rsn(corr.)/Rm = 11.1. Rln(corr.)/Rm = 2.4. Rlat(corr.)/Rm = 3.9.

LANE WELLS DEPARTURE CURVES DATA

	NORMALS			LATERAL		
Di/d	Rt/Rm	Ri/Rm	Ri/Rt	Rt/Rm	Ri/Rm	Ri/Rt
2	< 1	38	—	3.6	30	8.3
5	< 1	16.5	—	3.9	14	3.6
10	<< 1	12	—	3.7	12	3.2
15	<< 1	11.6	—	3.4	11.8	3.5

Rt/Rm = 3.75 Ri/Rm = 22 Ri/Rt = 5.8 Rt = 5.25

******** NOTE: All resistivities reported in Ohm-m **********

COMPANY : Simon Lebow

WELL : Orvis No. 3

FIELD : Ingalls

LOCATION : NE,SE,SW Sec. 22, T 19N, R 4E ; Payne Co. Okla.

FORMATION : Red Fork Sandstone

FROM HEADER

Rm = 1.4 @ 76 degrees F. Bit Size 9 inches

Rm = 1.0 @ 108 Degrees F. (B.H.T.)

Depth of Red Fork = 3460 ft. Temp. of Fmt. 105 °F

Rm @ Fmt. Temp. = 1.04 Fmt. Thickness 60 ft.

Resistivity of Shale (Normals) = 10 PSP = -120 mv

Resistivity of Shale (Lateral) = 10 SSP = -120 mv

UNCORRECTED DATA	CORRECTED DATA	CHART No.
Rsn = 33	Rsn = 33	A-1
Rln = 30	Rln = 30	A-2
Rlat = 35	Rlat = 26	A-3

Rsn(corr.)/Rm = 31.7. Rln(corr.)/Rm = 28.8. Rlat(corr.)/Rm = 25.

LANE WELLS DEPARTURE CURVES DATA

	NORMALS			LATERAL		
Di/d	Rt/Rm	Ri/Rm	Ri/Rt	Rt/Rm	Ri/Rm	Ri/Rt
2	≃10	95	9.5	21	65	3.1
5	10.5	50	4.8	20	40	2.0
10	7.5	38	5.1	19	33	1.7
15	< 1	40	—	18	33	1.8

Rt/Rm = 20.5 Ri/Rm = 52.5 Ri/Rt = 2.6 Rt = 21.3

******** NOTE: All resistivities reported in Ohm-m **********

COMPANY : MAGNOLIA PETROLEUM COMPANY

WELL : W.H. GROVE No. 12

FIELD : INGALLS

LOCATION : NW, NE, NW Sec. 27, T 19N, R 4E ; Payne Co. Okla.

FORMATION : Red Fork Sandstone

FROM HEADER

Rm = 1.0 @ 68 degrees F. Bit Size 7 7/8 inches

Rm = 0.5 @ 113 Degrees F. (B.H.T.)

Depth of Red Fork = 3480 ft. Temp. of Fmt. 109 °F

Rm @ Fmt. Temp. = 0.55 Fmt. Thickness 73 ft.

Resistivity of Shale (Normals) = 6 PSP = -71 mv

Resistivity of Shale (Lateral) = 8 SSP = -71 mv

UNCORRECTED DATA	CORRECTED DATA	CHART No.
Rsn = 18	Rsn = 20	A-1
Rln = 12.5	Rln = 12.5	A-2
Rlat = 20	Rlat = 16	A-3

Rsn(corr.)/Rm = 36.4. Rln(corr.)/Rm = 22.7. Rlat(corr.)/Rm = 29.1.

LANE WELLS DEPARTURE CURVES DATA

	NORMALS			LATERAL		
Di/d	Rt/Rm	Ri/Rm	Ri/Rt	Rt/Rm	Ri/Rm	Ri/Rt
2	< 1	110	—	25	65	2.6
5	< 1	60	—	25	43	1.7
10	< 1	48	—	24	38	1.6
15	<< 1	42	—	24	36	1.5

Rt/Rm = 25 Ri/Rm = 49 Ri/Rt = 2.0 Rt = 13.8

******** NOTE: All resistivities reported in Ohm-m **********

VITA 2

Donald Peter Ragusa

Candidate for the Degree of

Master of Science

Thesis: INTERPRETATION OF "OLD" ELECTRIC LOGS, RED FORK SANDSTONE, PAYNE COUNTY, OKLAHOMA

Major Field: Geology

Biographical:

Personal Data: Born in Tarrytown, New York, July 1, 1962. The son of Mr. and Mrs. John Ragusa.

Education: Graduated from Sleepy Hollow High School, North Tarrytown, New York, in June, 1980; received Bachelor of Science Degree in Geology from State University of New York at Cortland in January, 1985; completed requirements for the Master of Science Degree at Oklahoma State University in July, 1988.

Professional Experience: Teaching and research assistant for the Department of Geology, Oklahoma State University, January, 1986 to May 1988.