PL 044

D-15

statoil

PETROPHYSICAL EVALUATION
OF
WELL 1/9-3

DONE BY:
EVALUATION TECHNOLOGY SECTION
PRODUCTION DEPT. STATOIL
NOVEMBER 1978

Den norske stats oljeselskap a.s

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CONTENTS:

NORWAY OFFSHORE

LICENSE No. 044

WELL DATA

Well name	:	1/9-3
Location	:	56°24'56.20"N 02°54'15.15"E
Classification	:	Jurassic test
Prospect	:	1/9 Alpha structure
Drilling period	:	re-entry 21 May 1978 Rig off loc. 29 September 1978
KB elevation	:	35.77 m
Water depth	:	76 m
Objective	:	Ekofisk and Tor Formations Jurassic above salt

2. Abstracts

Well 1/9-3 is a deliniation well on the block 1/9-Alpha structure. The well is located 1.58 km north of the 1/9-1 well and 3.23 km from the Norwegian/UK median line.

The well was drilled in two phases with the jack-up rigs "Dyvi Gamma" and "Dyvi Beta".

The following data have been available for this evaluation:

- Log data
- Core data
- Drill Stem Tests

Log- and core data were digitized and stored in a computer.

2.1 Data quality

The quality of the suit of log data is partly poor, due to the following factors:

- Problems with depth measurements due to extensive stretch in the cable.
- Calibration problems.
- Difficult hole conditions (sticking).
- High pressure/temperature.

Based on the depth control difficulties, a log playback on drillers depth of the CDL/CNL/GR - log was made from the 9 5/8" csg shoe to TD. This log is the depth reference log for the computerized log interpretation of this well.

The log data have been correlated and calibrated to the core- and test data.

3. Summary

The carbonate reservoir has in this evaluation been divided into three zones.

Lithostratigraphically the zones comprise the Ekofisk- and a part of the Tor Formation. The actual top of Ekofisk form. is at 3087 m, but in this report the whole interval 3075 - 3157 m is referred to as the Ekofisk formation to simplify.

Table 1. shows the net/gross thickness and the net values of porosity, water saturation, and shale volume.

The Statoil CPI calculates a total net productive pay of 37.75 m of oil/ condensate.

Below 3230 m, no hydrocarbon saturation is seen.

TABLE I

Results of log interpretation, well 1/9-3

zone	Depth (m)	Gross thickness (m)	Net sand (m)	Net pay (m)	Av.porosity net pay (%)	Av. water sat. Net pay (%)	Av shale vol. Net pay (%)
1	3075-3119.5	44.5	32.	31.5	29.2	33.3	1.1
2	3119.5-3157	37.5	11.25	4.5	22.8	56.8	3.7
3	3157-3350	193.	168.25	1.75	28.1	49.2	1.7

Cut - off values:

Zone 1 & 2: $\emptyset \leq 20\%$, $Sw \geq 60\%$, $Vsh \geq 30\%$

Zone 3: $\emptyset \leq 15\%$, $Sw \geq 50\%$, $Vsh \geq 30\%$

4. Lithology

The top of the reservoir is at 3087 m. The lithology is a white - light grey chalk. It is hard, homogeneous and interbedded with white - light grey, soft - hard limestone. The interval 3119.5 - 3157 m is tight and contains several stringers of shale and marl. The argillaceous rocks are medium to reddish grey, firm and slightly calcareous.

Below 3157 m, chalk and limestone is interbedded, with an increase in limestone with depth. The chalk is predominantly hard and homogeneous, and the limestone is firm - hard.

5. Core data

96.9 m of core was recovered out of 116.6 m cored interval in the carbonate section.

Routine core analysis have been done on the cores by GECO. The measurements include saturation porosity, helium porosity, pore saturations and air/ liquid horizontal/ vertical permeabilities and grain density. Most of these results are presented on the 1/9-3 Reservoir Composite log in the Appendix.

Separate core analysis was done by the Statoil Petrophysical lab, and conform well with the GECO results.

5.1. Core porosity

Fig. 1 shows a cross plot of the core porosities versus the log derived porosities. The core porosities have been converted into reservoir conditions using:

$$\emptyset_{res} = \emptyset_{lab} \cdot 0.98$$

This assumes a net confining pressure of 2400 psi in the reservoir. This number is calculated from overburden- and pore pressure gradients. The plot shows the core porosities in average to be 1 - 2 % higher than the log porosities. This is in line with what is seen in other wells in the area.

5.2. Core permeability

The horizontal liquid permeabilities are shown on the analog presentation in appendix A. The horizontal air permeabilities are on average 45 % higher than the horizontal liquid permeabilities.

The vertical permeabilities are in general slightly lower than the horizontal.

The core helium porosities and horizontal liquid permeabilities were plotted against each other for the Ekofisk fm. (3105-3122 m) (Fig. 2), and Tor fm. (3165-3234 m) (Fig. 3).

These plots show good correlation trends, especially in the Tor fm. The best curve fit line was drawn and the relationship between permeability and porosity is calculated to be:

$$\text{Ekofisk: } K\,(\text{md}) = 97 \cdot \emptyset^{4.51} \qquad (\emptyset \text{ in fractions})$$
$$\text{Tor} \quad : K\,(\text{md}) = 1796 \cdot \emptyset^{5.64}$$

As seen from other 1/9 wells, the permeability in the Tor fm. at a given porosity is higher than in Ekofisk fm.

5.3 Saturation results

The oil- and water saturations were measured on the core plugs (Appendix).

In Ekofisk formation an average So of 10%, and Stw of 30% is seen.

In Tor formation So is still around 10%, while the Sw averages 40 - 45 %. This indicate a higher residual hydrocarbon saturation in Tor formation than in Ekofisk.

6. Cross - plots

The digitized log data have been used in several cross plots for input data selection to the log analysis.

The following cross plots have been used:

- FDC/CNL plots
- BHC/CNL plots
- FDC/BHC plots

- M - N plots
- "Pickett" plots
- Magnolia plots

- Sw versus Ø
- Core data/log data
- Rt vs Rxo

Some of these plots are presented in Chapter 11.

6.1 Estimation of Rw, Rmf

The formation water resistivity used in this analysis is based on a water production in the DST 1, in the Tor formation. Water of 67 500 ppm NaCl was produced at the end of flow no. 2, with a rate of 1850 bbl/d. This is considered to represent the formation water. Water of the same salinity is assumed for the Ekofisk formation. With average formation temperature for the Tor of 260°F and for Ekofisk 255°F, the resistivities are:

Ekofisk: Rw = .035 Ohm-m
Tor : Rw = .033 Ohm-m

The mud filtrate resistivity used is based on a Rt/Rxo cross plot in the water zone (below 3230 m). This plot (Fig. 4) show:

Rmf = 1.3 Rw

which gives for the two formations:
Ekofisk: Rmf = .045
Tor : Rmf = .043

The mud filtrate sample measured at the wellsite gives Rmf = .06, but is too high and considered not to be representive.

6.2 ρb vs ØN plots

Before the ØN was plotted, a borehole correction of 5 p.u. was applied to it.

Ekofisk formation

This plot (Fig. 5) indicates that the CDL (density log) is reading too high, i.e. too low porosities. The plot shows a normal trend, but is shifted downwards. The grain density from the cores is 2.71 (both for Ekofisk and Tor). This confirms the poor density log quality.

Nevertheless, the plot indicates hydrocarbon effect in the high porosity range, which mainly is represented by the porous Ekofisk (3087-3119.5 m).

Tor formation

This plot (Fig. 6) shows the same high density readings as in Ekofisk formation. Some hydrocarbon effect is present at a lower porosity level than in the Ekofisk.

A better porosity/ permeability relationship is apparent in the Tor formation than in the Ekofisk, which is confirmed by the plotted core data (Fig. 2&3).

To illustrate the shift due to high CDL reading, plots from the corresponding zones in 1/9-1 are shown (Fig. 5a, 6a). These plots show normal deviation from the limestone line with strong hydrocarbon effect, especially in the Ekofisk fm. (Fig. 5a).

6.3 ρb vs Δt

Also this plot (Fig. 7) shows the high density readings. However, the plot is considered good enough used to pick the shale parameters.

A hydrocarbon effect is seen for

$$\Delta t > 80 - 85 \ \mu sec/ft.$$

A Δt matrix value of 50 μsec/ft is indicated.

Tor formation

This plot (Fig. 8) shows no clear hydrocarbon effect. However, it gives a good trend and the plot was used to pick the Δtma value of 52 μsec/ft.

6.4 Δt vs ØN

Ekofisk formation

This plot (Fig. 9) also shows hydrocarbon effects of $\Delta t > 80 - 85$ μ sec/ft. The plot seems to be shifted slightly to the right towards higher ØN values.

Tor formation

A hydrocarbon effect for $\Delta t > 80$ μsec/ft is seen in Fig. 10, which seem to support that the Tor formation has a better porosity/ permeability relationship than the Ekofisk formation.

The plot is slightly shifted against higher ØN values.

6.5 M - N plots

Plots for the cleanest parts of "porous" Ekofisk formation, the entire Tor formation and the water filled Tor formation is shown on Fig. 11, 12 & 13 .

The plotted points are shifted downwards and towards the left from the calcite point. The shift in both M and N, probably reflects the too high CDL reading indicated by the porosity cross plots.

The two plots from the Tor formation indicate some hydrocarbon effect from the interval 3157-3230 m.

6.6 Pickett - plots

Porosity tool readings were plotted against Rt and Rxo to estimate the cementation exponent (m) (Fig. 14-21).

The Pickett plots probably reflect a poor log quality. The plots give a wide range of m values, especially from the Δt porosities.

The density Pickett plots give too low m values due to the high density readings, and are not included in this report.

Ekofisk formation

Pickett plots are not good in this formation, as the water- and mud filtrate saturations are a function of porosity and depth (Fig.22, and Appendix).

Therefore, the cleanest zone (3096-3110 m) has been chosen as the basis for the Pickett plots. This zone has a fairly constant water saturation, averaging 27% on the CPI in which a m of 2.1 has been used.

A trend line was then constructed through the plot of this particular zone (Fig.14, 15, 18, 19). The Δt plots seem to be on the high side, while the ØN plots support a m of 2.1.

With all the uncertainties involved in this tecnique, m of 2.1 was used in the final calculation, in spite of the higher value indicated by the Pickett plots.

This value of m agrees with what is seen from other wells in the 1/9-block.

Tor formation

This formation is 100% water saturated, from 3230 m to the base of the considered interval (3350 m). The Δt versus Rt Pickett plot shows a very distinct trend from this zone. However, the trend gives very low value of m (Fig. 16).

The ØN plots indicate higher values of m (1.85 - 2.0). (Fig.20,21). As the CNL is considered to read slightly too high, a higher value of m would be expected. This indicates that the deep induction curve probably is shifted towards lower resistivity readings.

7. Log interpretation of well 1/9-3

The following logs were obtained from the interval 3075 - 3350 m.

- Induction Electrolog/ BHC Acoustilog/ Gamma Ray/ SP. (IEL/BHC)
- Dual Laterolog/ Rxo/ Gamma Ray/ Caliper. (DLL)
- Compensated Density Log/ Compensated Neutron/ Gamma Ray/ Caliper. (CNL/CDL)
- Fracture Indication log (FIL)

Data from the GR, CDL, CNL, BHC, LLd, LLs, Rxo, ILd was digitized in the interval 3075-3350 m and stored in a computer.

In addition, the following core data was digitized:

K liquid Horizontal
Helium porosity
Grain density
Saturation results (Stw, So)

Log data was analysed, and correlated to the core data.

Input parameters and cut - off values used in the log evaluation are shown in Table 2.

1/9 - 3

TABLE 2

LOG EVALUATION INPUT PARAMETERS

	ZONE I	ZONE 2	ZONE 3
Interval (m)	3075-3119.5	3119.5-3157	3157-3350
ρma (g/cc)	2.71	2.71	2.71
Δt ma (μs/ft)	50	50	52
ρb sh (g/cc)	2.45	2,45	2.45
Øsh (l.u.)	30	30	30
Δt sh (μs/ft)	95	95	95
GRmax (API)	50	50	50
GRmin(API)	22	22	22
Rmf(Ohm-m)	0.045	0,045	0.043
Rw (Ohm-m)	0.035	0.035	0.033
Rsh(Ohm-m)	0.9	0.9	0.9
a	1	1	1
m	2.1	2.1	2.0
n	2.0	2.0	2.3
ρ fl(g/cc)	1.02	1.02	1.02
ρ hy(g/cc)	.6	.6	.6
BHT (°F)	255	255	260
Cut off: Ø	< 0.20	< 0.20	< 0.15
Vsh	> 0.30	> 0.30	> 0.30
Sw	> 0.60	> 0.60	> 0.50

Porosity

The CDL-log reads too high bulk density values, while the CNL shows a shift between two runs through the same zone. Therefore the porosity used in this log evaluation is based on the BHC-Acoustilog corrected for shale volume. Due to rather leight hydrocarbons, a hydrocarbon correction was applied and the final porosity used is as follows:

$$\emptyset = \emptyset_{BHC} \text{ corr} \cdot (1 - 0.15 \cdot \text{Shr})$$

The matrix parameters were determined from the cross - plots.

Shale volume

The shale volume is calculated from the GR, CDL-CNL crossplots and the "Q-log."

Resistivity

In the interval 3075-3230 m, the Rt and Rxo is obtained from the DLL (LLd and Rxo), corrected for invasion. Below the OWC at 3230m, the Rt is taken from the IEL (ILd). Rxo is taken from the Rxo-log. The "Pickett"-plots" from the water bearing zone may indicate a shift in the Rt values from the ILd. (Discussed in p. 12).

Exponents

Table 2 shows what exponents have been used in the computations.

• Cementation exponent (m)
This has been discussed under paragraph 6.6 (Pickett plots). Because of the rather poor log quality, data from core measurements and correlations to nearby wells, have been given a lot of consideration when picking the m values.

• Saturation exponent (n)
Based on the clean water production from DST 1, relative permeability curves from 1/9-1 have been studied to see at what level of water saturation, no hydrocarbons would be produced. Corresponding data from 1/9-3 has not yet been available. At the range of permeability present in the test interval (less than 1 md), a Sw of 58-60% indicate the limit.

The same relationship was then assumed for 1/9-3. A saturation exponent of 2.3 was found to fulfill this requirement.

For the Ekofisk formation, a saturation exponent of n = 2.0 is used.

Water saturation

Sw and the mud filtrate saturation in the flushed zone (Sxo) has been calculated by using the "Nigeria" water saturation formula:

$$\frac{1}{Rt} = \frac{Vsh^{c} \cdot Sw}{Rsh} + \frac{\emptyset^{m} \cdot Sw^{n}}{a \cdot Rw}$$

where a = lithology exponent
m = cementation exponent
n = saturation exponent
c = shale volume exponent (= 1.5)

The Statoil CPI is enclosed in the Appendix.

8. Cut-off sensitivity

Because of the probable poor log quality, no clear cut-off values are seen from the crossplots.

Table 3 shows a sensitivity test for three different sets of cut-offs. It is seen from the table that the "Porous" Ekofisk formation is very sensitive to porosity cut-off, and not so much to the water saturation. The "tight" Ekofisk is sensitive to both porosity and water saturation cut-offs.

The Tor formation is not sensitive to increase in porosity cut-off, but approximately 20 m increase in net pay thickness appears when water saturation cut-off is increased from 50% to 60%.

TABLE 3

SENSITIVITY TEST ON LOG EVALUATION

	Cut-offs			Gross thickness (m)	Net sand (m)	Net pay (m)	Ø net (%)	SW net (%)	Remarks
	Ø	Sw	Vsh						
3075-3119.5m	.20 .25 .20	.60 .60 .50	.30 .30 .30	44.5 44.5 44.5	32. 22.75 32.	31.5 22.75 29.5	29.2 31.4 29.6	33.3 30.1 31.8	Used in this evaluation
3119.5-3157m	.20 .25 .20	.60 .60 .50	.30 .30 .30	37.5 37.5 37.5	11.25 0.75 11.25	4.5 0.50 0.	22.8 25.4 22.4 (net sand)	56.8 59.1 63.6 (net sand)	Used in this evaluation
3157-3350 m	.15 .20 .15	.50 .50 .60	.30 .30 .30	193 193 193	168.25 113. 168.25	1.75 1.75 20.5	28.1 28.1 28.5	49.2 49.2 55.8	Used in this evaluation

The cut-off values used in the evaluation, presented in Table 1, probably give somewhat optimistic results for the Ekofisk formation, and pessimistic results for the Tor formation.

9. Fluid saturation distribution

Water saturation (Sw) is plotted against porosity (Ø) for the Ekofisk fm. (3075-3157 m, Fig. 22), and Tor formation (3157-3350 m, Fig.23).

Ekofisk formation

The porous part of the formation (3087-3119.5 m) shows an irreducible water trend, Sw·Ø = 0.09 (Fig. 22).

Some points, from the very base of this zone, plots above this trend and seem to fit another hyperbola (Fig. 22,23). These points are considered not to be at irreducible water saturation.

The tight part of the Ekofisk formation (3119.5-3157 m), is probably in the transition zone all together, which was confirmed by the results of DST 3.

Tor formation

The enclosed CPI shows a water saturation of 50 % or more throughout the Tor formation, and the Sw vs Ø (Fig. 24) plot, indicate the entire interval (3157-3230 m) to be in the transition zone.

Two DST´s were made from this interval, of which the top one produced water with 5% oil in emulsion and the lower one hydrocarbon free water.

10. Summary of Drill-Stem-Test data

DST-1 (3205.5-3214.5 m)

The test showed water with no hydrocarbons.
Rate 1850 BWPD on 3/4" choke.

DST-2 (3157.5-3180.5 m)

The test showed about 95% water and 5 % oil in an emulsion.
During the 2nd flow on 24/64" choke the rates were:

1100 BWPD
50 BOPD (^{O}API 34)
.17 MMSCF of gas

DST-3 (3125.5-3134.4 m)

Flowed 16-19 BBL/D, mainly water. Traces of oil and gas during last part of 2nd flow period.

DST-4 (3095.0-3113.0 m)

2. flow on 64/64" choke (before stimulation):
4.1 MMSCFD of gas (.71 spes. grav.)
350 BOPD (^{O}API 50)

3. flow on 48/64" choke (after 1 acid frac.)
18.5 MMSCFD of gas (.705 spes. grav.)
1400 BOPD (^{O}API 53)

3. flow on 48/64" choke (after 2. acid frac.)
22.9 MMSCFD of gas (. 71 spes. grav.)
2500 BOPD (^{O}API 50)

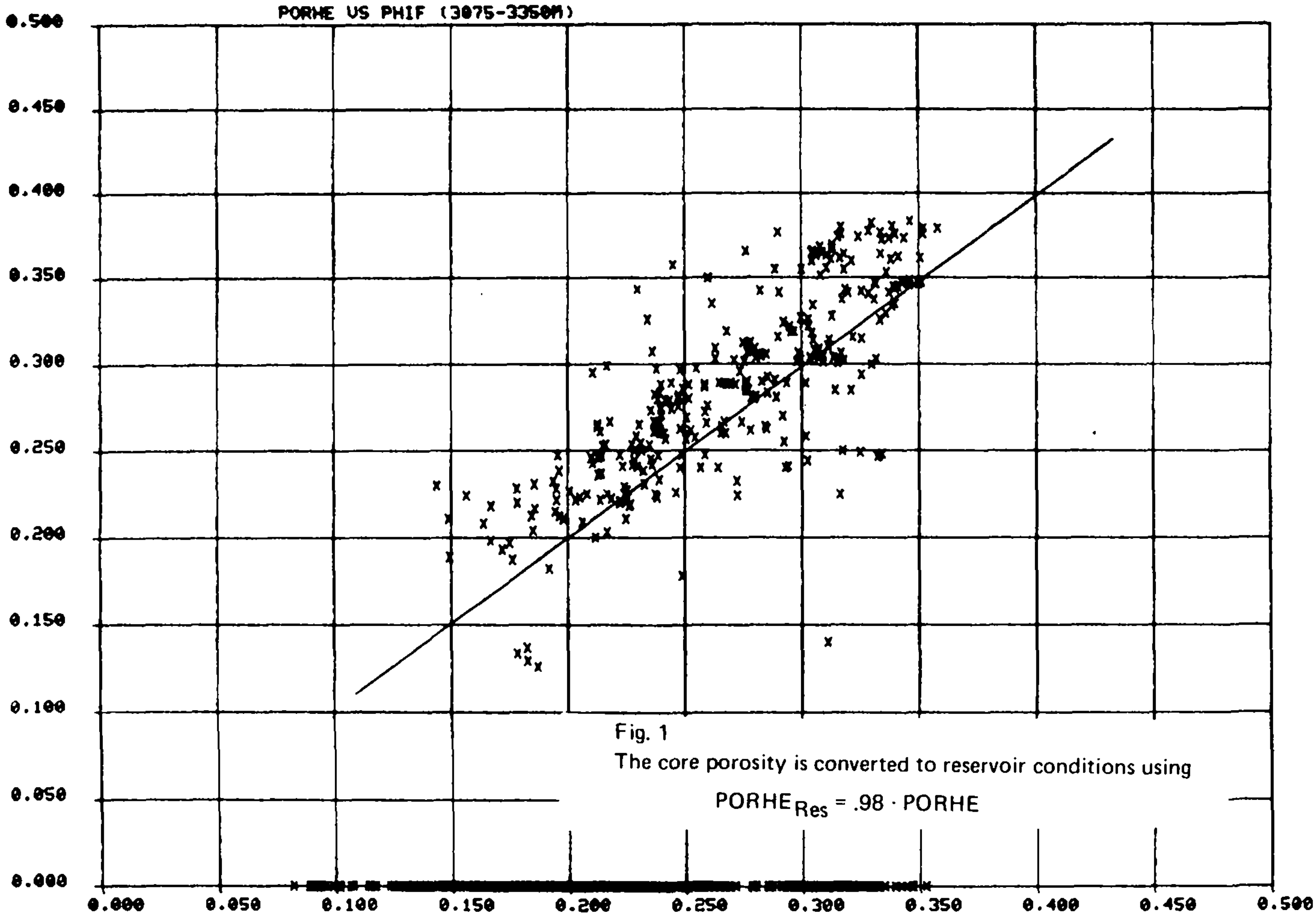


Fig. 1
The core porosity is converted to reservoir conditions using

$PORHE_{Res} = .98 \cdot PORHE$

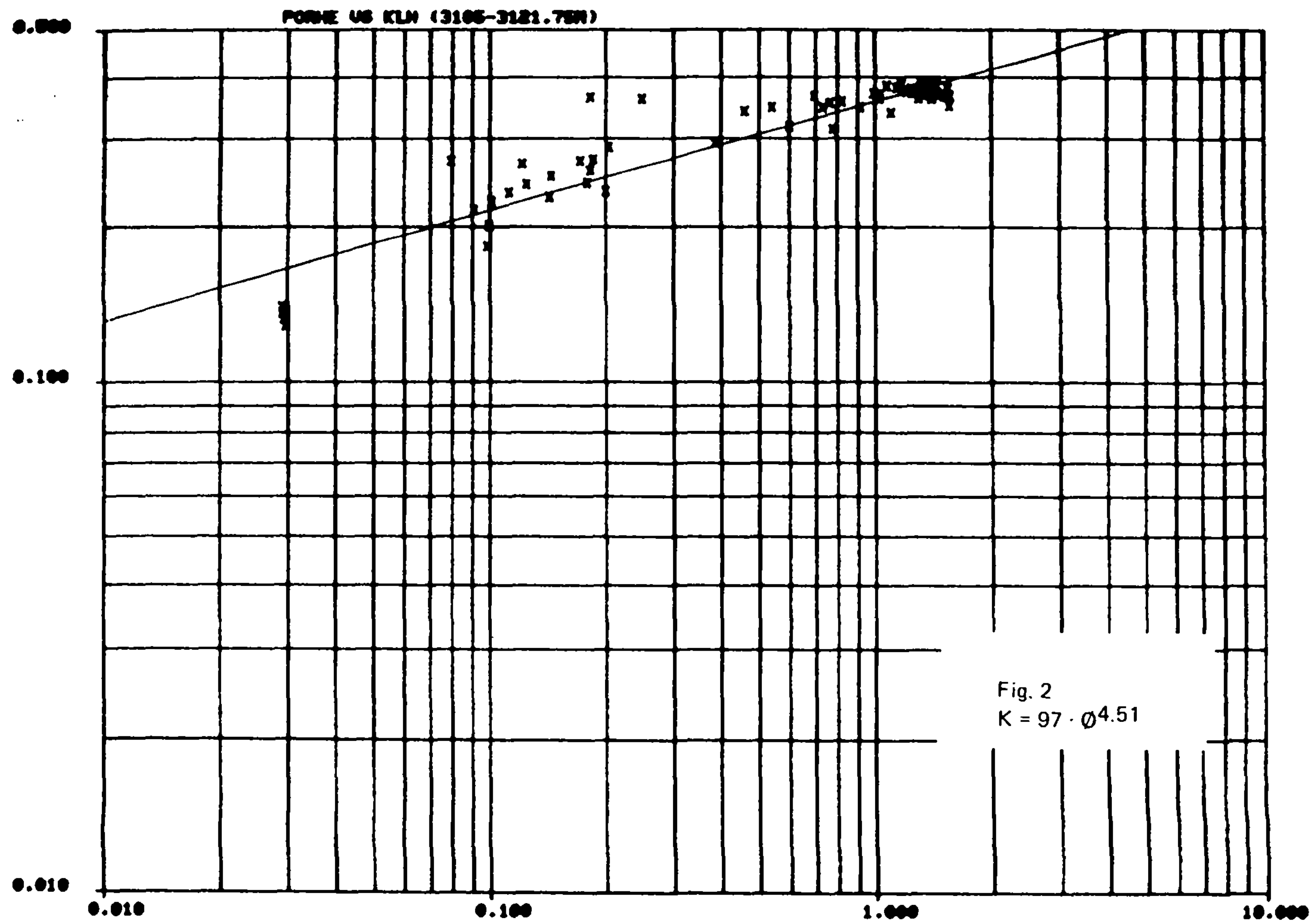


Fig. 2
$K = 97 \cdot \emptyset^{4.51}$

PLOTTED BY: RGR

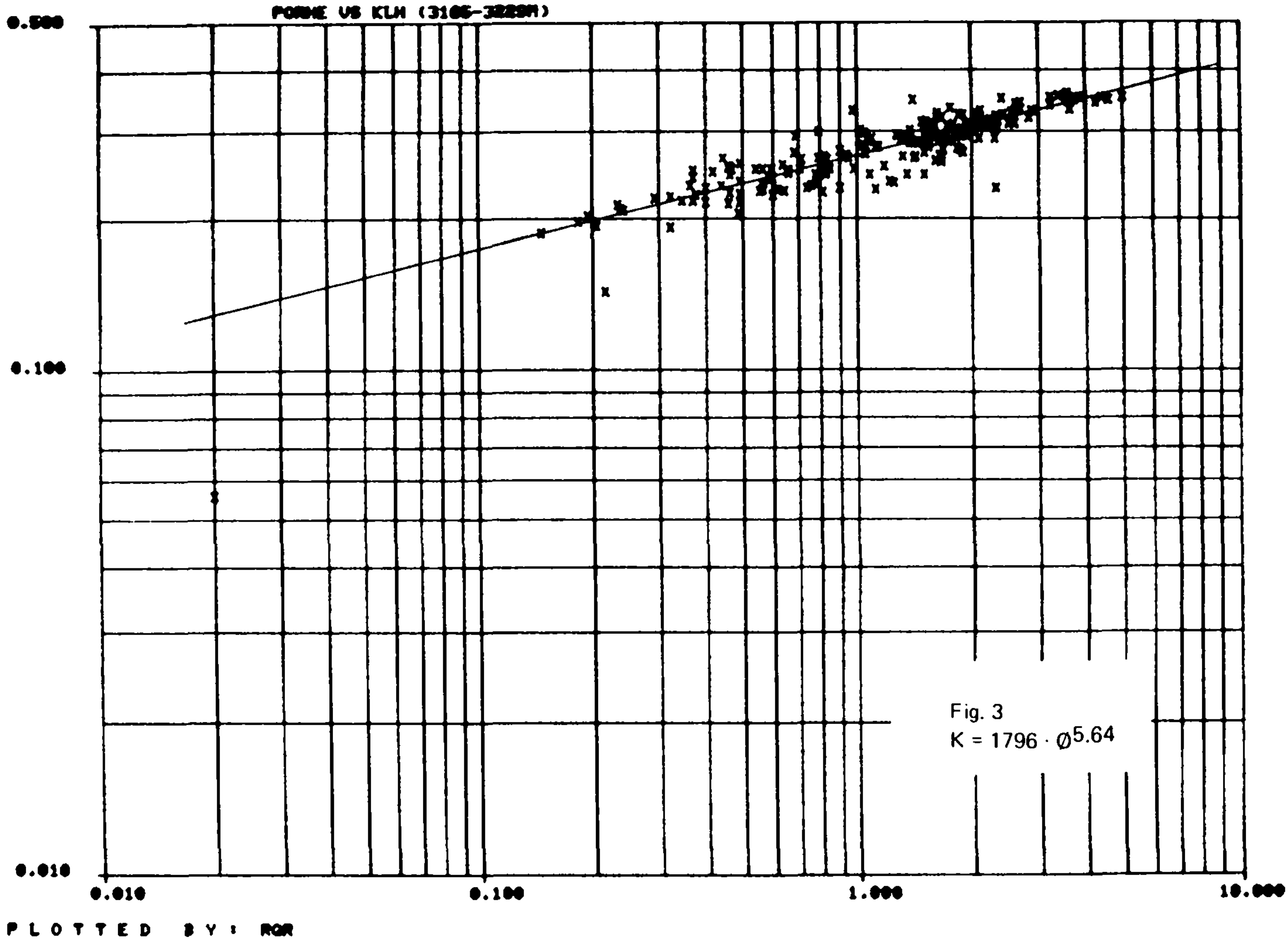


Fig. 3
$K = 1796 \cdot Ø^{5.64}$

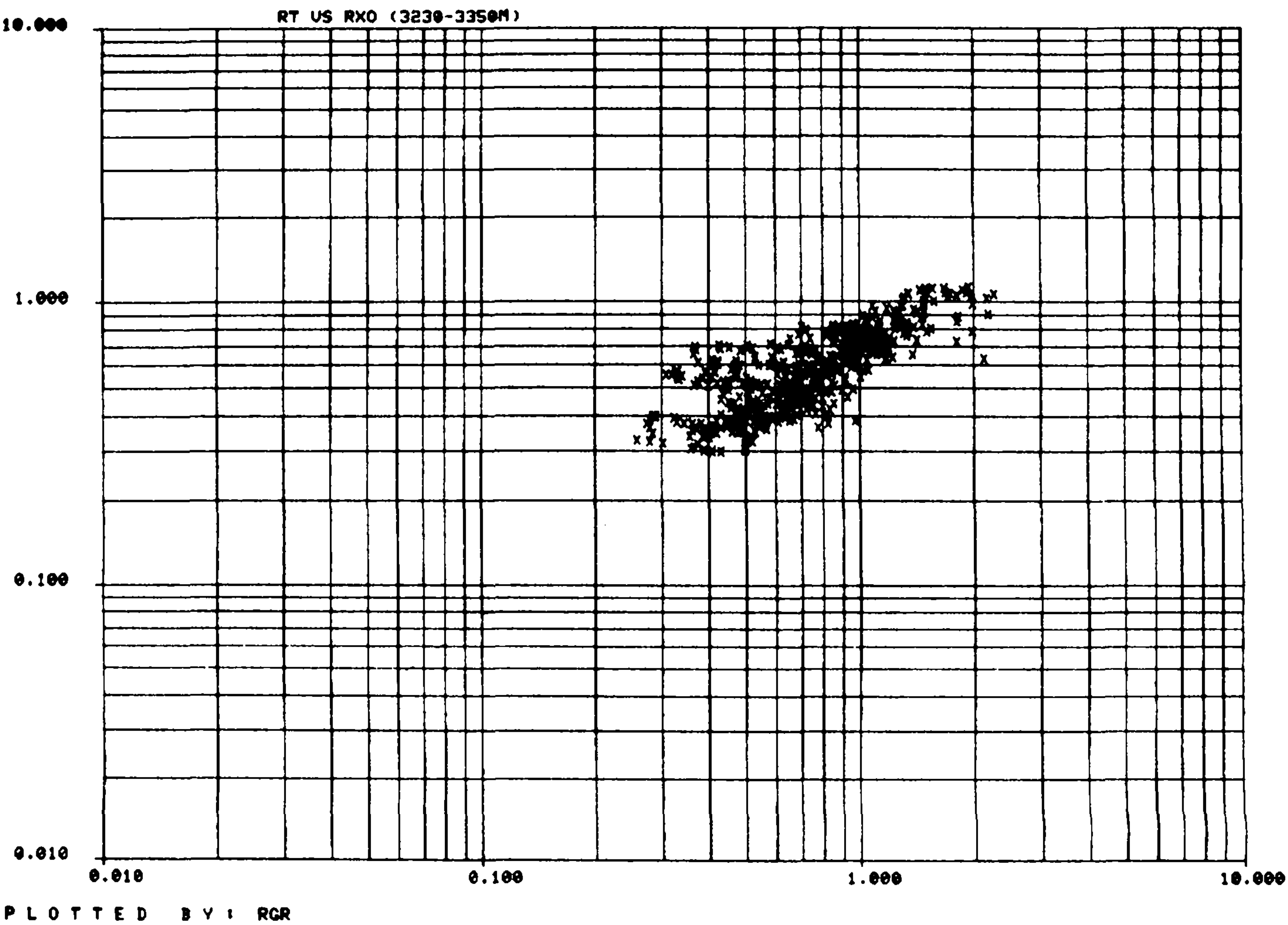


Fig. 4 Rmf = 1.3 Rw

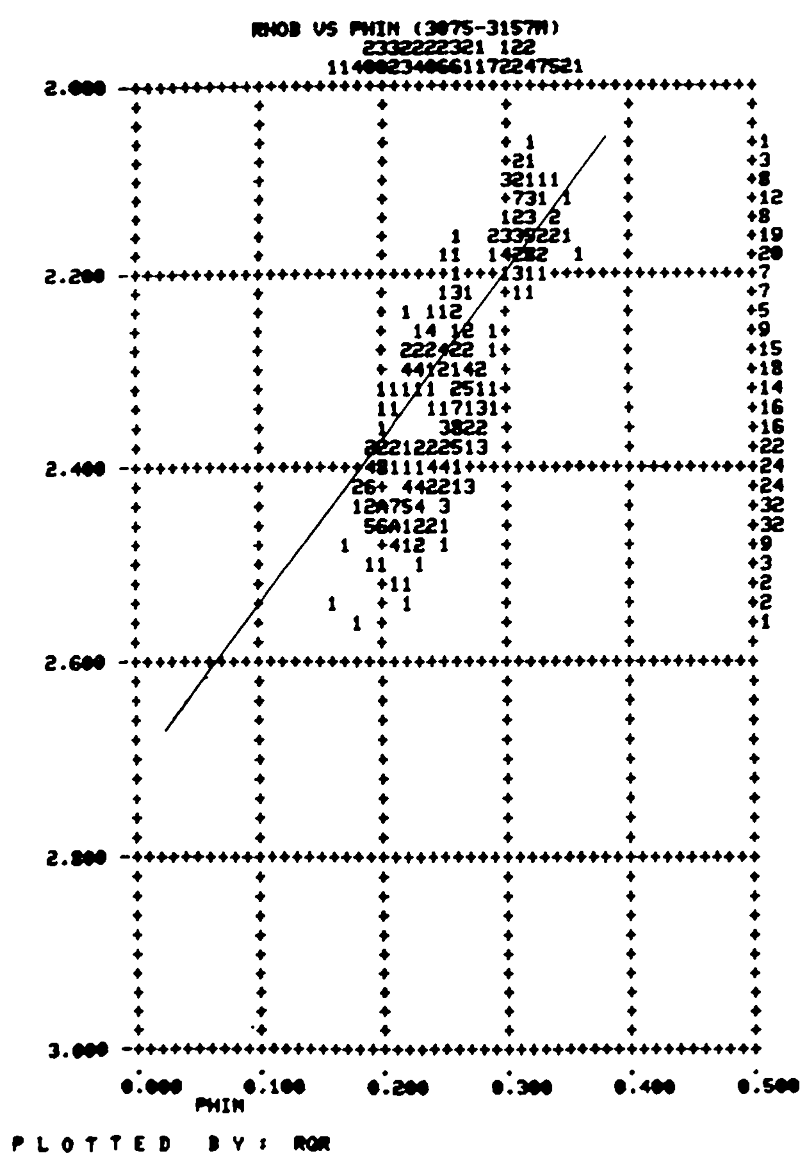


Fig. 5
RHOB reading too high

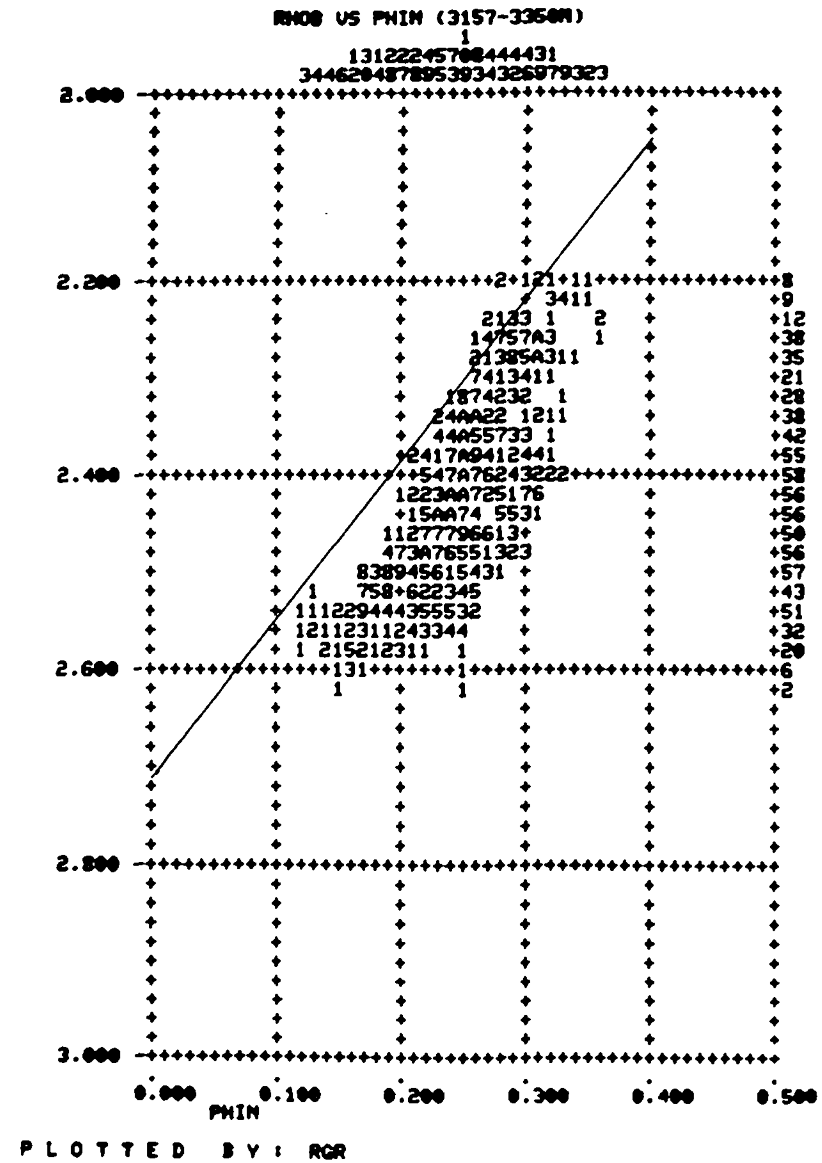


Fig. 6
RHOB reading too high

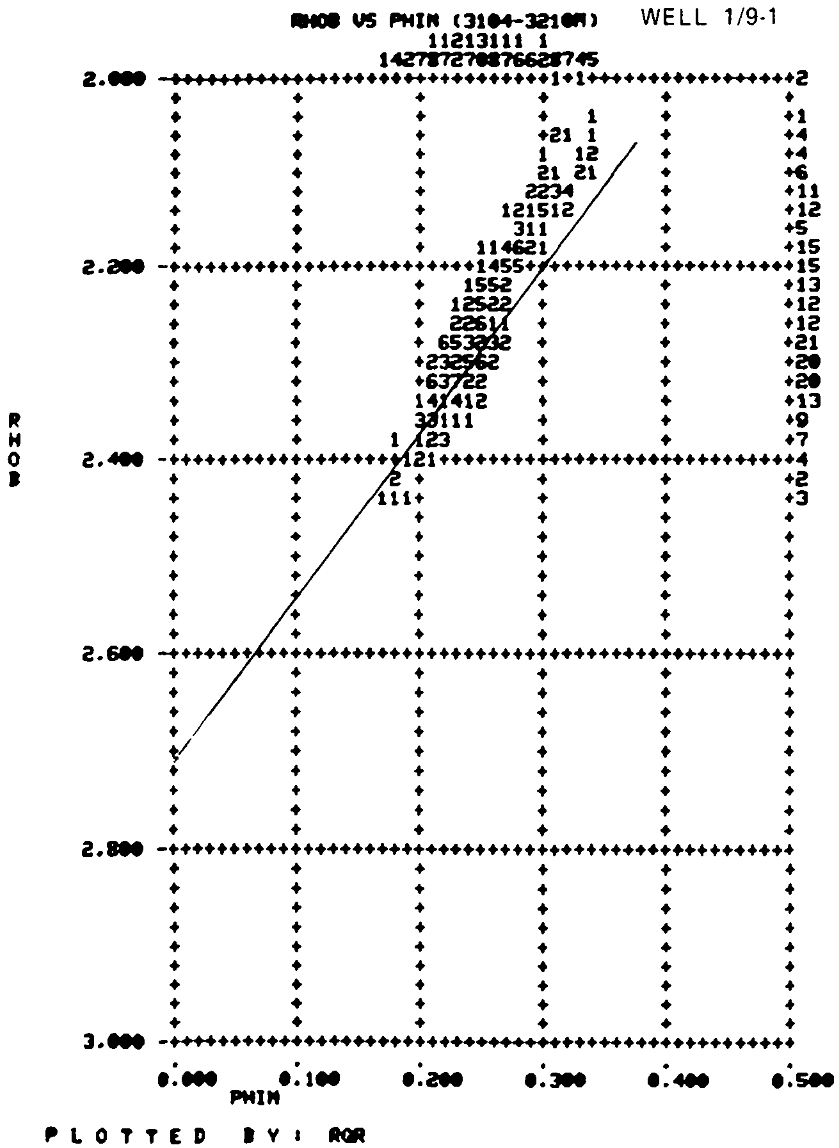

RHOB VS PHIN (3104-3210M)
WELL 1/9-1
RHOB
2.000
2.200
2.400
2.600
2.800
3.000
0.000
0.100
0.200
0.300
0.400
0.500
PHIN
PLOTTED BY: RGR

Fig. 6a

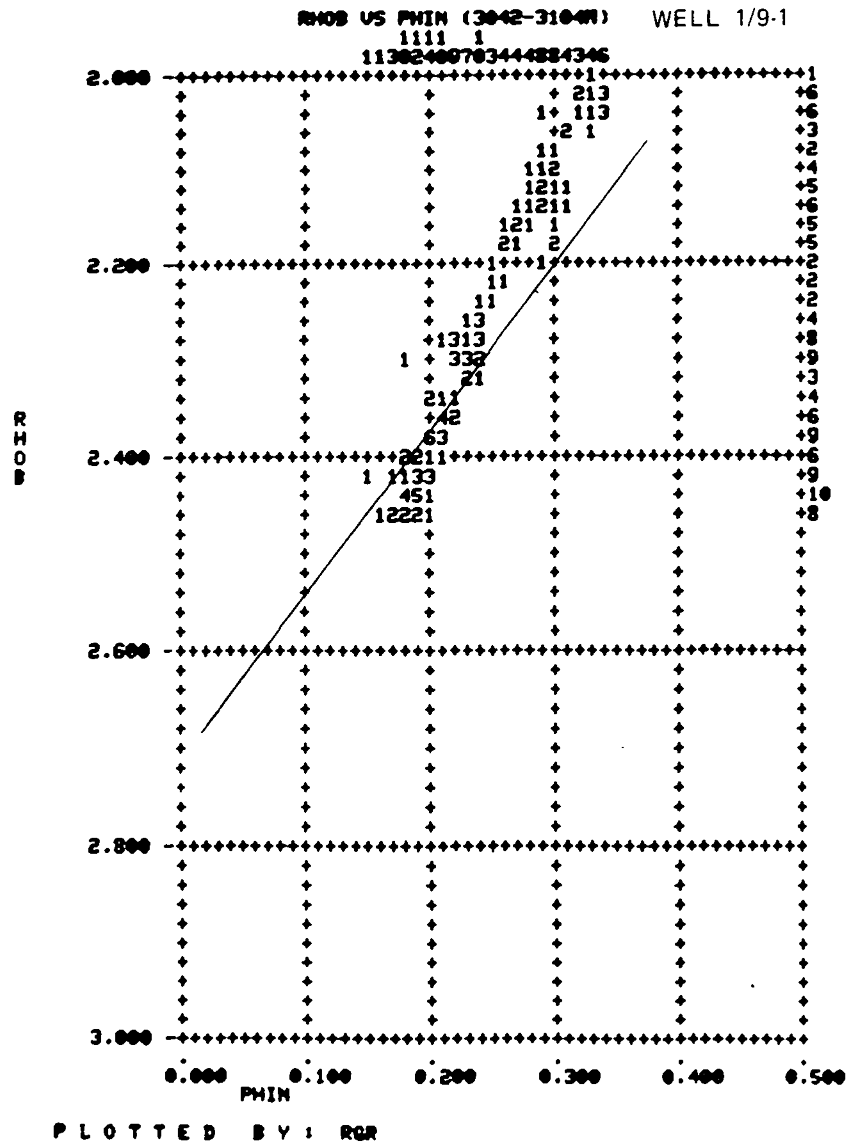

RHOB VS PHIN (3042-3104M)
WELL 1/9-1
RHOB
2.000
2.200
2.400
2.600
2.800
3.000
0.000
0.100
0.200
0.300
0.400
0.500
PHIN
PLOTTED BY: RGR

Fig. 5a

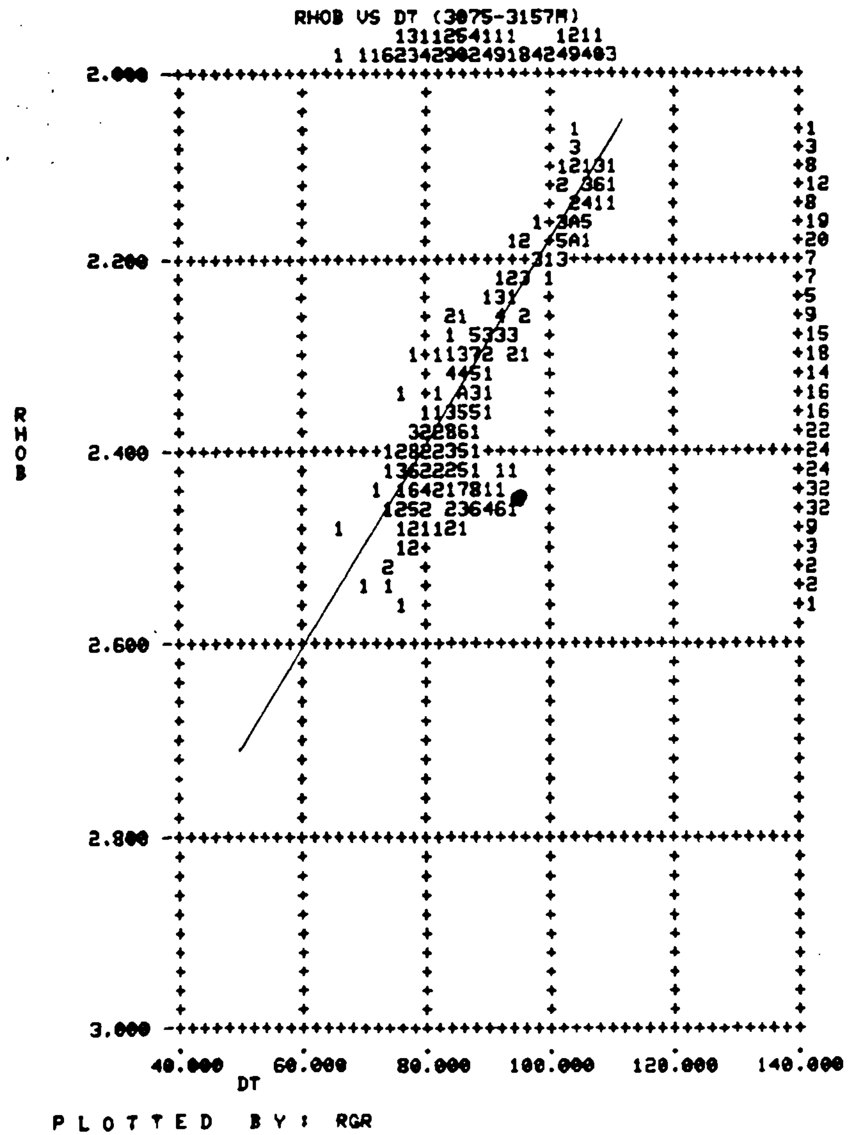


Fig. 7
DT ma = 50
DT sh = 95
RHOB sh = 2.45

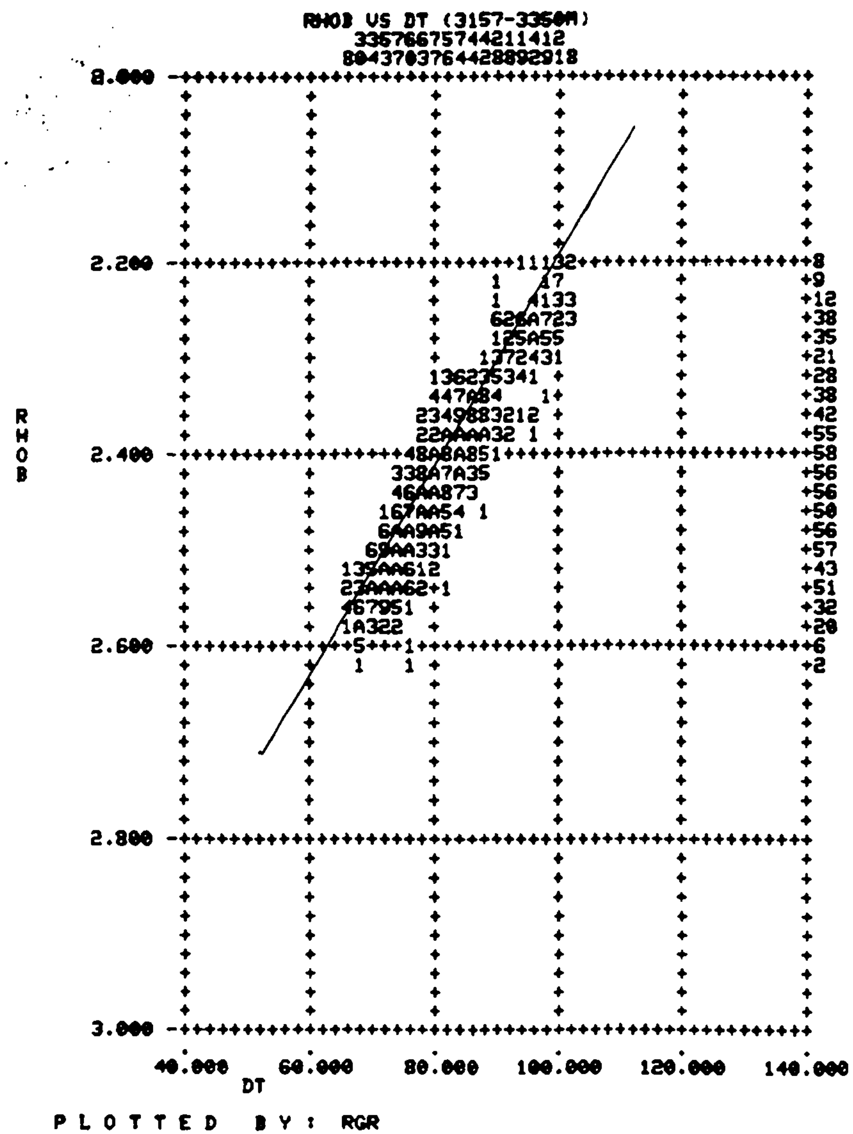


Fig. 8
DT ma = 52

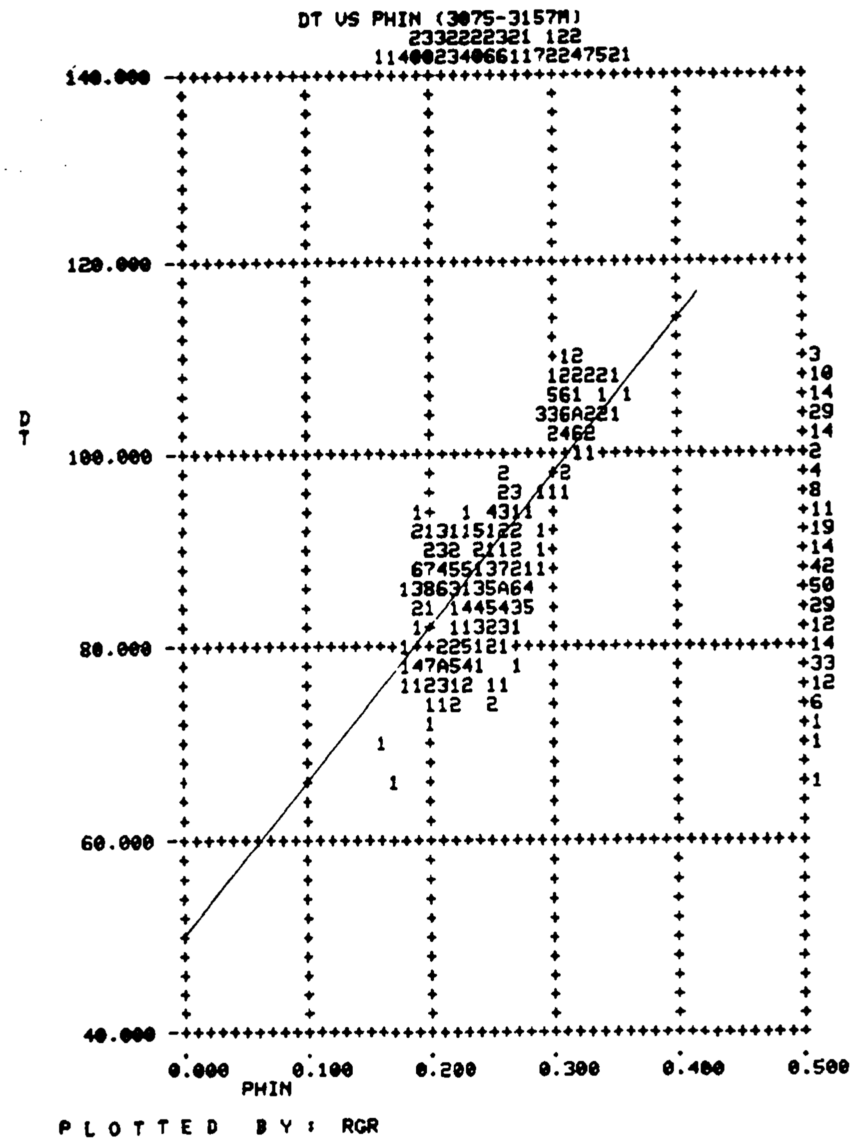

DT VS PHIN (3075-3157M)
DT
PHIN
PLOTTED BY: RGR

Fig. 9

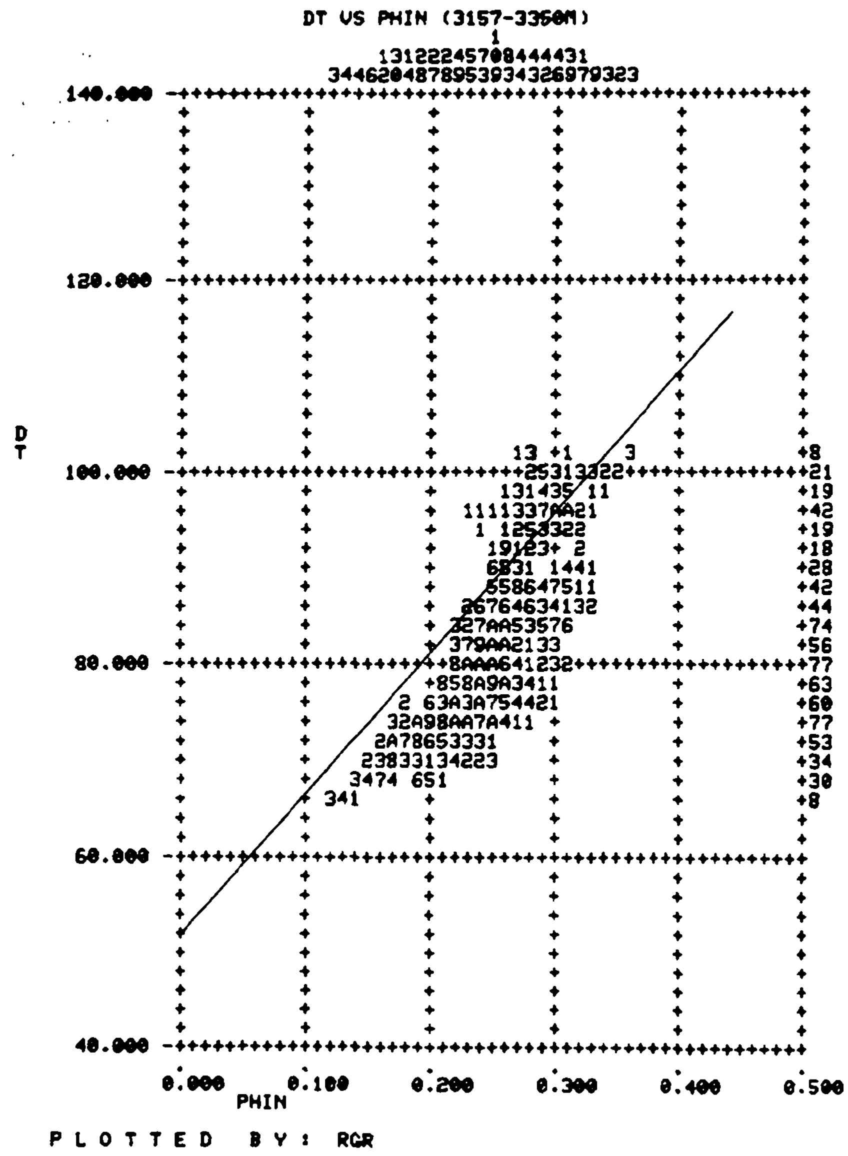

DT VS PHIN (3157-3350M)
DT
PHIN
PLOTTED BY: RGR

Fig. 10

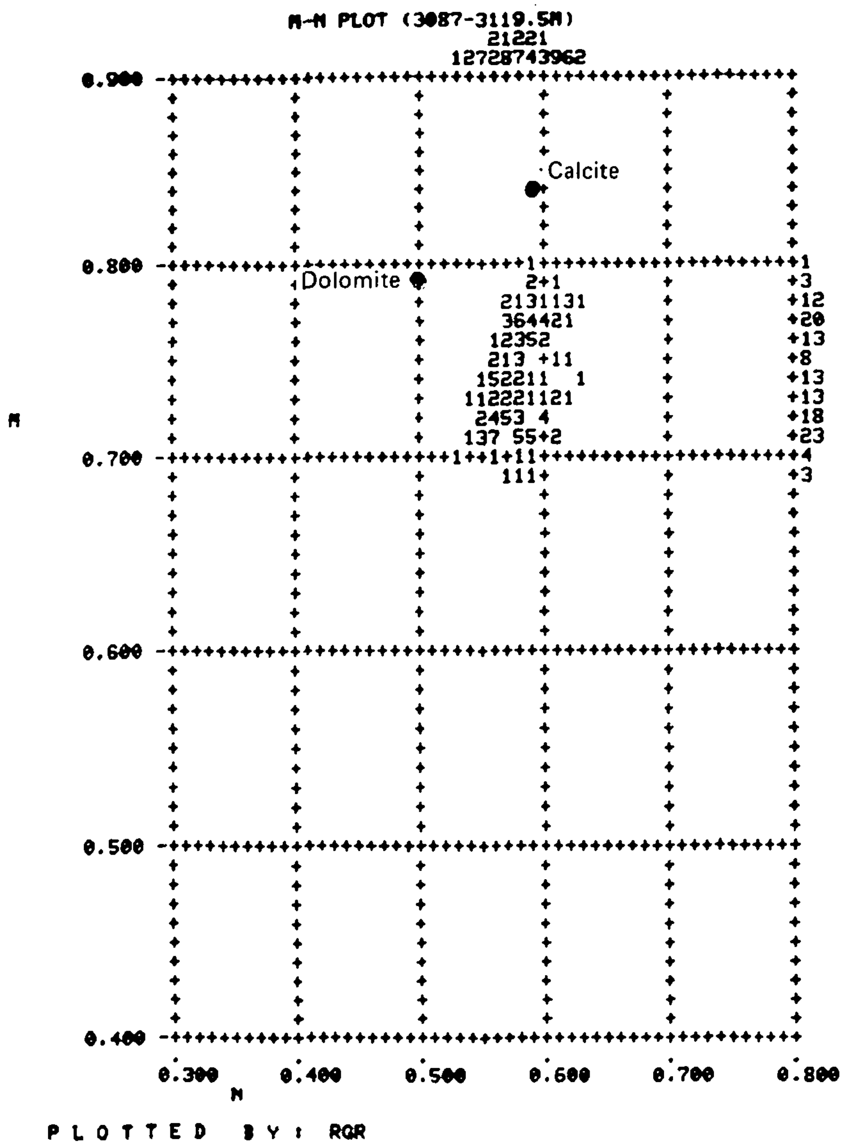

M-N PLOT (3087-3119.5M)
Calcite
Dolomite
M
N
PLOTTED BY: RGR

Fig. 11

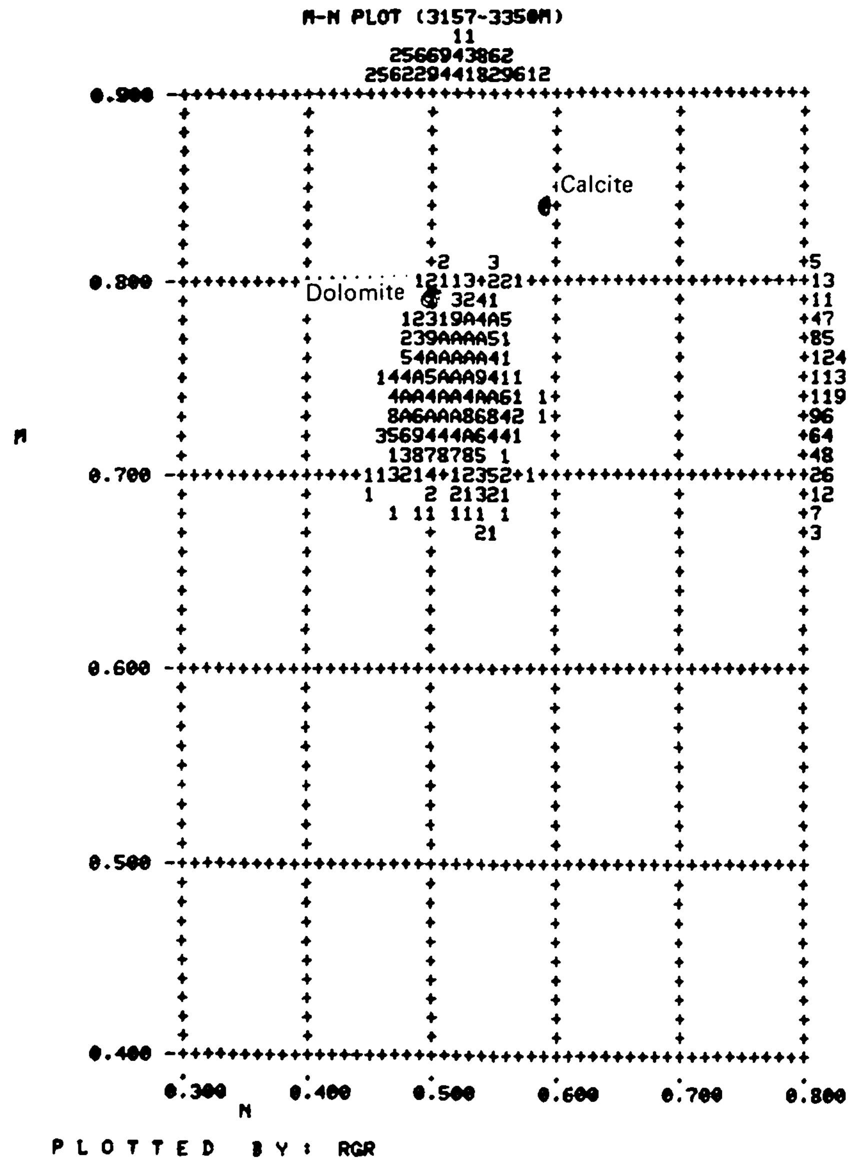

M-N PLOT (3157-3350M)
Calcite
Dolomite
M
N
PLOTTED BY: RGR

Fig. 12

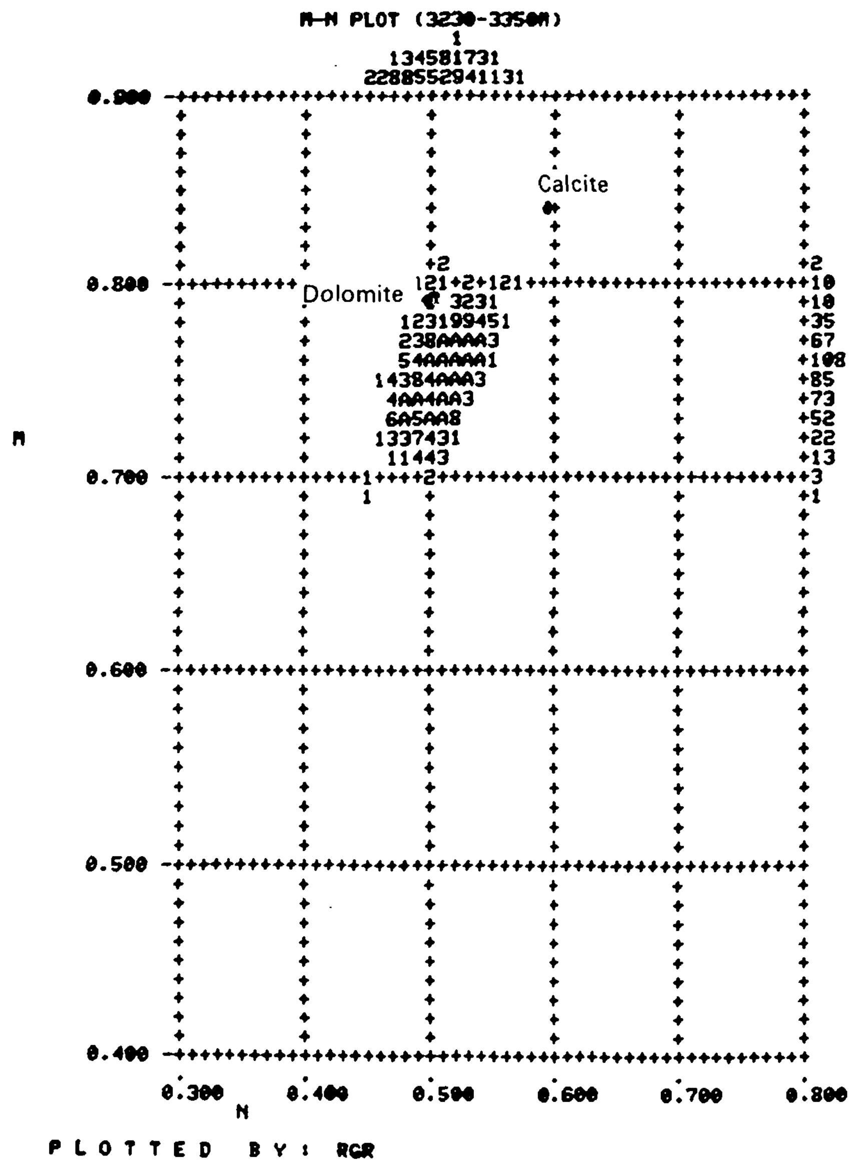
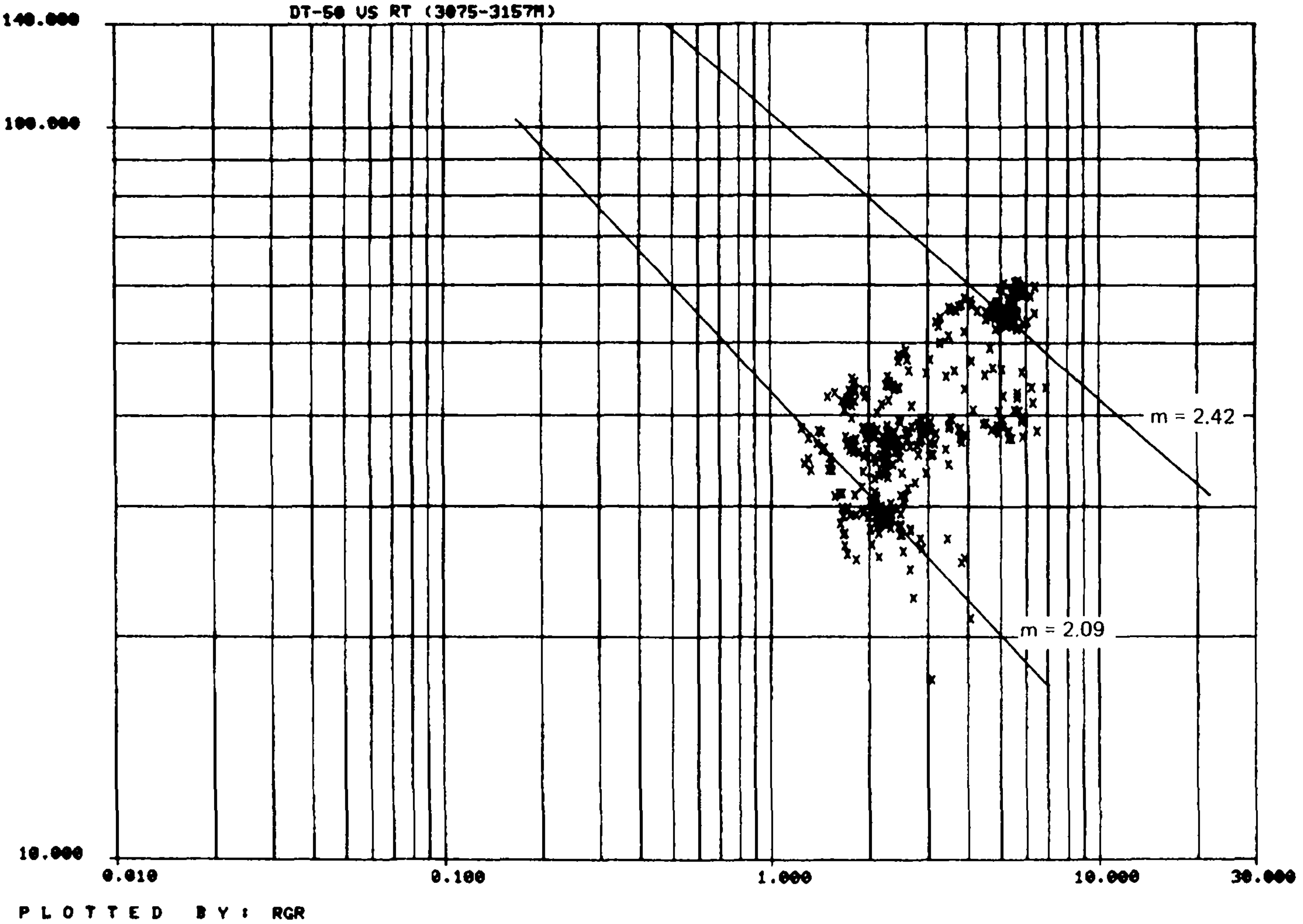
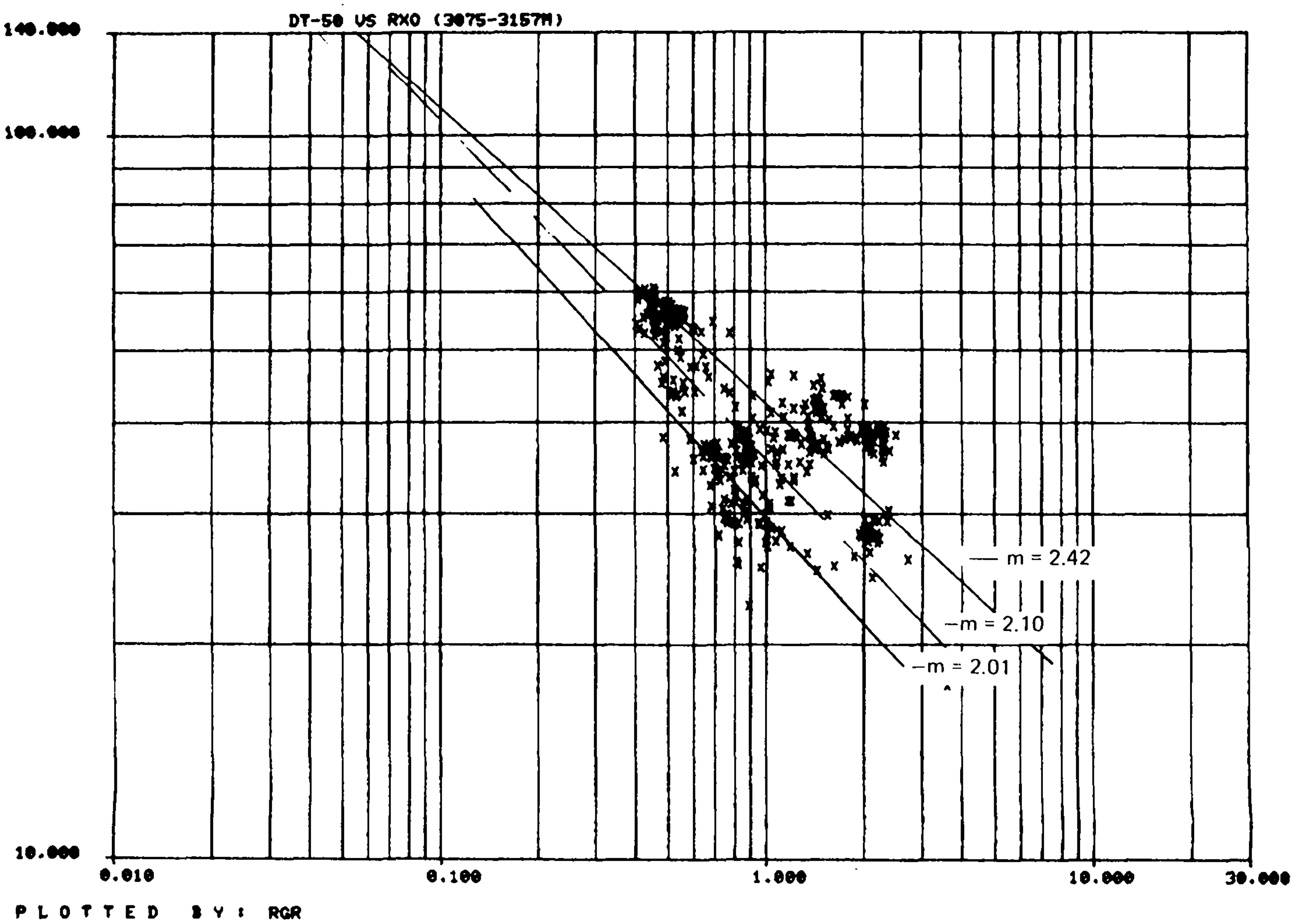

M-N PLOT (3230-3350M)
Calcite
Dolomite
0.900
0.800
0.700
0.600
0.500
0.400
M
0.300
0.400
0.500
0.600
0.700
0.800
N
PLOTTED BY: RGR

Fig. 13


DT-50 VS RT (3075-3157M)
140.000
100.000
10.000
0.010
0.100
1.000
10.000
30.000
m = 2.42
m = 2.09
PLOTTED BY: RGR
Fig. 14


DT-50 VS RXO (3075-3157M)
140.000
100.000
10.000
0.010
0.100
1.000
10.000
30.000
m = 2.42
m = 2.10
m = 2.01
PLOTTED BY: RGR
Fig. 15

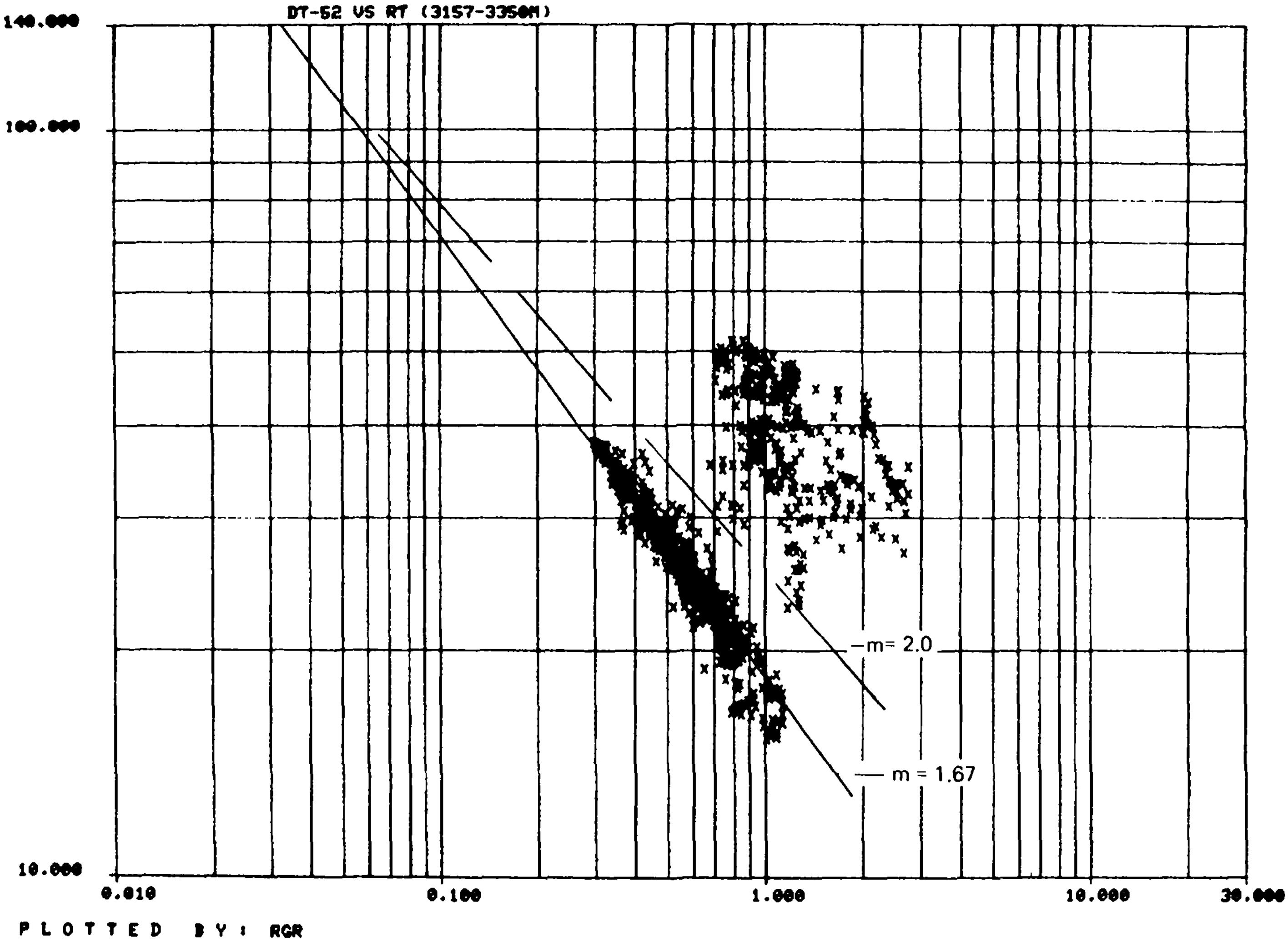

DT-52 VS RT (3157-3350M)
140.000
100.000
10.000
0.010
0.100
1.000
10.000
30.000
m= 2.0
m = 1.67
PLOTTED BY: RGR

Fig. 16

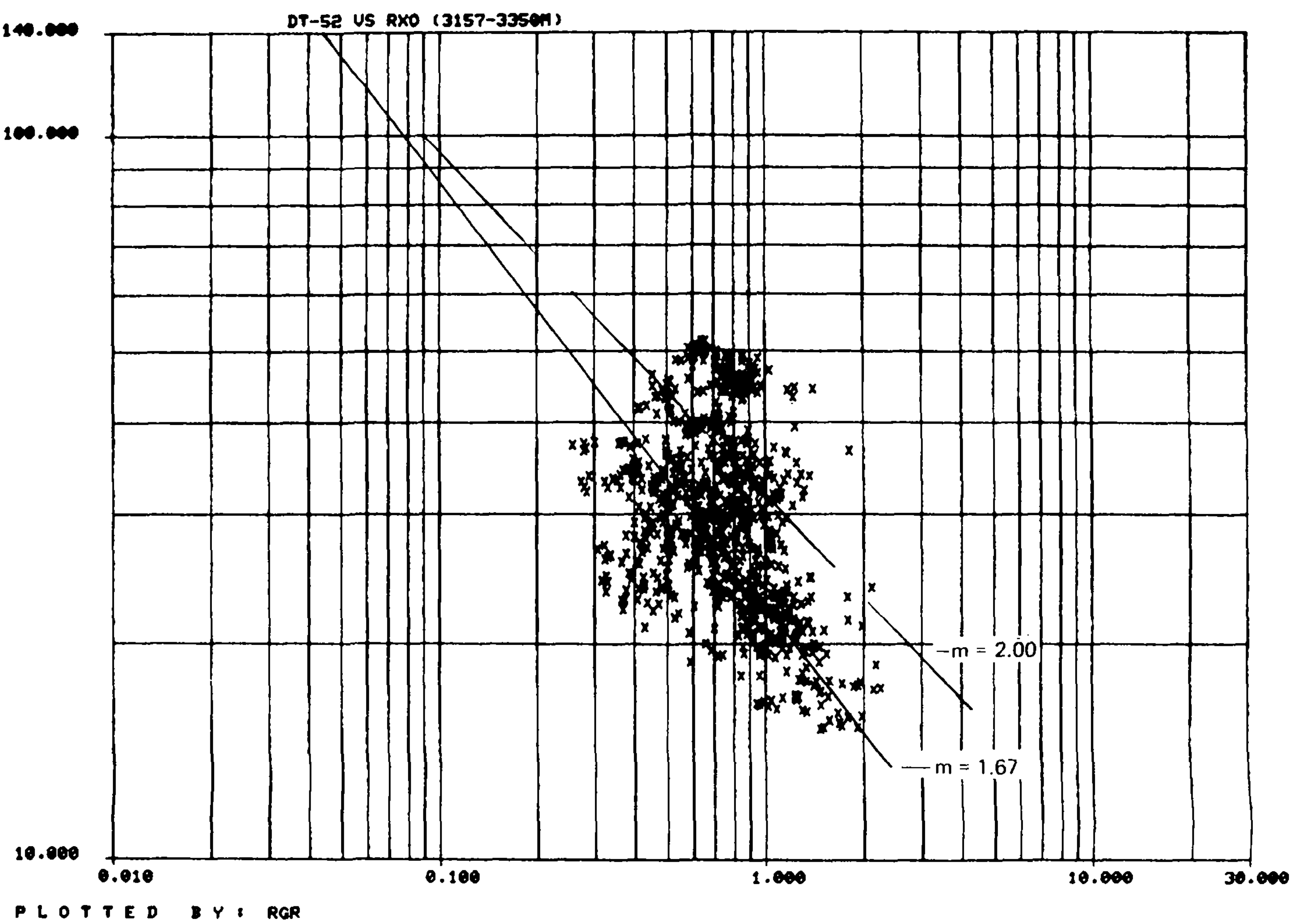

DT-52 VS RXO (3157-3350M)
140.000
100.000
10.000
0.010
0.100
1.000
10.000
30.000
m = 2.00
m = 1.67
PLOTTED BY: RGR

Fig. 17

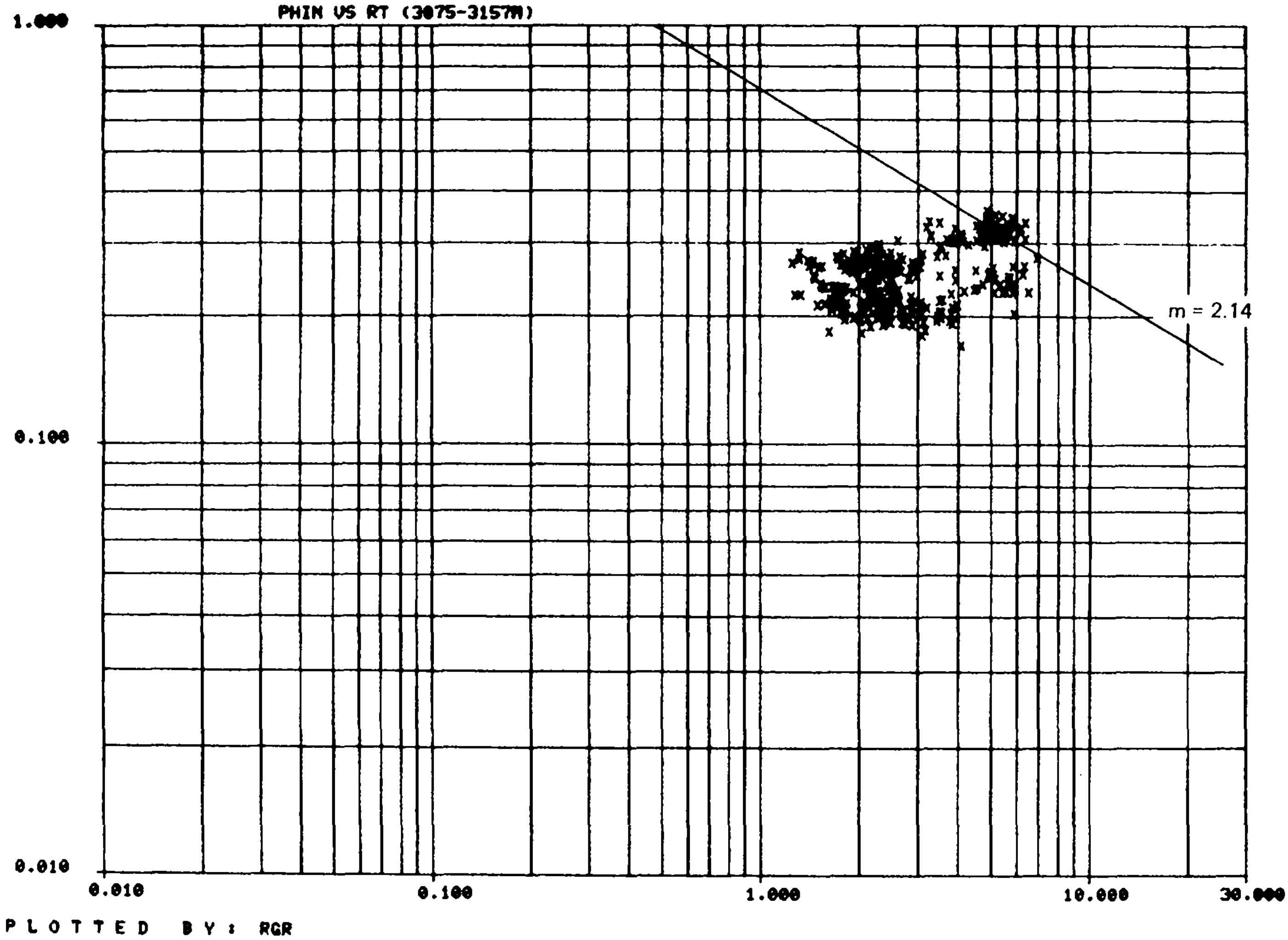

PHIN VS RT (3075-3157M)
1.000
0.100
0.010
0.010
0.100
1.000
10.000
30.000
m = 2.14
PLOTTED BY: RGR

Fig. 18

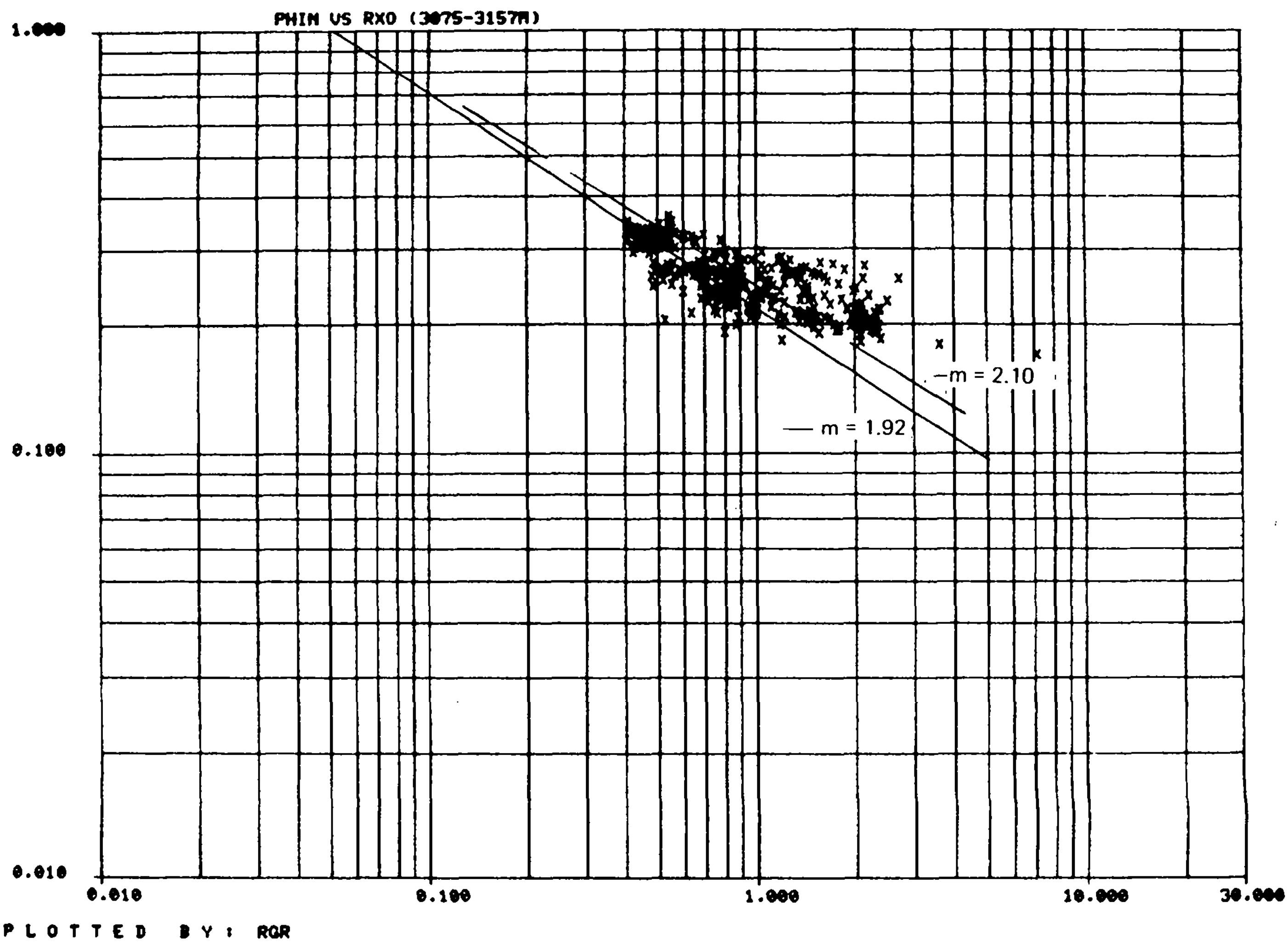
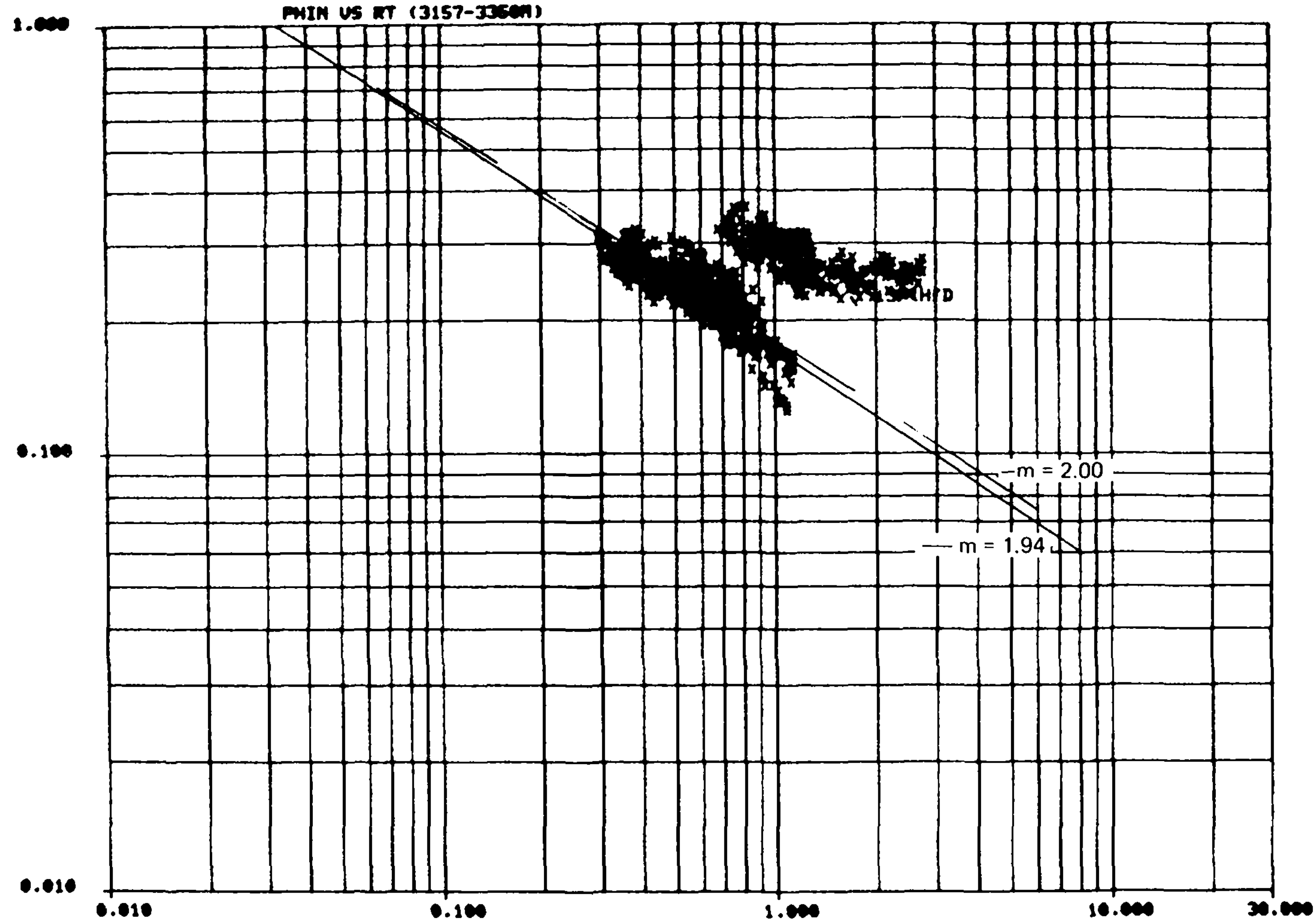
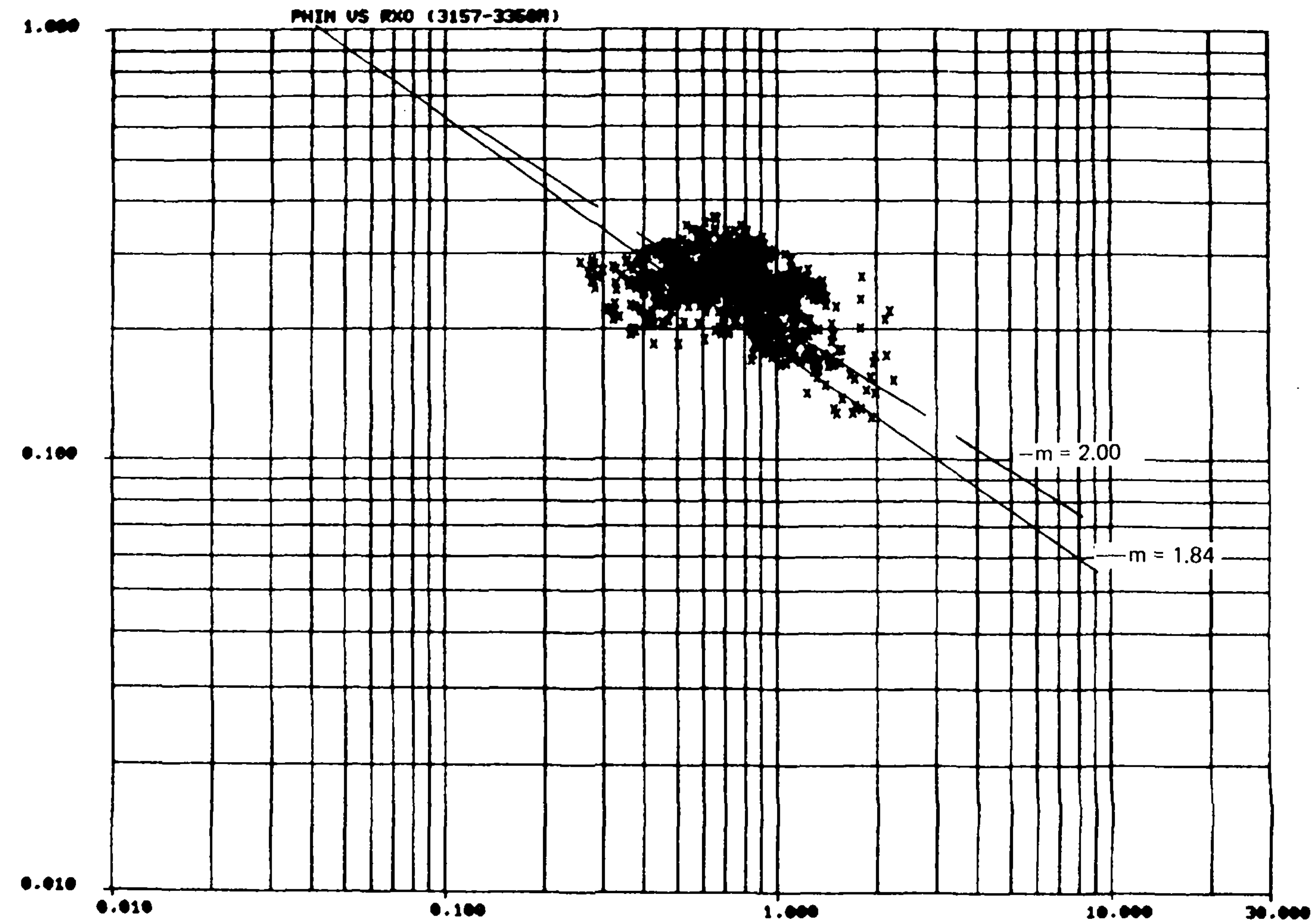

PHIN VS RXO (3075-3157M)
1.000
0.100
0.010
0.010
0.100
1.000
10.000
30.000
m = 2.10
m = 1.92
PLOTTED BY: RGR

Fig. 19



PLOTTED BY: RGR

Fig. 20



PLOTTED BY: RGR

Fig. 21

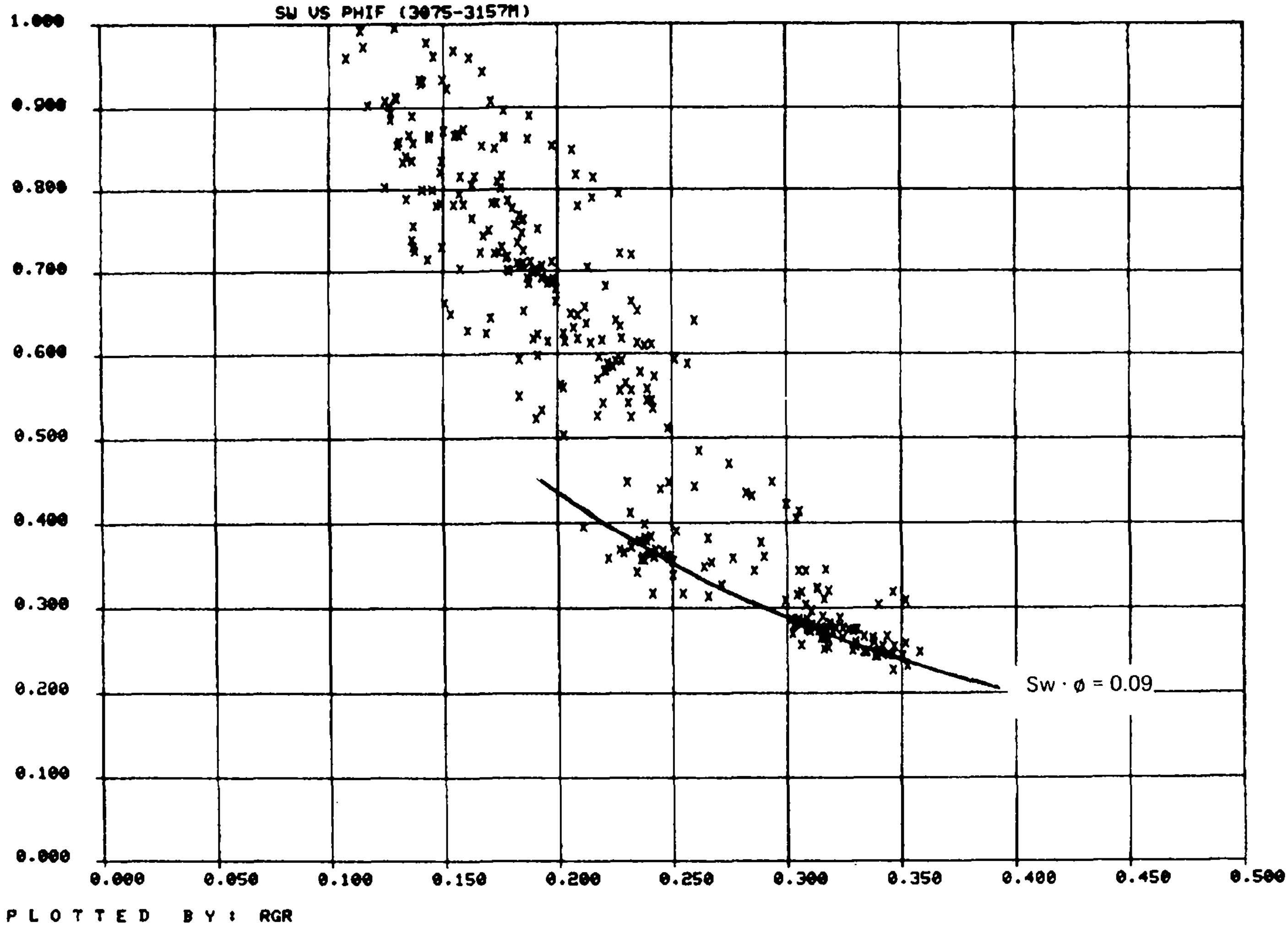

SW VS PHIF (3075-3157M)
1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
0.000
0.050
0.100
0.150
0.200
0.250
0.300
0.350
0.400
0.450
0.500
Sw · ø = 0.09
PLOTTED BY: RGR

Fig. 22

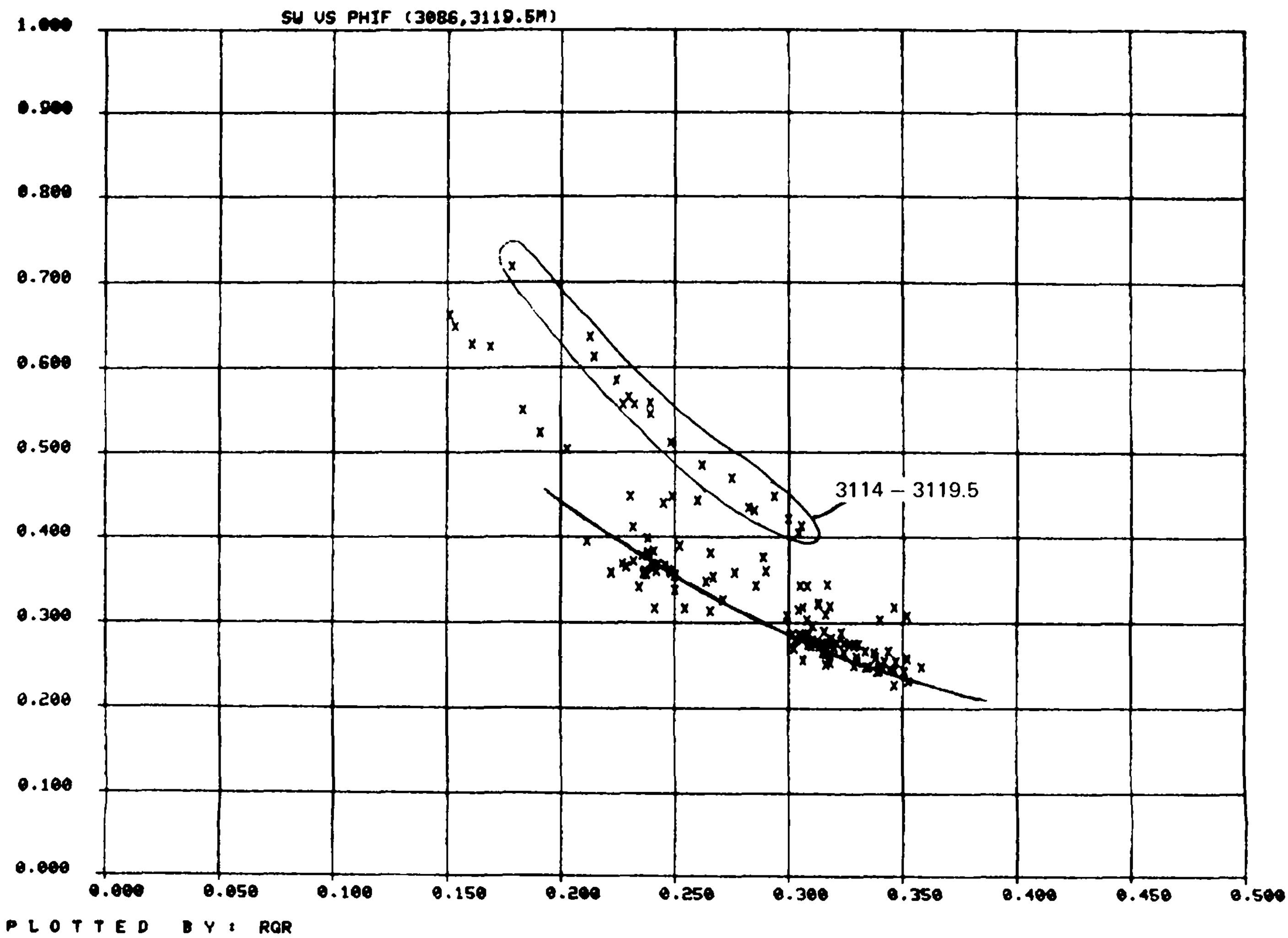

SW VS PHIF (3086,3119.5M)
1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
0.000
0.050
0.100
0.150
0.200
0.250
0.300
0.350
0.400
0.450
0.500
3114 – 3119.5
PLOTTED BY: RGR

Fig. 23

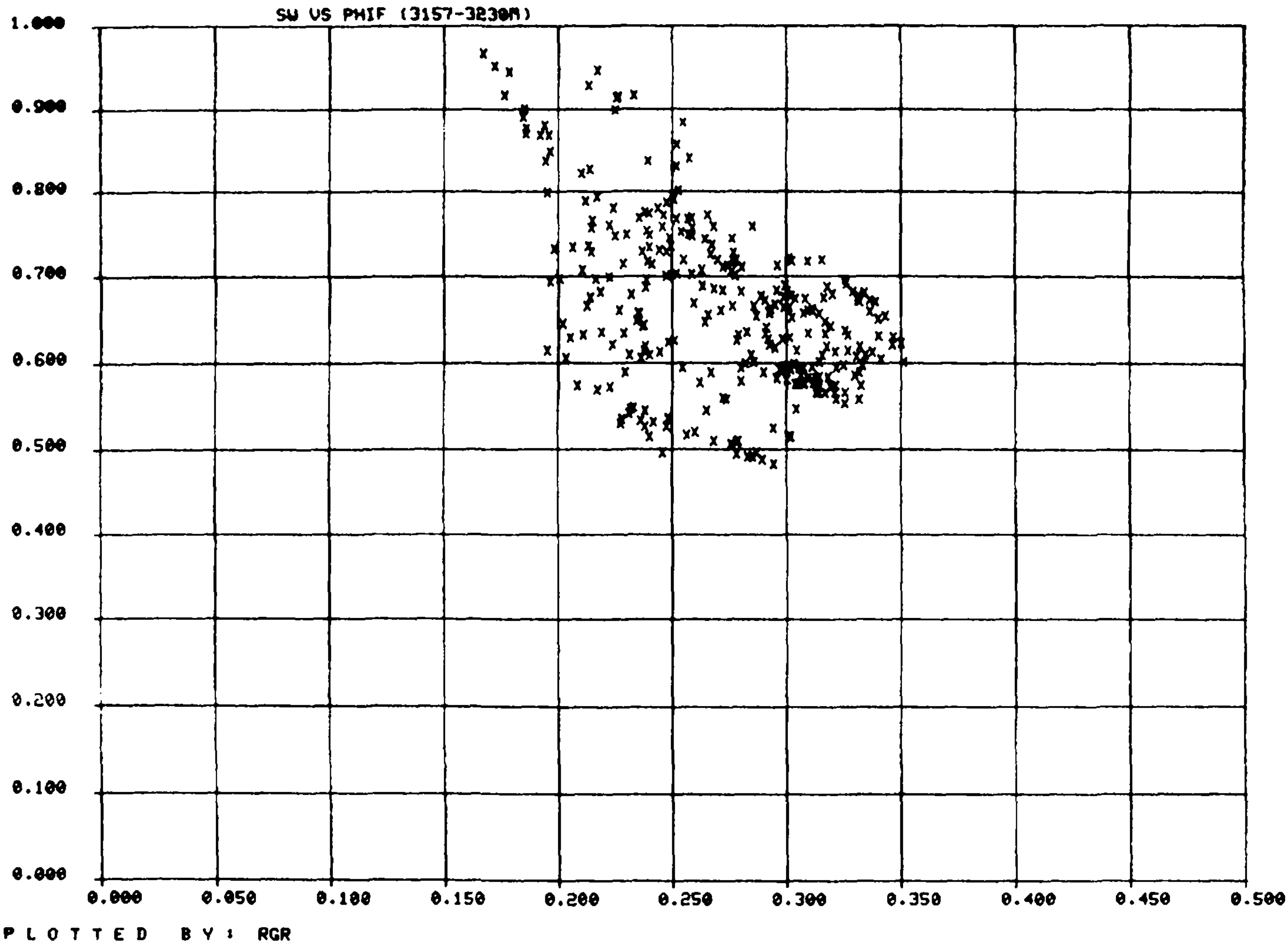

SW VS PHIF (3157-3230M)
1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
0.000
0.050
0.100
0.150
0.200
0.250
0.300
0.350
0.400
0.450
0.500
PLOTTED BY: RGR

Fig. 24

IRON MOUNTAIN

The following attachments are too large for the scanner. Please see copied header information.

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Den norske stats
oljeselskap a.s

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