COMPUTER-AIDED PETROLEUM WELL LOG ANALYSIS

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CERTIFICATION

This project titled, “Computer-Aided Petroleum Well Log Analysis”, by Timothy Oladele, Odedele, meets the regulations governing the award of Postgraduate Diploma in Computer Science of Federal University of Technology, Minna.

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ABSTRACT

In the past the process of well log interpretation was accomplished through manual interpolation using voluminous trade literatures/charts and stored the input/output data in filing cabinet within the company's premises. Upon the examination of the problems of existing system used in the past, a system to solve these problems and which introduced computer functionality to the interpretation of petroleum well logs was proposed. This computer - Aided well log interpretation programs is designed to cover the interpretation of Conventional Electric logs (Spontaneous potential logs, short Normal, Long Normal, Lateral logs and micrologs)

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CHAPTER 1
INTRODUCTION

Since the advent of the digital computer in petroleum engineering, most companies have endeavored to reduce the routine engineering work load by judicious application of this machine, called computer.

Well logging is a technique of making measurements in drill holes with probes designed to measure the physical and chemical properties of rocks and their contained fluids. Much information can be obtained from samples of rock brought to the surface in cores or bit cuttings, or from other clues while drilling, such as penetration rate; however, the greatest amount of information comes from well logs.

Well logs result from a probe lowered into the borehole at the end of an insulated cable. The resulting measurements are recorded graphically or digitally as a function of depth. These records are known as geophysical well logs, petrophysical logs, or more commonly well logs, or simply logs.

Although the most common uses of logs are for correlation of geological strata and location of hydrocarbon zones, there are many other important subsurface parameters that need to be detected or measured. Also, different borehole and formation conditions can require different tools to measure the same basic property. In petroleum engineering, logs are used to: identify potential reservoir rock; determine bed thickness; determine porosity; estimate permeability; locate hydrocarbon; estimate water salinity; quantify amount of hydrocarbons; estimate type and rate of fluid production; estimate formation pressure; identify fracture zones; measure borehole inclination; measure hole diameter; aid in setting casing; evaluate quality of cement bonding; locate entry, rate, and type of fluid into borehole. In geology and geophysics, they are used to: correlate between wells; locate faults; determine dip and strike of beds; identify lithology; deduce environmental deposition of sediments; determine thermal and pressure gradients.

As far as well logs analysis is concerned, efforts had been made to reduce these to computerized techniques. Therefore, the aim of this project is to make available to its prospective users sufficient technical information on Computer – Aided Petroleum Well Log Analysis. (CAPWLA). This computer – Aided well log interpretation programs is designed to cover the Conventional Electric logs

(Spontaneous potential logs, Short Normal, Long Normal, Lateral logs and micrologs)

Therefore, students of Petroleum Geology, Geophysics and of Petroleum Engineering will find it valuable in view of quick and reliable solution to log interpretation and formation evaluation problems.

Practicing well log analyst will find this computer – Aided Well Log Analysis (CAPWLA) sufficiently complete. This is because they will no longer require to consult voluminous trade literature to find the necessary charts appropriate to the solution of their problems.

Most of these charts have been simulated into the computer text file systems.

In particular, practicing geologist will find the conventional electric logs aspect of CAPWLA of great significance because, by training, they depend primarily on the qualitative evaluation of electric log in their subsurface correlation for lithology, stratigraphic and structural studies of sedimentary rocks.

The utilization of the computer programs will allow the determination of lithology, porosity, fluid content saturation, formation factor, true resistivity, invaded zone resistivity, invaded zone diameter (in case of deep mud filtrate invasion), flushed zone resistivity and formation pay thickness.

Well completion and production engineers should welcome CAPWLA as they depend to great extent on qualitative evaluation of well logs in designing casing cementing programs and well stimulation techniques

CAPWLA is specially designed to fulfill the needs of reservoir engineers and oil/gas property appraiser for whom well logs of various kinds are their primary tools.

Well logs are used by the reservoir engineer for the evaluation of effective pay thickness, porosity, fluid saturation, calculation of oil/gas originally in place, permeability and relative permeability of reservoir rocks.

The means by which these properties are calculated are coded in CAPWLA.

It is important to note that CAPWLA had eliminated the complex interpolation efforts of the log analyst. The programs had been coded to perform the interpolation and the relevant charts are called by the program for the necessary interpolation. Appendix A shows the charts already simulated in the text file systems of the computer.

Therefore the proposed system has the following characteristic features and merits:

i. The application will be based on a microcomputer or personal computer

ii. All relevant information will be stored in various databases on the PC

iii. Reduction of time and resources wastage resulting from manual interpolation and computation

iv. It produces very accurate and reliable results.

v. It will provide an easy to use interface that allows the following operation:

a. Easy storage of well log information.

b. Easy to update information on logging operations.

c. Easy to retrieve logging information by querying the database.

CHAPTER 2

LITERATURE REVIEW

The conventional electric log consists of spontaneous potential log, Resistivity logs (short normal, long normal, lateral curves and micrologs)

2.1 The Spontaneous Potential (SP) Curve

In 1928, Comrad and Marcel Schlumberger discovered that spontaneous polarization potential or self potential was generated in a well drilled with fresh mud. The Spontaneous potential, SP curve is a recording versus depth of the difference between the potential of a movable electrode in the borehole and the fixed potential of a surface electrode. The SP is used to:

i. Detect permeable beds;
ii. Locate their boundaries and to permit correlation of such beds;
iii. Determine the values of formation water resistivity, R_w and salinity in ppm;
iv. Give qualitative indication of bed shaliness;

The deflection on the sp curve is as a result of electric current flowing in the mud in borehole. The SP current are caused by electromotive forces in the formation which are of electrochemical and electro kinetic in nature

For the purpose of illustrating the electrochemical component of the SP, consider a thick permeable bed bounded by shale formation. Also assume that two electrolytes present are mud filtrate and interstitial water containing NaCl only.

In shale formation, the cations Na^+ moves from the more concentrated to the less concentrated solution but impervious to the Cl^- anions.

This movement of charged ions is an electric current and the force causing then to move constitutes a potential across the shale.

Another component of electrochemical potential is produced as the edge of the invaded zone where the mud filtrate and formation water are in direct contact.

In this case both Na^+ and Cl^- ions can transfer from either solution to the other.

Since Cl^- ions have greater mobility then Na^+ ions, the resultant flow is the flow of negative charge from the more concentrated solution to the less concentrated solution.

This flow of current is in opposite direction to the flow described in the upper paragraph.

If the permeable formulation is not shaly, Ec, the total electrochemical e.m.f corresponding to these two phenomenons is equal to

$Ec= -K \log a_w/a_{mf}$

Where a_w and a_{mf} are the chemical activities of the two solution (formation water and mud filtrate respectively at formation temperature.

K is a coefficient proportion to the absolute temperature (for Nacl formation water and mud filtrate equal 70.7 at 77^{0F}

However, permeable formation which constains some shales has the sp reduced.

Hence,

$$\text{Static sp}= -70.7\ (460+t_f)/537 \log (R_{mf}/R_w) \ldots\ldots.. (2)$$

Where

Static sp= Static spontaneous Potential (millivolts)

R_w and R_{mf} are the resistivity (in Ohm-m) of formation water and mud filtrate respectively at formation temperature.

t_f is formation temperature .

The limitation to the equation (2) is when the mud filtrate is saline, thus having the same resistivity as formation water.

The solution is to run a conductively focused current log which is outside the scope of this project.

Similarly, if the permeable formation contains some shale, the sp deflections will be reduced. There are specialized methods by Shell Petroleum Company, Schlumberger Company and S.J pirson used in analyzing shaly formation.This is also beyond the scope of this project. The project focuses on the analysis of convention electric log in clean formations.

Equation (2) had been reduced to sets of curves as shown in Fig 2.

The usual practice has been to manually perform numerous interpolations on these charts.

2.2 The Conventional Resistivity Logs.

The conventional resistivity survey consists 16 inch Short normal, 64 inch long normal and 18' 18" lateral curves. There is also wall resistivity log usually called the micro log.

In conventional logs, currents are passed through the formation via certain electrode and voltages are measured between certain others which provide the resistivity determination.

(a) In the normal device as shown in Fig X (Appendix B), a current of constant intensity is passed between A and B. The resulting potential difference is measured between the electrodes M and N on the side B.

The distance AM is called the spacing (16" for short normal and 64" for long normal).

Lateral Devices:- In a lateral device as shown in Fig 2X (Appendix B), a constant current is passed between A and B end the potential difference between electrodes M and N is measured.

The readings of the normal and lateral are affected by hole diameter, adjacent beds mud resistivity, mud filtrate invasion and Bed thickness. The readings are therefore corrected by means of charts prepare by Schlumberger Company or Lane well Company, See figures (6-11).

2.3 Micro Resistivity Device (Micro Log)

The microlog is used to measure R_{xo} (resistivity of the flushed zone) and to delineate permeable beds by detecting the presence of mud cake. The measurement of R_{xo} is useful for the accurate determination of true resistivity and hence saturation when the mud invasion is moderate. Similarly, the value of F, formation factor could be obtained from R_{xo} and R_{mf}.

With the micrologs tool, two short-spacing devices with different depths of investigation provide resistivity measurement of a very small volume of mud cake and formation immediately adjoining the borehole.

The two-inch micro normal has a greater depth than the 1x1 inch micro inverse.

The 2” micro normal is less influenced by mud cake and reads high resistivity thereby producing positive curve separation.

The positive curve separation is an indication of the presence of mud cake and hence permeable formulation. Under favorable conditions, R_{xo} values can be determined from the microlog using the (22) and charts (23-24) for D and H pad. The limitations of using micrologs are;

(i) The ratio R_{xo}/R_{mc} must be lower than 15

(ii) The mud cake thickness, tmc must not be greater than ½”(mud cake thickness, tmc is obtained from the caliper log).

(iii) Depth of invasion has to be more than 4”

2.4 Interpretation of Conventional Electrical Survey

2.4.1 Determination of Formation Water Resistivity , R_w and salanity.

The resistivity of the formation water is one of the basic data obtained using the spontaneous potential curve.

2.4.2 Determination of True resistivity, invaded zone resistivity and Depth of invasion.

The most difficult parameter to determine in most formation is the true resistivity, R_t because it depends on the condition of mud filtrate depth of invasion. In clean sand formulation, the depth of mud invasion is usually assumed to be shallow/ moderate in which case, the lateral tool measure,R_t while the short normal measures R_i

Conversely, if the depth of invasion of mud filtrate is deep, it would be inaccurate to have the assumption as that of the shallow invasion. In this case, the problem will involve solving for unknowns R_t , D_i and R_t .

In conventional Electric logging, this requires a complete departure curves which are available from the lane well logging company and schlumberger logging company.

The sample of the departure curves are as shown in figure (6) to (11)

2.4.3 Determination of porosity

Porosity of formation may be obtained from the values of R_{xo} derived from the microlog.

Using the Humble formula (S.J Pirson), we have

$\Phi = (0.62\ R_{mf}\ /R_{xo}\ (1 - Ros)^2\ )^{1/2.15}$

Where

Φ=Porosity (in percentage)

R_{mf} = mud filtrate resistivity ohm- m

R_{xo}= Flushed zone resistivity ohm-m

Ros= Residual oil saturation

The formation Factor, F can be also be determined using the formula

$F = (0.62/\ \Phi^{\ 2.15})$

2.4.4 Determination of water saturation

The water saturation is obtained according to Archie as

$S_w = \sqrt{}\ R_0/\ R_t$

Where

S_w =Water Saturation (in percentage)

R_0 =Resistivity(in ohm- m) of salt water- bearing horizon

R_0 can be also be calculated as

R_0=FRw

Where F= Formation factor

R_w= Formation water resistivity ohm-m (Obtained from sp curve)

2.5 Determination of Relative Permeability and reservoir fluid properties.

From petrophysical viewpoint, the relative permeability determines the relative distribution of the wetting and the non-wetting fluid phases within the reservoir rocks pore spaces. It also determines the relative ability of the fluids phases to flow simultaneously thorough the relative permeability to water, k_w is given by

$k_w = sw_m^{1/2} \ (R_o/R_t)^{3/2}$

Where sw_m= movable water saturation

R_t= true resistivity ohm-m

R_o= resistivity of salt water bearing formation

But, $sw_m = (s_w - s_{wi})/ (1 - s_{wi})$

Where s_{wi}= Irreducible water saturation

Relative permeability to oil, K_0 is

$K_0 = (1 - (s_w - s_{wi} / (1 - ROS - s_{wi}))^2$

Where ROS=Residual oil saturation

s_w= Water saturation

s_{wi}= Irreducible water saturation

ROS is also obtained from

$ROS = 1 - 1/\Phi \ (1 - s_{wi})/ (R_{mf}/ R_{x0})^{1/2}$

2.5.1 Oil viscosity at Reservoir Temperature (μ_0)

Knowing the API gravity of the oil to be produced, the chart in fig38 can be used to evaluate absolute viscosity μ, at a particular reservoir temperature.

Oil viscosity is then obtained using the empirical formula given (in S.J. Pirson) as

$\mu_0 = B_0 \mu / 1 + 4 (B_0 - 1) \mu$

Where B_0= formation Volume factor

μ=absolute viscosity (cp)

μ_o= oil viscosity(cp)

2.5.2 Water viscosity at reservoir Temperature

Fig39 can be used to evaluate water viscosity at a particular temperature and salanity

2.5.3 Determination of well productivity

Well productivity donates the simultaneous production of water and oil or gas at formation temperature.

The water oil Ratio may be determined by, $WOR = B_0 (K_w/K_0) (\mu_o / \mu_w)$

Where B_0= Formation Volume factor

K_w=Relative permeability to water

μ_0=Oil viscosity cp

μ_w=Water viscosity cp

K_0= Relative Permeability oil

μ_w=Water viscosity cp

2.6 Charts

The charts already stored in the text file systems of the computer include:

1. (R_{mf}/R_{we}) Vs static electrochemical Sp(mv) chart
2. R_w Vs $(R_w)_e$ chart (Schlumberger document)
3. Empirical correction chart for Sp curve
4. Bore – hole size correction charts for short normal, long normal and Lateral logs
5. Correction charts for bed thickness and adjacent bed effects (Schlumberger document)
6. Departure charts/curves for 2 normal logs (Lane – well document)
7. Chart for determination of flushed zone resistivity, R_{xo} (Schlumberger corporation).
8. Schlumbeger's chart for water saturation determination in shaly sands
9. Chart for determination of true formation factor, ft in shaly sand.
10. Shell's chart for determination of shalyness factor
11. Water viscosity chart
12. Absolute oil viscosity chart
13. Viscosity of natural gases (Sp. gravity 0.6, 0.7, and 0.8)
14. Chart for determination of residual oil by Craze and Buckley
15. Chart for average relation between porosity and permeability (from GE Achie)
16. Chart for the determination of invaded zone resistivity R_i and borehole diameter, d from a combination short normal (AM = 10in) Limestone 32in curve. (S.J Pirson document)
17. Mud filtrate resistivity, R_{mf}, versus mud resistivity, R_m chart (Continental oil company's document)
18. Mud cake resistivity, R_{mc}, versus mud resistivity, R_m chart (Continental oil company's document)

CHAPTER 3

PRINCIPLES OF WELL LOG INTERPRETATION

Here attention is concentrated on log analysis through manual process.

This process is what had been coded in the form of computer programs for quick and reliable computation.

The log interpretation through computer programs is presented in chapter 4.

3.1 CONVENTIONAL ELECTRIC LOGS

3.1.1 The spontaneous potential (sp) curves.

The spontaneous potential curve is used for the determination of formation water resistivity R_w, Ohm – m and Salinity in ppm.

It can also be used for lithology identification. The process involves using the charts (figures 1 – 5) in appendix A.

For the purpose of illustration, consider a log in fig 3.1(Appendix B) on which

ssp = -115, T = 155^0F, d = 7 7/8", R_m = 0.6, e = 15', R16 = 8.1 ohm – m

R64 = 4.3 ohm - m

From chart – Fig2, R_{mf}/R_{we} = 26

Then, proceed to chart in Fig3 for the conversion of R_{we} to R_w at formation temperature.

Similarly, proceed to chart in figure 5 to obtain the salinity using the value of Rw at formation temperature.

The value of formation water resistivity R_w = 0.026 Ohm – m

Water Salinity = 180,000 ppm

It is necessary to mention that the charts in Fig1a and 1b are used to obtain mud filtrate resistivity R_{mc} and mud cake resistivity, R_{mf} respectively at formation temperature.

For instance, if R_m = 0.6 ohm – m at 155^0F then R_{mf} = 0.43 ohm –m and Rmc = 0.87 ohm – m.

If necessary, sp reading can be corrected for bed thickness and invaded zone resistivity R_i using the chart in Fig 4.

Generally, for thick beds no correction is required. Similarly, for low resistivity and thick beds no correction is necessary.

3.1.2 The Normal Curves

The universally used electrode spacing are Am = 16in (short normal) and Am = 64 in (long normal).

These curves are affected by hole diameter, mud resistivity, bed thickness and adjacent bed.

There exist charts for correcting these disturbing factors.

Therefore, charts in figures 6 -7 are the Lanewell interpretation charts for borehole size correction for short normal, borehole size correction for long normal, Bed thickness and adjacent bed effects (short normal) and Bed thickness and adjacent bed effect (long normal) respectively.

3.1.2.1 Determination of True Resistivity, R_t, invaded zone resistivity R_i and Diameter of invasion D_i by the Two Normal and porosity balance method.

Most conventional electric logs provide a combination of two normal resistivity curve of standard spacing

AM = 16in (short normal)

AM = 64in (Long normal)

After corrections for borehole diameter effect (for borehole size different from 7 7/8 in) and for bed thickness and adjacent bed effects, the two – normal departure charts are available from lane – well company for which figures 14 – 17 are example for hole diameter 7 7/8 in

For values of R16/Rm and R64/Rm, there exist corresponding values of R_i/R_m and R_t/R_m for any specified invasion diameter Di/d = 2, 5, 10 and 15

In the absence of Lateral curve, porosity balance scheme is adopted in order to evaluate the values of R_t, R_i and D_i. Porosity balance scheme is used where the value from either a 100percent salt water saturated zone or from a porosity tool (if available)

For the purpose of illustration, consider a log in fig 3.1 which shows an oil zone overlying an obvious salt – water bearing zone.

The apparent readings are

ssp = -115mv

R16 = 8.1 ohm – m

R64 = 4.3 ohm – m

R_o = 0.6 ohm –m

e = 15ft

d = 7 7/8"

R_s = 1.2

Bed thickness and adjacent bed effects correction gives

R16corr = 9.1 ohm – m

R64corr = 6.3 ohm – m

Now, proceed to the departure curves (fig 14 – 17), thus a table is constructed as follows:

Table 1.0

Di/d	R_i/R_m	R_t/R_m	R_i/R_t
2	30	8.0	3.75
5	17	8.0	2.13
10	15	6.5	2.31
15	14.8	5.0	2.96

From sp curve, R_w = 0.026 ohm – m

Hence, sand formation factor F = 0.6/0.026 = 23 and porosity Ø = 18percent (using Humble formula)

Since, this is water – wet rock, R_z/R_w = 7.0 or R_z = 0.18 (From chart in fig 1c)

Assuming ROS = 30percent

Ri = FRz/(1 – ROS)^2 = 8.5

and R_i/R_m = 14.1

Thus, an invasion diameter is between 10 to 15d with R_i = 8.5 and R_t = 3.6 ohm – m

Water saturation (Archie's equation) = 41%

3.1.2.2 Porosity Determination from the short Normal curve.

Short normal curve can be used to compute porosity when porous formations are sufficiently invaded.

This can be achieved by using its chart in fig 12

For illustration purposes, compute the porosity in the oil zone when

R16 = 8.1 ohm - m

Sp = -115 mv

R_m = 0.6

ROS = 20%

Using the chart in figure 12

AM/d = 2

Porosity, Ø = 19.5 percent

F = 26

3.1.3 Lateral Curves

The objective of Lateral curve is to measure Rt, that is the resistivity of uninvaded formation. The standard electrode spacing is 0A = 18'8"

Similarly, lateral curves are affected by borehole size, mud resistivity R_m, Bed thickness and adjacent bed effect.

The charts in figures 8 – 9 (Lane – well company) are used for the correction of borehole size, Bed thickness and adjacent bed effects.

Chart in figure 11 is the schlumberger chart for borehole size correction.

3.1.3.1Determination of R_t, R_i, and D_i by the combined Normal – Lateral interpretation charts

As shown in the preceding sections, the combination of two normal can be used to evaluate R_t, R_i and D_i provided porosity of the formation is known.

But, with an additional lateral lateral curve as shown in figures 18 – 21 the scheme of porosity balance is not necessary.

For instance, consider a log in fig3.2 (Appendix C) in which the effective pay is much thicker and as such the readings on the normal curves requires no correction.

By using the departure curves of the combination of normal – lateral, the following table is obtained using $R16/R_m = 15.1$ and $R18'8"/R_m = 6.0$

Table 2.0

D_i/d	R_i/R_m	R_t/R_m	R_i/R_t
2	40	5.5	7.27
5	18	5.8	3.10
10	16.5	5.7	2.72
15	14.5	5.5	2.64

The values of R_i/R_t obtained by the two normal methods and by the normal – lateral method are plotted. From the graph $D/d_i = 9d$, $R_i/R_m = 16.0$, $R_t/R_m = 5.75$.

Hence, $R_i = 9.6$

$R_t = 3.45$

3.1.4 Micrologs

The purpose of microlog is to measure the formation factor of porous formation by measuring the flushed zone resistivity R_{xo}. It measures an effective porosity rather than total porosity.

The microlog provides a short lateral (or micro inverse) of spacing AO = 1 ½" and a small normal (or micro – normal) of spacing Am = 2". Microlog could be H or D pad type.

The presence of a uniformly thick mud cake is observed by a positive separation between micro normal and micro inverse curves, that is the 2" curve reads higher them the 1 ½" curve.

Micro Caliper on the other hand measures mud cake thickness.

The schlumberger chart in figure23 is used to determine mud cake thickness t_{mc} from D – pad and H – pad microlog devices. Similarly charts in fig 24 a & b are used to calculate R_{xo} from D – pad and H – pad devices respectively.

For example, consider the log shown in fig 3.3 (Appendix B)

The pertinent data at 7066' – 7076 level of perforation are as follows:

$t = 144^0F$

R_m at $156^0F = 0.36$ ohm – m

R_m at $144^0F = 0.40$ ohm – m

R_{mf} at $144^0F = 0.25$ ohm –m from chart

R_{mc} at $144^0F = 0.9$ ohm – m from chart

d = 9 in

t_{mc} = ¾ in by micro caliper

$R_{1X1} = 1.5$ ohm – m

$R_2 = 2.6$ ohm – m

By chart in fig, 22.0

$R_{1X1}/R_2 = 0.6$

t_{mc} = ¾ in

$R_{xo}/R_2 = 5.5$

$R_{xo} = 14.3$ ohm – m

R_{xo}/R_{mf} = 14.3/0.25 = 57.2

if ROS = 20 percent

Ø = 14.7 percent (Humble's formula)

Ø = 14.7 percent (Archie's formula)

F = 39.0

3.2 Other Conventional Electric Logs

3.2.1 CASE STUDY 1

The log of Fig C3.1 (Appendix B) shows clean sand moderately invaded by mud filtrate. The sp curve reaches static deflection and it is presumed that R_w can be dependably calculated from it. Using manual and computer method, obtain all relevant information from the logs such as R_w, formation factor F, R_t, R_i, R_{xo}, S_w, porosity Ø, Reservoir fluid and rock properties, and recovery forecast. Compare your results

Given that:

R_m = 2.6 ohm – m at 170^0F BHT

Depth = 5016ft

Oil gravity = 30^0 API

Dm = 1.2; PH = 11.6; f = 7cc/30min; SIP = 2530psi

Permeability = 1500 md (From core analysis)

eev = 38 ft

d = 7 7/8"

The apparent readings from the logs are:

SSP = -77mv

R_{16}" = 28 ohm – m

R_{64}" = 17 Ohm –m

R_{19}" = = 13 ohm – m

$R_{1X!}$ = 9.5 ohm – m

R_2 = 12.5 ohm - m

3.2.2 POROSITY DETERMINATION

Quantitative Analysis of Microlog (D – pad)

R_m at formation temp = 2.6 0hm –m

From fig 1b R_{mf} = 2.35 ohm – m

Fig R_{mc} = 2.15

R_2 = 12.5 ohm – m

R_1 = 9.5 ohm – m

R_1/R_{mc} = 4.4

R_2/R_{mc} = 5.8

From fig 24a R_{xo}/R_{mc} = 15

R_{xo} = 15*12.5

R_{xo} = 32.25

Thus $F = R_{xo} * (1. - ROS)^2/R_{mf}$

$\Phi = (0.62)/F)^{1/2.15}$ (Humble formula)

$\Phi = (1/F)^{1/m}$ (Archie formula, m= cementation factor)

Therefore

ROS	Formation factor F	Porosity % (Humble)	Porosity % (Archie)
0	13.72	23.2	25.2
0.15	9.9	27.1	29.9

5.2.2 Porosity determination from short Normal

AM/d = 2.0

ASP = -77

$R16/R_m$ = 28/2.6 = 10.8

From chart fig 12

ROS	Formation factor F	Porosity
0	15.2	22.0
0.15	11.5	26.0

3.2.3 Spontaneous Potential Curve

Apparent Static Sp = -77mv

Formation Temperature = 170^0F

Bed thickness = 38ft

From chart in fig 2

$(R_{mf}/R_w)_e = 8.7$

$R_{we} = R_{mf}/(R_m/R_w)_e$

$R_{we} = 2.35/8.7$

$= 0.27$

From chart in fig 3 $R_w = 0.38$

Formation water resistivity, $R_w = 0.38$ ohm –m

From chart in fig 5

Formation water salinity = 65500ppm

3.2.4 Quantitative Analysis of Normal and Lateral Curves

3.2.4.1 Determination of R_t, R_i and D_i

3.2.4.2 Correction of R16, R64 and R19

From chart (Bed thickness/adjacent bed effect for short normal) R16c = 28.6 ohm – m. Since d = 7.875" no borehole correction is required.

Similarly, From chart R64c = 18.5 ohm – m

and from chart R19c = 13 ohm – m

Three methods will be demonstrated for the determination of R_t, R_i and D_i as follows:

(a). if no mud filtrate invasion/moderate invasion is assured then R19 reads R_t while R16 reads R_i and of course $D_i = 0$ (in computer solution variable meth = 1)

(b). For deep invasion of mud filtrate, two normal curve and porosity balance scheme will be adopted (in computer solution, meth (variable) is set to 2)

(c). For deep mud filtrate invasion, two normal curve and Lateral curve scheme (complete departure curve analysis will be adopted) (in computer solution variable meth is set to 3)

3.2.4.3 Method 1

From the above corrected values of R16 and R19, then

$R_i = 28.1$ ohm – m

$R_t = 13.0$ ohm – m

D_i is negligible

5.4.2 Two Normal Curves and Porosity Balance Scheme

From the departure curves in fig 14 – 17, a table is obtained using

R16c/Rm = 10 76

R64c / Rm = 7.1

D_i/d	R_i/R_m	R_t/R_m	R_i/R_t
2.0	20.	5.9	3.39
5.0	12.	5.8	2.07
10.0	10.5	5.6	1.92
15.	10.5	5.0	2.22

Using a value of porosity (Humble & Archie) $\Phi = 27.1\%$ Ros = 0.15 from microlog analysis.

For clean water wet rock, the value of z may be selected as follows:

z = 5percent when $10 < \Phi < 18$percent

z = 7.5percent when $18 < \Phi < 25$percent

z = 10percent when $25 < \Phi$

Hence $z = 0.1$

From chart in fig 1b $R_{mf} = 2.35$

From SSP curve $R_w = 0.37$

From chart in fig 1c $R_z / R_w = 4.0$ using $R_{mf}/R_w = 6.4$

$R_z = 4 * 0.37$

$R_z = 1.48$

Hence $Ri = (F * R_z) / (1 - ROS)^2$

$= (9.9 * 1.48) / (1 - 0.15)^2$

$= 20.3$

$R_i = 20.3$

$R_i/R_m = 7.81$

Obviously, the invaded diameter is at least 15

Thus $R_t/R_m = 5.0$

$R_t = 13.0$ ohm- m

3.2.4.4 Two Normal curves and Lateral curve

From the departure curve in fig that is Two normal an d Lateral departure curve analysis, the tables are obtained using

R16c/Rm = 10.76

R64/Rm = 7.1

R19/Rm = 5

The first table is similar to the table obtained in method 2.

The next table shown below is obtained from Normal – Lateral combination charts in fig 18 – 21

D_i/d	R_i/R_m	R_t/R_m	R_i/R_t
2.0	24.	4.9	4.9
5.0	13.5	5.	2.7
10.0	11.	4.5	2.4
15.	10.	4.9	2.0

Plot the graph of R_i/R_t for the two normal – lateral curves against Di/d.

From the point of intersection

$D_i/d = 12.$

$R_i/R_t = 2.2$

$R_i/R_m = 11$

Hence,

$R_i = 28.50$ ohm – m

$R_t = 13$

$D_i = 94.5"$

The following points are to be noted.

A. There may be the need to correct the apparent reading for the bed thickness and invaded zone resistivity.

For this particular example,

$R_i = 28.1$ ohm – m

$R_i/R_m = 10.76$

Thus from chart in fig 4

%Sp = 100.

Correction factor = 1.0

Hence, App. SSp = -77 * correction factor

App. SSp = -77

B. In the case of the analysis of microlog, when tmc is known accurately from caliper log, chart in fig 22 is used for the determination of R_{xo}.

On the other hand, if tmc is unknown and R_{mc} is known, then R_{xo} is obtained from chart in fig 24a for Dpad microlog or chart in fig 24b for Hpad microlog. The chart in fig 23 is also used to calculate tmc for D – pad and H – pad microlog

3.2.5 Determination of water saturation Sw

If the porosity $\Phi = 27.1$, $F = 9.90$

$Ro = FR_w$

$Ro = 9.91*0.37$

$Ro = 3.66$

$S_w = \sqrt{}Ro/Rt = \sqrt{}3.66/13$

$= 0.53$

$= 53\%$

3.2.6 Determination of Permeability

From chart in fig 38 the irreducible water saturation $S_{wi} = 15\%$

The saturation of movable water, $Sw_m = S_w - S_{wi}/\ 1 - S_{wi}$

Hence $Sw_m = (0.53 - 0.15)/(1 - 0.15) = 0.38/\ 0.85$

$Sw_m = 0.447$

Relative permeability to water $K_w = Sw_m{}^{1/2}\ (Ro/R_t)^{3/2}$

$K_w = (0.45)^{1/2} * (3.66/13)^{3/2}$

$K_w = 0.100$

From chart in fig38 $S_{wi} = 15\%$ using porosity = 27.1% and Permeability K = 15000 and

Relative Permeability to oil, $K_o = 1 - (S_w - S_{wi}/1\text{-}S_{wi}\text{-}Ros)^2$

$K_o = (1.\text{-}(0.53\text{-}0.15/(1.\text{-}\ 0.15\ \text{-}0.15)))^2$

$K_o = (0.4571)^2$

$K_o = 0.21$

3.2.7 Determination of Fluid Properties

Water Viscosity $\mu_w = 0.36cp$ from chart in fig 39

From chart in fig 41 Absolute Viscosity $\mu = 6.0cp$

Hence $\mu_o = Bo\mu/1{+}4(Bo - 1)\ \mu$

$= (1.3*6)/(1+4*0.3*6)$

$= 0.95cp$

3.2.8 Detrmination of well productivity

$WOR = Bo.(Kw/Ko)\ (\mu_o/\mu_w)$

$= 1.3 * (0.106/0.21)\ (0.95/0.36)$

$= 1.63$

Productivity Index, $PI = hkk_o/\mu_oB_o$

$= (22*1500*0.21/0.95*1.3)*10^{-}\ \ = 7.1$

3.3 CASE STUDY 2

The log of Fig C3.2 (Appendix B) shows a formation which exhibit oil – wetted properties. Using manual and computer method obtains all relevant information from the log similar to those in example 1. Compare the results of both methods

Given that:

R_m = 0.84 at 130°F; T_f at 6850' = 130°F

Depth = 6825ft

Oil gravity = 30° API

e = 49'

d= 9'

Permeability = 100 md (From the core analysis)

Apparent Readings from the logs are:

ASP = -55mV

$R_{16"}$ = 145 ohm-m

$R_{64"}$ = 420 ohm-m

$R_{19'}$ =1500 ohm-m

R_{1x1} = 3.0"

R_2 = 4.5"

Analysis of Oil wet sand

R_m @ t0F = 0.84, R_{mf} = 0.6, R_{mc} = 1.15

6.1 Porosity Determination

6.1.1 Microlog Analysis (D – Pad)

d = 9

R_1 = 3.0

R_2 = 4.5 ohm – m

R_1/R_{mc} = 2.6

R_2/R_{mc} = 3.9

From chart in fig24a, R_{xo}/R_{mc} = 12.0

R_{xo} = 13.80

Thus $F = R_{xo} * (1. - Ros)^2/R_{mf}$

$\Phi = (0.62/F)^{1/2.15}$

or $\Phi = (1/F)^{1/m}$

Hence

Ros	Formation factor, F	Porosity % (Humble)	Porosity % (Archie)
0.	23	18.5	19.2
0.15	17.5	21	22.2

6.1.2 Porosity determination from short normal

Am/d = 1.8

Asp = -85mv

$R16/R_m$ = 145/0.84 = 173

Ros	Formation factor, F	Porosity %
0.	618	4.0
0.3	330	5.5

6.2 Determination of R_w and Salinity

R_m @ t^0F = 0.84 ohm – m, SSP = -85mv, t^0F = 130, d = 9”

Hence, $R_{mf} = 0.6$ ohm – m

$R_{mc} = 1.15$ ohm – m

from chart

$R_{mf}/R_{we} = 13.$

$R_{we} = R_{mf}/\ (R_{mf}/R_{we}) = 0.046$

$R_w = 0.058$

Formation water resistivity, Rw = 0.058 ohm – m

Formation water salinity = 72,000ppm

Due to wide discrepancy between the porosity derived from the wall resistivity tool and short normal, oil wet sand is suspected.

Determination of saturation exponent in the flushed zone

$S_{xo} = 1 - (Ros)_f = n\sqrt{FR^{mf}/R_{xo}}$

and invaded zone

$S_{xi} = 1 - (Ros)_i = n\sqrt{FR_{mf}/R_i}$

Hence ,$(1- (Ros)_f/ 1-(Ros)_i)^n = R_i/R_{xo}$

$(Ros)_f = 0.1$

$(Ros)_i = 0.7$

Thus, n = 2.9

Now compute F, $1 - (Ros)_f = 3\sqrt{FR_{mf}/R_{xo}}$

Hence, F = 16.8 and $\Phi = 21.6$

Similarly, $1- (Ros)_i = 3\sqrt{FR_{mf}/R_i}$

Hence, F = 16.5 and $\Phi = 21.8$

Therefore, Porosity = 22.0%

Archie $S_w = 9.4\%$ (Which is ridiculously low)

Tixier $S_w = (R_i/R_t)^{1/n-1}\ (R_w/R_{mf})^{n-1}$

$R_w = 0.057$ (As shown later)

Sw = 0.17

6.3 Permeability determination

Given K = 100md

Chart in fig38 $S_{oi} = 0.25$ $So_m = 0.73$

$K_o = 0.45$ $K_w = 0.0056$

6.4 Fluid Properties determination

Given API = 30^0, $B_o = 1.2$

μ_o= 2.0cps, μ_w = 0.54cps (From chart in fig39 using Salinity of

6.5 Determination of oil well productivity

WOR = 0.06

CHAPTER 4

SOFTWARE IMPLEMENTATION

4.1 Introduction

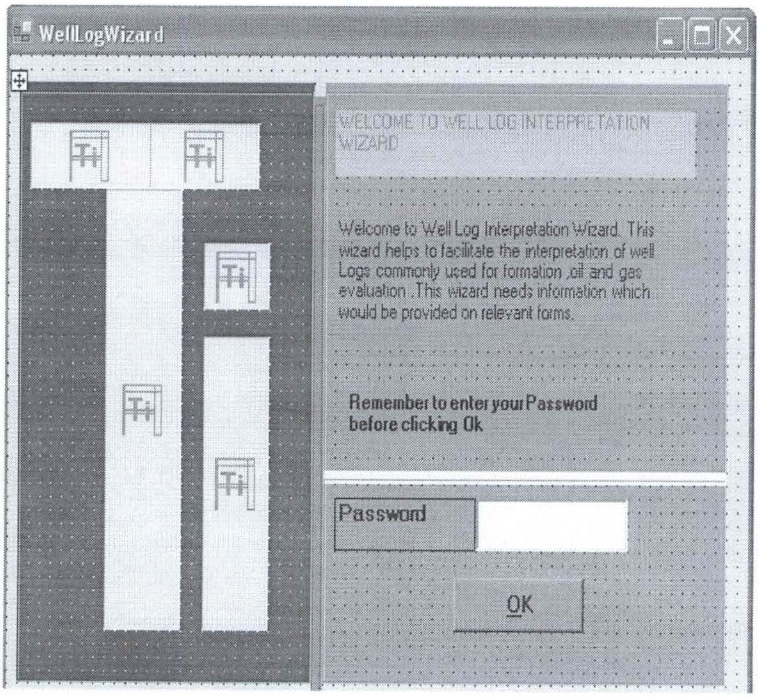
Given the necessary input parameters for the log to analyze, the software generates appropriate data such formation water resistivity, formation water salinity, flushed zone resistivity, formation factor, porosity, water/oil saturation, irreducible water/oil saturation and other formation evaluation data. The software is user friendly and interactive. The software is developed using Visual Basic .NET Language.

4.2 General Procedure using the software

An important feature of the program is that it accepts data inputs in a predetermined sequence. Essentially the overall procedures to use the software for formation evaluation are as follows:

- Specify log type
- provide all relevant information
- Calculate the required data
- Plot necessary graphs where required
- Save and/or print solution

4.3 Stating the software

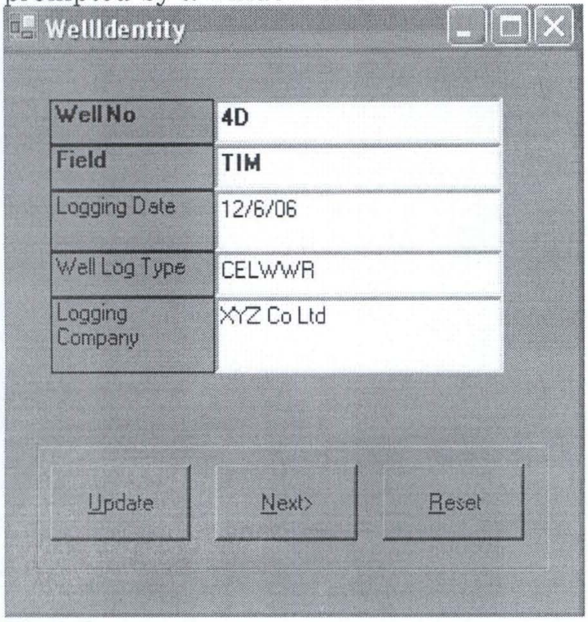


Welcome to Well Log Interpretation Wizard. This wizard helps to facilitate the interpretation of well Logs commonly used for formation ,oil and gas evaluation .This wizard needs information which would be provided on relevant forms.

Remember to enter your Password before clicking Ok

Fig 1.0

To launch the software double
•Click on CAPWLA icon on your desktop or CAPWLA sub menu on your programs menu bar. This launches the WellLogwizard as depicted by the interface as in fig 1.0 above.
After entering your password you click, if the password is correct you will be prompted by a window shown below



Well No	4D
Field	TIM
Logging Date	12/6/06
Well Log Type	CELWWR
Logging Company	XYZ Co Ltd

Fig 2.0

There are three buttons on this interface arranged horizontally at the bottom of the form.

a. **Update** –To update the SQL database with the information provided about the well. The information include Well No, Field, and Log type. The naming convention of log type involves using abbreviation of the log, for instance Convention Electric, Log water Wet Rock can be written as CELWWR.

Convention Electric Log Oil Wet Rock can be written as CELOWR.

b. **Next** –To display WellLogMainMenu as shown in fig 3.0

c. **Reset**-To clear the information given

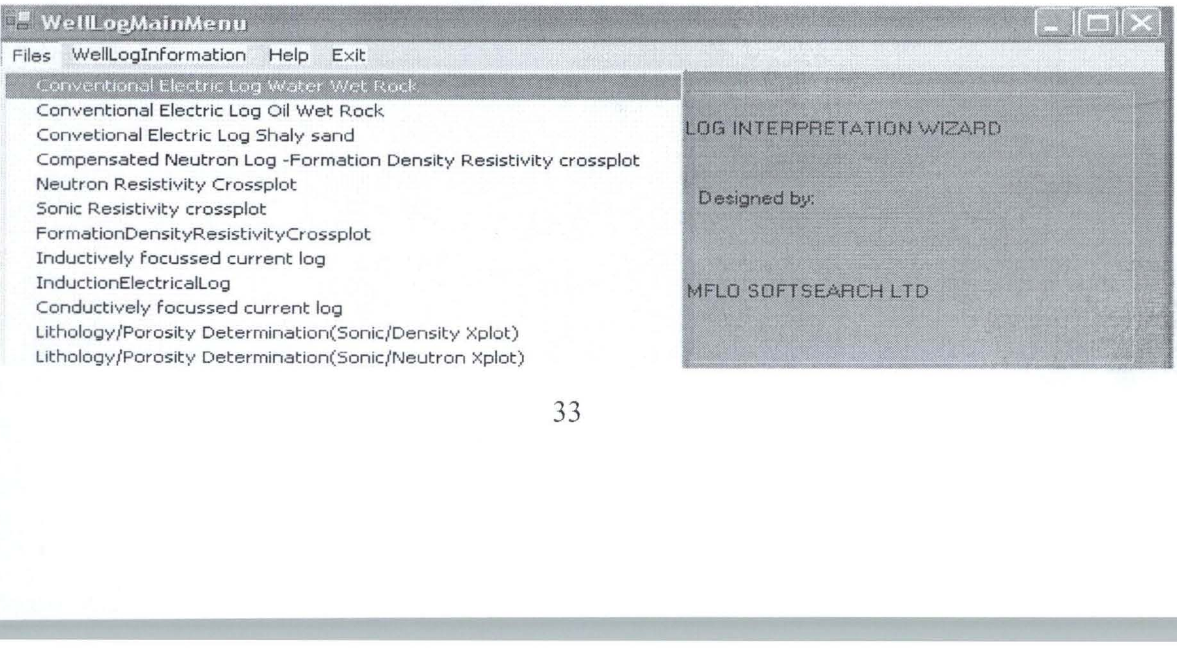


Fig 3.0

On WellLogMainMenu ,you have the following menu items on the menu bar;

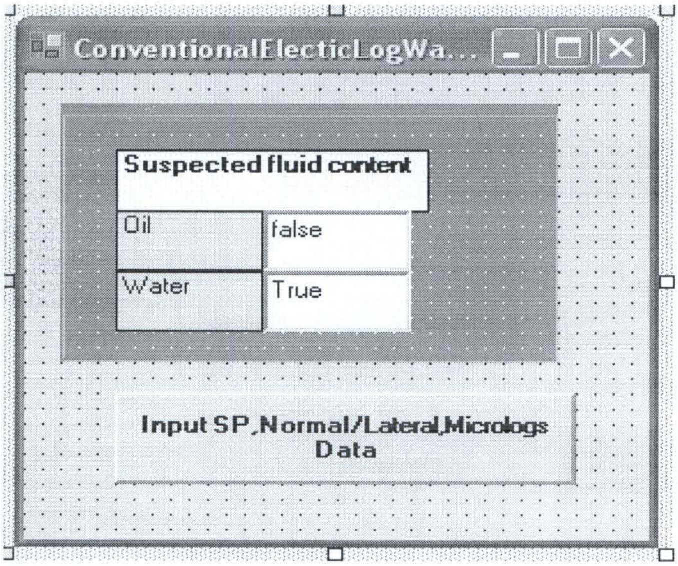
a. Files
b. WellLogInformation: This utility enables the user to obtain information on previously analyzed logs.
c. Help
d. Exit: To return to previous interface, click Exit

The file menu displays various types of log combination you intend to analyze as shown above.

To select a particular type of log combination, you simply **click** on it.

For instance, if you want to interprete a Conventional Electric log (Water wet sand), in menu list shown in fig 3.0, click on it.

This displays the interface in fig 4.0



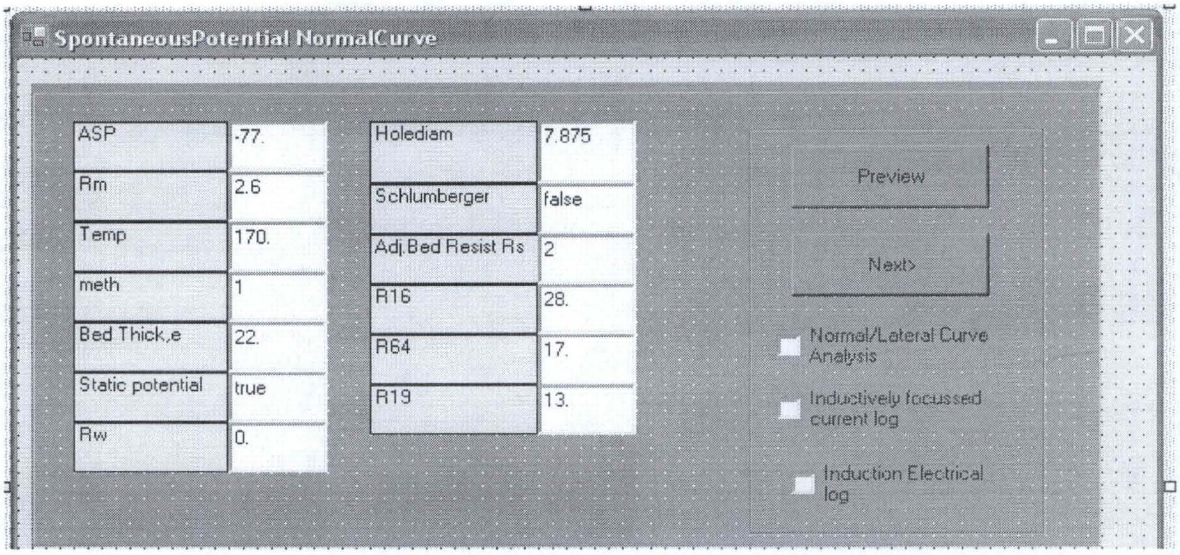
Suspected fluid content	
Oil	false
Water	True

Fig 4.0

Data Capture

a. Click input SP Normal/Lateral,Micrulog Data

b. Enter the information as depicted on the spontaneous potential/Normal curve data interface as shown in fig 5.0



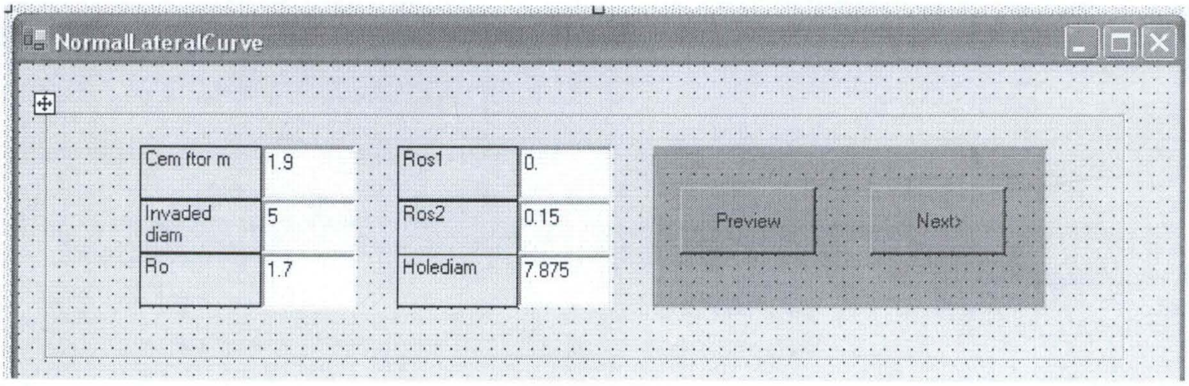
ASP	-77.	Holediam	7.875
Rm	2.6	Schlumberger	false
Temp	170.	Adj.Bed Resist Rs	2
meth	1	R16	28.
Bed Thick,e	22.	R64	17.
Static potential	true	R19	13.
Rw	0.		

Fig5.0

c. Click preview to view Sp data/results

d. Check normal/Lateral curveAnalysis checkbox control to display the normal/Lateral interface or check inductively focused current log checkbox control to display the inductively focused current log interface or check induction Electrical log checkbox control to display the induction Electrical log

e. **Click** Next to display the normal/Lateral interface as shown in fig6.0



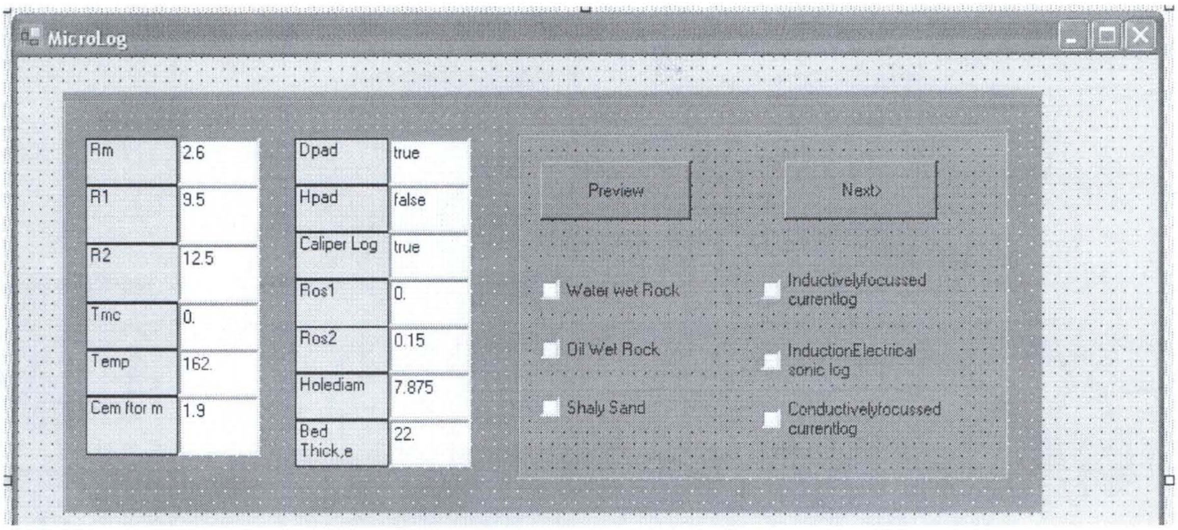
Cem ftor m	1.9	Ros1	0.
Invaded diam	5	Ros2	0.15
Ro	1.7	Holediam	7.875

Fig6.0

f. Enter the information as depicted on the NormalLateral curve interface as shown in fig 6.0

g. Click preview to display NormalLateral curve results.

h. Click Next to display microlog curve interface as depicted in fig 7.0



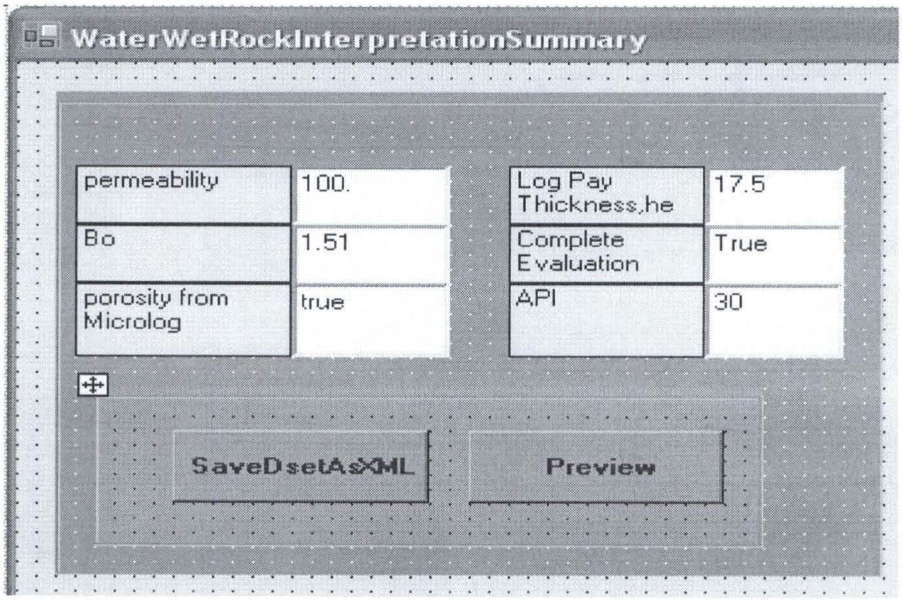
Rm	2.6	Dpad	true
R1	9.5	Hpad	false
R2	12.5	Caliper Log	true
Tmc	0.	Ros1	0.
Temp	162.	Ros2	0.15
Cem ftor m	1.9	Holediam	7.875
		Bed Thick,e	22.

Fig 7.0

i. In similar manner, enter the information as depicted in fig 7.0

j. Click preview to display the results

k. After checking the water wet rock checkbox control, click Next to display water wet rock interpretation summary interface as depicted in fig 8.0



permeability	100.	Log Pay Thickness,he	17.5
Bo	1.51	Complete Evaluation	True
porosity from Micrology	true	API	30

Fig 8.0

l. After entering the appropriate data, click preview to display results.

m. Click button saveDsetAsXML to save the input/output data as XML document.

n. For other conventional Electric log interpretation, you follow similar steps.

4.4 Testing the programs

4.4.1 Conventional Electric Logs

4.4.2 CASE STUDY1 (Interpretation of water wet rocks)

The log of Fig C3.1 (Appendix B) shows clean sand moderately invaded by mud filtrate. The sp curve reaches static deflection and it is presumed that R_w can be dependably calculated from it. Using manual and computer method, obtain all relevant information from the logs such as R_w, formation factor

F, R_t, R_i, R_{xo}, S_w, porosity Ø, Reservoir fluid and rock properties, and recovery forecast. Compare your results.

Given that:

R_m = 2.6 ohm – m at 170^{0}F BHT

Depth = 5016ft

Oil gravity = 30^0 API

Dm = 1.2; PH = 11.6; f = 7cc/30min; SIP = 2530psi

Permeability = 1500 md (From core analysis)

eev = 38 ft

d = 7 7/8"

The apparent readings from the logs are:

ASP = -77mv

R_{16}" = 28 ohm – m

R_{64}" = 17 0hm –m

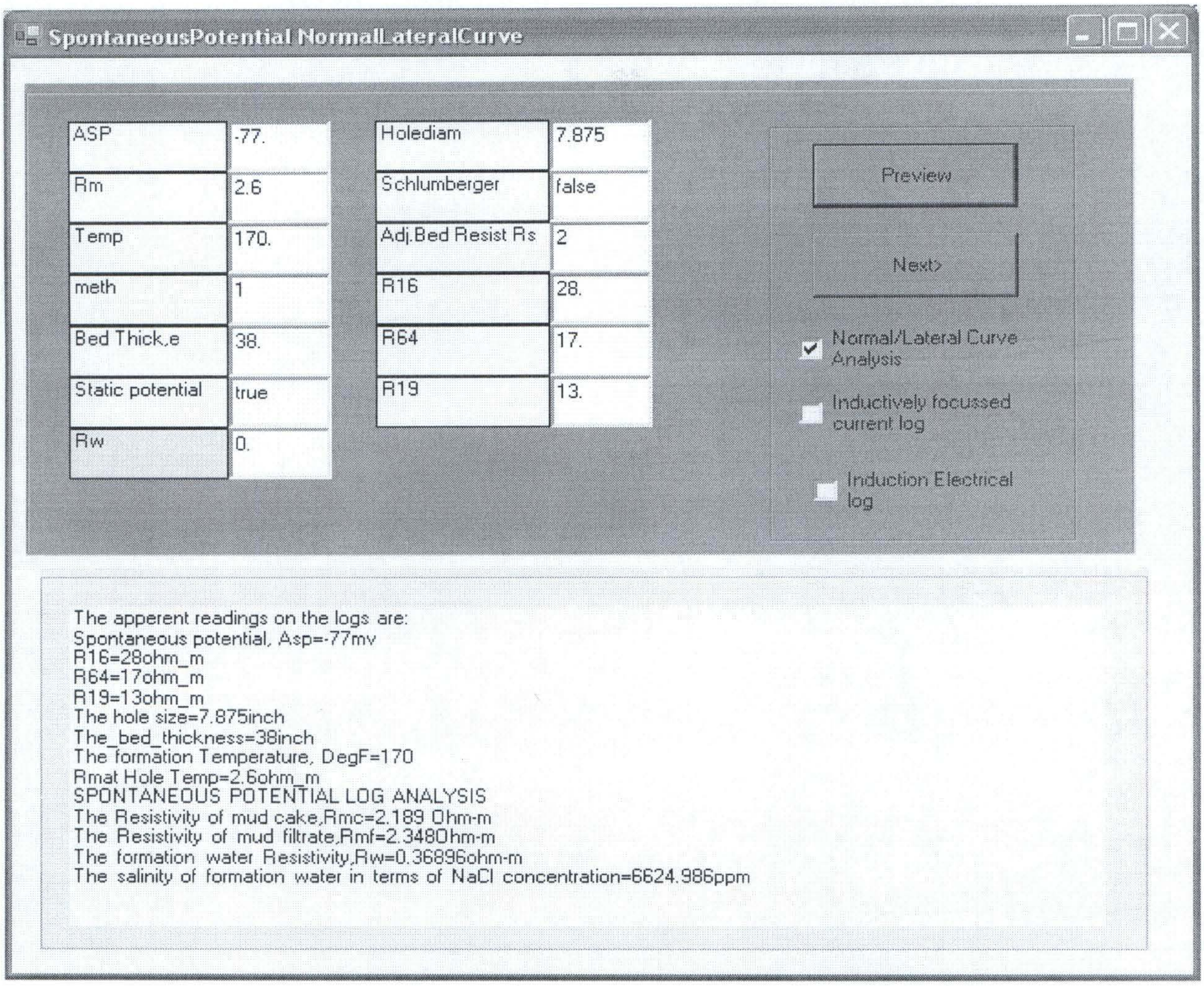
R_{19}" = = 13 ohm – m

$R_{1X!}$ = 9.5 ohm – m

R_2 = 12.5 ohm - m

Step1: Determination of formation water resistivity, Rw and salinity

. After entering the appropriate data as shown in fig 4.4a, the values of R_w and salinity in ppm are shown below



ASP	-77.	Holediam	7.875
Rm	2.6	Schlumberger	false
Temp	170.	Adj.Bed Resist Rs	2
meth	1	R16	28.
Bed Thick.e	38.	R64	17.
Static potential	true	R19	13.
Rw	0.		

☑ Normal/Lateral Curve Analysis
☐ Inductively focussed current log
☐ Induction Electrical log

```
The apperent readings on the logs are:
Spontaneous potential, Asp=-77mv
R16=28ohm_m
R64=17ohm_m
R19=13ohm_m
The hole size=7.875inch
The_bed_thickness=38inch
The formation Temperature, DegF=170
Rmat Hole Temp=2.6ohm_m
SPONTANEOUS POTENTIAL LOG ANALYSIS
The Resistivity of mud cake,Rmc=2.189 Ohm-m
The Resistivity of mud filtrate,Rmf=2.348Ohm-m
The formation water Resistivity,Rw=0.36896ohm-m
The salinity of formation water in terms of NaCl concentration=6624.986ppm
```

Fig 4.4a

Step2: Analysis of normal/Lateral curves

After entering the appropriate data as shown in fig 3.4b, the correction of normal/Lateral apparent readings for borehole diameter, Bed thickness and adjacent bed effects are accomplished here.

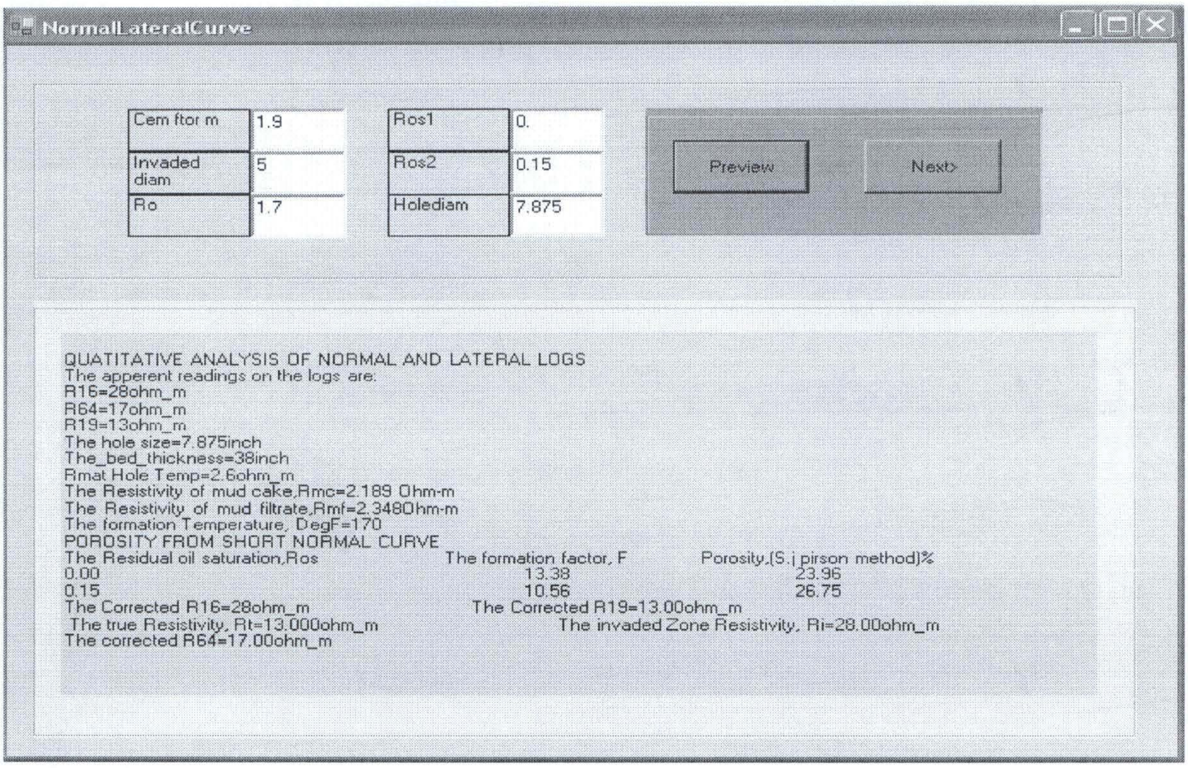
Similarly, rigorous departure curve analysis (in case depth of mud filtrate invasion is to be investigated) can also computed here.

This is accomplished by setting the value of METH to either 2 or 3 as explained in chapter 2.

In this particular case study the mud filtrate invasion is assumed to be moderate (METH=1in fig4.4b).

Porosity determination using short normal is also computed as shown in fig 4.4b

Fig 4.4b



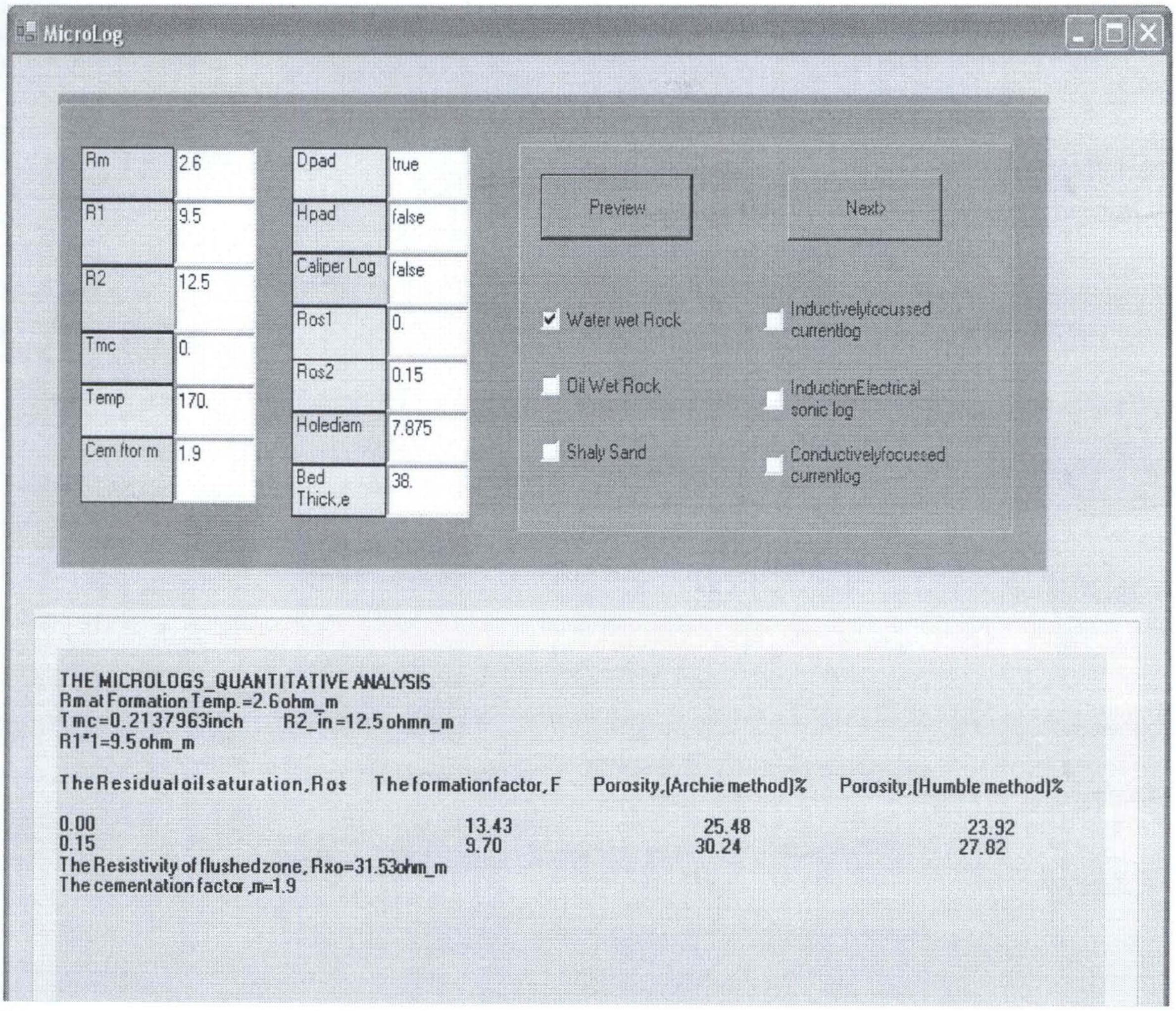
Cem ftor m 1.9
Invaded diam 5
Ro 1.7
Ros1 0.
Ros2 0.15
Holediam 7.875

```
QUATITATIVE ANALYSIS OF NORMAL AND LATERAL LOGS
The apperent readings on the logs are:
R16=28ohm_m
R64=17ohm_m
R19=13ohm_m
The hole size=7.875inch
The_bed_thickness=38inch
Rmat Hole Temp=2.6ohm_m
The Resistivity of mud cake,Rmc=2.189 Ohm-m
The Resistivity of mud filtrate,Rmf=2.348Ohm-m
The formation Temperature, DegF=170
POROSITY FROM SHORT NORMAL CURVE
The Residual oil saturation,Ros                The formation factor, F            Porosity,(S.j pirson method)%
0.00                                                 13.38                                 23.96
0.15                                                 10.56                                 26.75
The Corrected R16=28ohm_m                          The Corrected R19=13.00ohm_m
 The true Resistivity, Rt=13.000ohm_m                          The invaded Zone Resistivity, Ri=28.00ohm_m
The corrected R64=17.00ohm_m
```

Step3: Determination of R_{xo}, F and porosity using either H or D pad microlog.

Here you enter the microlog readings R_{1x1}, R_2 and other data such as hole diameter, temperature, mud cake thickness(from caliper log if available), cementation factor, residual oil saturation and formation thickness.

The flushed zone resistivity R_{xo}, formation factor F, and porosity are computed as shown in fig4.4c.



Rm 2.6
R1 9.5
R2 12.5
Tmc 0.
Temp 170.
Cem ftor m 1.9

Dpad true
Hpad false
Caliper Log false
Ros1 0.
Ros2 0.15
Holediam 7.875
Bed Thick,e 38.

☑ Water wet Rock
☐ Oil Wet Rock
☐ Shaly Sand
☐ Inductivelyfocussed currentlog
☐ InductionElectrical sonic log
☐ Conductivelyfocussed currentlog

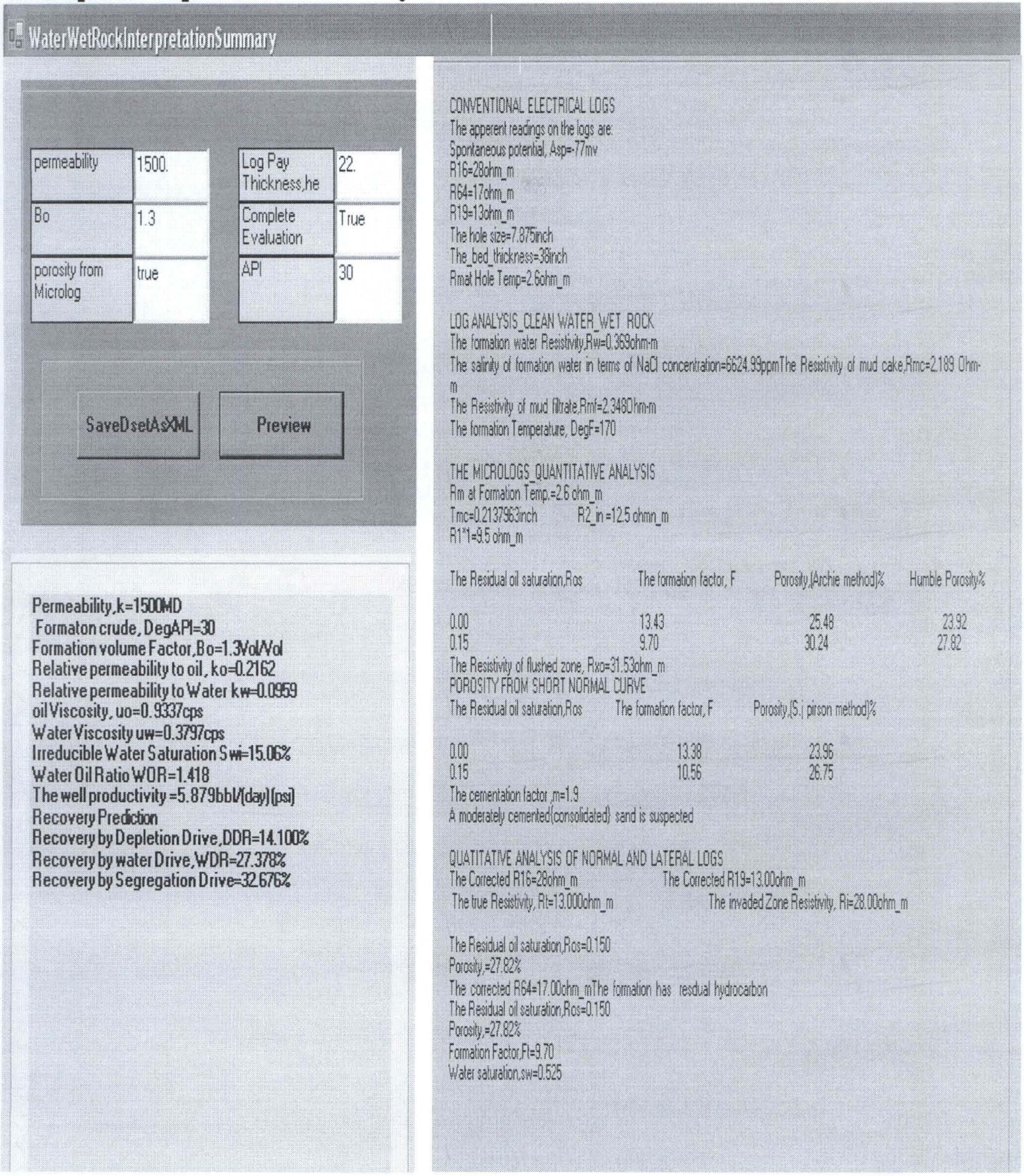
```
THE MICROLOGS_QUANTITATIVE ANALYSIS
Rm at Formation Temp.=2.6ohm_m
Tmc=0.2137963inch      R2_in=12.5 ohmn_m
R1*1=9.5 ohm_m

TheResidualoilsaturation,Ros   Theformationfactor,F   Porosity,(Archie method)%   Porosity,(Humble method)%

0.00                           13.43                    25.48                       23.92
0.15                           9.70                    30.24                       27.82
The Resistivity of flushedzone, Rxo=31.53ohm_m
The cementation factor ,m=1.9
```

Fig4.4c

Step4: Interpretation summary



permeability	1500.	Log Pay Thickness,he	22.
Bo	1.3	Complete Evaluation	True
porosity from Microlog	true	API	30

```
Permeability,k=1500MD
 Formaton crude, DegAPI=30
Formation volume Factor,Bo=1.3Vol/Vol
Relative permeability to oil, ko=0.2162
Relative permeability to Water kw=0.0959
oil Viscosity, uo=0.9337cps
Water Viscosity uw=0.3797cps
Irreducible Water Saturation Swi=15.06%
Water Oil Ratio WOR=1.418
The well productivity =5.879bbl/(day)(psi)
Recovery Prediction
Recovery by Depletion Drive,DDR=14.100%
Recovery by water Drive,WDR=27.378%
Recovery by Segregation Drive=32.676%
```

```
CONVENTIONAL ELECTRICAL LOGS
The apperent readings on the logs are:
Spontaneous potential, Asp=-77mv
R16=28ohm_m
R64=17ohm_m
R19=13ohm_m
The hole size=7.875inch
The_bed_thickness=38inch
Rmat Hole Temp=2.6ohm_m

LOG ANALYSIS_CLEAN WATER_WET ROCK
The formation water Resistivity,Rw=0.369ohm-m
The salinity of formation water in terms of NaCl concentration=6624.99ppmThe Resistivity of mud cake,Rmc=2.189 Ohm-
m
The Resistivity of mud filtrate,Rmf=2.348Ohm-m
The formation Temperature, DegF=170

THE MICROLOGS_QUANTITATIVE ANALYSIS
Rm at Formation Temp.=2.6 ohm_m
Tmc=0.2137963inch          R2_in =12.5 ohmn_m
R1"1=9.5 ohm_m

The Residual oil saturation,Ros          The formation factor, F          Porosity,(Archie method)%     Humble Porosity%

0.00                                     13.43                                 25.48                     23.92
0.15                                     9.70                                  30.24                     27.82
The Resistivity of flushed zone, Rxo=31.53ohm_m
POROSITY FROM SHORT NORMAL CURVE
The Residual oil saturation,Ros       The formation factor, F        Porosity,(S.j pirson method)%

0.00                                           13.38                 23.96
0.15                                           10.56                 26.75
The cementation factor ,m=1.9
A moderately cemented(consolidated) sand is suspected

QUATITATIVE ANALYSIS OF NORMAL AND LATERAL LOGS
The Corrected R16=28ohm_m                      The Corrected R19=13.00ohm_m
 The true Resistivity, Rt=13.000ohm_m                      The invaded Zone Resistivity, Ri=28.00ohm_m

The Residual oil saturation,Ros=0.150
Porosity,=27.82%
The corrected R64=17.00ohm_mThe formation has  resdual hydrocarbon
The Residual oil saturation,Ros=0.150
Porosity,=27.82%
Formation Factor,Ft=9.70
Water saturation,sw=0.525
```

4.4.3 Other conventional Electric Log (Oil wet rocks)

The log of Fig C3.2 (Appendix B) shows a formation which exhibit oil – wetted properties. Using manual and computer method obtains all relevant information from the log similar to those in example 1. Compare the results of both methods

Given that:

R_m = 0.84 at 130^{o}F; T_f at 6850' = 130^{o}F

Depth = 6825ft

Oil gravity = 30^{o} API

e = 49'

d= 9'

Permeability = 100 md (From the core analysis)

Apparent Readings from the logs are:

ASP = -55mV

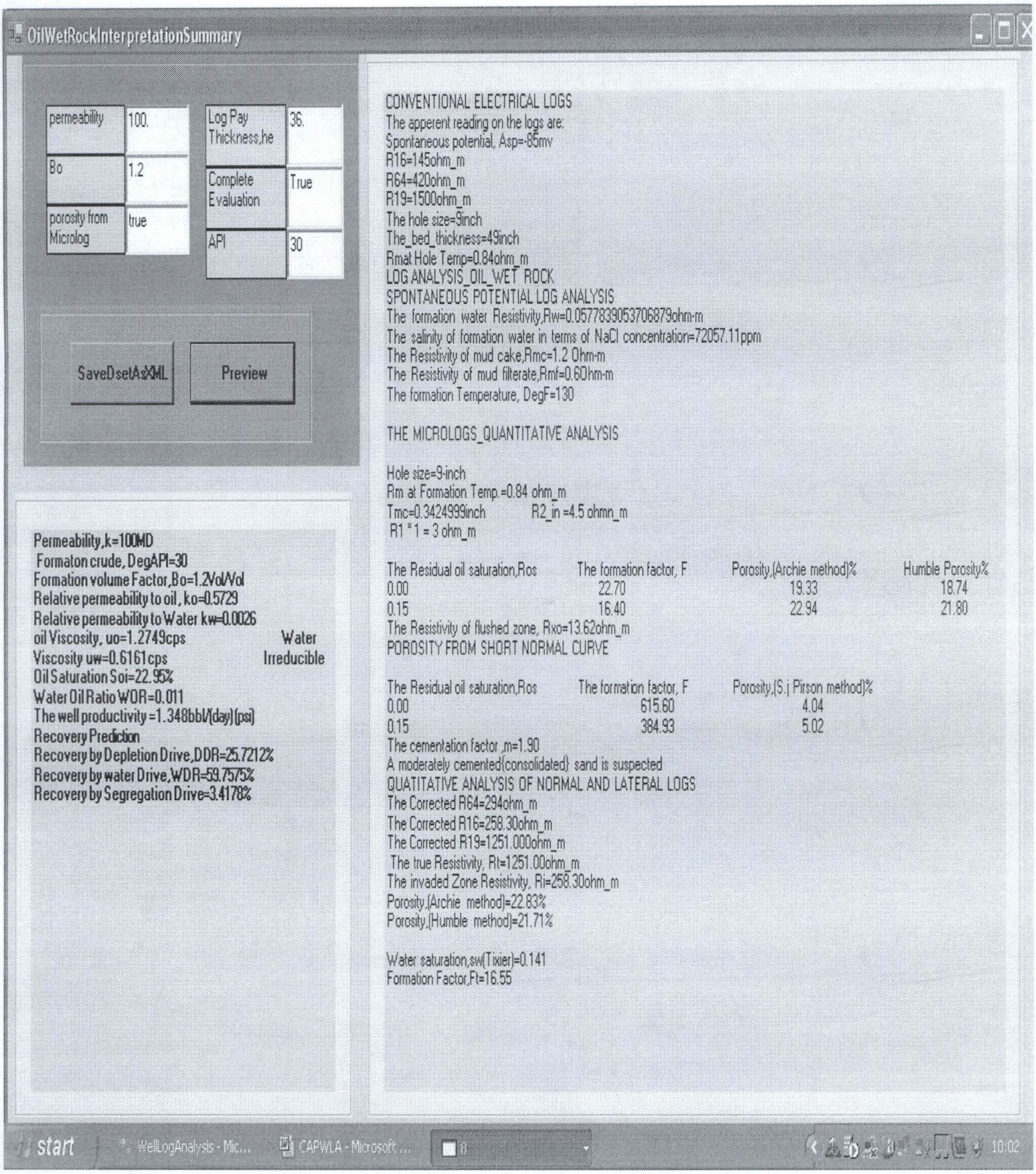
R_{16}" = 145 ohm-m

R_{64}" = 420 ohm-m

R_{19}' =1500 ohm-m

R_{1x1} = 3.0"

R_2 = 4.5""



permeability 100.
Bo 1.2
porosity from Microlog true
Log Pay Thickness,he 36.
Complete Evaluation True
API 30

```
Permeability,k=100MD
 Formaton crude, DegAPI=30
Formation volume Factor,Bo=1.2Vol/Vol
Relative permeability to oil , ko=0.5729
Relative permeability to Water kw=0.0026
oil Viscosity, uo=1.2749cps                    Water
Viscosity uw=0.6161cps                   Irreducible
Oil Saturation Soi=22.95%
Water Oil Ratio WOR=0.011
The well productivity =1.348bbl/(day)(psi)
Recovery Prediction
Recovery by Depletion Drive,DDR=25.7212%
Recovery by water Drive,WDR=59.7575%
Recovery by Segregation Drive=3.4178%
```

```
CONVENTIONAL ELECTRICAL LOGS
The apperent reading on the logs are:
Spontaneous potential, Asp=-85mv
R16=145ohm_m
R64=420ohm_m
R19=1500ohm_m
The hole size=9inch
The_bed_thickness=49inch
Rmat Hole Temp=0.84ohm_m
LOG ANALYSIS_OIL_WET ROCK
SPONTANEOUS POTENTIAL LOG ANALYSIS
The formation water Resistivity,Rw=0.0577839053706879ohm-m
The salinity of formation water in terms of NaCl concentration=72057.11ppm
The Resistivity of mud cake,Rmc=1.2 Ohm-m
The Resistivity of mud filterate,Rmf=0.6Ohm-m
The formation Temperature, DegF=130

THE MICROLOGS_QUANTITATIVE ANALYSIS

Hole size=9-inch
Rm at Formation Temp.=0.84 ohm_m
Tmc=0.3424999inch          R2_in =4.5 ohmn_m
 R1 *1 = 3 ohm_m

The Residual oil saturation,Ros      The formation factor, F      Porosity,(Archie method)%      Humble Porosity%
0.00                                          22.70                        19.33                      18.74
0.15                                          16.40                        22.94                      21.80
The Resistivity of flushed zone, Rxo=13.62ohm_m
POROSITY FROM SHORT NORMAL CURVE

The Residual oil saturation,Ros      The formation factor, F      Porosity,(S.j Pirson method)%
0.00                                              615.60                   4.04
0.15                                              384.93                   5.02
The cementation factor ,m=1.90
A moderately cemented{consolidated} sand is suspected
QUATITATIVE ANALYSIS OF NORMAL AND LATERAL LOGS
The Corrected R64=294ohm_m
The Corrected R16=258.30ohm_m
The Corrected R19=1251.000ohm_m
 The true Resistivity, Rt=1251.00ohm_m
The invaded Zone Resistivity, Ri=258.30ohm_m
Porosity,(Archie  method)=22.83%
Porosity,(Humble  method)=21.71%

Water saturation,sw(Tixier)=0.141
Formation Factor,Ft=16.55
```

4.4.4 Other conventional Electric Log (Shaly sand rocks)

The log of fig C3.3 (Appendix B) shows a formation which exhibits certain degree of shalyness as observed in the upper sand shown whereas the lower sand which is saturated with formation water gives a static Sp deflection using the manual and computer method, obtain all relevant information similar to these obtain the previous examples. Compare your results.

Given that:

d = 9"; BHT = 180^0F at 11135^1; t_f at level = 162^0F

Depth = 9234ft

Oil gravity = 30^0 API

R_m = 0.90 ohm-m at BHT; R_m = 0.85 at 162^0f

Permeability = 100 md (From the core analysis)

e = 221

Apparent Readings from the logs are:

ASP = -50mV

SSP = -117mV

R_{1x1} = 1.5 ohm-m

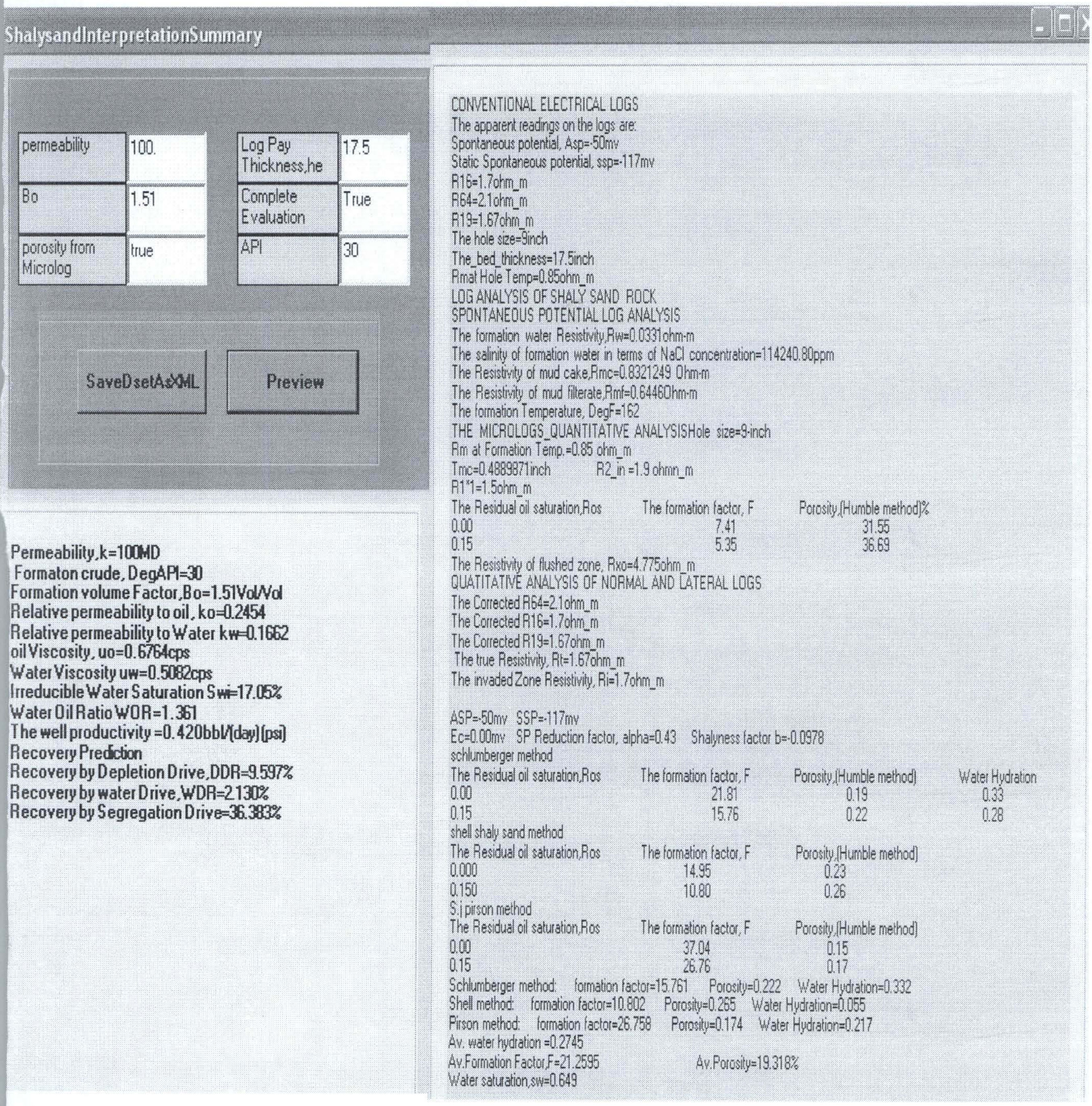
R_2 = 1.9 ohm-m

R_{16}" = 1.7 ohm-m

R_{64}" = 2.1 ohm-m

R_s = 0.5 ohm-m

R_{19} = 1.67 ohm-m



permeability	100.	Log Pay Thickness,he	17.5
Bo	1.51	Complete Evaluation	True
porosity from Microlog	true	API	30

```
Permeability,k=100MD
 Formaton crude, DegAPI=30
Formation volume Factor,Bo=1.51Vol/Vol
Relative permeability to oil, ko=0.2454
Relative permeability to Water kw=0.1662
oil Viscosity, uo=0.6764cps
Water Viscosity uw=0.5082cps
Irreducible Water Saturation Swi=17.05%
Water Oil Ratio WOR=1.361
The well productivity =0.420bbl/(day)(psi)
Recovery Prediction
Recovery by Depletion Drive,DDR=9.597%
Recovery by water Drive,WDR=2.130%
Recovery by Segregation Drive=36.383%
```

```
CONVENTIONAL ELECTRICAL LOGS
The apparent readings on the logs are:
Spontaneous potential, Asp=-50mv
Static Spontaneous potential, ssp=-117mv
R16=1.7ohm_m
R64=2.1ohm_m
R19=1.67ohm_m
The hole size=9inch
The_bed_thickness=17.5inch
Rmat Hole Temp=0.85ohm_m
LOG ANALYSIS OF SHALY SAND  ROCK
SPONTANEOUS POTENTIAL LOG ANALYSIS
The formation  water Resistivity,Rw=0.0331ohm-m
The salinity of formation water in terms of NaCl concentration=114240.80ppm
The Resistivity of mud cake,Rmc=0.8321249 Ohm-m
The Resistivity of mud filterate,Rmf=0.6446Ohm-m
The formation Temperature, DegF=162
THE  MICROLOGS_QUANTITATIVE ANALYSISHole  size=9-inch
Rm at Formation Temp.=0.85 ohm_m
Tmc=0.4889871inch          R2_in =1.9 ohmn_m
R1"1=1.5ohm_m
The Residual oil saturation,Ros        The formation factor, F        Porosity,(Humble method)%
0.00                                             7.41                          31.55
0.15                                             5.35                          36.69
The Resistivity of flushed zone, Rxo=4.775ohm_m
QUATITATIVE ANALYSIS OF NORMAL AND LATERAL LOGS
The Corrected R64=2.1ohm_m
The Corrected R16=1.7ohm_m
The Corrected R19=1.67ohm_m
 The true Resistivity, Rt=1.67ohm_m
The invaded Zone Resistivity, Ri=1.7ohm_m

ASP=-50mv   SSP=-117mv
Ec=0.00mv   SP Reduction factor, alpha=0.43    Shalyness factor b=-0.0978
schlumberger method
The Residual oil saturation,Ros        The formation factor, F        Porosity,(Humble method)        Water Hydration
0.00                                             21.81                     0.19                          0.33
0.15                                             15.76                     0.22                          0.28
shell shaly sand method
The Residual oil saturation,Ros        The formation factor, F        Porosity,(Humble method)
0.000                                      14.95                     0.23
0.150                                      10.80                     0.26
S.j pirson method
The Residual oil saturation,Ros        The formation factor, F        Porosity,(Humble method)
0.00                                       37.04                     0.15
0.15                                       26.76                     0.17
Schlumberger method:    formation factor=15.761    Porosity=0.222    Water Hydration=0.332
Shell method:    formation factor=10.802    Porosity=0.265    Water Hydration=0.055
Pirson method:    formation factor=26.758    Porosity=0.174    Water Hydration=0.217
Av. water hydration =0.2745
Av.Formation Factor,F=21.2595                        Av.Porosity=19.318%
Water saturation,sw=0.649
```

CHAPTER 5

VALIDATION AND DISCUSSION OF RESULTS

5.1 Validation of Results

To verify the software, three examples on Conventional Electric Log from literature (Well Log Analysis by S.j. pirson) were used to assess the validity of the software.

The results are presented in Tables 4.5.1, 4.5.2 and 4.5.3.

The results reasonably agreed with the results obtained from the literature and manual calculations.

The variances with the results are as result of rounding off/approximation that characterized the manual calculations.

The software is modular in design, interactive and user friendly. The log apparent readings and results are captured as XML documents/SQL database with facility to update as new information are captured

Table 4.5.1 Conventional Electric Log (Water wet rocks)

Variables	**Literature (Well Log Analysis by S.J pirson)**	**Hand calculation**	**CAPWLA Software**
Mud filtrate Resistivity, R_{mf} Ohm-m	**2.35**	**2.35**	**2.38**
Mud cake Resistivity, R_{mc} Ohm-m	**2.15**	**2.15**	**2.19**
Invaded zone Resistivity, R_i Ohm-m			
True Resistivity, R_t Ohm-m	**13.0**	**13**	**13**
Formation water Resistivity, R_w Ohm-m	**0.4**	**0.38**	**0.369**
Formation	**6200.0**	**6550.0**	**6600.0**

water Salinity, ppm			
Flushed zone Resistivity, R_{xo} Ohm-m	32.4	32.25	31.53
Formation factor, F	If Ros=0. F=13.8 If ROS=0.15 F =10.	If Ros=0. F=13.72 If ROS=0.15 F =9.9	If Ros=0. F=13.43 If ROS=0.15 F =9.7
Porosity, Φ	If Ros=0. Φ =24% If ROS=0.15 Φ =28%	If Ros=0. Φ =23.2% If ROS=0.15 Φ =27.1%	If Ros=0. Φ =23.93% If ROS=0.15 Φ =27.8%
Water saturation, S_w	52%	53%	52.5%
Irredicible Water saturation, S_{wi}	15%	15%	15%
Oil Viscosity μ_o cps	0.93	0.95	0.94
Water Viscosity μ_w cps	0.38	0.36	0.38
Relative perm. to oil, K_o	0.22	0.21	0.216
Relative perm. to water, K_o	0.096	0.10	0.095
Water oil Ratio, WOR	1.39	1.63	1.48
Productivity	6.95	7.1	5.9

Index, PI			

Table 4.5.2 Conventional Electric Log (Oil wet rocks)

Variables	Literature (Well Log Analysis by S.J pirson)	Hand calculation	CAPWLA Software
Mud filtrate Resistivity, R_{mf} Ohm-m	0.6	0.6	0.6
Mud cake Resistivity, R_{mc} Ohm-m	1.15	1.15	1.2
Invaded zone Resistivity, R_i Ohm-m	355	300	258
True Resistivity, R_t Ohm-m	1260.0	1250	1251
Formation water Resistivity, R_w Ohm-m	0.056	0.058	0.0577
Formation water Salinity, ppm	75000.0	72000.0	72000.0
Flushed zone Resistivity, R_{xo} Ohm-m	13.8	13.8	13.62

Formation factor, F	16.5	16.5	16.56
Porosity, Φ	21.5%	21.5%	21.7%
Water saturation, S_w	19.4%TixierEquation N=2.9	17.0%TixierEquation N=2.9	14.3%TixierEquation N=2.9
Irredicible Oil saturation, S_{oi}	25%	25%	23%
Oil Viscosityμ_o	2.0	2.0	1.28
Water Viscosity μ_w	0.5	0.54	0.6
Relative perm. to oil, K_o	0.45	0.45	0.57
Relative perm. to water, K_w	0.0056	0.0056	0.0026
Water oil Ratio, WOR	0.06	0.06	0.011
Productivity Index, PI			1.35

Table 4.5.3 Conventional Electric Log (Water wet shaly sand rocks)

Variables	Literature (Well Log Analysis by S.J pirson)	Hand calculation	CAPWLA Software
Mud filtrate Resistivity, R_{mf} Ohm-m	0.65	0.65	0.645
Mud cake Resistivity, R_{mc} Ohm-m	1.0	0.83	0.833
Invaded zone Resistivity, R_i Ohm-m			
True Resistivity, R_t Ohm-m	1.67	1.67	1.67
Formation water Resistivity, R_w Ohm-m	0.035	0.035	0.033
Formation water Salinity, ppm	110000.0	109000.0	114000.0
Flushed zone Resistivity, R_{xo} Ohm-m	3.65	4.48	4.78
Formation factor, F	**Shell** **If Ros=0. F=13.5** **If ROS=0.15** F =10.0	**Shell** **If Ros=0. F=12.9** **If ROS=0.15** F =9.4	**Shell** **If Ros=0. F=14.9** **If ROS=0.15** F =10.8

	Schlumberger If Ros=0. F=13.8 If ROS=0.15 F =20.	Schlumberger If Ros=0. F=20.7 If ROS=0.15 F =14.97	Schlumberger If Ros=0. F=21.8 If ROS=0.15 F =15.76
	s.j pirson	s.j pirson	s.j pirson
	If Ros=0. F=28 If ROS=0.15 F =22.5	If Ros=0. F=35.4 If ROS=0.15 F =25.7	If Ros=0. F=37.04 If ROS=0.15 F =26.76
Porosity, Φ	Shell If Ros=0. Φ=13.5% If ROS=0.15 Φ =10. % $\Phi_{h=}$ 23.3%	Shell If Ros=0. Φ =24% If ROS=0.15 Φ =27.9 % $\Phi_{h=}$ 15.4%	Shell If Ros=0. Φ =23% If ROS=0.15 Φ = 26% $\Phi_{h=}$ 5.5%
	Schlumberger If Ros=0. Φ =13.8% If ROS=0.15 Φ =20. % $\Phi_{h=}$ 23.3%	Schlumberger If Ros=0. Φ =19.2% If ROS=0.15 Φ =22.4% $\Phi_{h=}$ 32.0%	Schlumberger If Ros=0. Φ =19% If ROS=0.15 Φ=22.0% $\Phi_{h=}$33.2%
	s.jpirson	s.jpirson	s.jpirson
	If Ros=0. Φ =28% If ROS=0.15 Φ =22.5% $\Phi_{h=}$ 23.3%	If Ros=0. Φ =15.3% If ROS=0.15 Φ =12.4% $\Phi_{h=}$ 23.3%	If Ros=0. Φ =15% If ROS=0.15 Φ =17% $\Phi_{h=}$ 21.7%
Final F	21.25	12.18	21.26
Final porosity, Φ	Φ =19.3%	Φ =25.1%	Φ =19.3%

Water hydration, Φ_h	**27%**	**27%**	**27.4%**
Water saturation, S_w	**66%**	**66%**	**64.3%**
Irredicible Water saturation, S_{wi}	**20%**	**20%**	**17.1%**
Oil Viscosityμ_o	**0.68**	**0.68**	**0.676**
Water Viscosity μ_w	**0.5**	**0.5**	**0.508**
Relative perm. to oil, K_o	**0.25**	**0.25**	**0.245**
Relative perm. to water, K_w	**0.174**	**0.174**	**0.166**
Water oil Ratio, WOR	**1.58**	**1.48**	**1.4**
Productivity Index, PI	**0.425**	**0.425**	**0.420**

5.2 Recommendations

Three examples on Conventional Electric Log from literature (Well Log Analysis by S.j. pirson) were used to assess the validity of the software. The results are presented in Tables 4.5.1, 4.5.2 and 4.5.3.

The results reasonably agreed with the results obtained from the literature and manual calculations.

The variances with the results are as result of rounding off/approximation that characterized the manual calculations.

In view of the fact that:

(i) computer provides more accurate results

(ii) human interpolation/computation is usually associated with errors

(iii) a lot of time and resources are wasted using manual process.

The computer method is highly recommended.

5.3 CONCLUSION

It is hereby concluded that the computer method produces highly more accurate results and saves a lot of time and resources.

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13. Wylie M.R.J "The Fundamentals of Electric log interpretation" 2nd Edition New York 1957 pg112-126

APPENDIX A

LISTS OF NOTATIONS/VARIABLES

..

Public variables	**stores**
ASP	Apparent Spontaneous Potential log reading
SSPt	Static Spontaneous Potential log reading
Rm	Mud Resistivity
d	Hole size
R_t	True resistivity
R_z	Mix Water resistivity in the invaded zone
eev	Bed thickness
R_o	Resistivity of clean water bearing zone
Temp	formation temperature
Depth	Well Depth
R_w	Formation water resistivity
PPmv	Salinity in parts per million (ppm)
R_{mc}	Mud cake resistivity
R_2	Micro normal reading
Schlumberger	Boolean variables
R_1	Micro inverse reading on microlog
T_{mc}	Mud Cake thickness
ROS	Residual oil saturation
RSV	Adjacent bed resistivity
R16	Apparent reading on short normal
R64	Apparent reading on Long normal
R19	Apparent reading on Lateral Log
METH	(METH=1, Moderate/shallow mud filtrate invasion,short normal reads R_i Lateral tool reads R_t) (METH=2, Deep invasion, 2 normal curves & porosity balance scheme, METH =3 Deep invasion, 2 normal curves & Lateral curve)for the determination of R_i, R_t and D_i
R_{mf}	Mud filtrate resistivity
R_i	invaded zone resistivity
R_{XO}	Flushed zone resistivity
Rosf	Flushed zone residual oil saturation

Rosi	invaded zone oil saturation
Perm	Permeability
Apor	Archie porosity
HPor	Humble porosity
Wellspacing	Well spacing
S_w	Water saturation
S_{xi}	Water saturation in invaded zone
S_{Xo}	Water saturation in flushed zone
B_o	Formation volume factor
S_{wi}	irreducible water saturation
R16c	Corrected short normal reading
R64c	Corrected long normal reading
R19c	Corrected lateral log reading
invDiam, D_i	invaded zone diameter
Oil, Gas, Water	Boolean variables
F	Formation Factor
SINVDIAM	Shallow invaded diameter
MINVDIAM	Moderate invaded diameter
DEEPINVDIAM	Deep invaded diameter
WOR	Water oil ratio
PI	Productivity index
VISCO	Oil Viscosity
VISCW	Water Viscosity
DDR	Depletion Drive Recovery
WDR	Water Drive Recovery
SDG	Segregation and gravity drive
K_o	Relative oil permeability
K_w	Relative water permeability
Sw_{nm}	Non movable water saturation
Sw_m	Movable water saturation
CELOWR	Convention Electric Log Oil Wet Rock
CELWWR	Convention Electric Log Water Wet Rock
CELSSWWR	Convention Electric Log Shaly sand Water Wet Rock

APPENDIX B

Sample Well Logs and Interpretation Charts

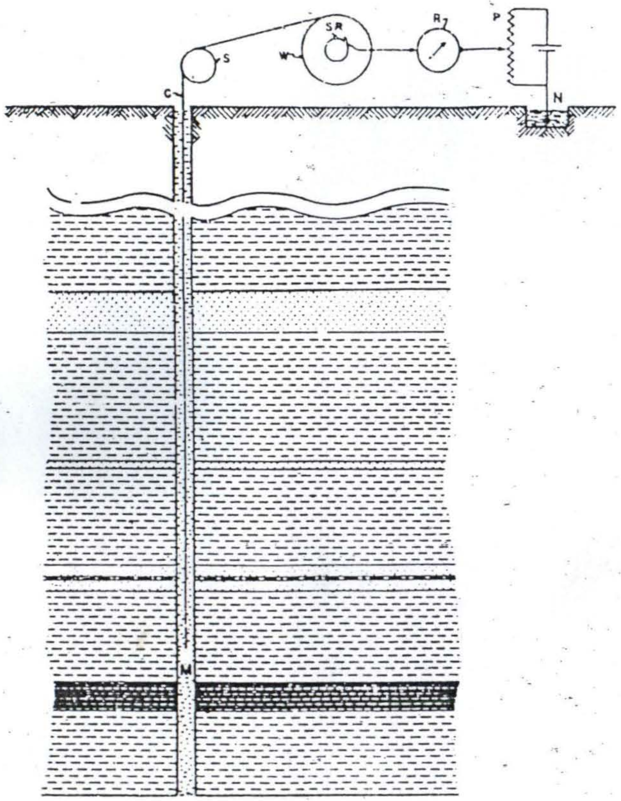


Fig. 6-1. Schematic circuit for recording SP logs. Reprinted with permission of Schlumberger Well Surveying Corporation.

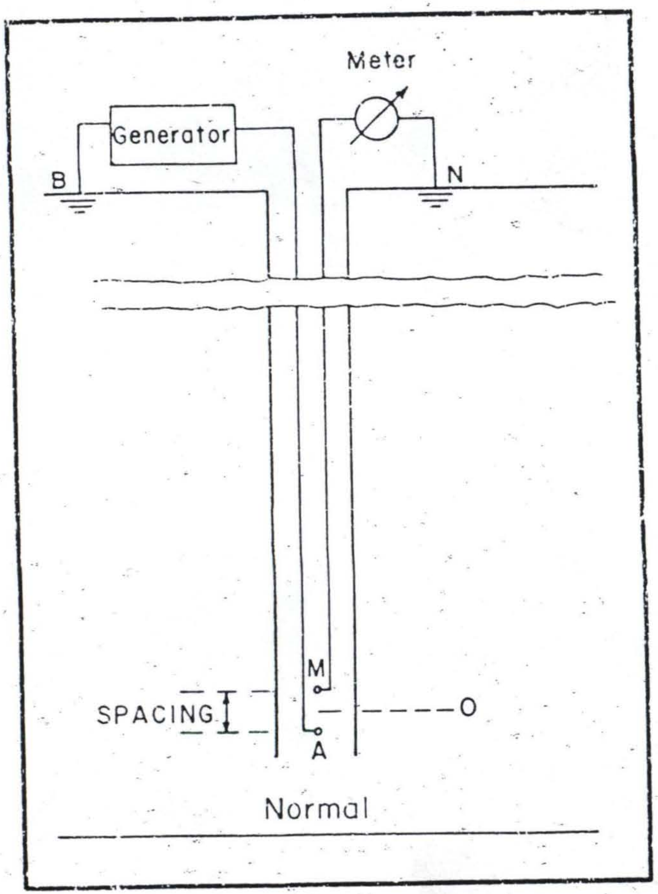


Fig. 8-1 — Normal device — basic arrangement.

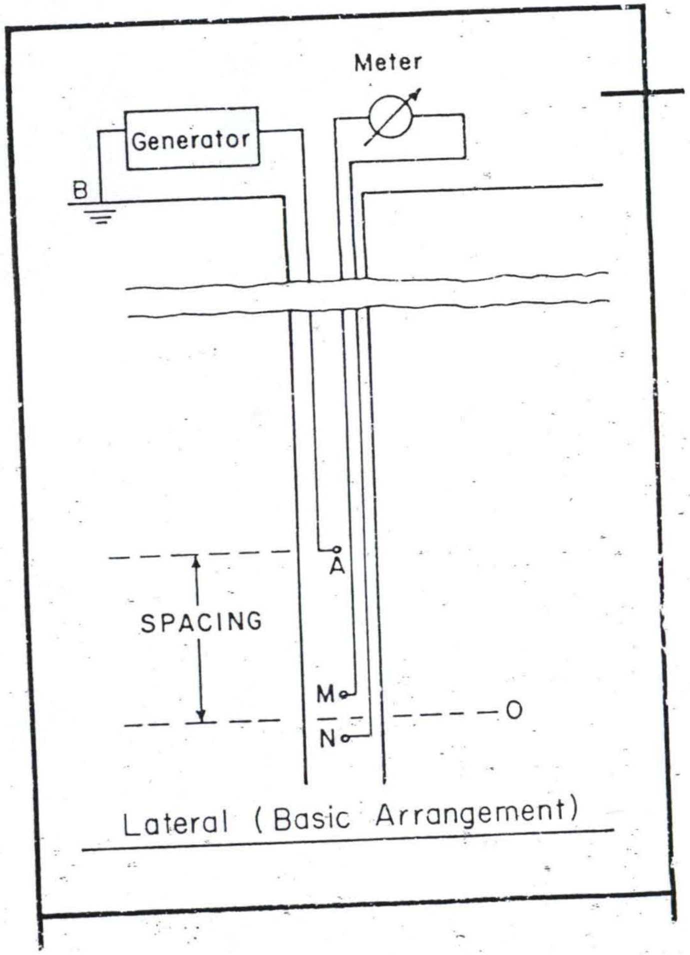


Fig 2x

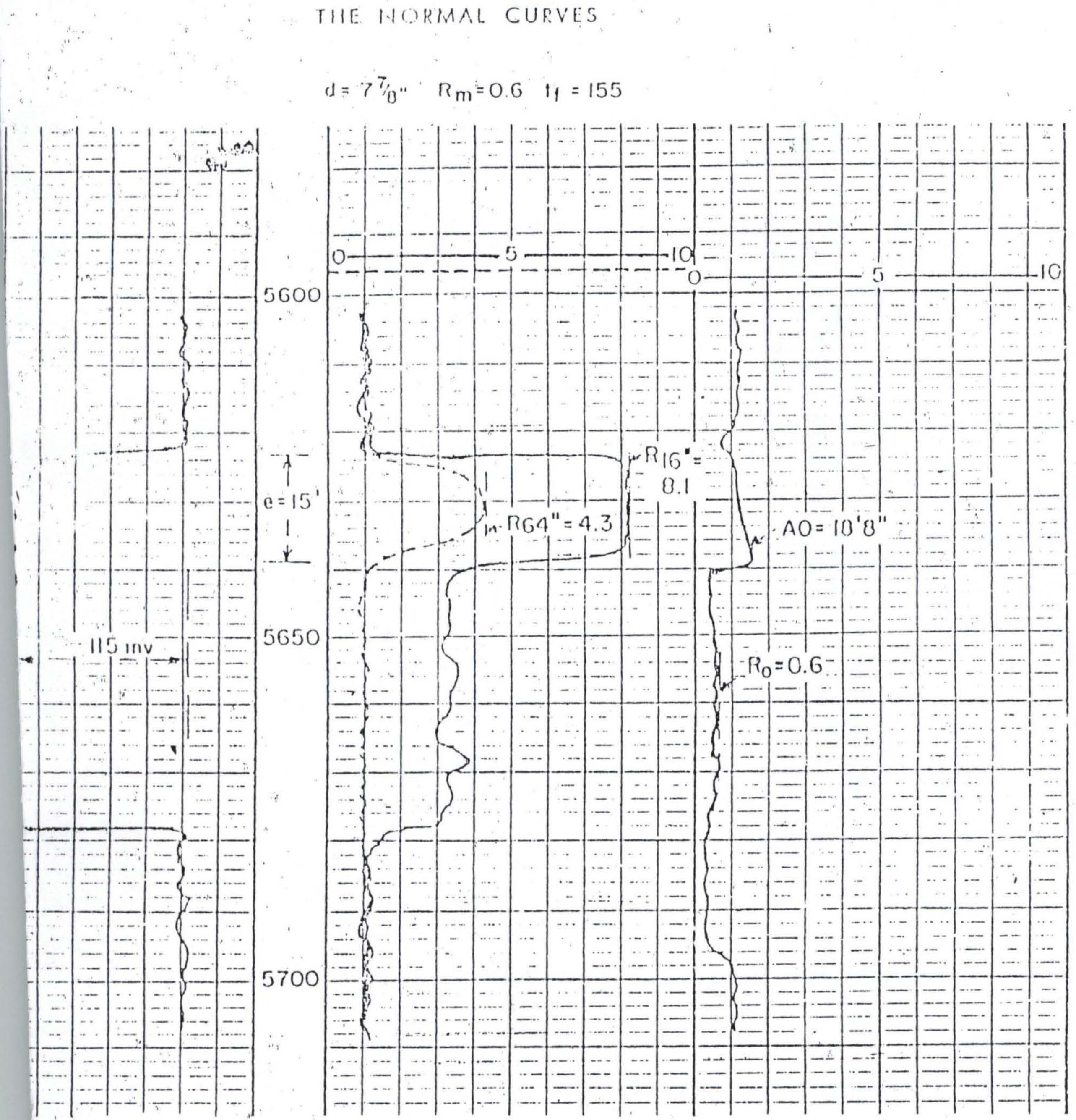


Fig. 3·1. Example of Gulf Coast type electric log.

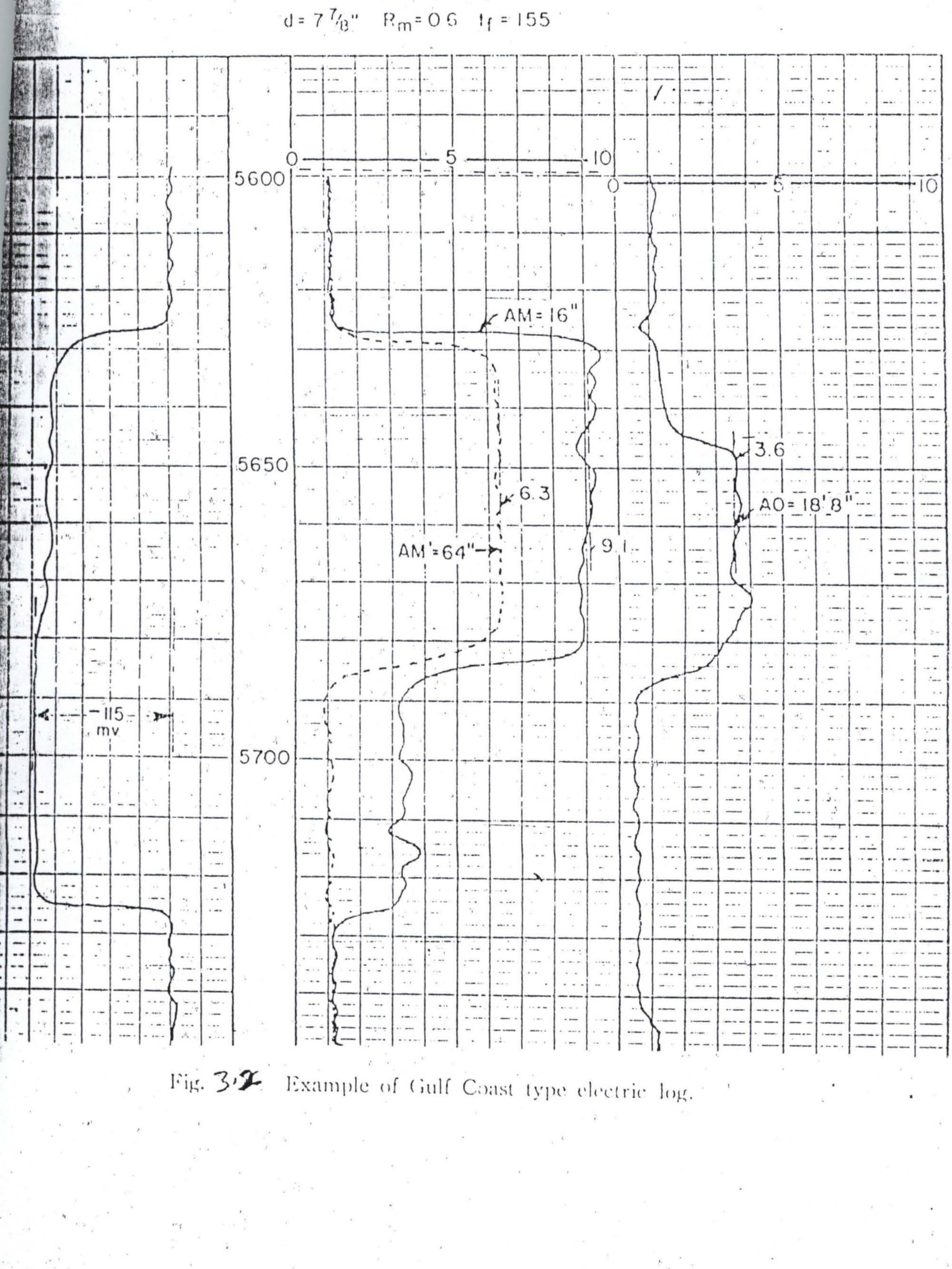


Fig. 3.2 Example of Gulf Coast type electric log.

The example illustrates the ability of the MicroLog to locate porous permeable zones. The movement of the pads against the borehole face also gives a MicroCaliper that confirms mud cake deposition in permeable zones and indicates caving sections such as may be present in shales and other hole conditions important to the completion of the well.

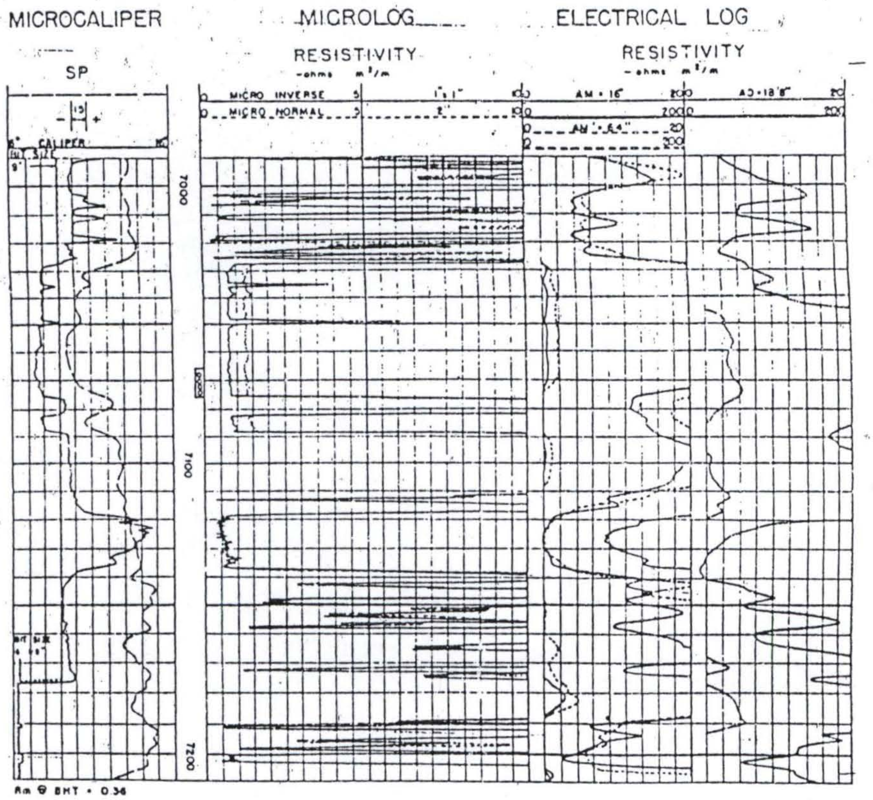


Fig. 3·3 Comparison of Microlog and microcaliper with the standard electrical survey. Note the separation of the microinverse and micronormal curves. Courtesy Schlumberger Well Surveying Corporation.

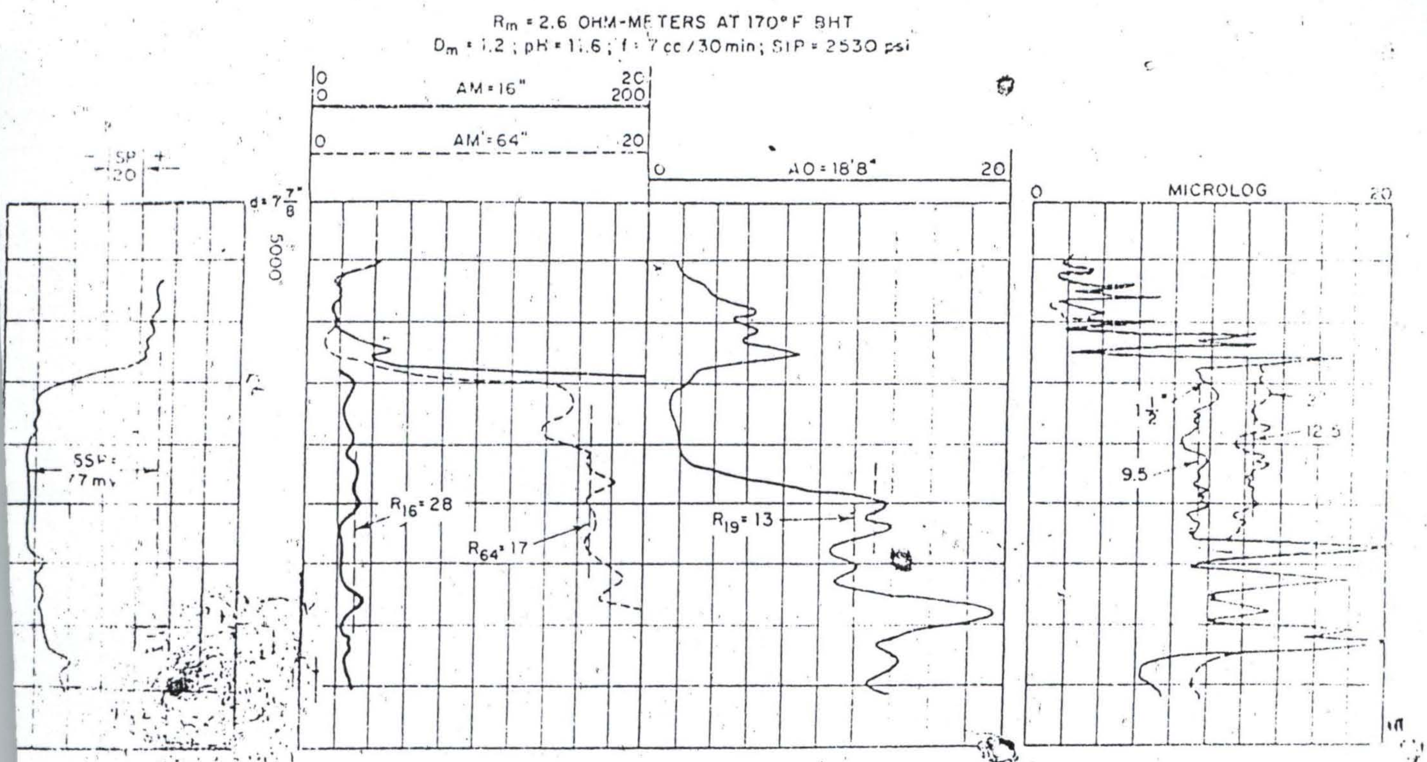


Fig. C3.1 Gulf-Coast-type example log in clean water-wet formation.

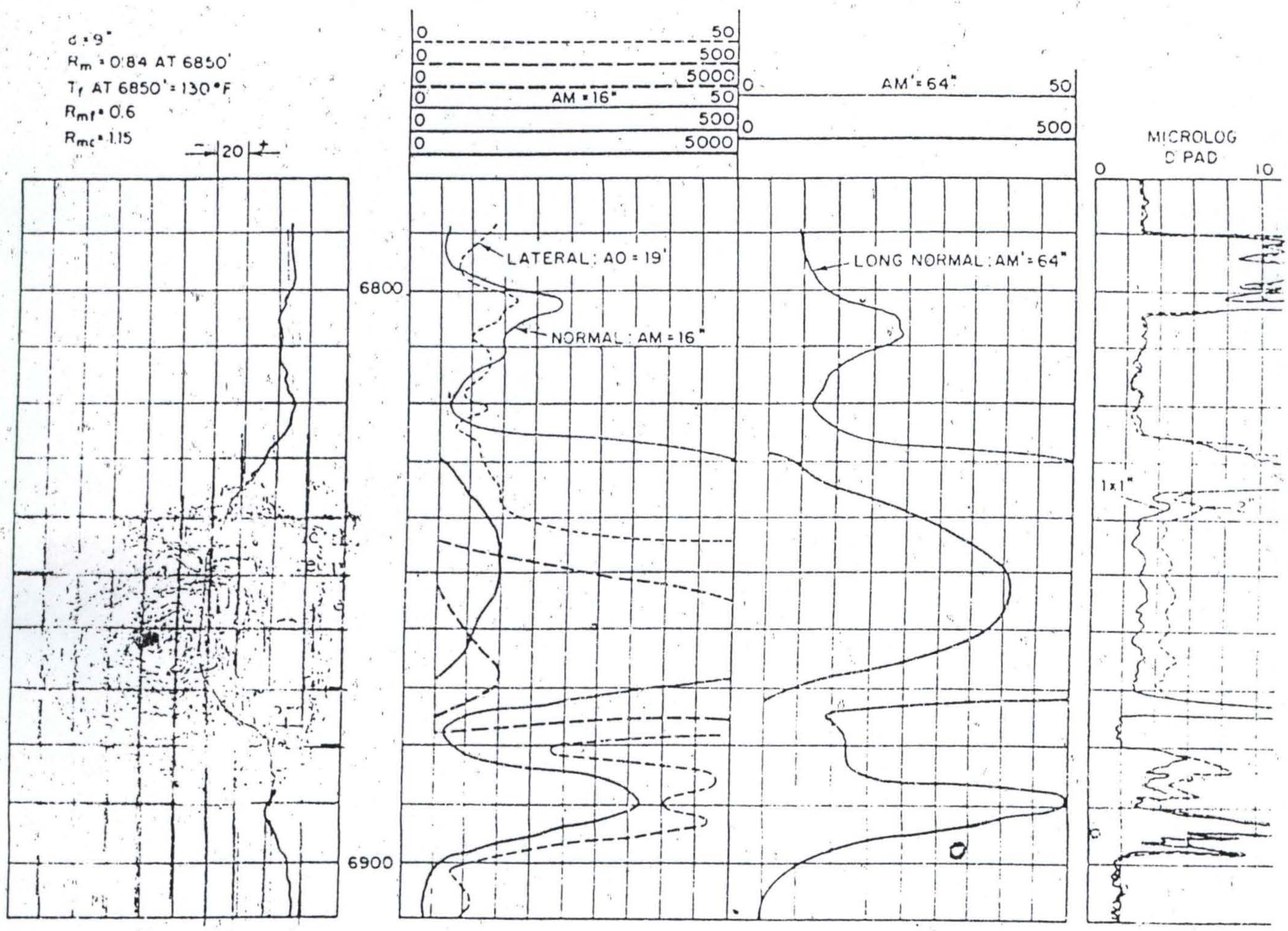


Fig: C 3.2 Example log in an oil-wet sand (So. Oklahoma).

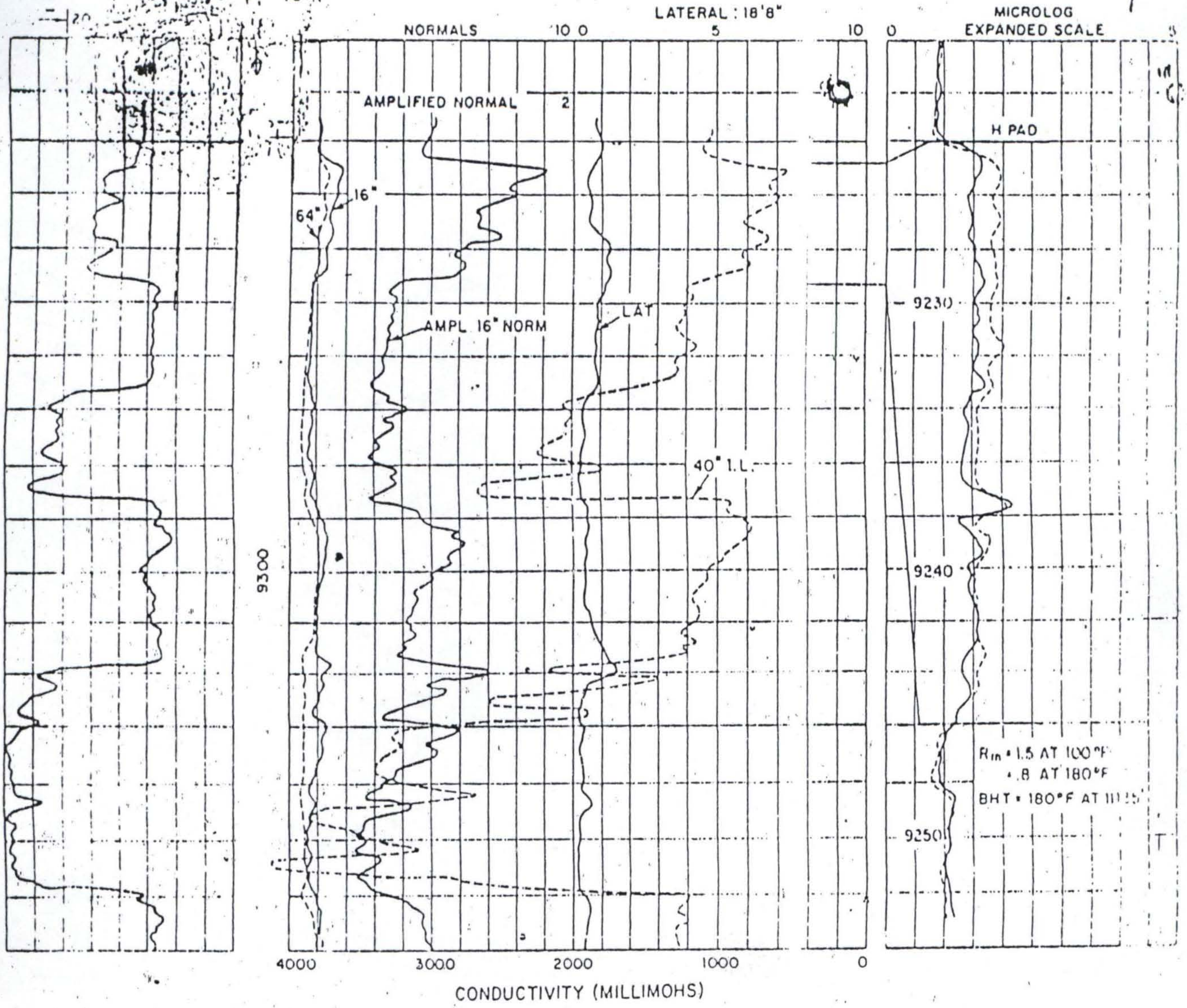


Fig. C3.3 Example log in shaly sand (Mississippi).

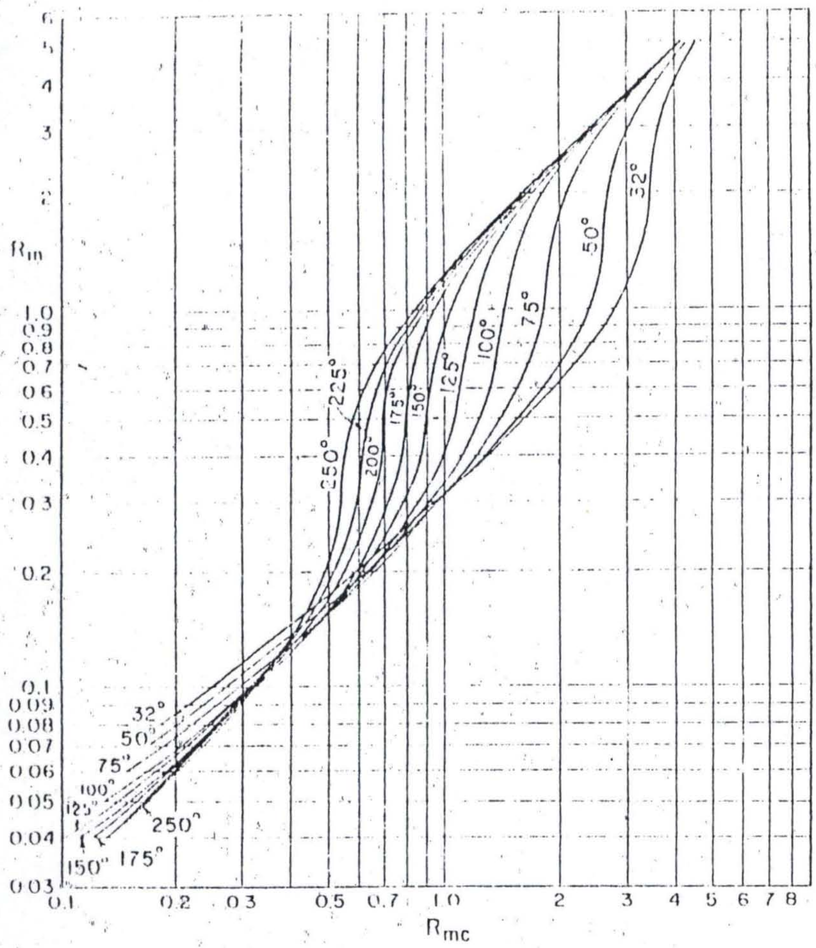


Fig. 1a Mud-cake resistivity, R_{mc}, versus mud resistivity, R_m. Reprinted with permission of Continental Oil Company.

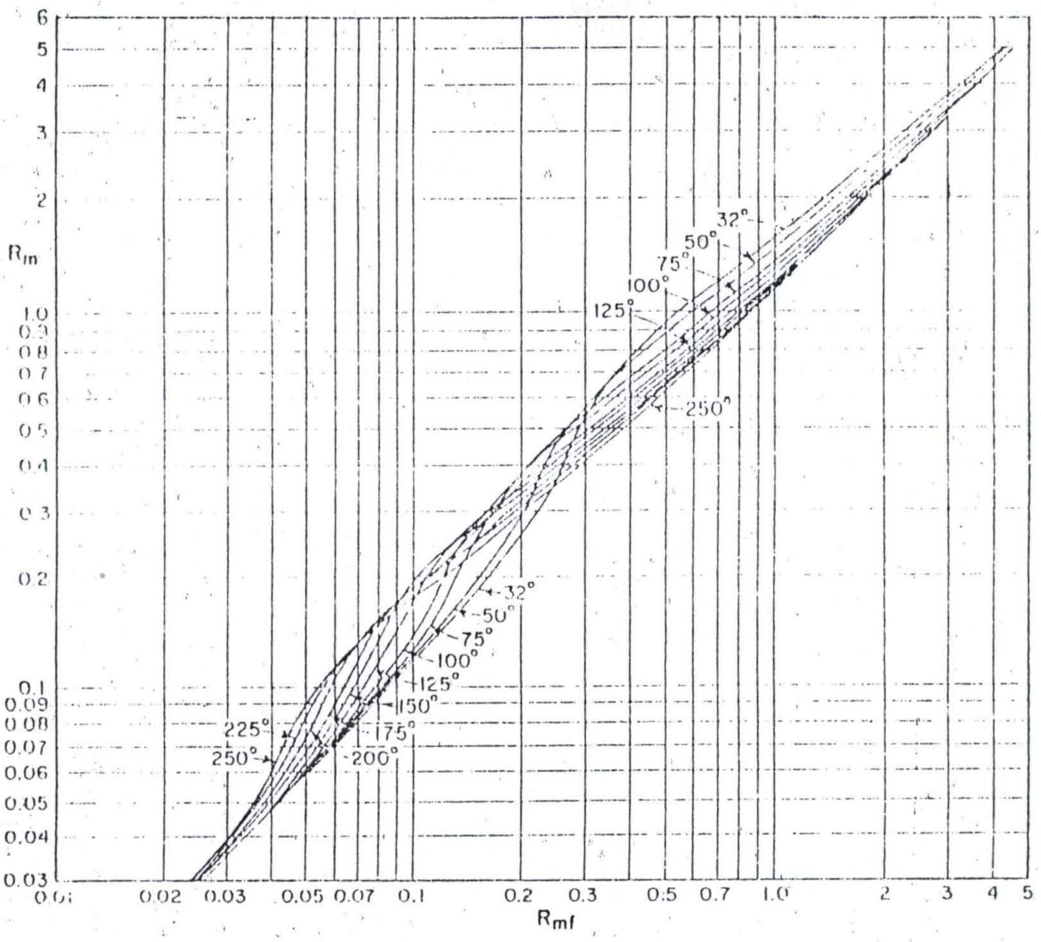


Fig. 1b. Mud-filtrate resistivity, R_{mf}, versus mud resistivity, R_m. Reprinted with permission of Continental Oil Company.

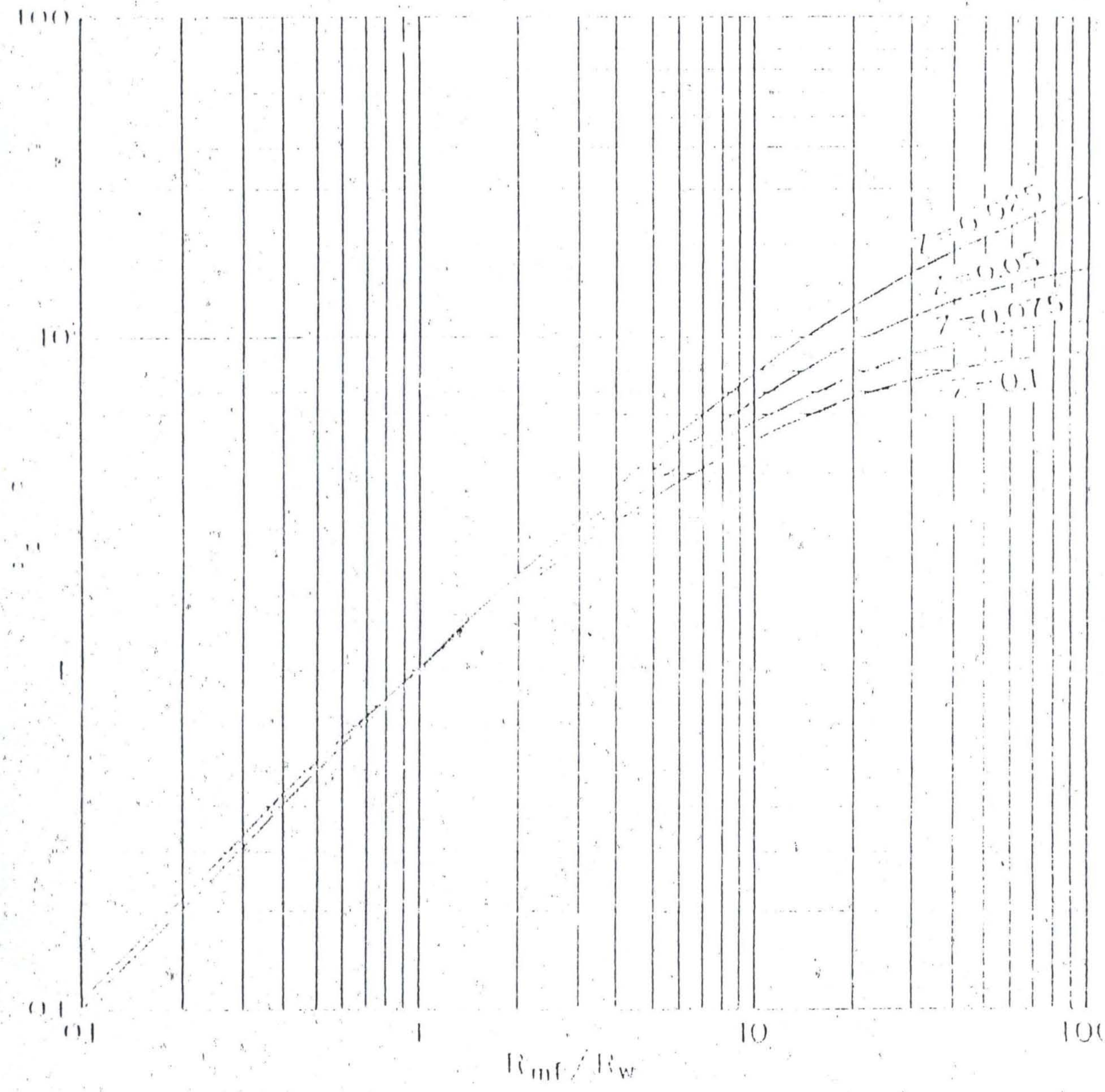


Fig 1.6. Water resistivity, R_z, in the invaded zone of water-wet rocks as a function of formation water and mud-filtrate characteristics. After Tixier, reprinted with permission of Schlumberger Well Surveying Corporation.

R_{we} DETERMINATION FROM THE SSP

(CLEAN FORMATIONS)

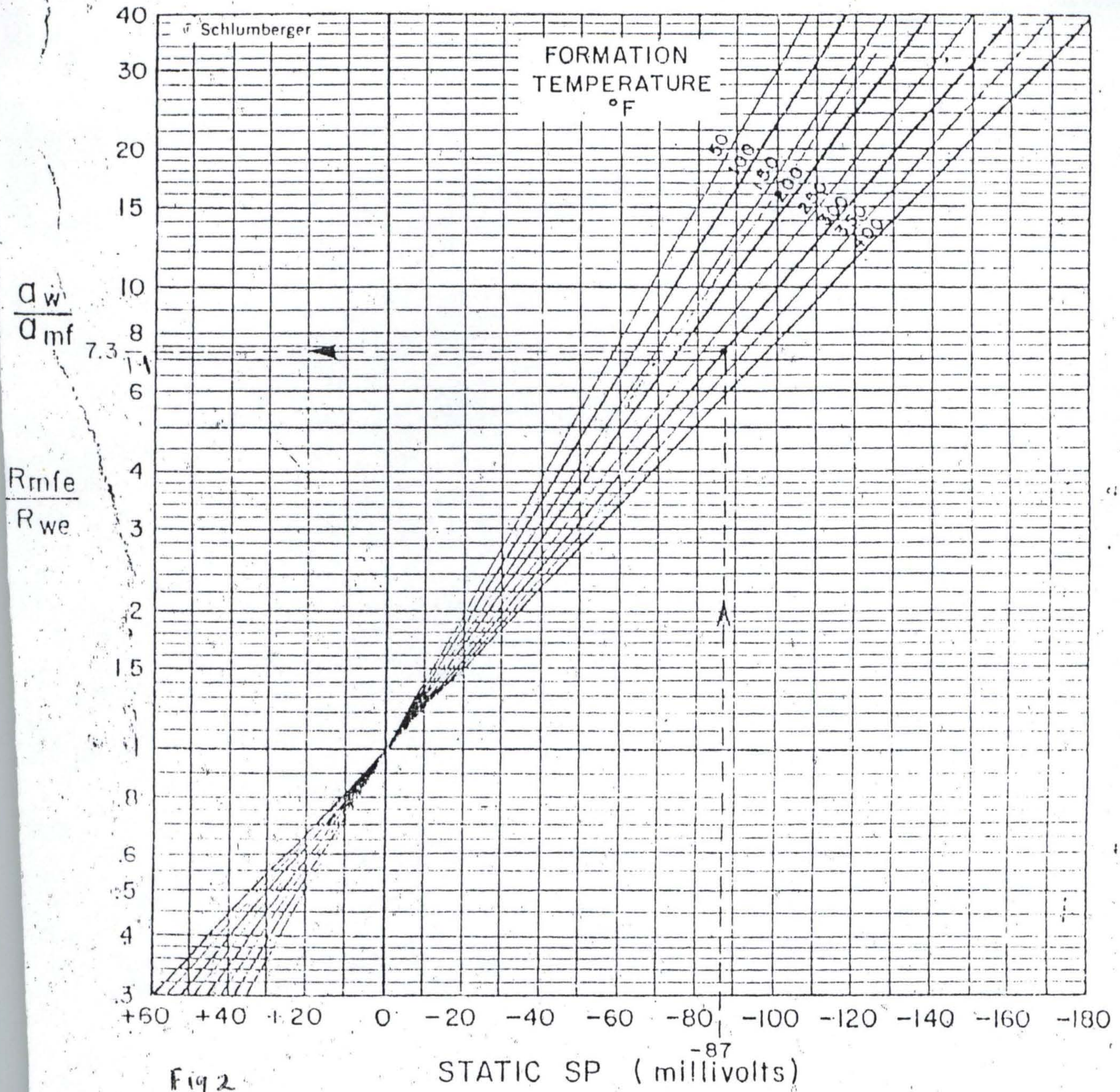


Fig 2

Preferably determine SSP from a thick, homogeneous bed using the shale base line from a good adjacent shale. If necessary correct the SP for bed thickness and invasion to get SSP (Chart SP-3). Determine formation temperature. (Chart Gen-6 may be used if necessary.)

Example of use of Chart SP-1: SSP = −87 mv, T = 300°F. Find from Chart $R_{mfe}/R_{we} = 7.3$.

For predominantly sodium chloride muds determine R_{mfe} as follows:

a. If R_{mf} at 75° is greater than 0.1 ohm-m, correct R_{mf} to formation temperature using Chart Gen-9, and use $R_{mfe} = 0.85R_{mf}$.

b. If R_{mf} at 75° is less than 0.1 ohm-m use Chart SP-2 to derive a value of R_{mfe} at formation temperature.

For other muds, see remarks on next page.

Using results of steps 2 and 3, compute $R_{we} = R_{mfe}/(R_{mfe}/R_{we})$. Go to Chart SP-2 for conversion of R_{we} to R_w at formation temperature.

SP 1

R_w VERSUS R_{weq} AND FORMATION TEMPERATURE[3]

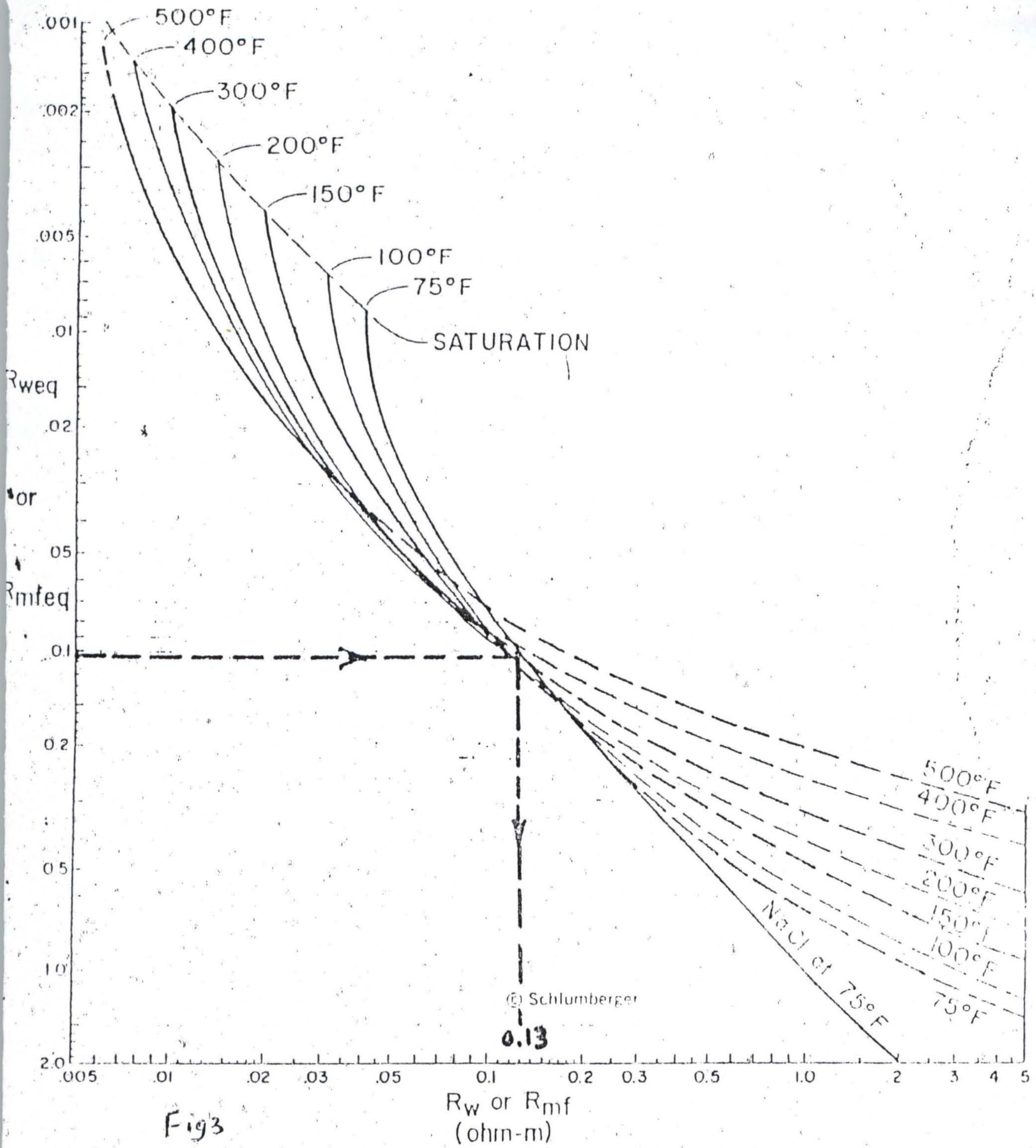


Fig 3

Use the solid lines of this chart for predominantly NaCl waters. The dashed lines are approximate for "average" fresh formation waters (where effects of salts other than NaCl become significant). The dashed portions may also be used for gyp-base mud filtrates.

Example: R_{weq} = .025 at 150°F. From chart, R_w = .038

Special procedures for muds containing Ca or Mg in solution are discussed in the reference. Lime-base muds usually have a negligible amount of Ca in solution, and may be treated as regular mud types.

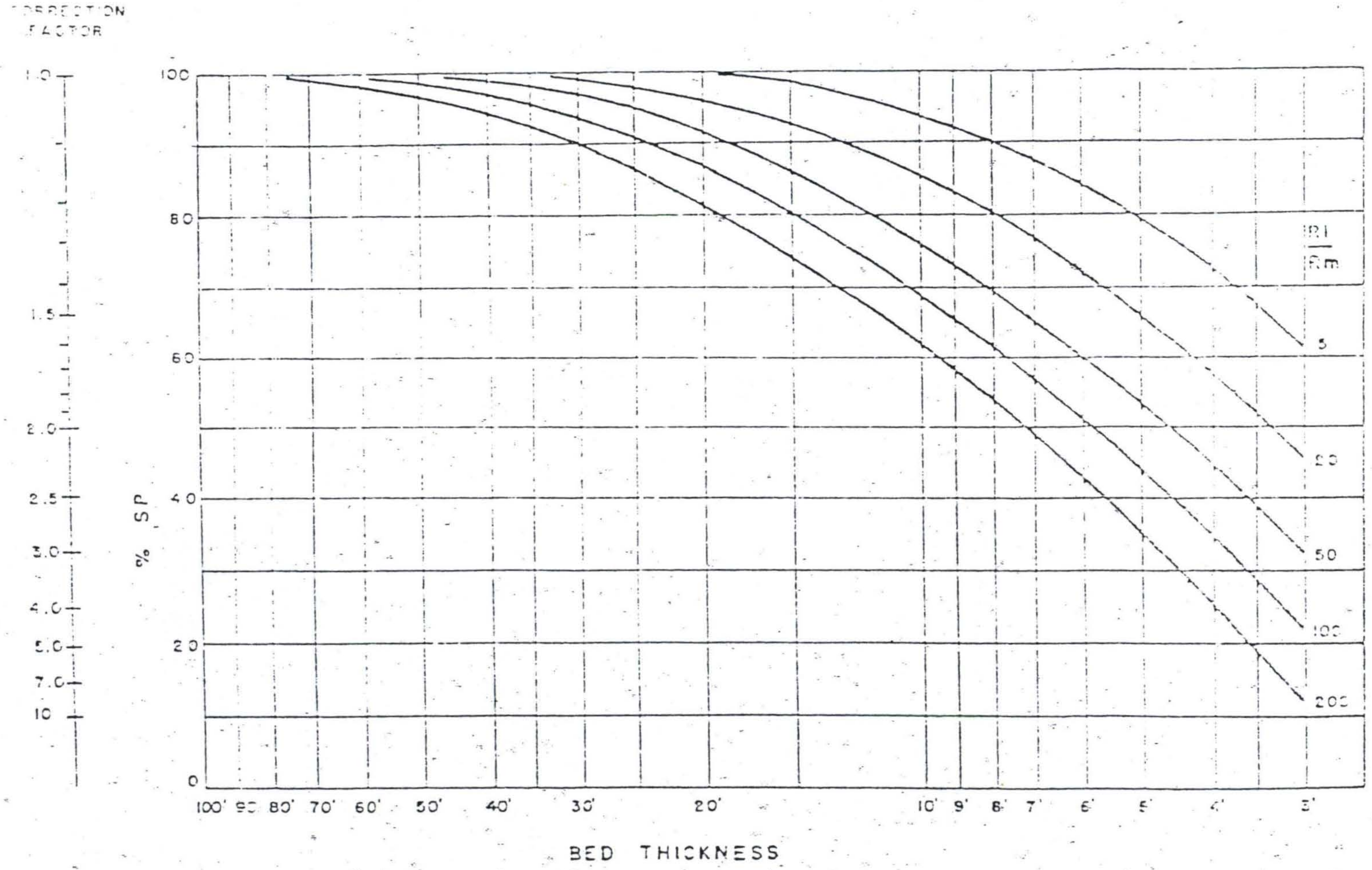


Fig. 4 Empirical correction chart for the SP curve. Courtesy Schlumberger Well Surveying Corporation.

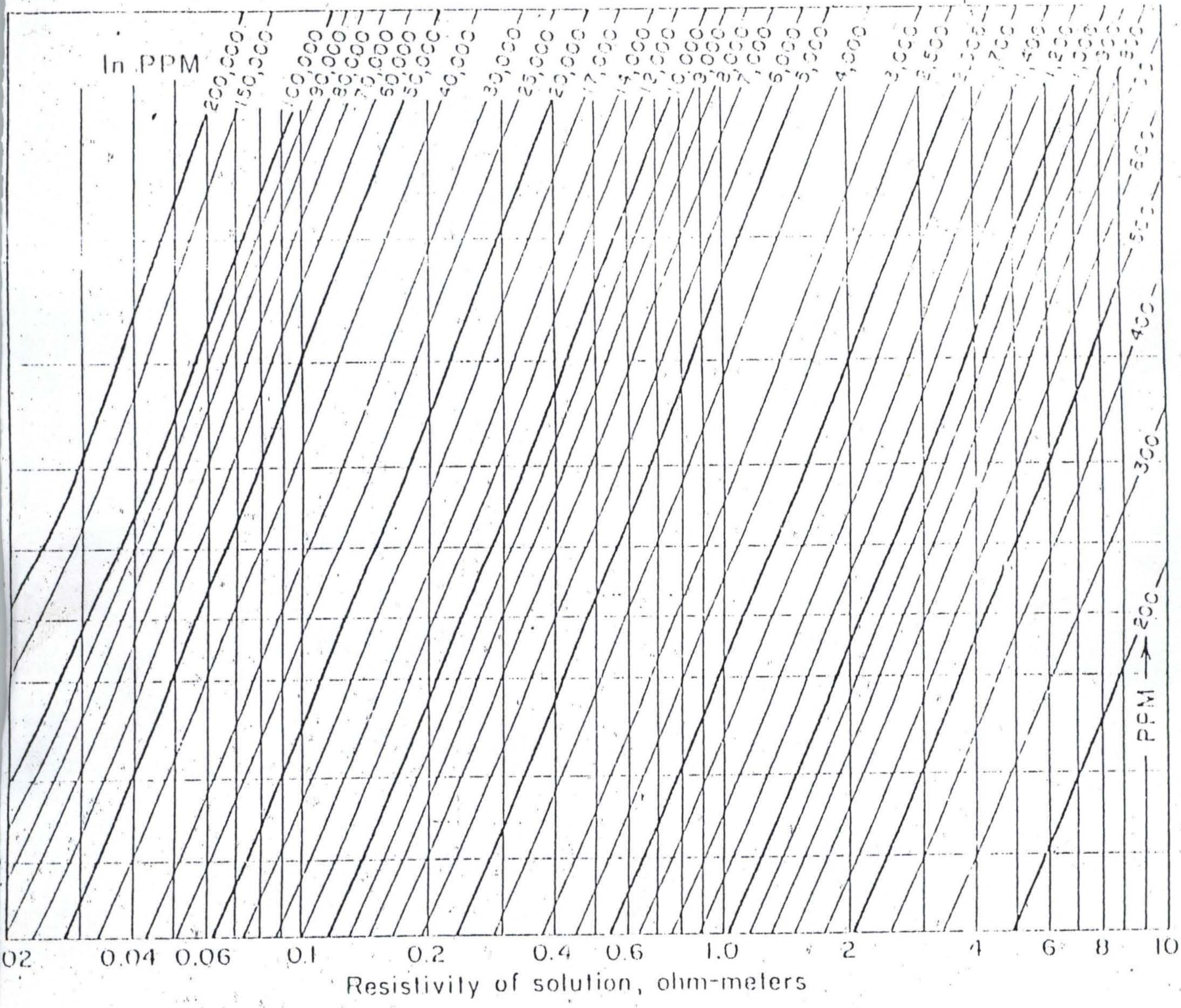


Fig. 5 Resistivity of NaCl aqueous solutions (R_w) as a function of salinity (ppm) and temperature. Reprinted with permission of Schlumberger Well Surveying Corporation.

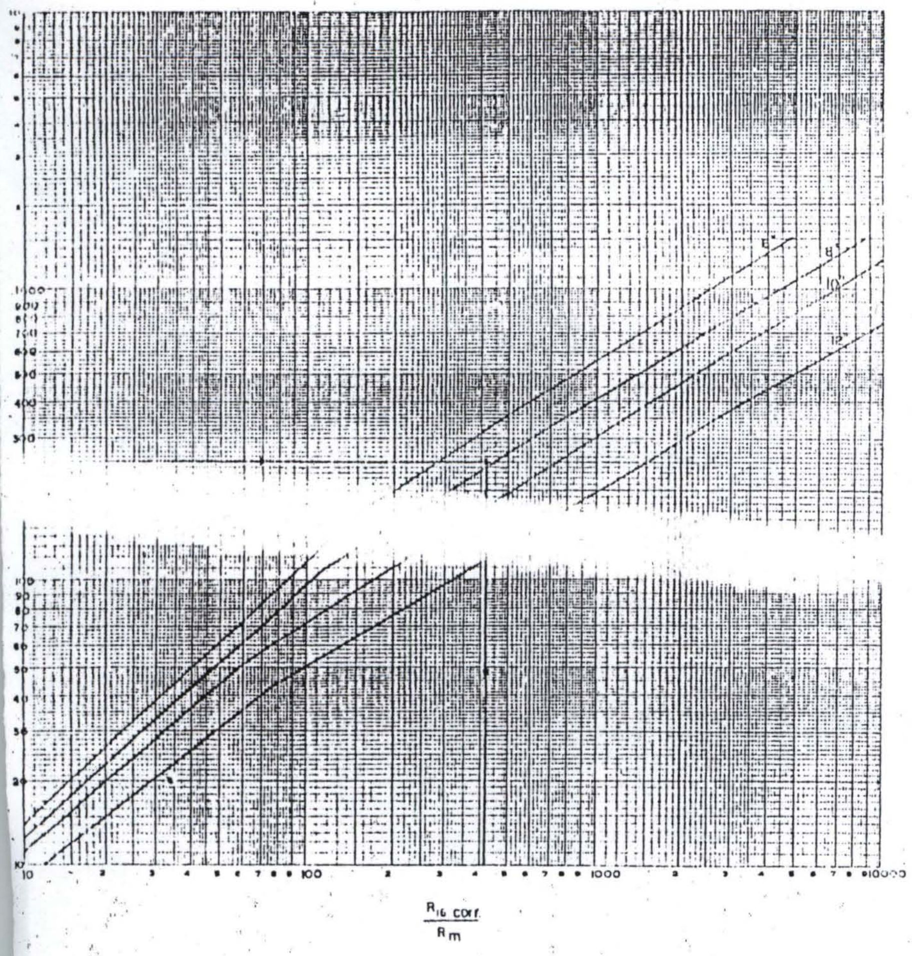
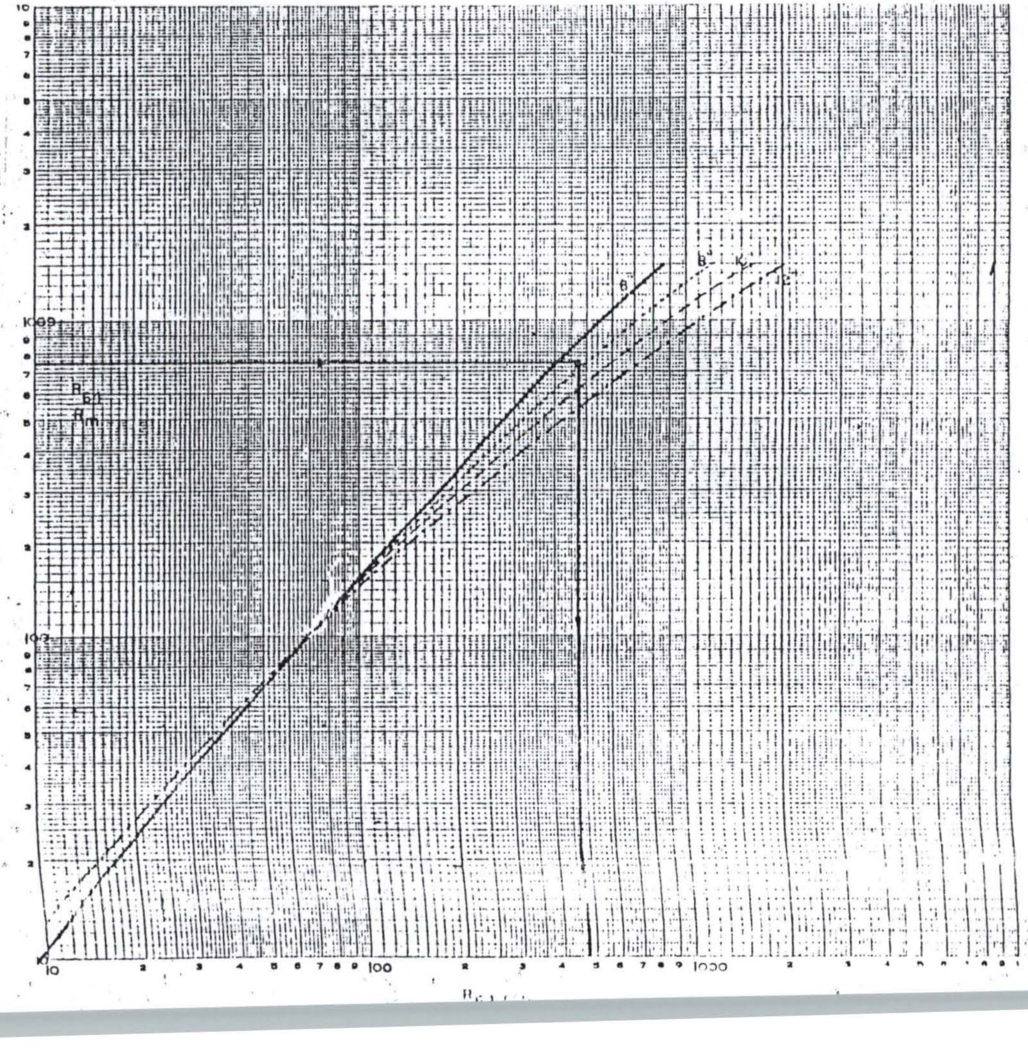


Fig. 6a. Bore hole size correction chart for short normal (AM' = 16 in.).

Fig. 6b. Bore-hole size correction chart for long normal (AM' = 64 in.).



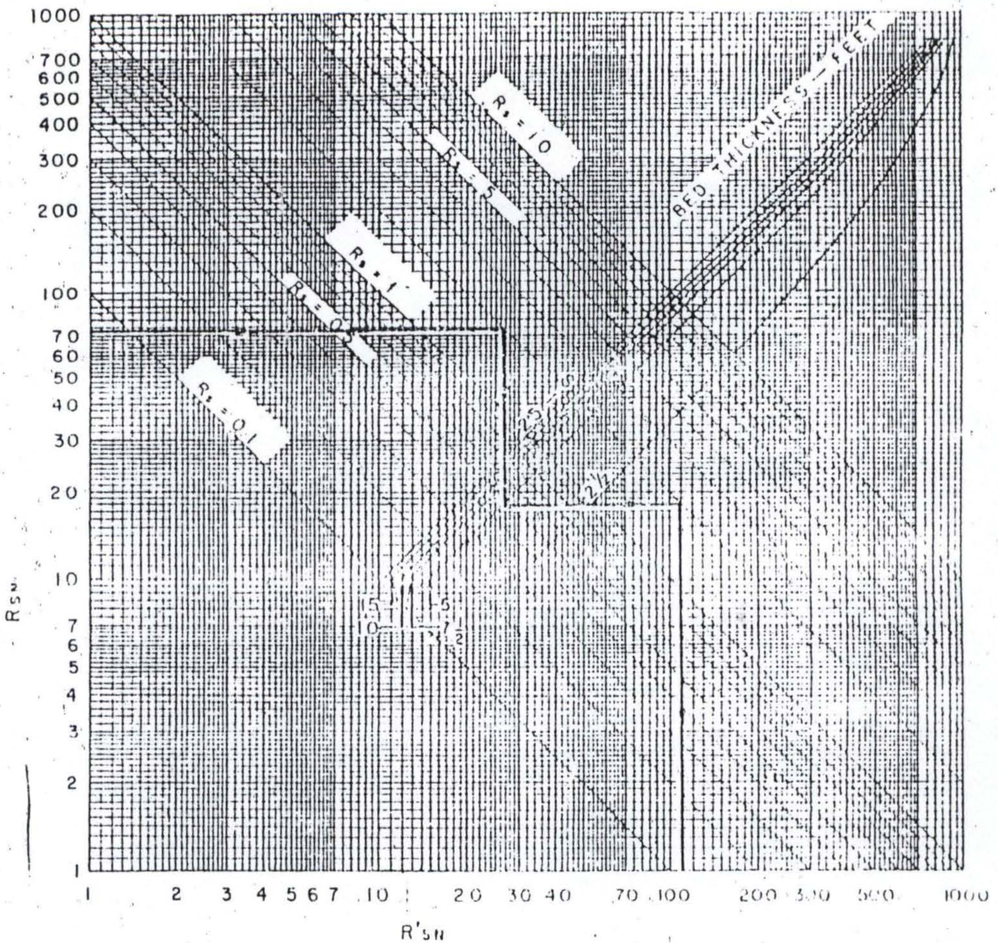


Fig. 7a Short normal (AM = 16 in.) correction chart for bed thickness and adjacent bed effects. Reprinted with permission of Lane-Wells Company.

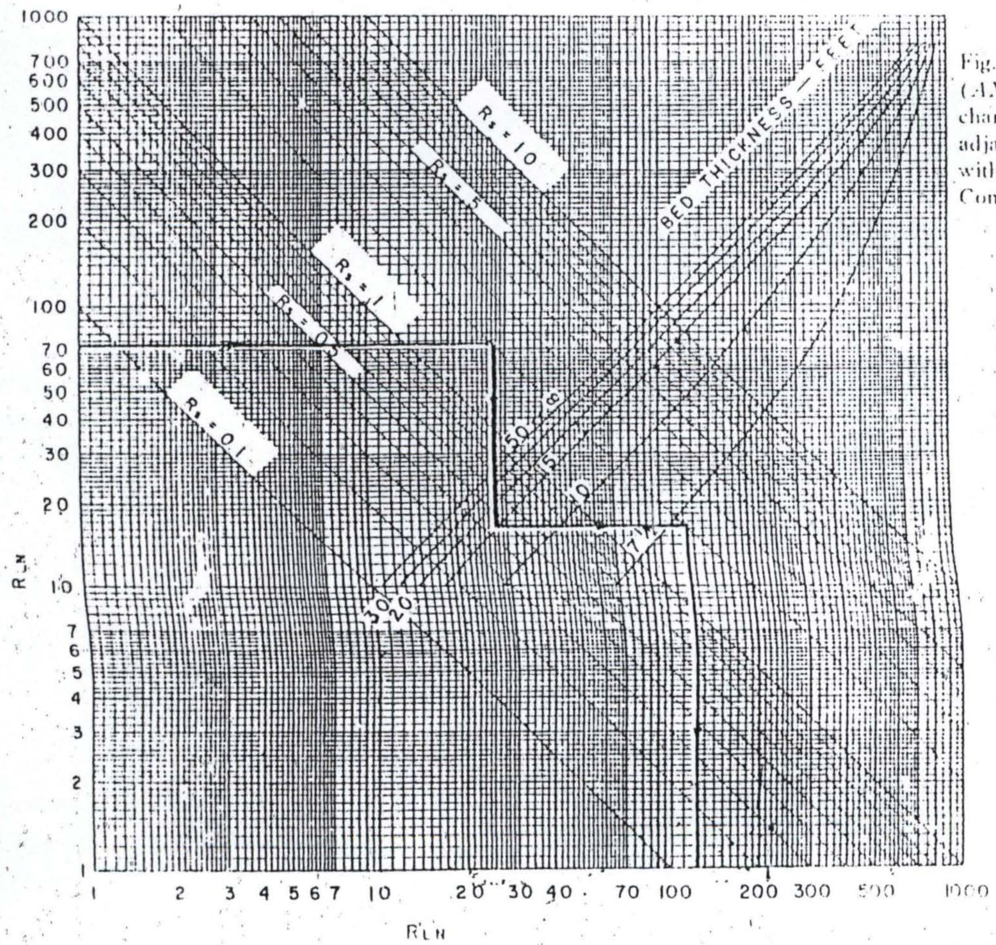


Fig. 7b Long normal (AM = 64 in.) correction chart for bed thickness and adjacent bed effects. Reprinted with permission of Lane-Wells Company.

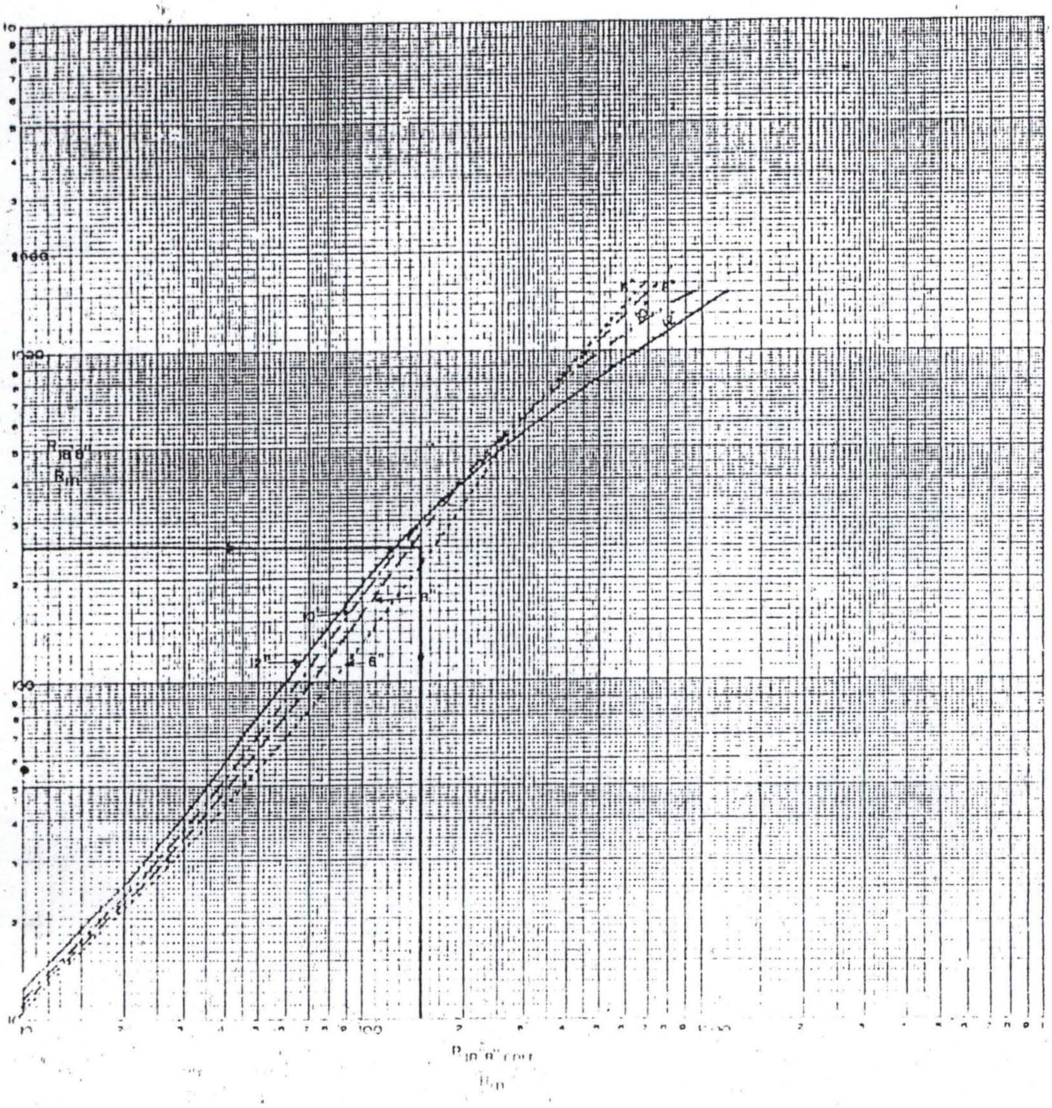


Fig. 8 · Bore-hole size correction chart for lateral curve (AO [illegible]

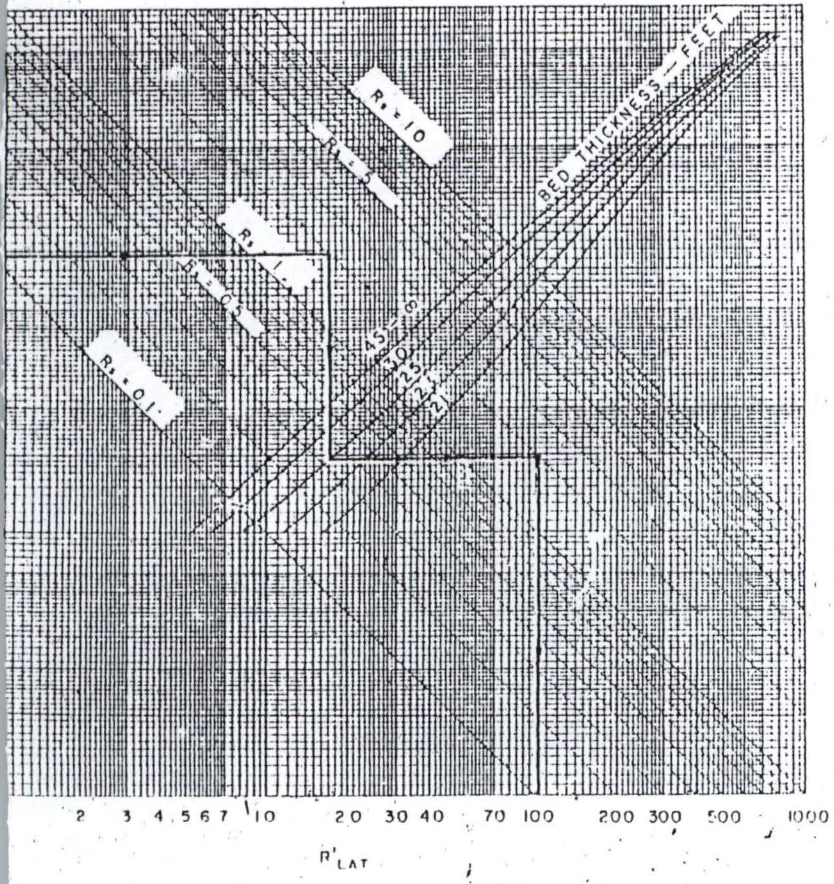


Fig. 9 . Lateral (AO = 18 ft 8 in.) correction chart for bed thickness and adjacent bed effects. Reprinted with permission of Lane-Wells Company.

BOREHOLE CORRECTION FOR 16-INCH NORMAL

RECORDED WITH ELECTRICAL LOG

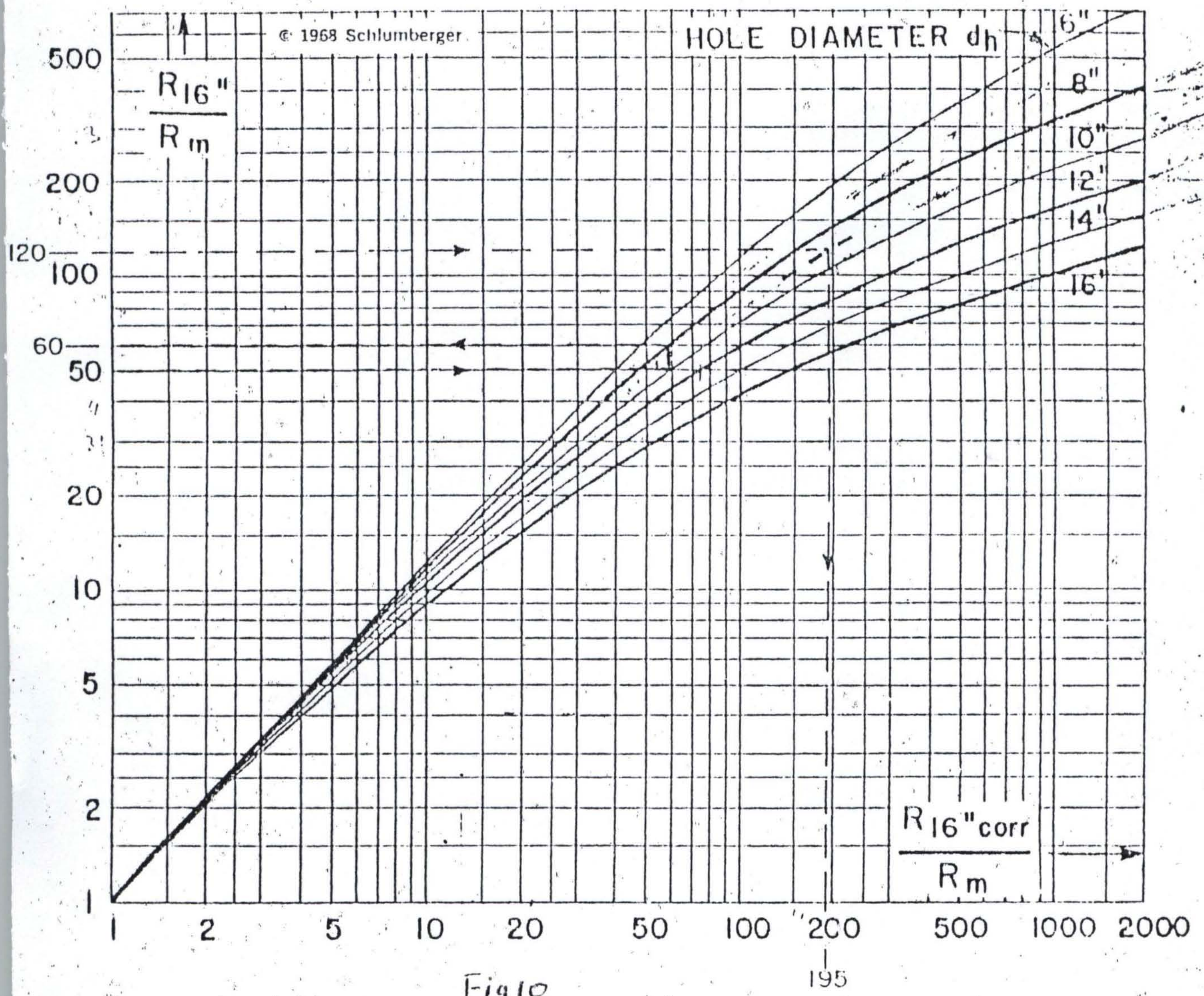


Fig10

1. *Thick Beds*

Example: $R_{16''}$ = 60 ohm-m, R_m (at formation temperature) = 0.5, hole size = 9".

Solution: $R_{16''corr}/R_m$ = 195, and $R_{16''corr}$ = 195 × 0.5 = 97.5.

2. *Correction to 8-inch Hole Size*

Before using the log readings in charts Rcor-11 and Rcor-12 correct to 8"-hole-size reading. Enter with $R_{16''}/R_m$. Proceed horizontally to solid curve for actual hole size. Proceed vertically to 8"-hole-size diameter line. Read $R_{16''}/R_m$ for 8" hole on scale at left.

Example: $R_{16''}/R_m$ = 50 in 10" hole. Find $R_{16''}/R_m$ = 60 in 8" hole.

BOREHOLE CORRECTION FOR 18′8″ LATERAL

RECORDED WITH ELECTRICAL LOG

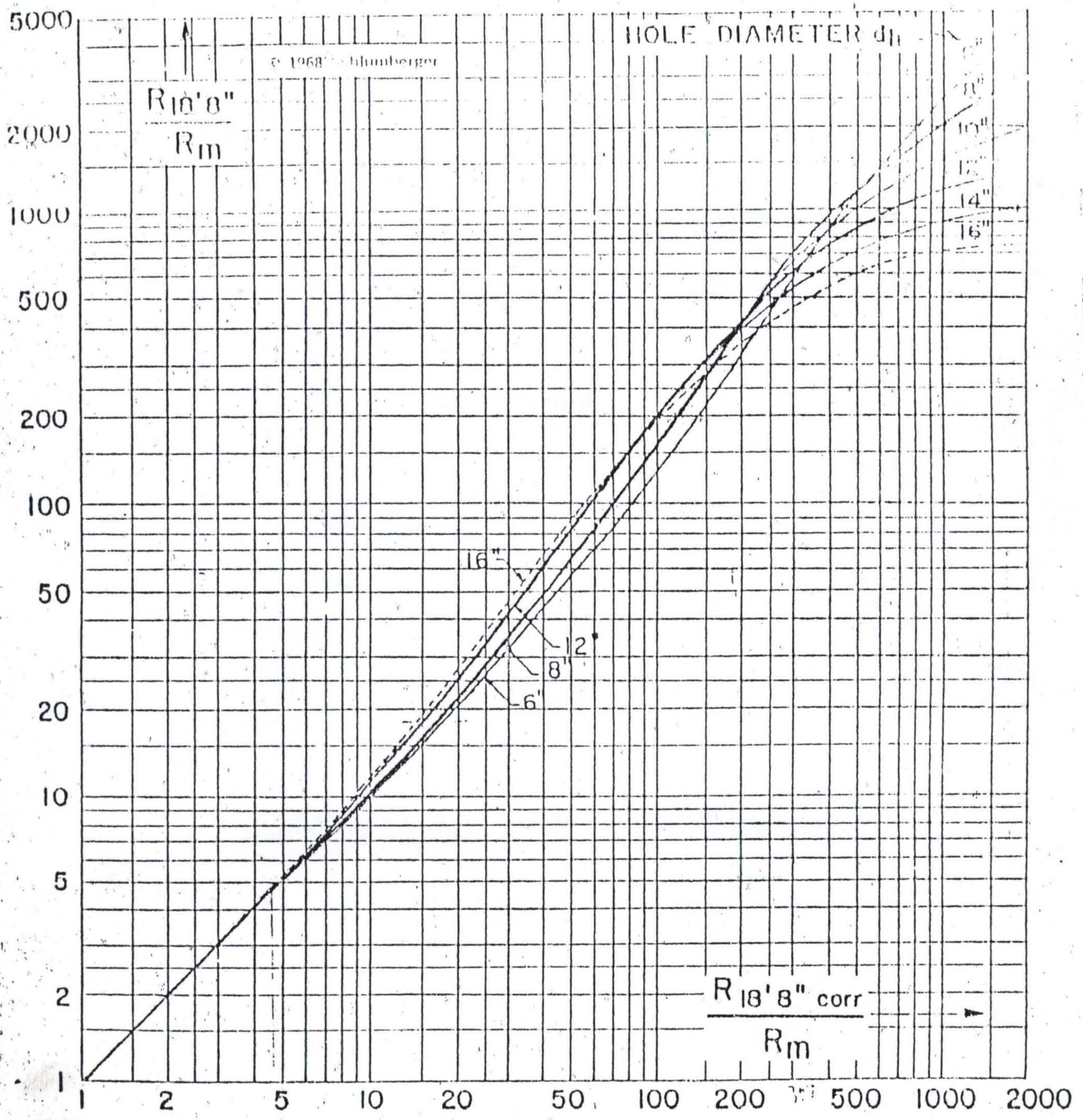
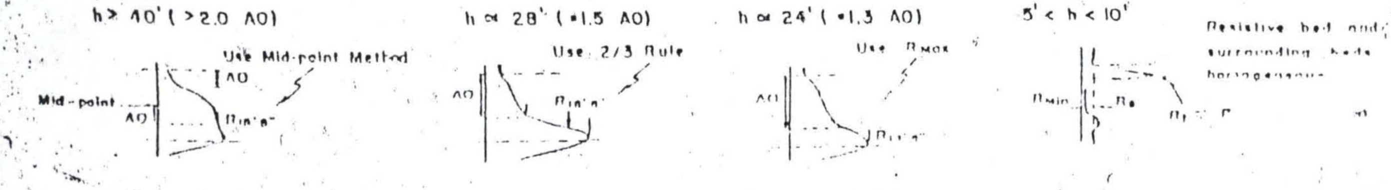


Fig 11

Procedure is similar to that described for 16-inch Normal. Since the Lateral is an unsymmetrical curve, special rules, summarized in the sketches below, apply for picking the value of $R_{18'8''}$. AO, the lateral spacing, equals 18′8″.



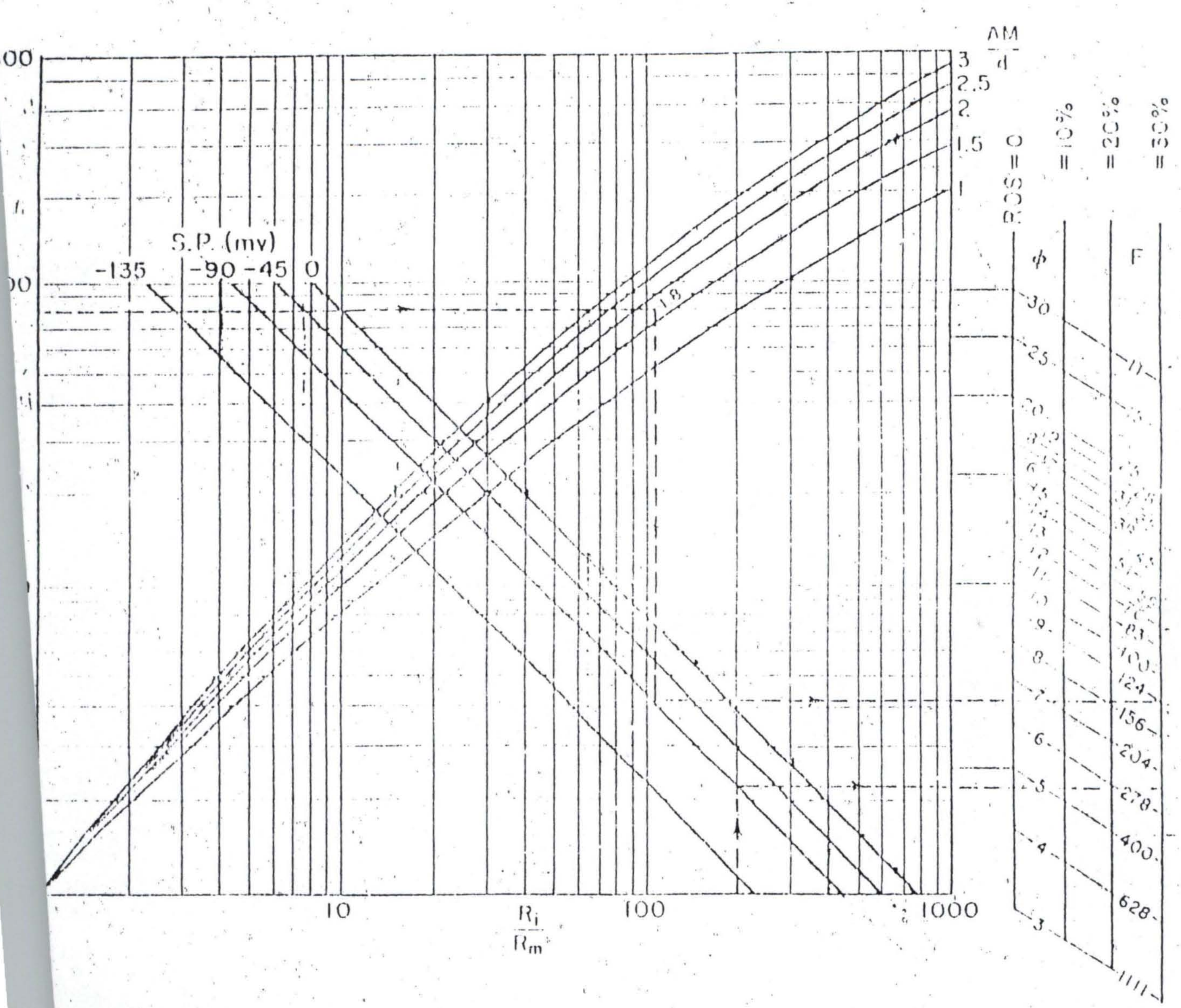


Chart for determination of porosity and formation factor from the short normal curve 16 in.). From S. J. Pirson, "Formation Evaluation by Log Interpretation," *World Oil* (April, une, 1957).

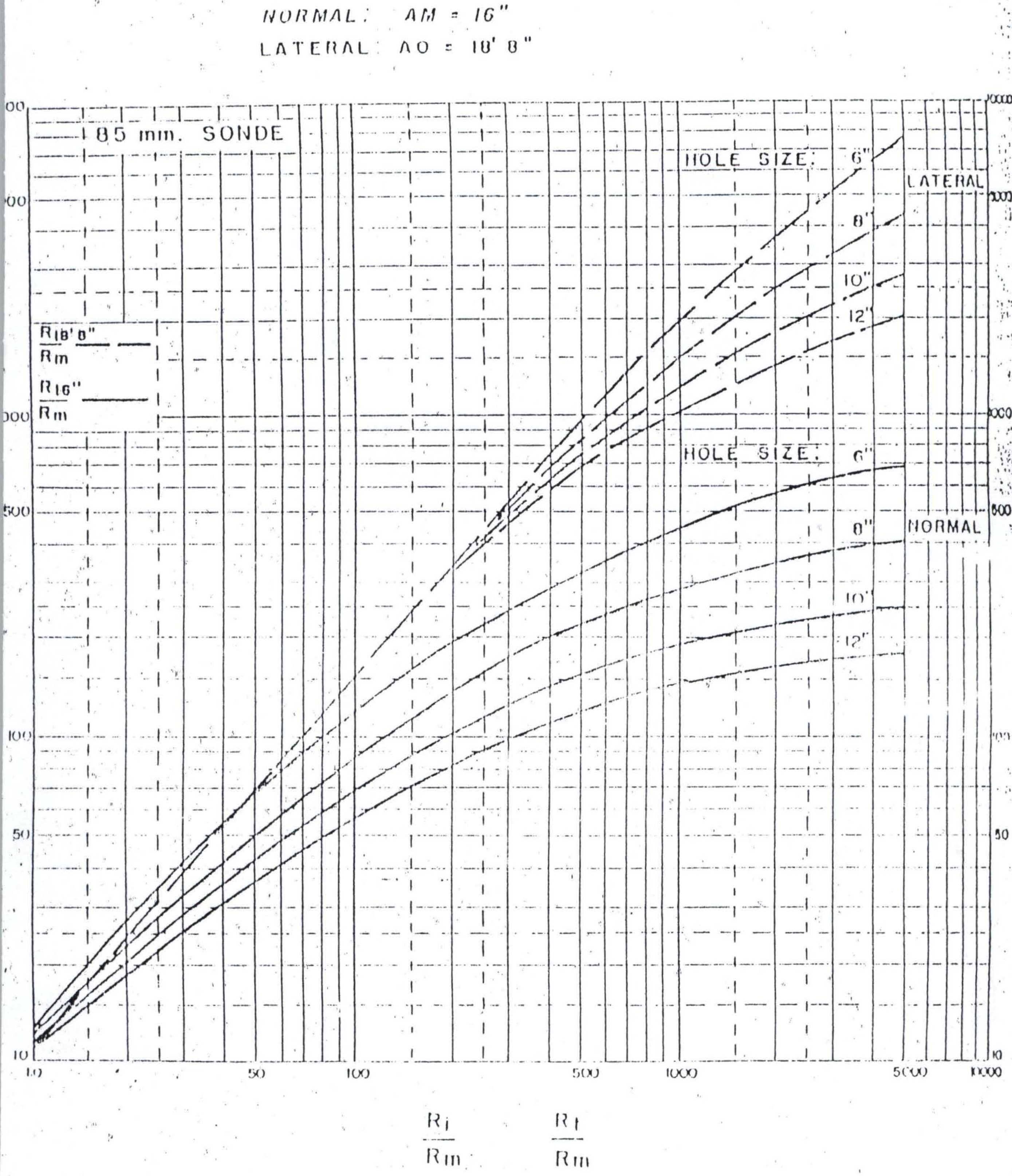


Fig. 13 — Simplified resistivity departure curves for normal and lateral devices. Courtesy Schlumberger Well Surveying Corporation.

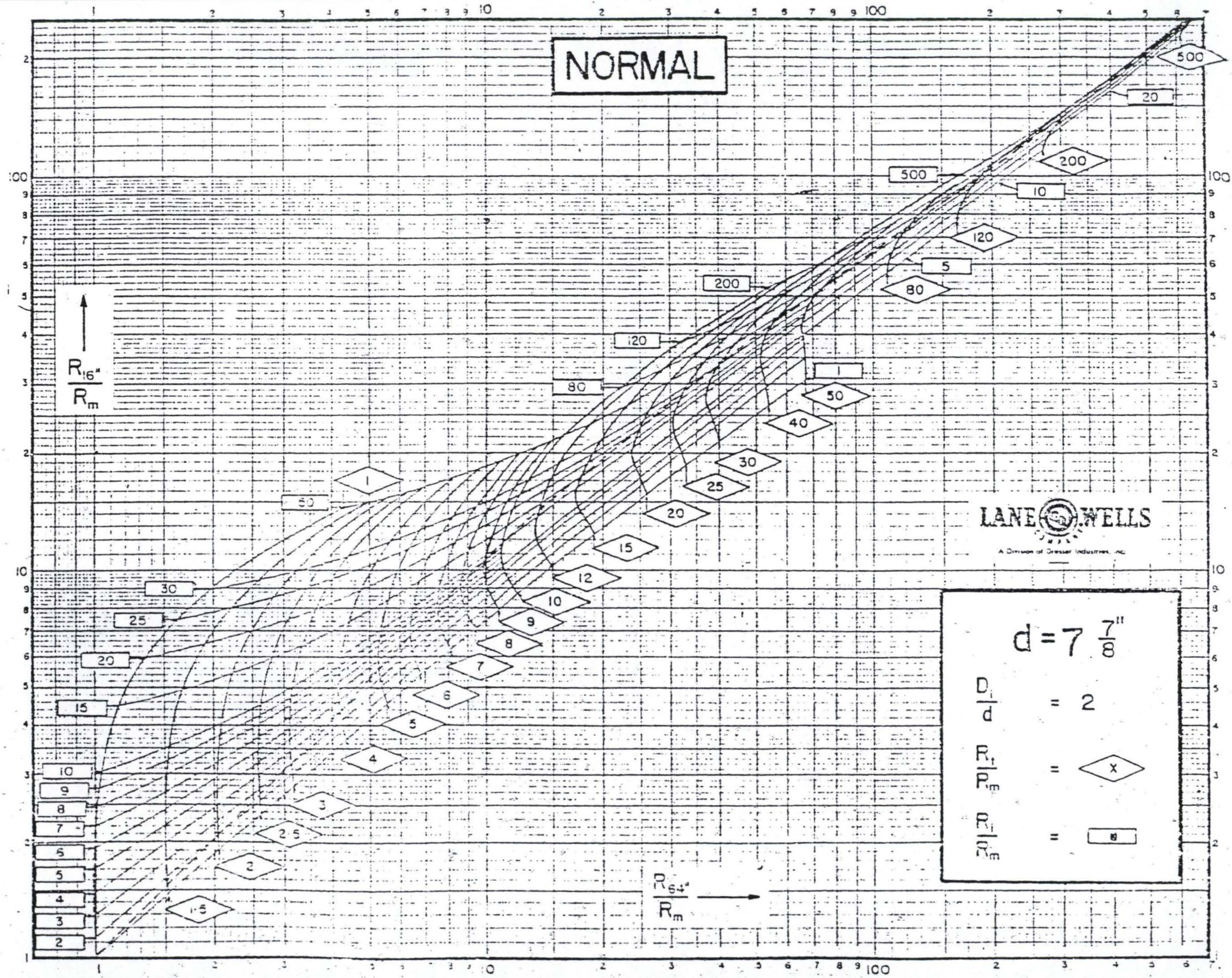
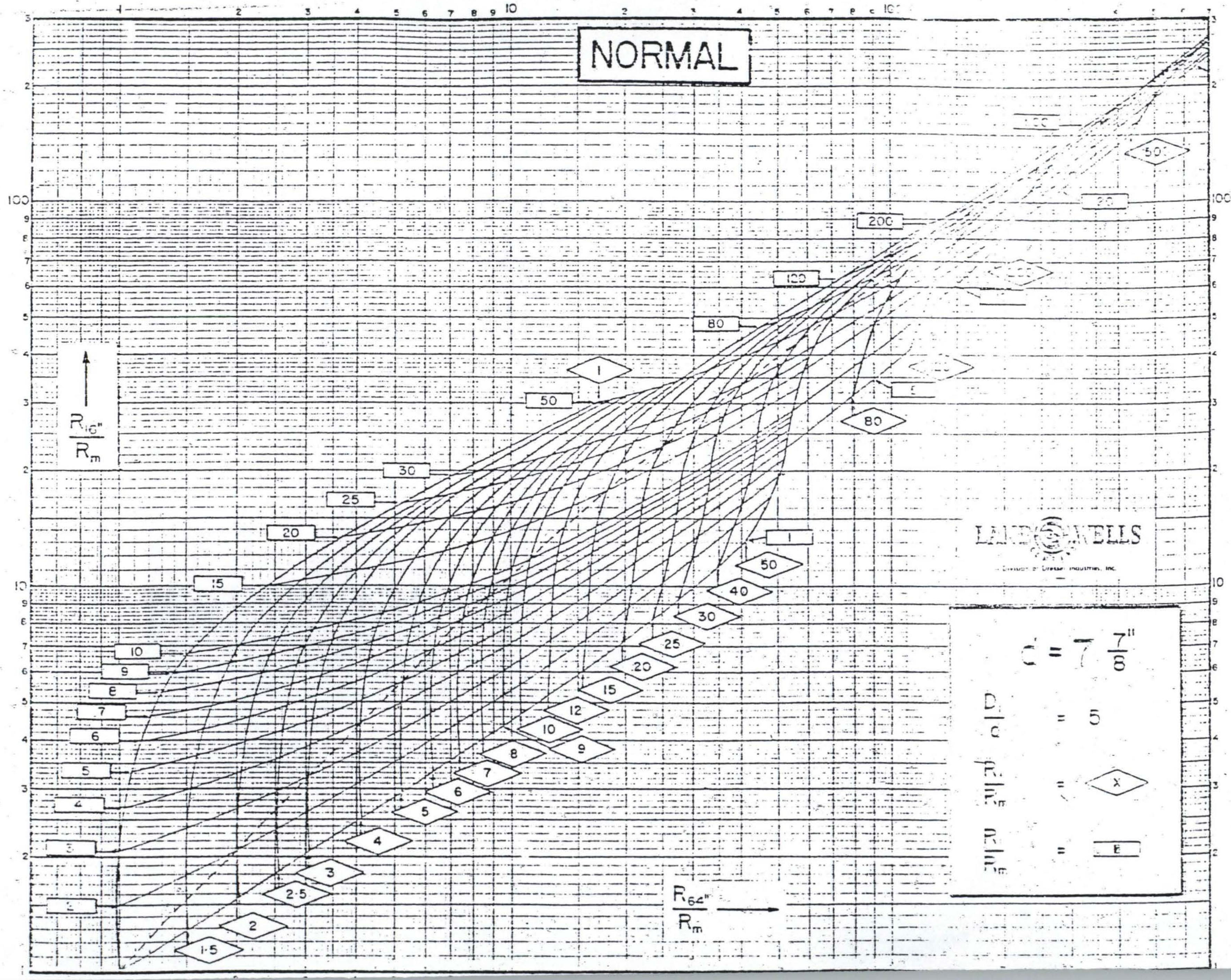


Fig 14 [illegible] normal interpretation charts for the determination of R_i, D_i and R_t in a 7⅞ in. bore [illegible] of Lane-Wells Company.


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

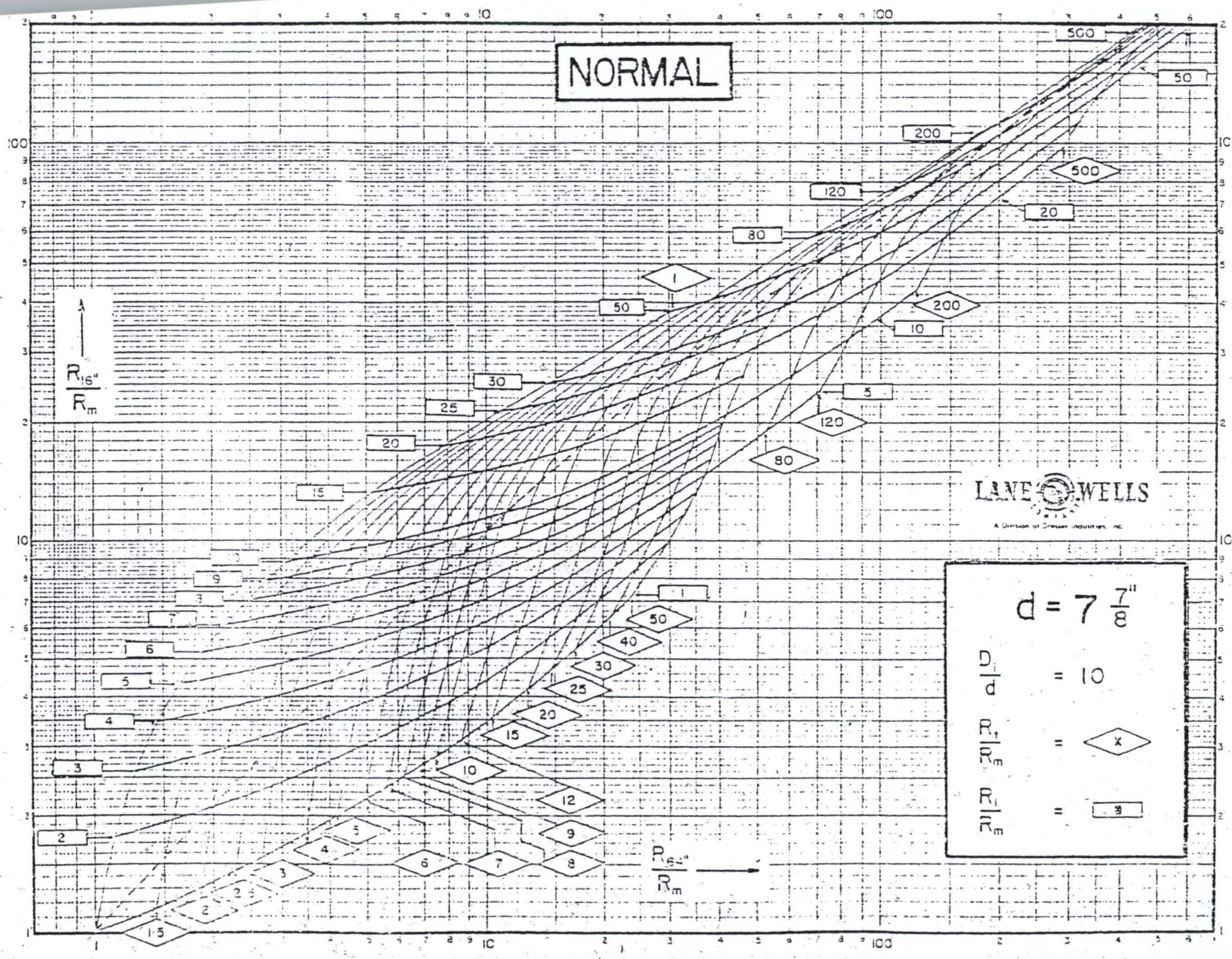

NORMAL
$\frac{R_{16''}}{R_m}$
$\frac{R_{64''}}{R_m}$
1.5
2
2.5
3
4
5
6
7
8
9
10
12
15
20
25
30
40
50
80
120
200
500
LANE WELLS
A Division of Dresser Industries, Inc.
$d = 7\frac{7}{8}''$
$\frac{D_i}{d} = 10$
$\frac{R_t}{R_m} =$ ◇ x
$\frac{R_i}{R_m} =$ ▭
1
10
100

Fig. 16 (cont.)

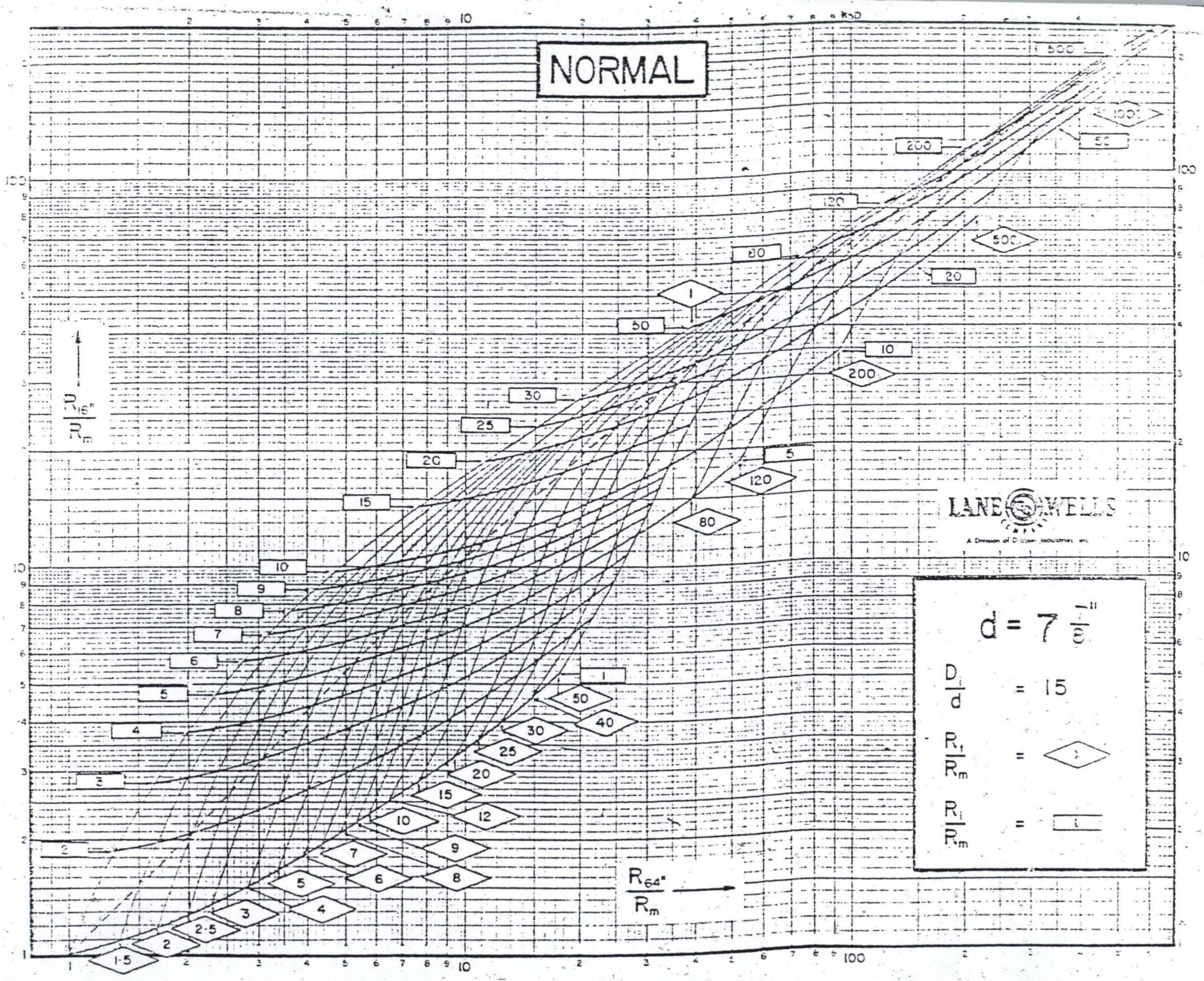
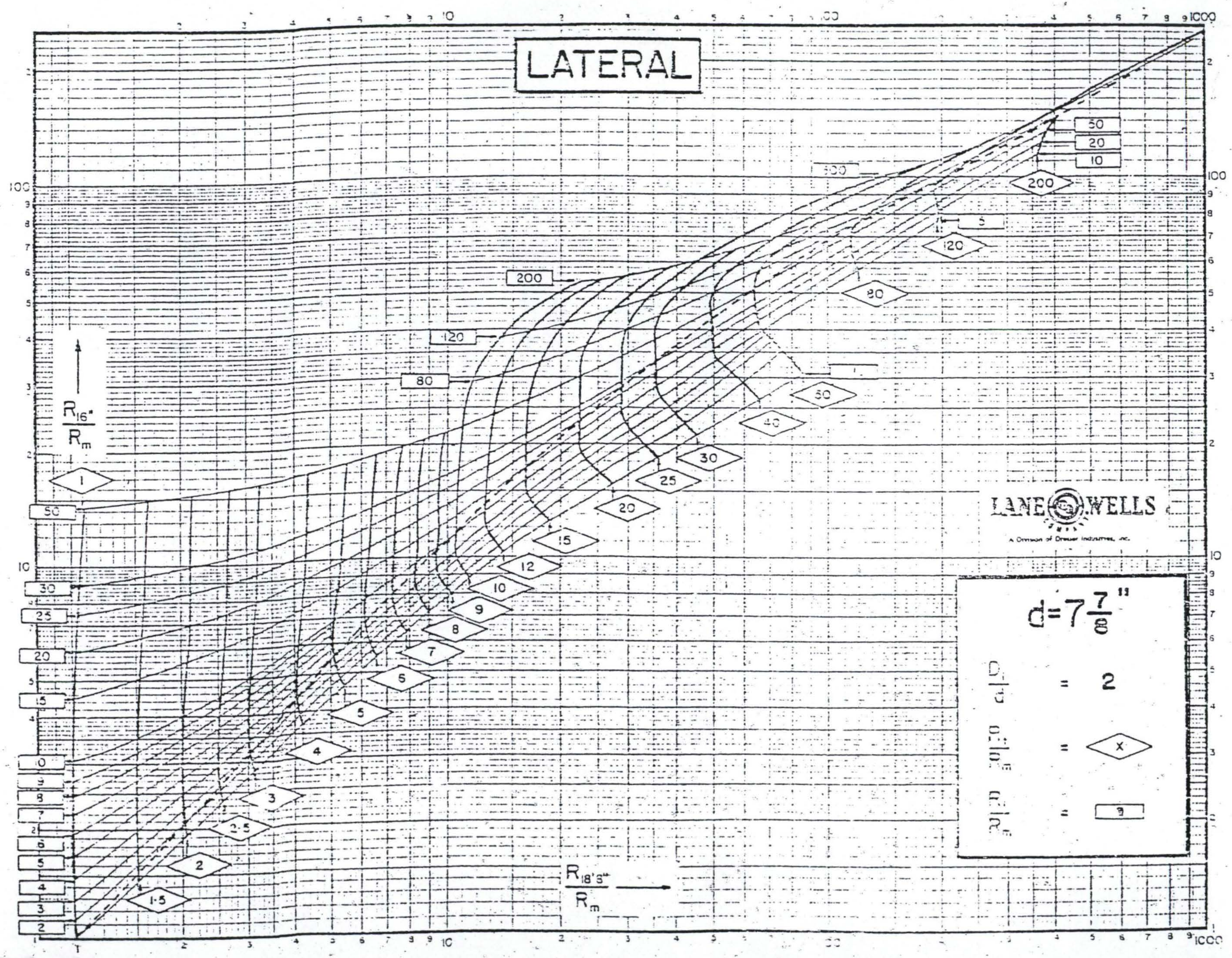
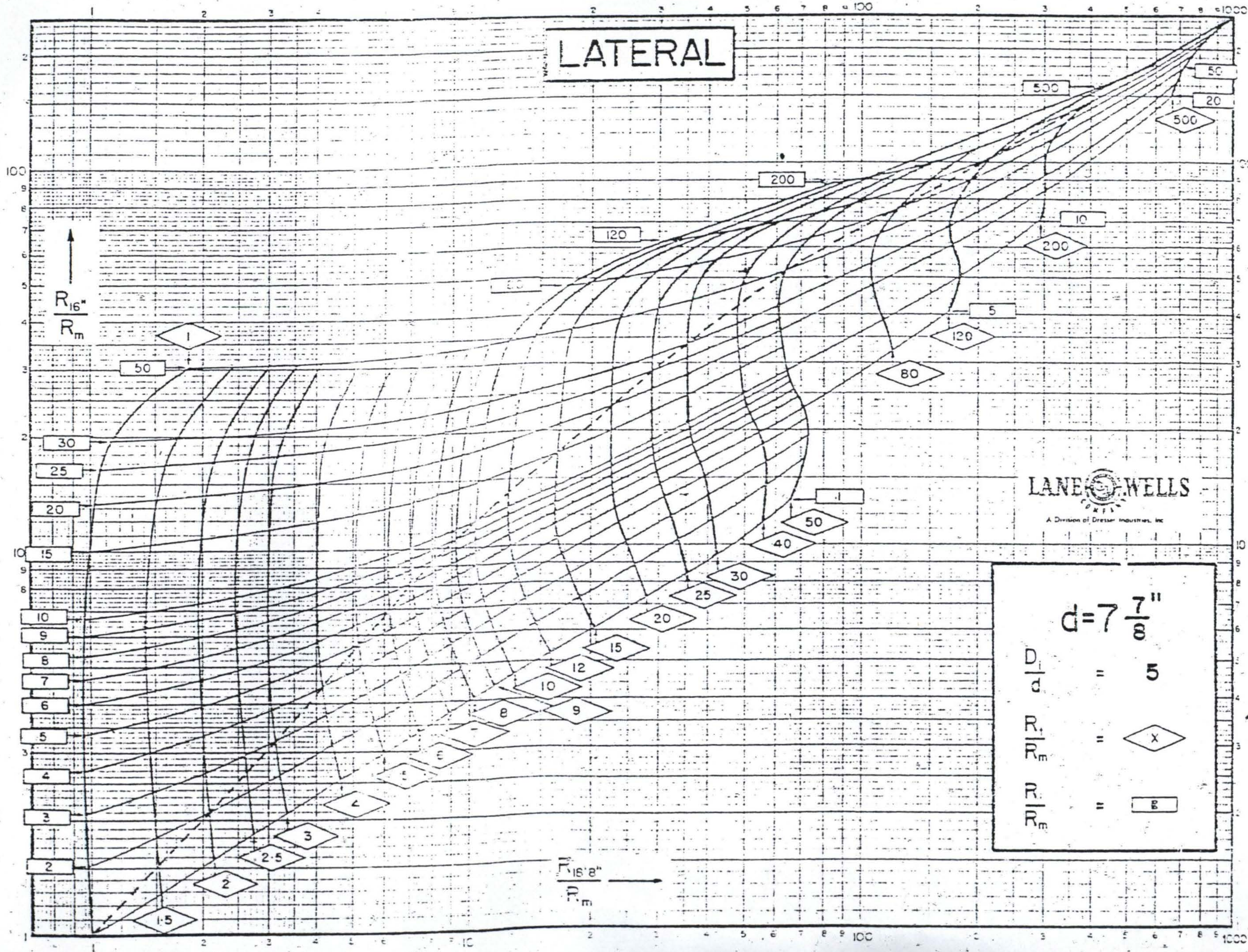
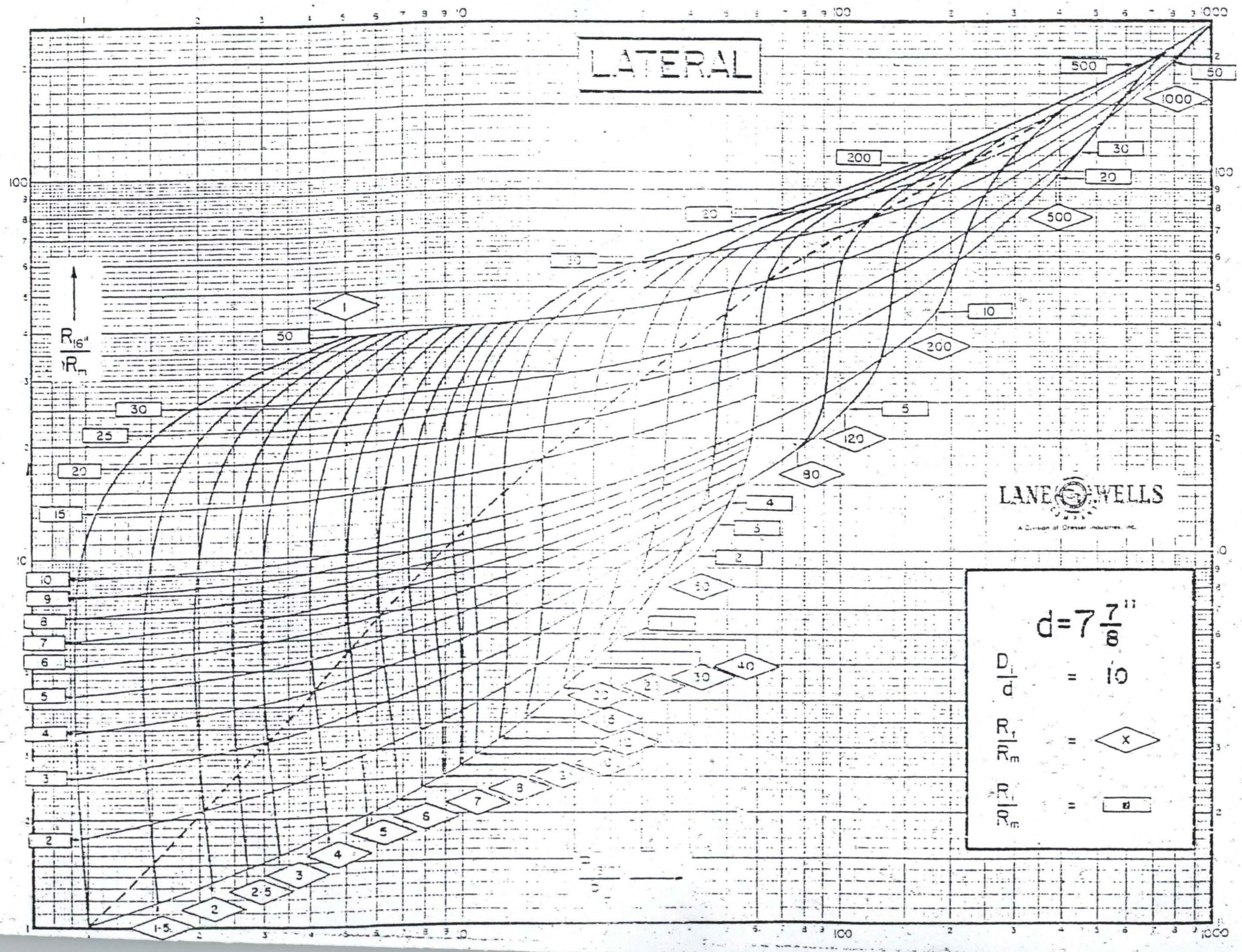

NORMAL
$\frac{R_{16''}}{R_m}$
$\frac{R_{64''}}{R_m}$
LANE-WELLS COMPANY
A Division of Dresser Industries, Inc.
$d = 7\frac{7}{8}''$
$\frac{D_i}{d} = 15$
$\frac{R_t}{R_m} =$ ◇
$\frac{R_i}{R_m} =$ ▭
1.5
2
2.5
3
4
5
6
7
8
9
10
12
15
20
25
30
40
50
80
120
200
500
1000
1
5
10
20
50
120
200
500

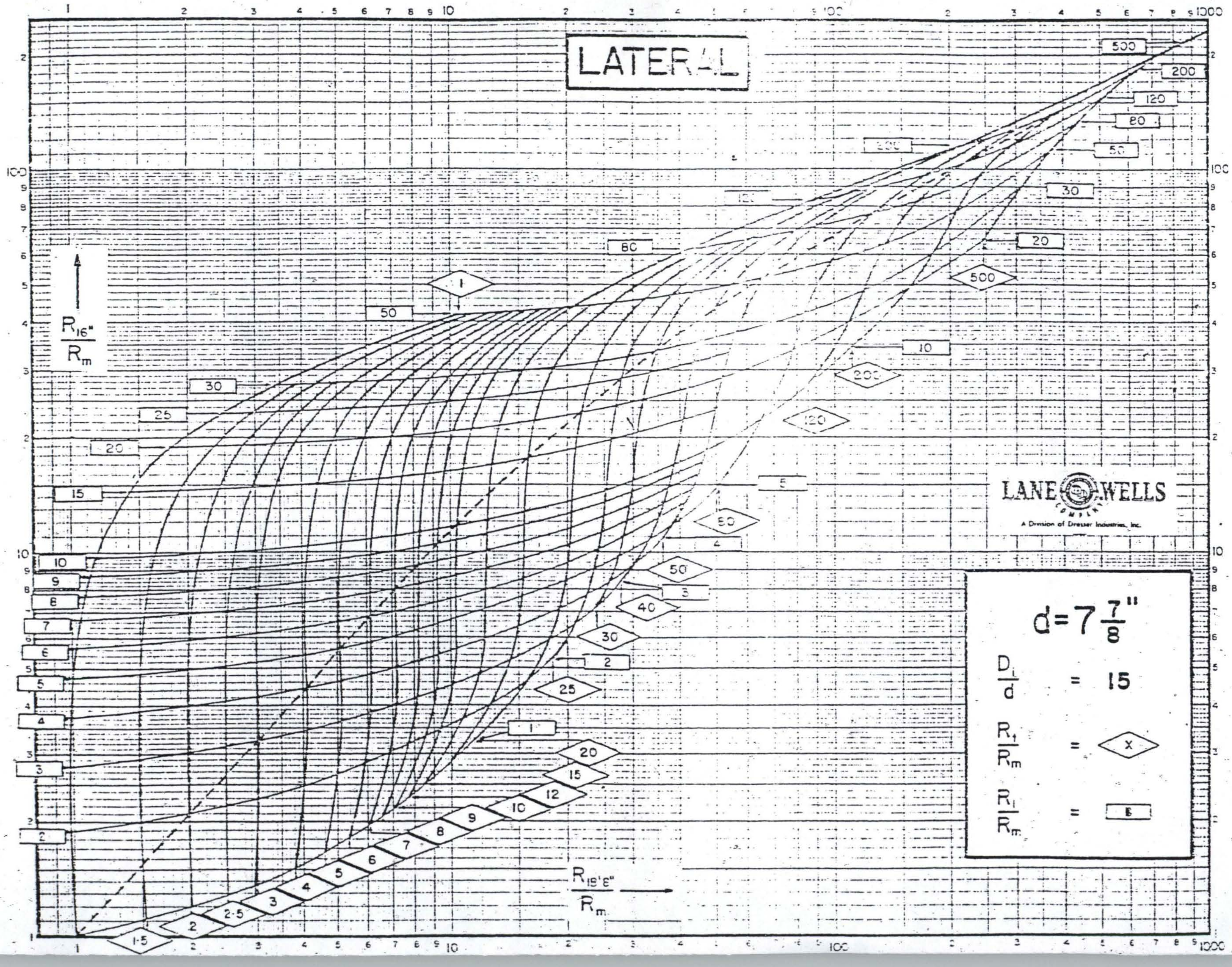
Fig. 17 (cont.)



[illegible] lateral interpretation charts for the determ [illegible]


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


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


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

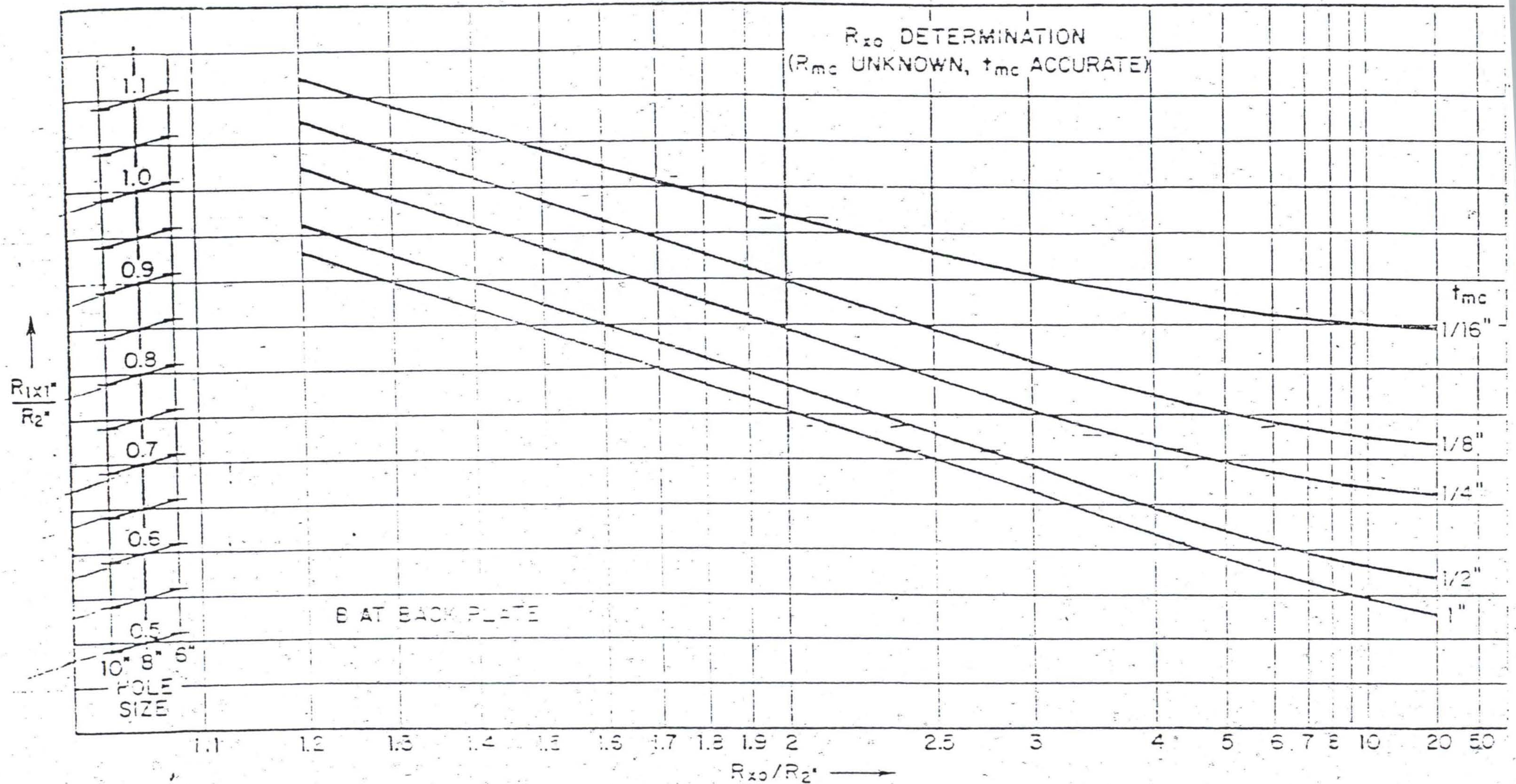
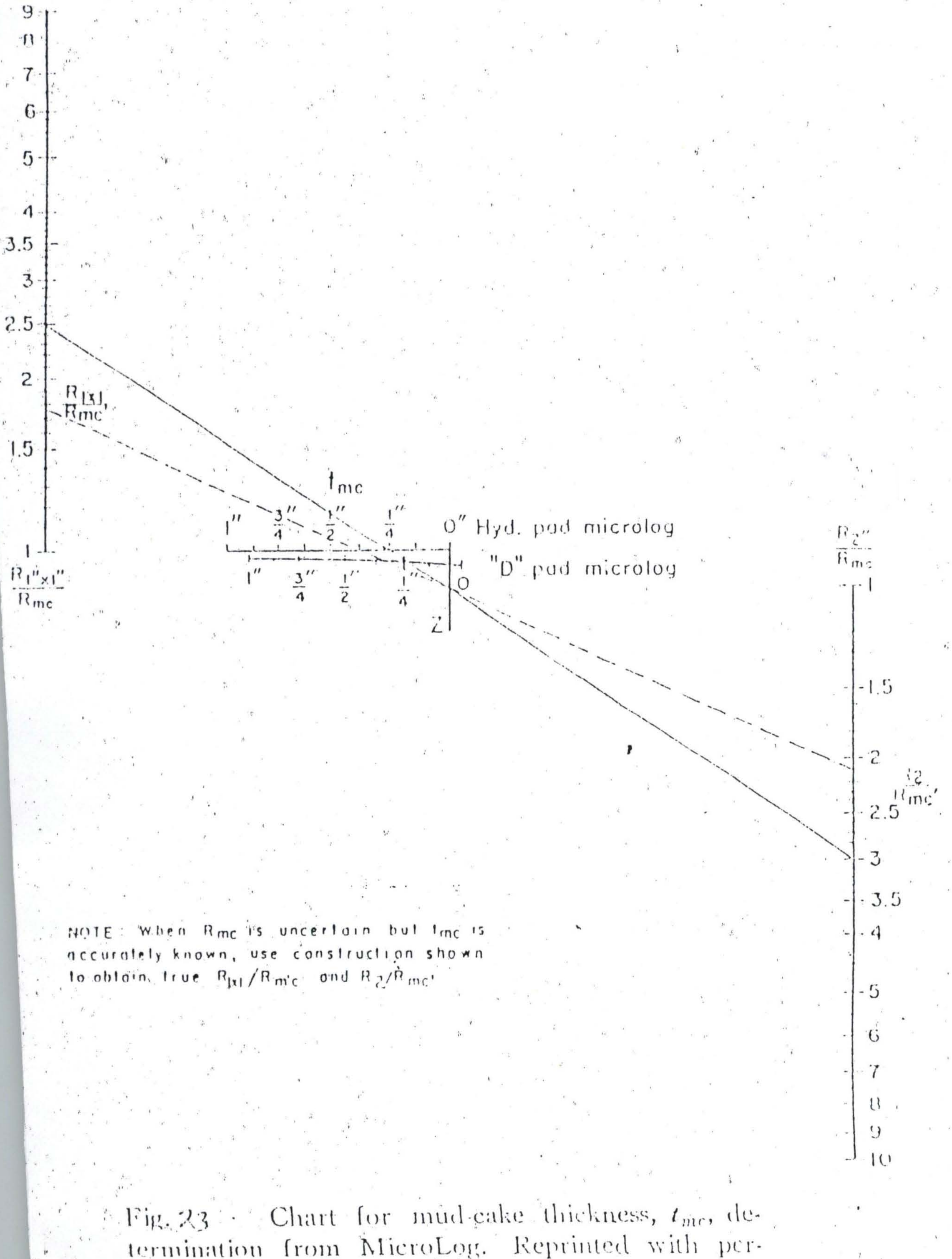
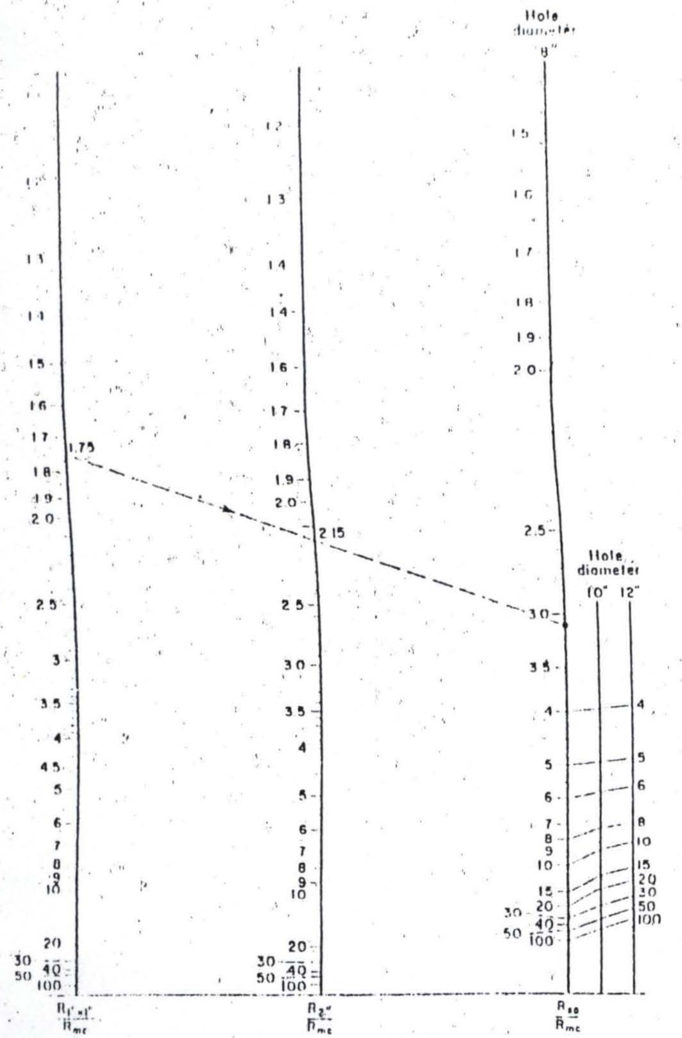


Fig. 22 Chart for determination of flushed-zone resistivity, R_{xo}, when mud-cake thickness, t_{mc}, is accurately known from a caliper log; R_{mc} being unknown. Reprinted with permission of Schlumberger Well Surveying Corporation.



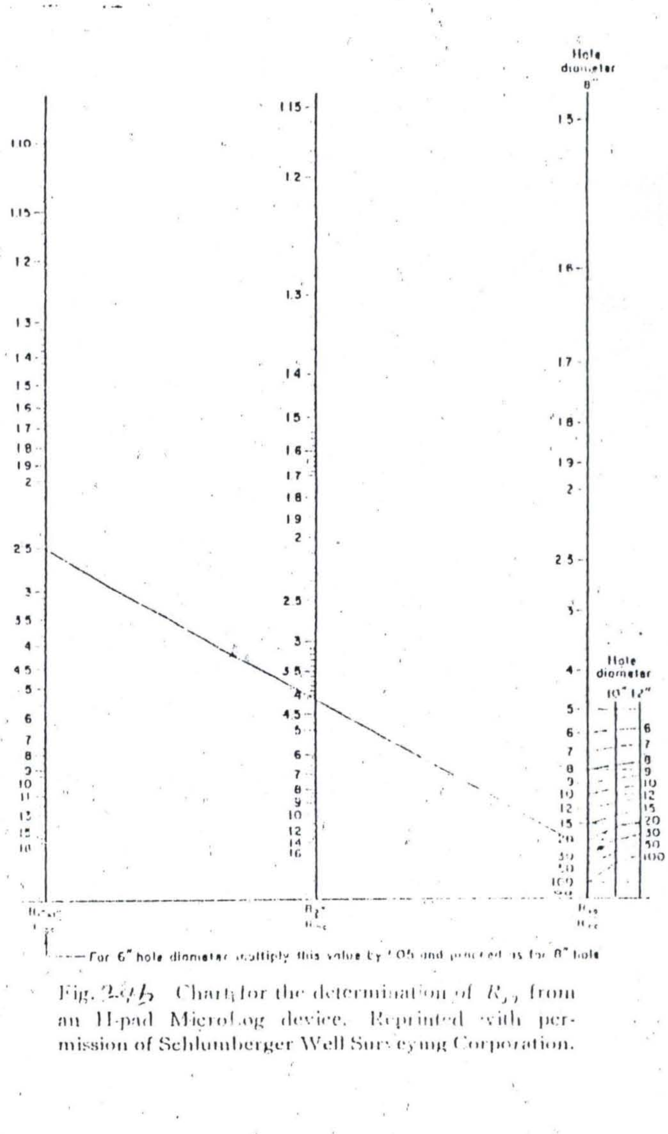
NOTE: When Rmc is uncertain but tmc is accurately known, use construction shown to obtain true Rlxl/Rm'c and R2/Rmc'

Fig. 23 · Chart for mud-cake thickness, t_{mc}, determination from MicroLog. Reprinted with permission of Schlumberger Well Surveying Corporation.



For 6" hole diameter multiply this value by 1.07 and proceed as for 8" hole

Fig. 24a Chart for the determination of R_{xo} from a D-pad MicroLog device. Reprinted with permission of Schlumberger Well Surveying Corporation.



For 6" hole diameter multiply this value by 1.05 and proceed as for 8" hole

Fig. 24b Chart for the determination of R_{xo} from an H-pad MicroLog device. Reprinted with permission of Schlumberger Well Surveying Corporation.

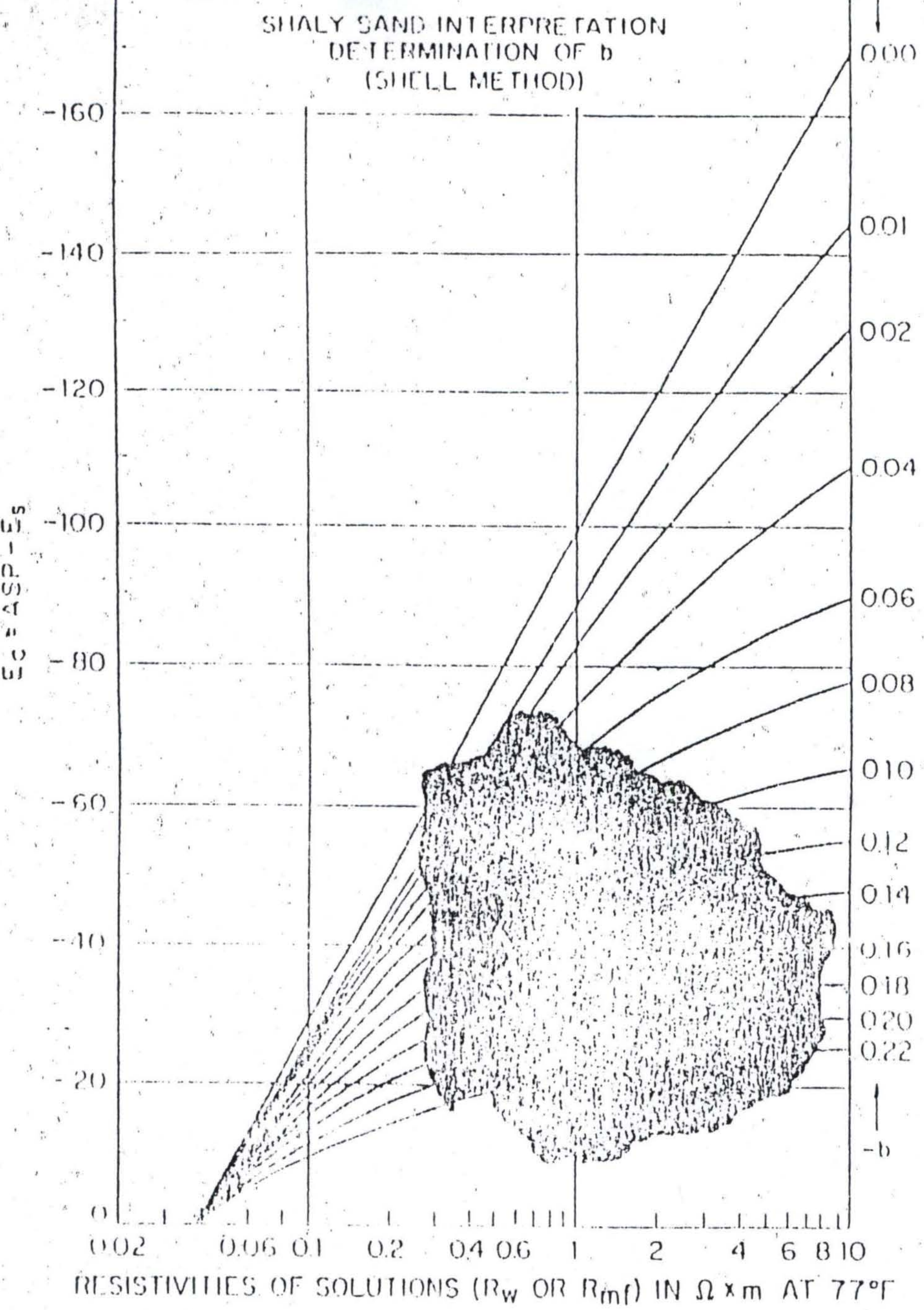


Fig. 34. Determination of shalyness factor *b* (Shell method). After J. H. Hill and J. D. Milburn, "Effect of Clay and Water Salinity on Electrochemical Behavior of Reservoir Rocks," *AIME Journal of Petroleum Technology* (March 1956).

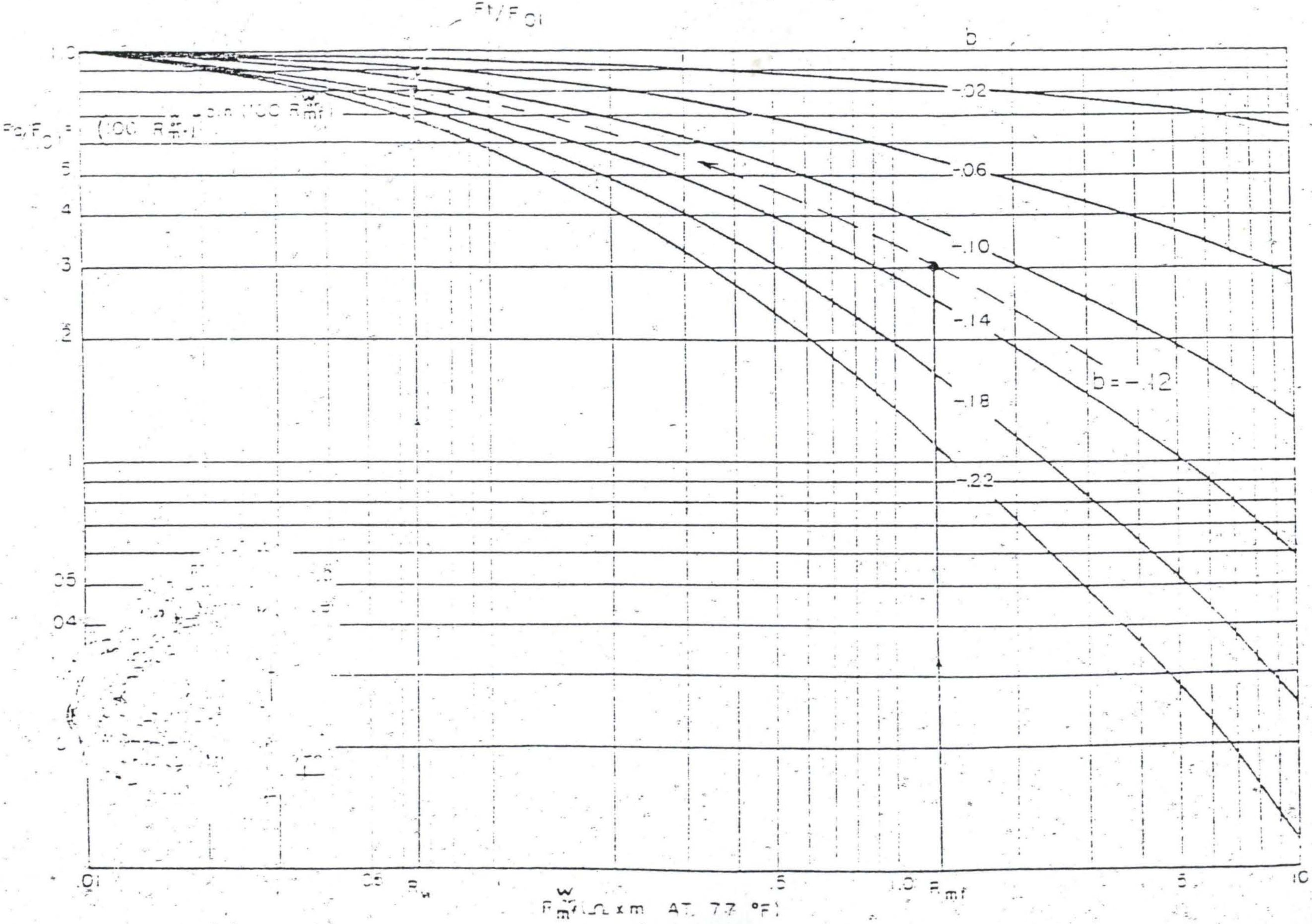


Fig. 4. Determination of true formation factor, F_t, in shaly sands. After J. H. Hill and J. D. Milburn "Effect of Clay and Water Salinity on Electrochemical Behavior of Reservoir Rocks," *AIME Journal of Petroleum Technology*, March 1956).

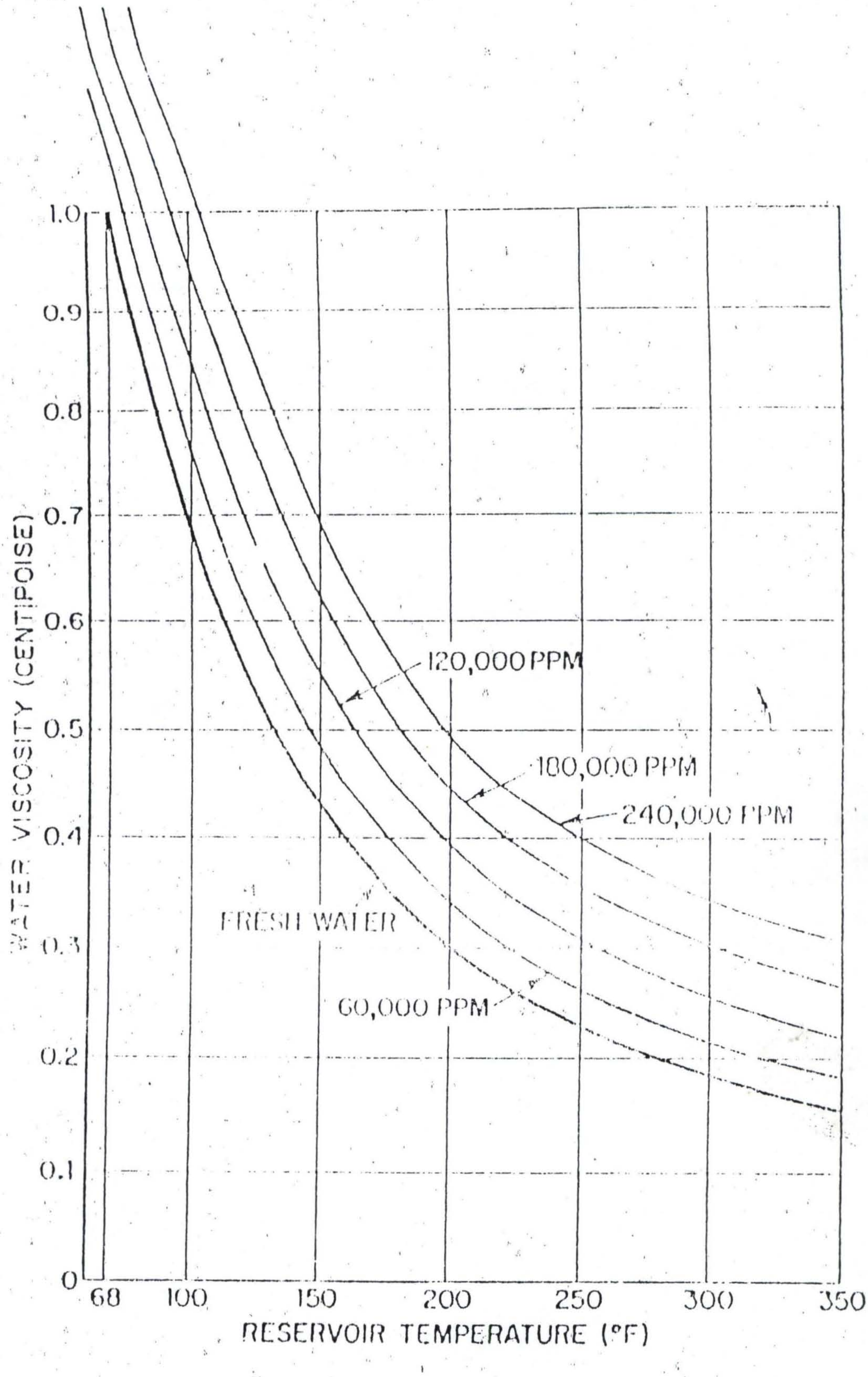
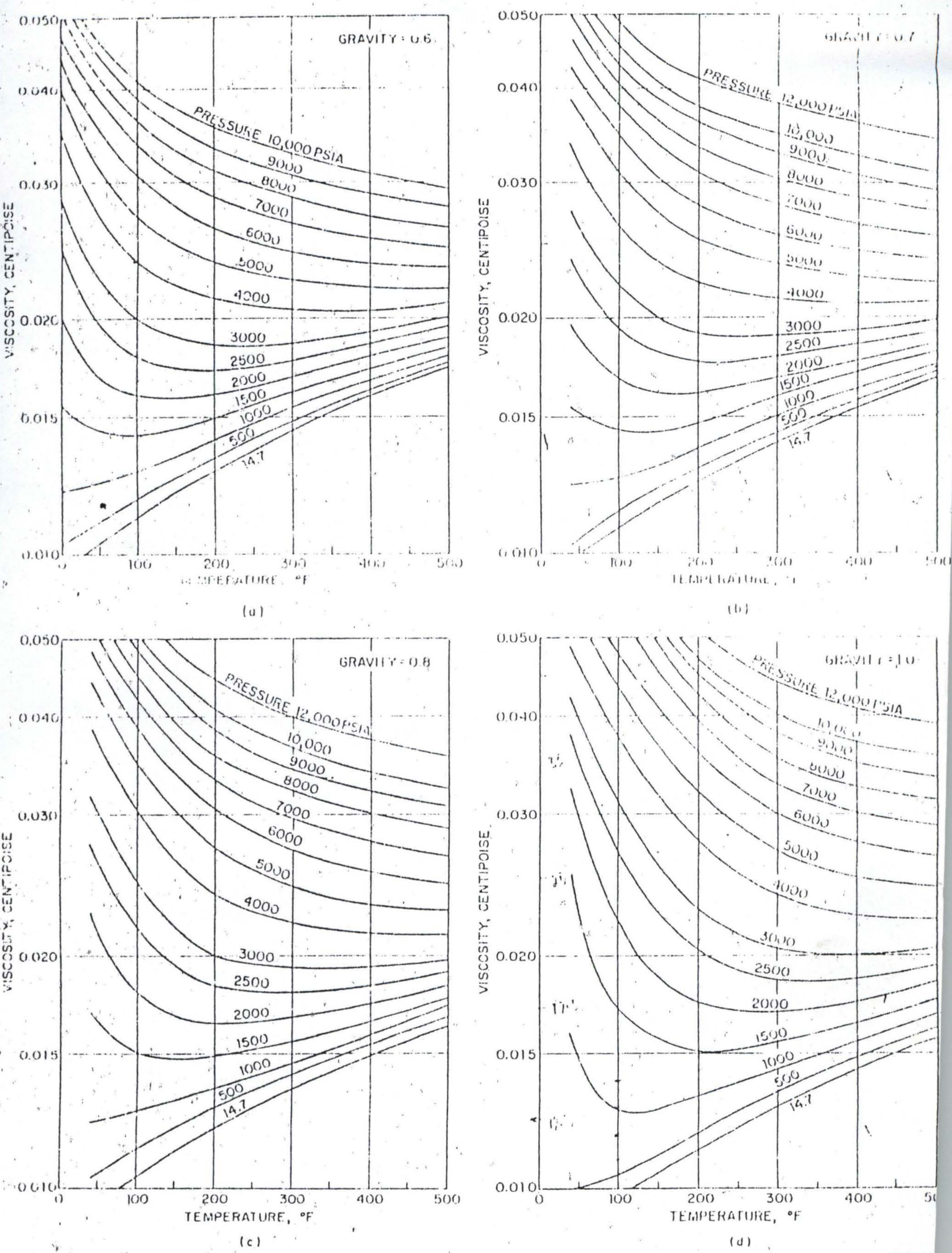


Fig. 39: Water viscosity (μ_w) as a function of temperature and salinity (ppm NaCl).



(a) (b) (c) (d)

Fig. 40 Viscosity of natural gases (μ_g). From D. L. Katz, *et al.*, *Natural Gas Engineering* (New York: McGraw-Hill Book Company, Inc., 1959).