CHEVRON STANDARD LIMITED

MEDICAL ARTS BUILDING, 329A - 6TH AVENUE S.W., CALGARY, ALBERTA.

May 26, 1966

The Oil and Natural Gas Conservation Board
Department of Mines and Natural Resources
Legislative Building
Province of Manitoba
Winnipeg 1, Manitoba

Attention: Mr. Stuart Anderson
Chairman

Dear Sirs:

Chevron Standard Limited, under and pursuant to The Mines Act, Revised Statutes of Manitoba 1954, and amendments thereto, hereby, on behalf of itself and other Working Interest Owners in the Virden-Roselea Field, requests the Board to hold a hearing to consider and approve the following:

1. "PLAN FOR UNIT OPERATION GOVERNING THE UNITIZED MANAGEMENT OPERATION AND FURTHER DEVELOPMENT OF VIRDEN-ROSELEA UNIT NO. 3" pursuant to Section 73 of The Mines Act.
2. "PROPOSAL FOR PRESSURE MAINTENANCE BY WATERFLOODING" pursuant to Section 59 of The Mines Act.
3. "APPLICATION FOR A UNIT MAXIMUM PERMISSIBLE RATE OF PRODUCTION" pursuant to Section 59 of The Mines Act.

Enclosed please find ten copies of each of the following:

1. "PLAN FOR UNIT OPERATION GOVERNING THE UNITIZED MANAGEMENT OPERATION AND DEVELOPMENT OF VIRDEN-ROSELEA UNIT NO. 3".
2. "PROPOSAL FOR PRESSURE MAINTENANCE BY WATERFLOODING" which includes:
   (a) APPENDIX I - Investigation of the Feasibility of Waterflooding.
   (b) APPENDIX II - Details of Operation to be Conducted in Proposed Unit Area.
3. "APPLICATION FOR A UNIT MAXIMUM PERMISSIBLE RATE OF PRODUCTION".

At the hearing, we would also like to refer the Board to the following references:

1. Engineering Report entitled "Waterflood Evaluation - Proposed Virden-Roselea Unit No. 3 - Virden-Roselea Field, Manitoba - February, 1966".

2. "Rate Cumulative Decline Curves - Virden-Roselea Field".

3. "Primary History and Prediction Curves" for all wells and leases in the proposed Unit area.

In addition we are also enclosing the following information:

1. A list of Royalty Owners in the proposed Unit area, which may assist the Board in sending out notices of the hearing.

2. Discussion of Virden-Roselea Unitization and Participation Formula for the Proposed Virden-Roselea Unit No. 3.

An early consideration of our request would be greatly appreciated.

Yours very truly,

J. G. TROWELL, Chairman pro-tem
Proposed Virden-Roselea Unit No. 3
Operating Committee

Encl.

WATERFLOOD EVALUATION

VIRDEN ROSELEA FIELD

MANITOBA

CONFIDENTIAL VR#1

VIRDEN ENGINEERING
SEPTEMBER 1963

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LIST OF FIGURES AND TABLES

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WATERFLOOD EVALUATION
VIRDEN ROSELEA FIELD, MANITOBA

SUMMARY:

I. INTRODUCTION:

The purpose of this study was to investigate the feasibility of secondary recovery of oil by waterflooding the Mississippian limestone reservoir in the proposed portion of the Virden Roselea field.

II. FINDINGS:

1. The estimated original oil-in-place from volumetric calculations within the proposed Unit area was 41,000,000 barrels.

2. The indicated ultimate primary performance for the proposed area is 5,300,000 barrels or 12.9% of the original oil-in-place. The estimated cumulative production for the area to January 1, 1965 will be 3,200,000 barrels or 7.8% of the original oil-in-place.

3. The bottom hole pressure in the area has declined to an average pressure of approximately 200 psi.

4. Waterflood calculations indicate a total ultimate primary plus secondary recovery of 14,400,000 barrels or 35% of the original oil-in-place in the proposed unit area.

III. CONCLUSION:

The area outlined in FIGURE 1 should be waterflooded as a substantial increase in ultimate recovery can be realized.

RESERVOIR STUDY
PROPOSED VIRDEN ROSELEA WATERFLOOD

This report is a reservoir study of the proposed Virden Roselea Waterflood Area. The area is outlined on the map in Figure 1.

GENERAL:

The majority of the wells in the proposed Virden Roselea Waterflood Area were drilled during 1954 to 1957 with the peak drilling period being between November 1954 and March of 1955 when 27 wells went on production. The wells on Section 21 were the last to be drilled with Lsd. 5-21 being the final well placed on production during January, 1962.

There are 70 wells in the proposed unit area of which 37 belong to Calstan, 13 to CEGO, 4 to Frontenac, 4 to Kranz, 3 to Continental, 3 to Sun, 2 to Teck Corp., 2 to Canadian Superior and 1 each to Shannon Oils Ltd. and K & N Oils Ltd.

GEOLOGY:

The Virden Roselea Field lies on the northeast flank of the Williston Basin with the Town of Virden on the western edge. The field is basically a stratigraphic trap in the Mississippian, the limits being partially controlled by a structural nosing.

The reservoir rocks are part of the Lodgepole Formation of Lower Mississippian age, and are underlain by Ordovician, Silurian and Devonian sediments. The overlying deposits are Jurassic and Cretaceous sediments, and glacial drift. The reservoir rocks are mainly clastic limestone, subdivided by thin interbeds of argillaceous limestone, The Lodgepole Formation has been dubdivided into three members, the Scallion Member, the Virden Member and the Whitewater Lake Member in ascending order. All three are oil bearing in the Virden area. The Whitewater Lake Member is oil bearing only at the western extremities of the Virden Roselea field.

The Scallion Member is predominantly a finely crystalline cherty limestone with fragmental interbeds conformable with the underlying Bakken Formation, and is approximately 200 feet thick within the field area. The upper productive portion of the Scallion Member is commonly known as the "Cherty Zone" and has up to 35 feet of pay.

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The Lower Virden Member consists mainly of oolitic limestones interbedded with argillaceous limestone or calcareous shale, hence its common name, the "Oolitic Zone". These oolite bands are cyclic in nature and total four in the area, the Fourth, Third, Second and First Oolites in ascending order. A Fifth Oolite or Fifth Fragmental has been described but generally blends into the Cherty Zone. Overlying the "Oolites" are argillaceous limestones and shales.

Above this lies the Upper Virden Member, a bioclastic limestone mainly Crinoidal debris, sometines crystalline, called the "Crinoids" or "Crinoidal".

The overlying Whitewater Lake Member within the field is generally dolomitized argillaceous, and anhydritic.

As mentioned before, the field is partially controlled by structure. This is in the form of a true structural nosing, reflected somewhat by the Lodgepole erosion surface. Wells in which the Lodgepole Formation is structurally high generally show the effect of post Lodgepole movement. This results in a fracture system which in some places is anhydrite infilled. There is little evidence of any degree of movement along the fracture planes. The breccia zones within the Scallion Member are thought to be due to infilling of cracks, which extended to the erosion surface during the Watrous transgression, and are not fault breccias. The structures are thought to be low angle folds with a maximum dip of five degrees.

COMPLETION TECHNIQUES:

The wells drilled from 1954 to 1956 inclusively were, with few exceptions, completed by cementing the production casing at the top of the Oolite pay section leaving the Oolites and Cherty Zone open. The exceptions are 9 and 10-24-10-26 and, 1 and 9-26-10-26. Total depth was in some cases just a few feet into the Cherty Zone and well above the base of the effective oil saturation. Some of these wells were later deepened (Section 30).

The wells drilled in 1957 (Section 28 and 29) were completed by setting the casing through the entire pay section and selectively perforating the desired intervals.

Most of the wells were initially completed with an acid wash and squeeze, followed in later years by some type of hydraulic fracturing. Most of the wells in the proposed waterflood area have been reworked and 31 of the wells have been hydraulically fractured.

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Very little hydraulic fracturing has been conducted on Sections 20,21, and 30. Section 30, for example, has had a fracture treatment on only two of the thirteen wells.

Re-stimulation in recent years has proved ineffective, primarily due to the lack of reservoir pressure. Selective stimulation of the separate porous sections has proved to be difficult because of the relatively thin zones and the threat of communication immediately behind the casing.

ISOPACHS:

The best guide to effective pay thickness determination is core analysis. In the proposed waterflood area 26 wells have core analysis although most are only partial as far as the Cherty Zone is concerned. Several wells, particularly those on Section 30, were completed open hole with only a few feet of Cherty Zone open; then at some later date they were deepened with no cores or logs available on this lower Cherty Zone section. For this reason, it was necessary to attempt a correlation of Cherty Zone pay on Section 30 with offsetting wells on Sections 25 and 29, to extrapolate the Cherty Zone pay to the base of effective oil saturation.

It was decided to treat the reservoir as four separate zones for oil-in-place calculations. The Oolitic, Sandhill, and Crinoidal Zones had more complete information than the Cherty Zone since in most of the 26 cases they were analyzed. It was not necessary to depend on extrapolation to such a large degree for the drawing of pay Isopachs of these three zones.

The pay Isopachs for the Cherty, Oolitic, Sandhill, and Crinoidal Zones are presented in Figures 2, 3, 4, and 5 respectively. The reliability of the extrapolated pay thicknesses in the Cherty Zone varies with the availability of good bases for correlation.

Isopachs of permeability were also drawn for each of the four zones. However, since core analyses were limited in areas, the reliability of these Isopachs for any particular well is directly proportional to the distance of this well from a well that has a core analysis.

Figures 6, 7, 8, and 9 present the permeability Isopachs for the Cherty, Oolite, Sandhill, and Crinoidal Zones respectively.

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SUBSURFACE FLUID ANALYSIS

A Reservoir Fluid Study was made by Core Laboratories Inc. on subsurface samples from Calstan Virden 13-24-10-26. These tests were run in June, 1954. The results of the study are listed below:

1. The saturation pressure of the reservoir fluid was 170 psig at the reservoir temperature. This indicated that the reservoir existed in an undersaturated condition.

2. Differential vaporization of the fluid resulted in the liberation of 89 SCF of vapor per barrel of residual liquid. The initial formation volume factor was 1.048 bbl per bbl.

3. The liquid phase viscosity varied from 3.36 centipoise at saturation pressure to a maximum of 4.75 centipoise at zero pressure.

BOTTOM HOLE PRESSURES

The bottom hole pressure surveys in the proposed waterflood area have been very scant. The bottom hole pressure in Calstan Virden 12-25-10-26 was determined at 792 psig during a survey in 1956. In 1961 the pressure in Calstan Virden 9-24-10-26 was found to be 403 psig.

The greatest drawback to running bottom hole pressure surveys is the long shut-in times required to obtain a complete pressure build-up, and the resulting lost production which cannot be recovered until the end of the well's life.

Sonic measurements reveal that most wells in the area are pumped off and are thus in an advanced stage of pressure depletion. The pressures in the proposed Virden Roselea Waterflood Area have probably declined to an average pressure of 200 psi.

PRIMARY PERFORMANCE

Decline curves have been prepared for all wells in the proposed waterflood area, however, the primary reserves on an individual well basis could not be accurately established since some wells have not established a definite decline trend.

A rate versus time plot for the total proposed waterflood area does establish a definite decline trend. This curve was employed in the determination of remaining primary reserves. (See Figure 10).

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By projecting the average daily production rate curve of the proposed area, an indicated ultimate primary recovery of 5,300,000 barrels, or 12.9% was obtained. The indicated remaining primary recoverable reserves will be 2,100,000 barrels as of January 1, 1965, which is the assumed date of waterflooding. The estimated cumulative production for the area to January 1, 1965, will be 3,200,000 barrels or 7.8% of the estimated original oil in place.

WATERFLOOD RECOVERY PREDICTION

The prediction of waterflood recovery is based on a combination of Welge's displacement efficiency concept, Dykstra and Parson's vertical sweep efficiency or permeability variation efficiency, and the concept of areal sweep efficiency in pattern flood as defined by Caudle, Erickson and Slobod, and Dyes, Caudle and Erickson.

Although no flood tests have been conducted on cores from the Virden Roselea field, it was felt that results of tests on North Virden Scallion cores would be reasonably representative. The secondary prediction for the Virden Roselea proposed waterflood was made using the same methods that were used for the North Virden Scallion Unit, although some changes were necessary.

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APPENDIX I

RESERVES AND PRIMARY PERFORMANCE

A. ORIGINAL STOCK TANK OIL-IN-PLACE

The original stock tank oil-in-place was calculated from the equation:

$$N = 7758\ \phi\ A_h S_{oi}\ 1/\beta$$

where N = stock tank oil-in-place, barrels.
ϕ = average footage weighted porosity, fractional
A = surface area, acres
h = effective pay thickness, feet
S_{oi} = initial oil saturation, fractional
β = formation volume factor, res. bbls/S.T. bbl.

1. POROSITY, AREA AND THICKNESS

The isopach maps were planimetered to give the average pay thickness for each Zone. An average footage weighted porosity was obtained for each Zone from available core analysis in the area.
The results are as follows:

Zone	Average Pay Thickness	Average Porosity	Subsurface Area (Acres)
Crinoidal	9.0 ft.	9.8%*	1320
Sandhill	4.0	12.2	1940
Oolites	8.0	11.1	2800
Cherty	18.4	13.3	2800
TOTAL	39.4		

2. OIL SATURATION

The average initial oil saturation (S_{oi}) for each zone was determined as follows:

* Value used in North Virden Scallion study.

(a) **CHERTY ZONE**

The oil saturation determination was based on the analyses of the oil base cores from Calstan South Virden 12-1-10-26 and 15-11-10-26. The laboratory water saturations, assumed to be true water saturations, were plotted against the corresponding air permeabilities for each sample. A straight line relationship exists between the logarithm of the permeability and the water saturation, therefore, a best fit straight line on the plot on semilog paper gives a permeability versus water saturation plot as presented in Figure 11.

The Cherty Zone average air permeability was determined in the following manner:

All analyzed samples of 1 md maximum horizontal air permeability and greater were grouped into permeability ranges and a permeability distribution plot was obtained. By plotting the logarithm of permeability against distribution (plotted as percent greater than) on probability paper a straight line was obtained.

The median air permeability or the 50% point is defined as the point at which one-half the rock has permeability greater than at this 50% value and one-half has a value less than this value. This point then represents a reasonable average of effective reservoir permeability. The plot for the Virden Roselea Cherty Zone is shown in Figure 12.

The median air permeability in Figure 12 is 14.5 md which corresponds with a water saturation of .54 or an initial oil saturation of .46 or 46%.

It is believed that there is usually a good correlation between porosity and water saturation in carbonate reservoirs. From the oil base cores of Calstan South Virden 12-1-10-26 and 15-11-10-26, the log of porosity was plotted against water saturation. The best fit curve as established by the method of least squares indicated a water saturation of 51% at the area average porosity of 13.3%. This corresponds with an initial oil saturation of 49%. (See Figure 13).

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The initial oil saturation as determined from permeability manipulation was 46% and 49% as determined from porosity manipulation. For this study a Cherty Zone initial oil saturation of 48% was used.

(b) OOLITIC ZONE

The distribution plot of Oolite samples constructed as described above is shown in Figure 14. As can be seen from Figure 15, there appears to be no correlation between permeability and water saturation in the Oolitic Zone.

Porosity was plotted versus water saturation and a best fit curve was drawn employing the method of least squares (Figure 16). The initial oil saturation from this plot, at the weighted average Oolitic Zone porosity for this area, was 48%. This was the figure used for the Oolitic Zone for this study.

(c) SANDHILL

By applying the above procedure to the Sandhill Member the following results were obtained:

The initial oil saturation from the permeability versus water saturation plot at a median air permeability of 8.1 md was 48% (See Figures 17 and 18). As can be seen from Figure 18, the Sandhill zone in 12-1-10-26 and 15-11-10-26 is not really representative of the Sandhill over the proposed waterflood area as few samples are near the field average.

From the porosity versus water saturation plot (Figure 19), the initial oil saturation at the average footage weighted porosity of 12.2%, was 57%, however, an average initial oil saturation of .52 or 52% was used for the Sandhill Member in this study.

(d) CRINOIDAL

From the permeability distribution plot (Figure 20), the median value of the air permeability was found to be 8.5 md. When this value was applied to the plot of the water saturation versus the logarithm of permeability (Figure 21), a non-representative value was obtained for the initial oil saturation.

On a plot of water saturation versus the logarithm of air permeability for the oil base cores from Calstan South Virden 12-1-10-26 and 15-11-10-26, it was found that most of the points fall near the best-fit line constructed for the North Virden Scallion Cherty Zone (See Figure 22). Although the crinoidal is much less permeable, it must be lithologically similar to the Cherty Zone, at least in respect to water saturation varying with permeability.

The plot of porosity versus water saturation (Figure 23) showed that with increasing porosity the water saturation also increased, indicating the lack of a relationship between porosity and water saturation. For this reason and because there was no other reliable data available and also because of the lithologic similarity with respect to water saturation variance with permeability of the crinoidal and the Cherty zones, it was assumed that the water saturation in the Crinoidal Zone was 52% and therefore the initial oil saturation was .48 or 48%.

3. FORMATION VOLUME FACTOR

The formation volume factor, β was obtained from a subsurface fluid analyses of samples from Calstan Virden 13-24-10-26. The value of β used in this study, was 1.05 bbl/bbl.

4. ORIGINAL OIL IN PLACE

The original oil-in-place calculations for each of the four zones are as follows:

CHERTY ZONE

N = 7758 (.133) (51520) (0.48) (1/1.05)
= 24,300,000 barrels.

or using average figures.

N = 7758 (.133) (40) (.48) (1/1.05)
= 18,800 bbl/ft/40 acre lease

or N = 7758 (.133) (.48) (1/1.05)
= 470 bbl/acre-foot

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OOLITIC ZONE

N = 7758 (.111) 22400) (0.48) (1/1.05)
= 8,900,000 barrels

or N = (7758) (.111) (.40) (.48) (1/1.05)
= 15,700 bbls/ft/40 acre lease

or N = (7758) (.111) (.48) (1/1.05)
393 bbls/acre-foot

SANDHILL ZONE

N = 7758 (.122) (7760) (.52) (1/1.05)
= 3,700,000 barrels

or N = (7758) (.122) (40) (.52) (1/1.05)
= 18,700 bbls/ft/40 acre lease

or N = (7758) (.122) (.52) (1/1.05)
= 468 bbls/acre-foot

CRINOIDAL ZONE

N = (7758) (.098) (11870) (.48) (1/1.05)
= 4,115,000 barrels

or N = (7758) (.098) (40) (.48) (1/1.05)
= 13,900 bbls/ft/40 acre lease

or N = (7758) (.098) (.48) (1/1.05)
= 347 bbls/acre-foot

A summary of the original oil in place and their relative amounts are as follows:

	Oil In Place	Percent of Total
Cherty Zone	24,300,000	59%
Oolitic Zone	8,900,000	22%
Sandhill Zone	3,700,000	9%
Crinoidal Zone	4,100,000	10%
TOTAL	41,000,000	100%

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B. PRIMARY PERFORMANCE

The primary reserves of the proposed Virden Roselea Waterflood Area have been estimated at 5,300,000 barrels. This represents a recovery factor of:

$$RF = \frac{5,300,000}{41,000,000} = 12.9\%$$

or, on an average well basis (producing from all zones)

$$N = 0.129 \; (18,800)\,(18.4) + (15,700)\,(8.0) + (18,700)\,(4.0) + (13,900)\,(9.0)$$

$$= 0.129\,(671,000)$$

$$= 87,000 \text{ barrels}$$

These figures are from the above oil-in-place calculations and refer to a well draining all zones and with average pay thickness.

APPENDIX II

INJECTIVITY AND FLOOD PREDICTION

A. INJECTIVITY CALCULATIONS

The formula employed in the calculations of the water injectivity rates is presented below.

$$Q = \frac{0.003541\ K_w h \Delta P}{\mu \beta (\ln d/r_w - 0.6190)}$$

where Q = injection rate, bbl/day

K_w = reservoir permeability to water, millidarcies

h = vertical section, feet

ΔP = pressure differential (P surface + P well bore - P reservoir)

μ = viscosity of injection water at reservoir conditions, centipoise

d = distance from injection well to producing well in flood pattern, feet

r_w = effective well bore radius, feet

This is derived from Darcy's flow formula and is applied to an average Virden Roselea well assuming the following:

P_{wb} = 0.433 psi/ft X 2100 ft = 900 psi fresh water?

Pinj = 1100 psi (not to exceed overburden pressure)

Pres = 500 psi (average over flood life)

$\therefore \Delta P$ = 1100 + 900 - 500 = 1500 psi

μ = 0.864 cp at reservoir temperature

d = 1320 feet, between injection and nearest producer

r_w = 25 feet (radius of fracturing and acidizing assumed)

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Therefore:

$$= \frac{(0.0035411)\ (1500)\ (k_w h)}{0.864\ (\ln \frac{1320}{25} - 0.6190)}$$

$$= 1.84 \text{ bwpd/md. ft.}$$

This simplified form of the formula was applied to the average permeabilities and pay sections.

Where core analyses were available they were employed in the injectivity determinations*. If they did not include the total pay section allotted to a well (i.e. Cherty Zone pay extrapolated), the K_W obtained from core analyses was also extrapolated. Where core analyses were not available, the average K_W for the proposed waterflood area was used for each of the four zones with the pay thickness being obtained from pay Isopachs.

CHERTY ZONE

= 1.84 $K_w h$
= 1.84 (3.2) (18.4)
= 108 BWPD
or = 5.9 BWPD/ft. of Cherty Zone pay

OOLITIC ZONE

= 1.84 (6.3) (8.0)
= 93 BWPD
or = 11.6 BWPD/ft. of Oolitic Zone pay

SANDHILL ZONE

= 1.84 (2.65) (4.0)
= 20 BWPD
or = 4.9 BWPD/ft. of Sandhill Zone pay

CRINOIDAL ZONE

= 1.84 (1.4) (9.0)
= 23 BWPD
or = 2.6 BWPD/ft. of Crinoidal Zone pay

* Of the fourteen proposed injection wells only four have core analysis.

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Sample calculations for total injectivity in all zones for specific wells are as follows:

CEGO Virden 7-30-10-25 (Core Analysis)

(Sandhill)	=	1.84	(7.3)	(15.6)	= 209
(Oolites)	=	1.84	(1.1)	(16.2)	= 33
(Cherty Zone)	=	1.84	(6.6)	(25)	= 302

TOTAL = 544 BWPD

CALSTAN Virden 15-24-10-26 (Using Area Average K_w)

(Crinoidal)	=	(2.6)	(9)	= 23
(Sandhill)	=	(4.9)	(6)	= 29
(Oolites)	=	(11.6)	(9.2)	= 107
(Cherty Zone)	=	(5.9)	(25)	= 148

TOTAL = 307 BWPD

The indicated total injectivity for the eleven proposed injection wells is 3600 BWPD. (See Table 1)

The above injectivities should be considered as order of magnitude estimates for the proposed Virden Roselea Waterflood. They do however demonstrate satisfactory injectivity for flooding. They are conservative for two reasons:

1. A 5-spot pattern steady state formula was used whereas the planned injection well density for the unit area is considerably less.

2. The formula was applied to all wells regardless of the stimulation method and is considered to be inappropriate for fractured wells.

B. WATERFLOOD RECOVERY PREDICTION

1. Welge Method - Displacement Efficiencies

The fractional flow (Fw & Fo Vs Sw) curve (See Figure 24) was constructed using data from laboratory tests by California Research Corporation for the North Virden Scallion Field.

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It was found necessary to shift this curve to the right because of the indicated 86% f_w when the average water cut for the area is 64%. For this field the water cut should be essentially of the same magnitude as f_w since the formation volume factor is 1.05 reservoir barrels/stock tank barrel. The other alternative would have been to assume that the water saturation was considerably less than 52% and use the curve as it was. The water saturation was satisfactorily established at 52%, thus the curve was shifted to the right such that at a water saturation of 52%, the fraction of water flowing was 64%.

TABLE II and Figure 25 present the displacement efficiencies for various water-oil ratios.

The displacement efficiencies at water breakthrough and at a WOR of 10.5 are 30.2% and 36.5% respectively.

2. DYKSTRA-PARSONS - VERTICAL SWEEP EFFICIENCY

From graphs prepared by Dykstra and Parsons* and shown in Figures 26, 27, 28 and 29, the vertical sweep efficiency or coverage was obtained for the various water-oil ratios once the permeability variation V and the mobility ratio γ were obtained.

The Cherty Zone permeability variation was used in the calculations (See Figure 12).

$$V = \frac{14.5 - 4.53}{14.5} = 0.69$$

$$\gamma = \frac{krw}{kro} \frac{\mu o}{\mu w}$$

where γ = mobility ration

krw = relative permeability to water at end of flood

kro = relative permeability to oil at initial water saturation

μw = viscosity of injected water at reservoir conditions

μo = viscosity of oil at reservoir conditions

The relative permeabilities to oil and water were obtained from graphs plotted from data in California Research Corporation's Report on water flood tests for North Virden Scallion (See Figures 30 and 31).

At the median air permeability of 14.5 md the permeability to oil is 6.7 md and the permeability to water is 1.24.

The oil viscosity μ_o = 3.48 cp at 80° and 600 psi.
The water viscosity μ_w = 0.864 cp at 80° and 600 psi.
The mobility ratio $\gamma = \frac{(1.24)}{(6.7)} \frac{(3.48)}{(0.864)} = 0.75$

The following results were obtained from the graphs: (See also Figure 32)

WOR Bbl/bbl	Coverage (E_v)
1	0.44
5	0.72
25	0.89
100	0.95

3. AREAL SWEEP EFFICIENCY

Since the mobility ratio M (reciprocal of the ratio γ) for the proposed Virden Roselea Water Flood was of essentially the same value as used for the North Virden Scallion study, the same results were used and are listed below.

M (North Virden Scallion) = 1.30
M (Virden Roselea) = 1.33

Water Cut	WOR (Bbl/bbl)	Areal Sweep Eff. (E_a)
0.0	0.0	0.58
0.5	1.0	0.73
0.6	1.5	0.79
0.7	2.3	0.85
0.8	4.0	0.93
0.9	9.0	0.97
0.91	10.0	0.976

These figures are shown graphically in Figure 33 as WOR Versus E_a.

4. WATERFLOOD RECOVERY EFFICIENCY

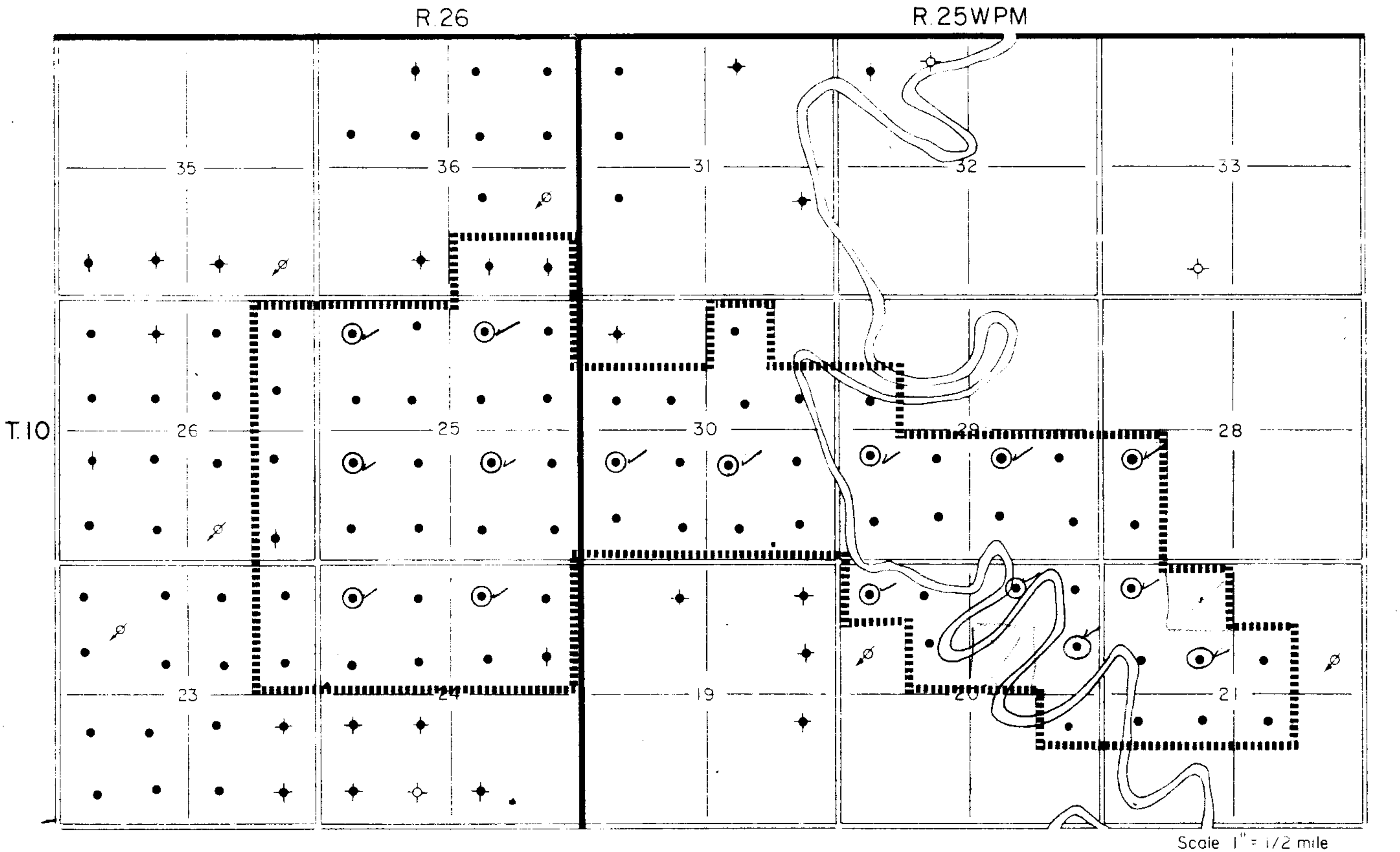
Only one set of flooding efficiencies were applied to the total oil-in-place. The efficiencies used were based on the Cherty Zone. Any error incurred is believed to be within the accuracy of the prediction methods.

Table III indicated the three flooding efficiencies E_d, E_v and E_a as functions of WOR. Waterflood recovery R is the product of the three fractional recoveries. Also presented on this table are the stock tank oil cut and the stock tank WOR.

Recovery versus stock tank oil cut is shown graphically in Figure 34. A recovery of 12.4% of the original oil-in-place is indicated to breakthrough, at which point the oil cut drops to 36%.

Assuming that waterflooding is initiated January 1, 1965, the remaining oil-in-place is estimated at 37,800,000 barrels. The predicted recovery to breakthrough is 5,100,000 barrels or 12.4% of the original oil-in-place. The ultimate secondary recovery is estimated at 11,200,000 barrels or 27.2% of the original oil in place. The predicted total recovery would be composed of 3,200,000 barrels of primary oil production to January 1, 1965, and 11,200,000 barrels of secondary oil production for a total of 14,400,000 barrels or 35% of the original oil-in-place.

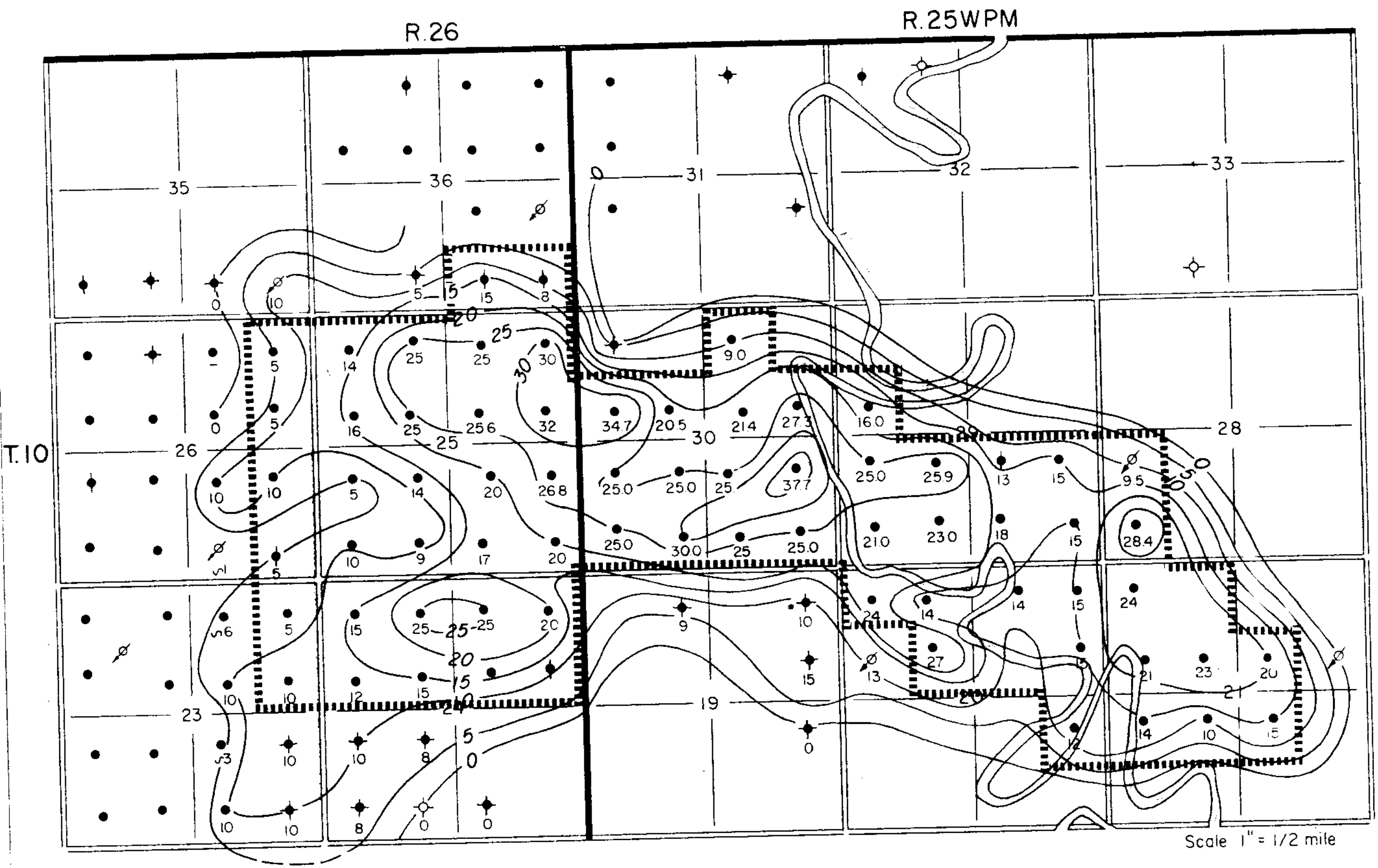
Assumptions made in the prediction are that the economic limit is 7 BOPD/well and that the area will be produced to a water-oil ratio of 10.5.



N.E. VIRDEN ROSELEA

PROPOSED VIRDEN ROSELEA WATERFLOOD AREA

FIGURE 1

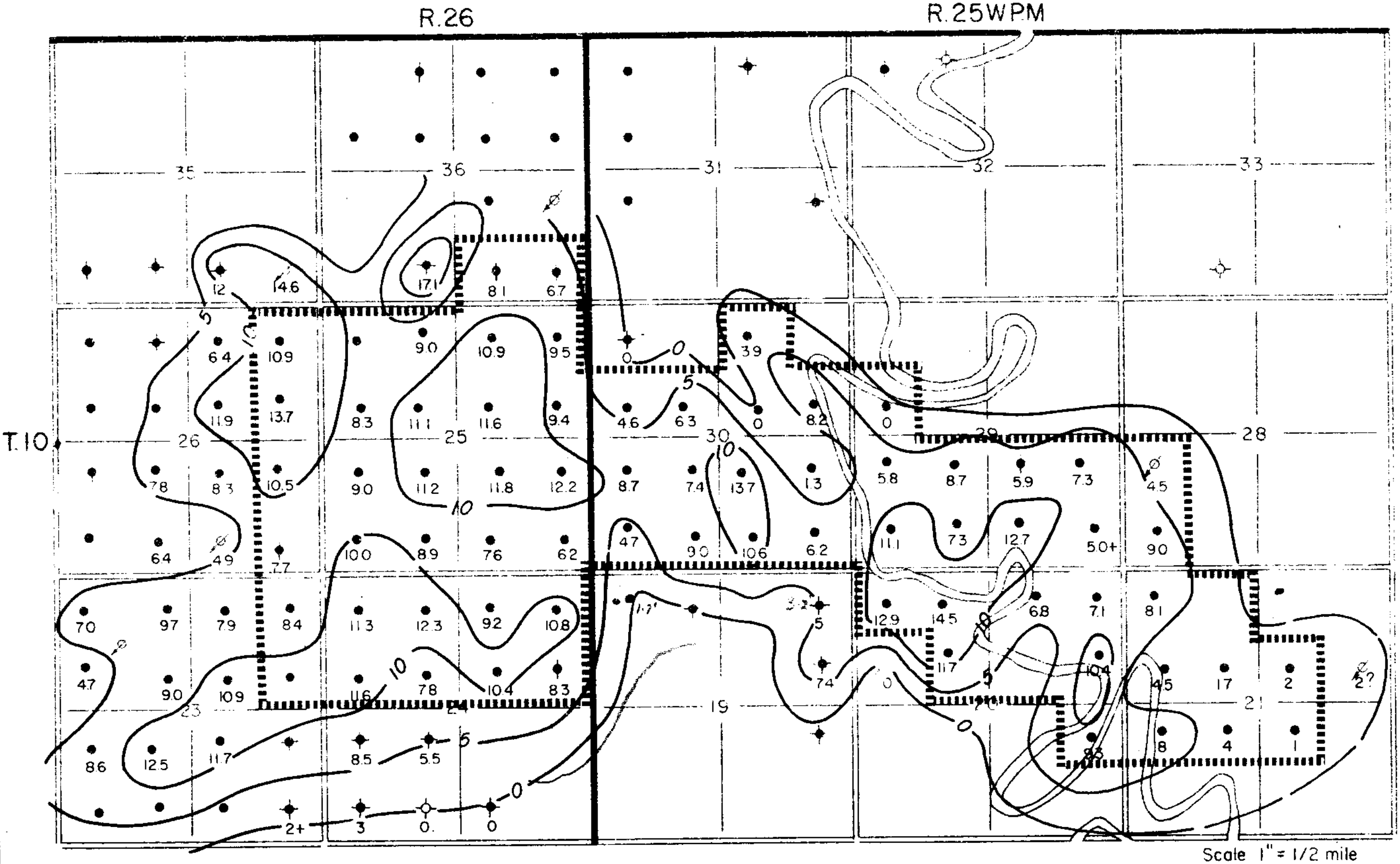


N.E. VIRDEN ROSELEA

ISOPACH OF TOTAL CHERTY ZONE PAY

CONTOUR INTERVAL 5'

FIGURE 2

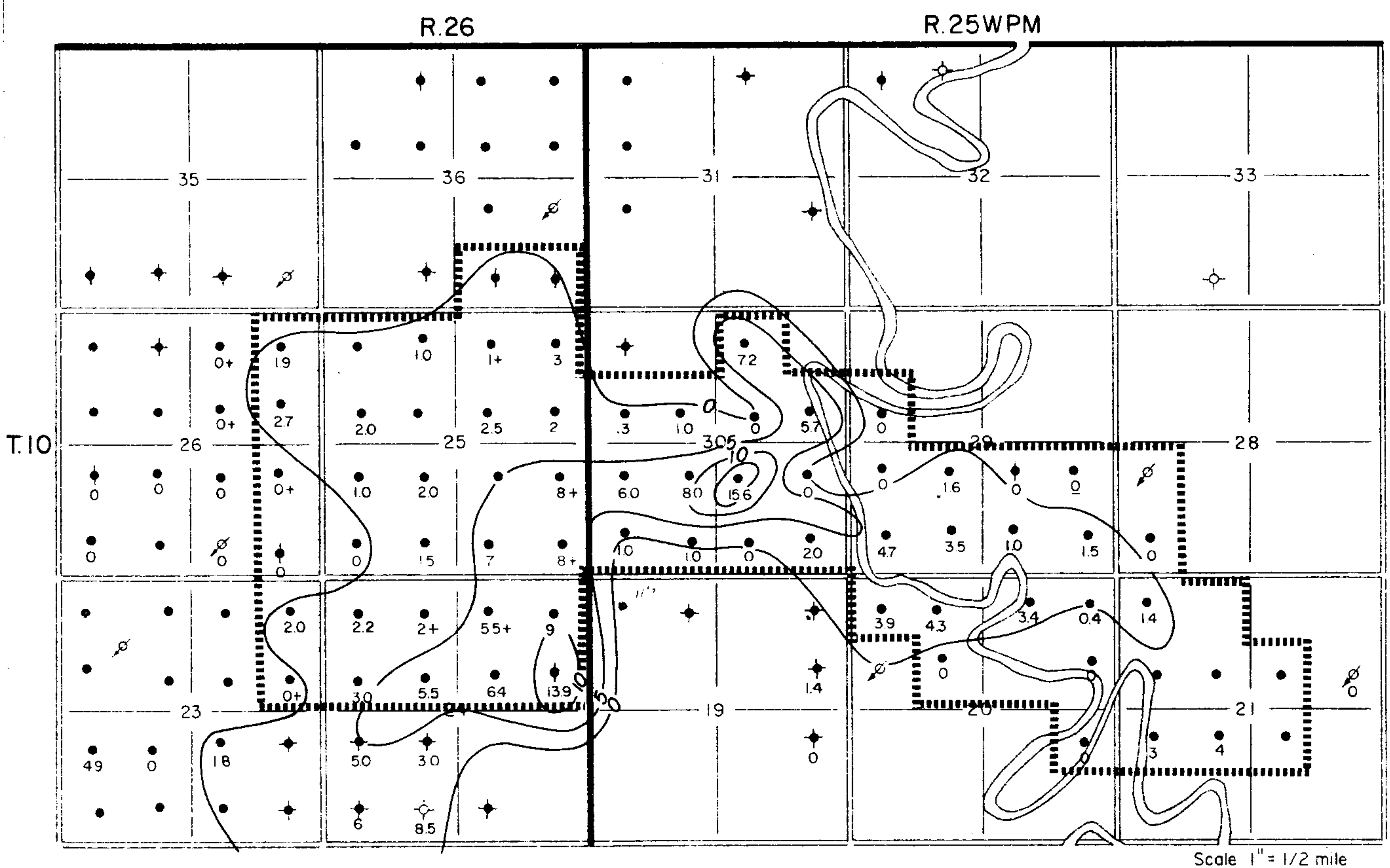


N.E. VIRDEN ROSELEA

ISOPACH OF TOTAL OOLITIC ZONE PAY

CONTOUR INTERVAL 5'

FIGURE 3

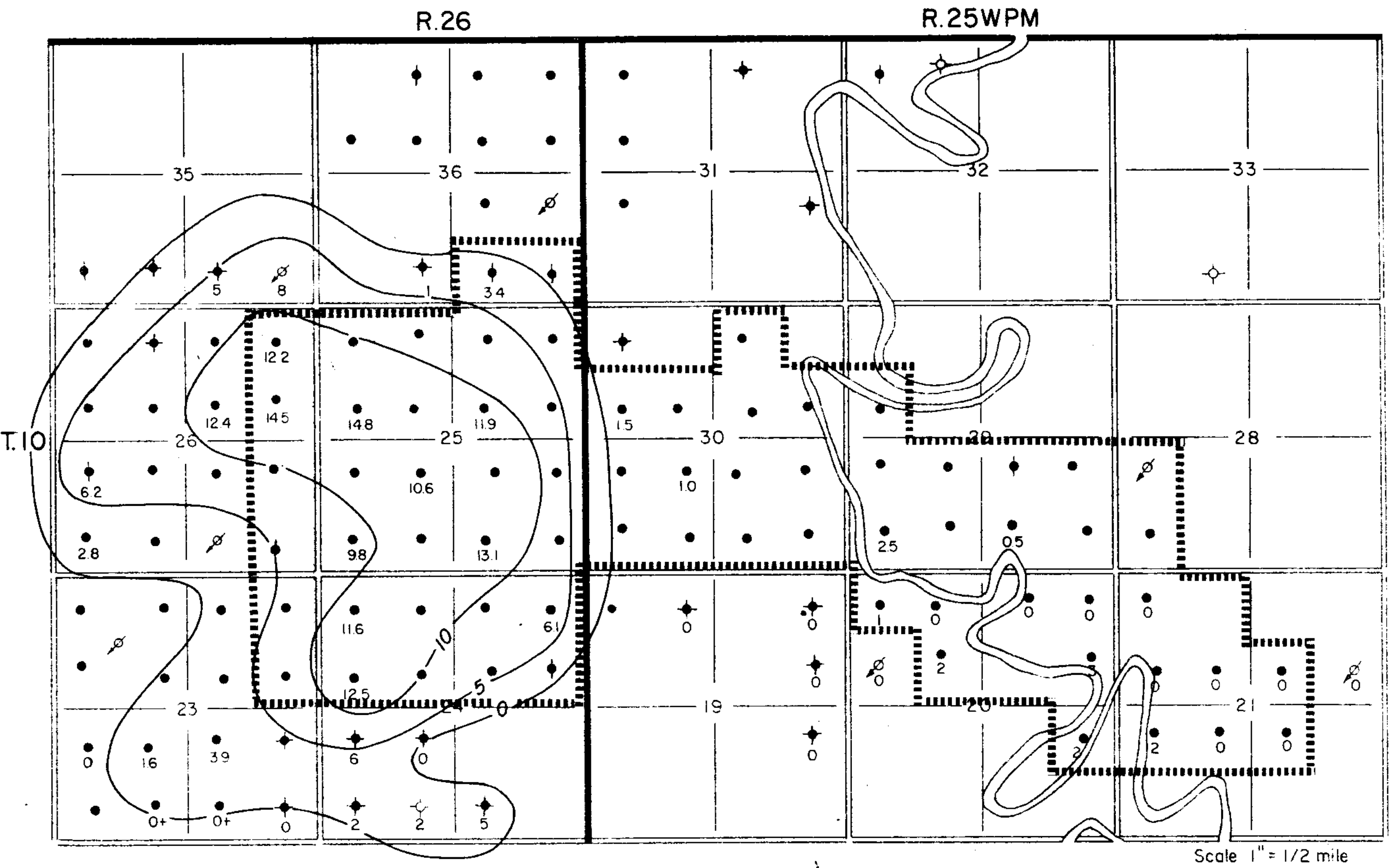


N.E. VIRDEN ROSELEA

ISOPACH OF TOTAL SANDHILL ZONE PAY

CONTOUR INTERVAL 5'

FIGURE 4

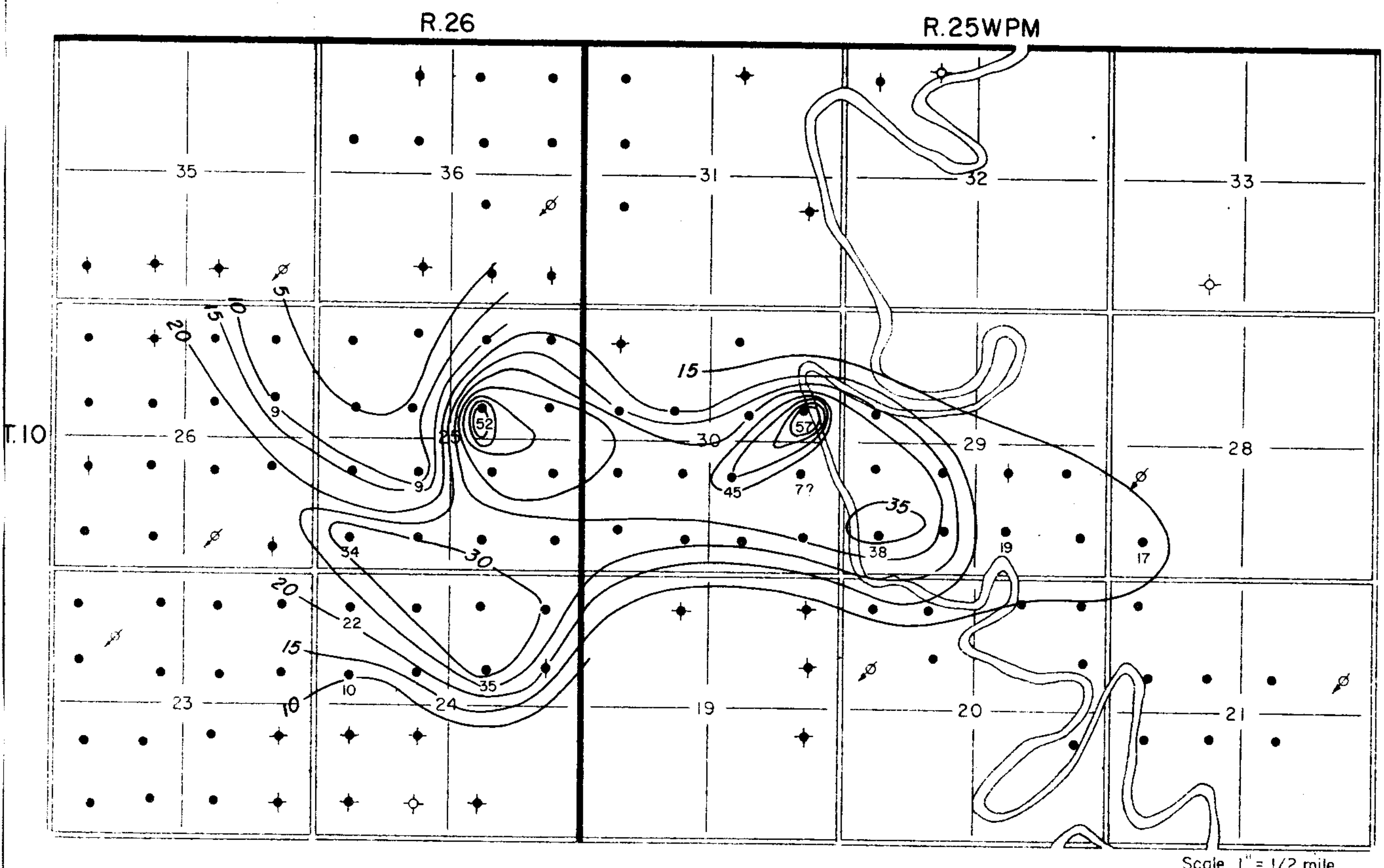


N.E. VIRDEN ROSELEA

ISOPACH OF TOTAL CRINOIDAL ZONE PAY

CONTOUR INTERVAL 5'

FIGURE 5



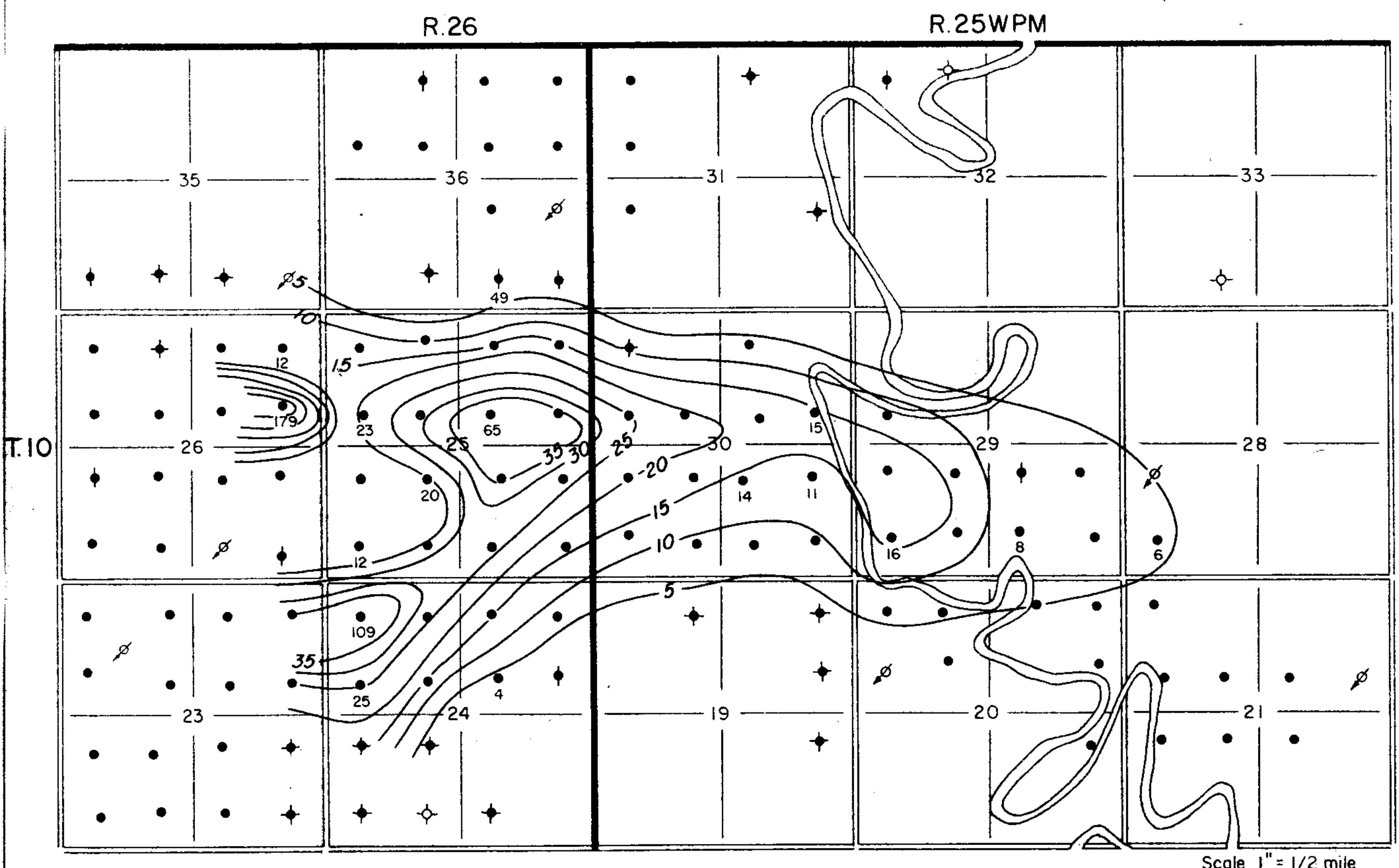
N.E. VIRDEN ROSELEA

ISOPACH OF CHERTY ZONE PERMEABILITY

CONTOUR INTERVAL 5'

(ALL VALUES FROM CORE ANALYSIS)

FIGURE 6



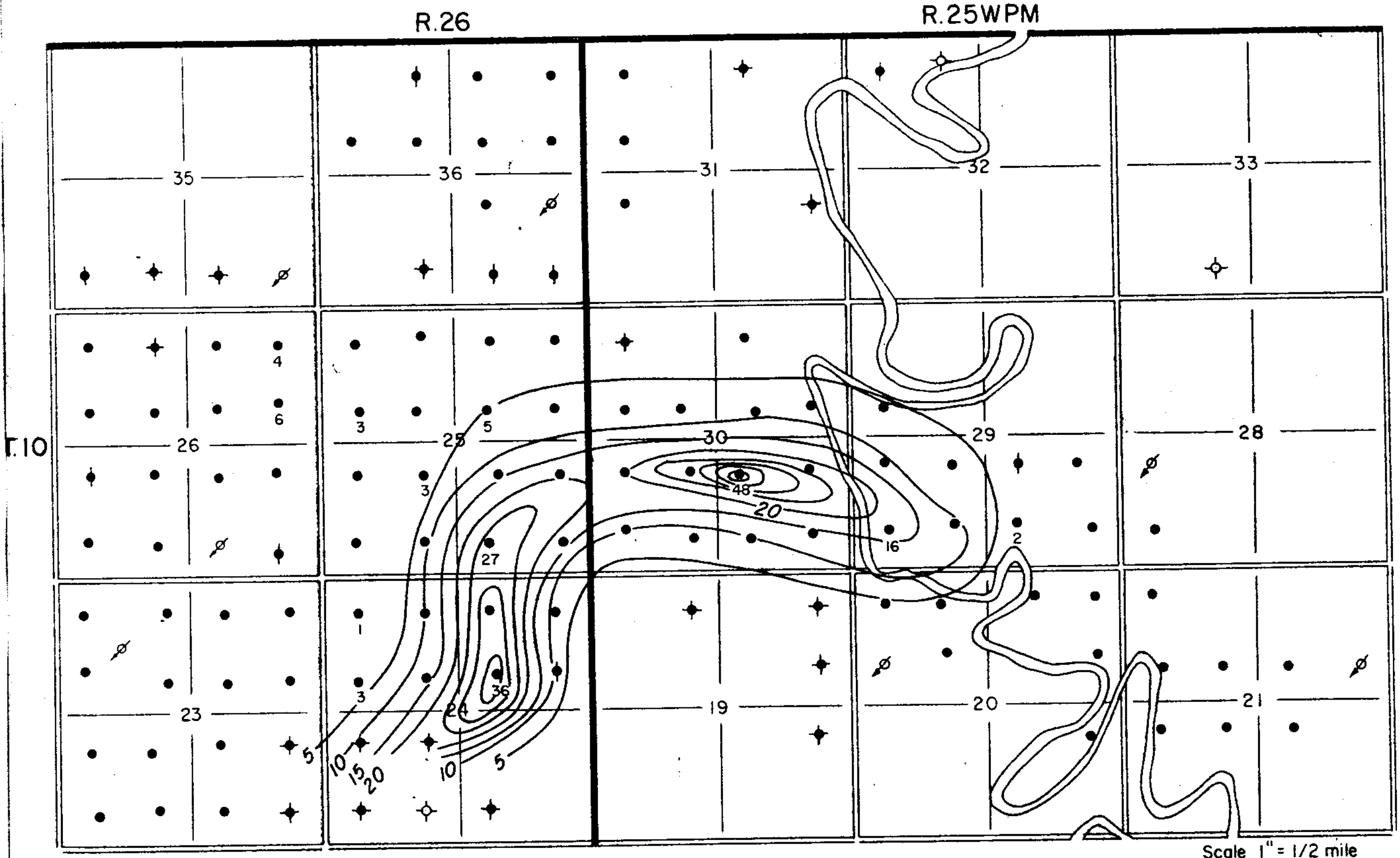
N.E. VIRDEN ROSELEA

ISOPACH OF OOLITIC ZONE PERMEABILITY

CONTOUR INTERVAL 5'

(ALL VALUES FROM CORE ANALYSIS)

FIGURE 7



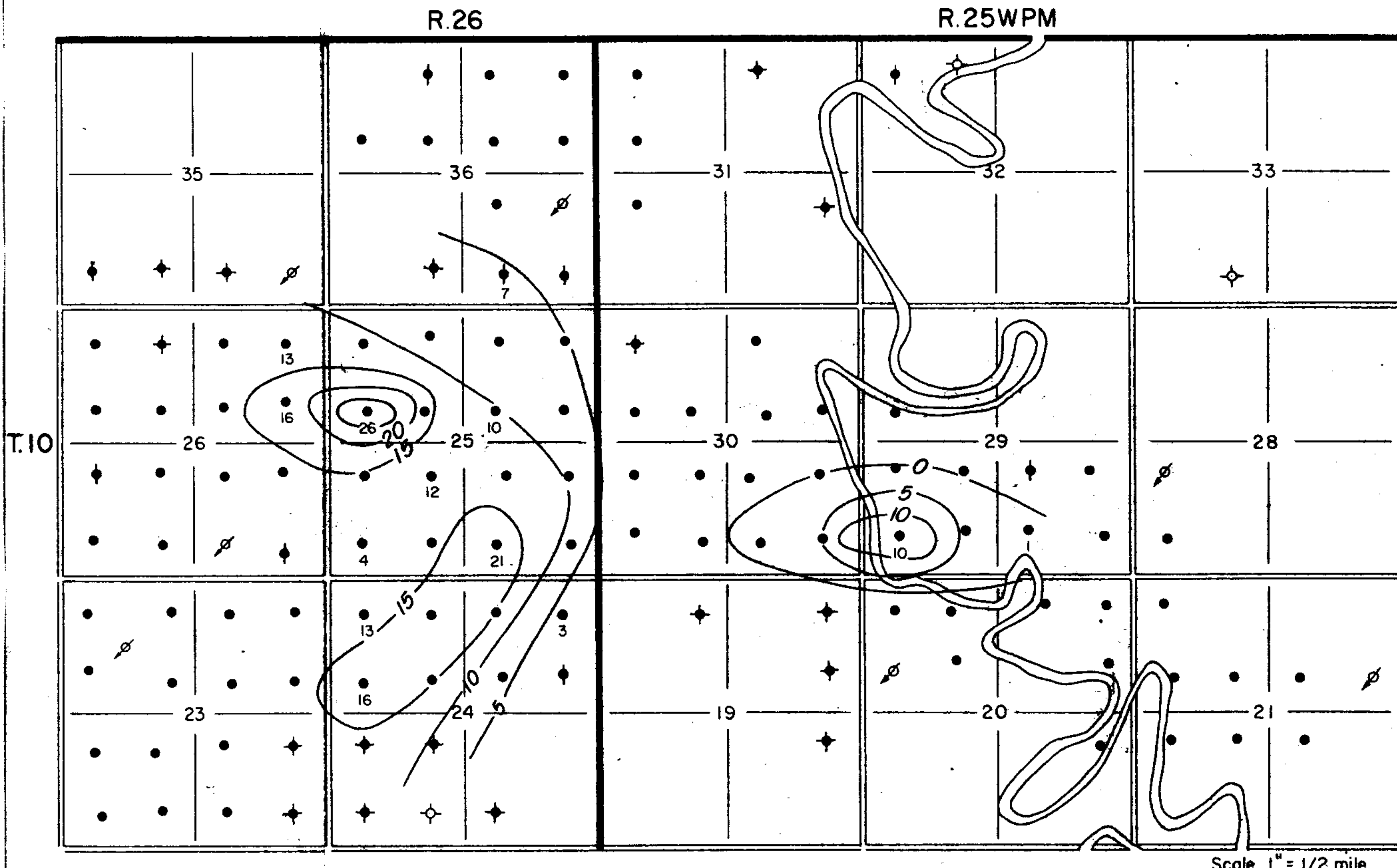
N.E. VIRDEN ROSELEA

ISOPACH OF SANDHILL ZONE PERMEABILITY

CONTOUR INTERVAL 5'

(ALL VALUES FROM CORE ANALYSIS)

FIGURE 8



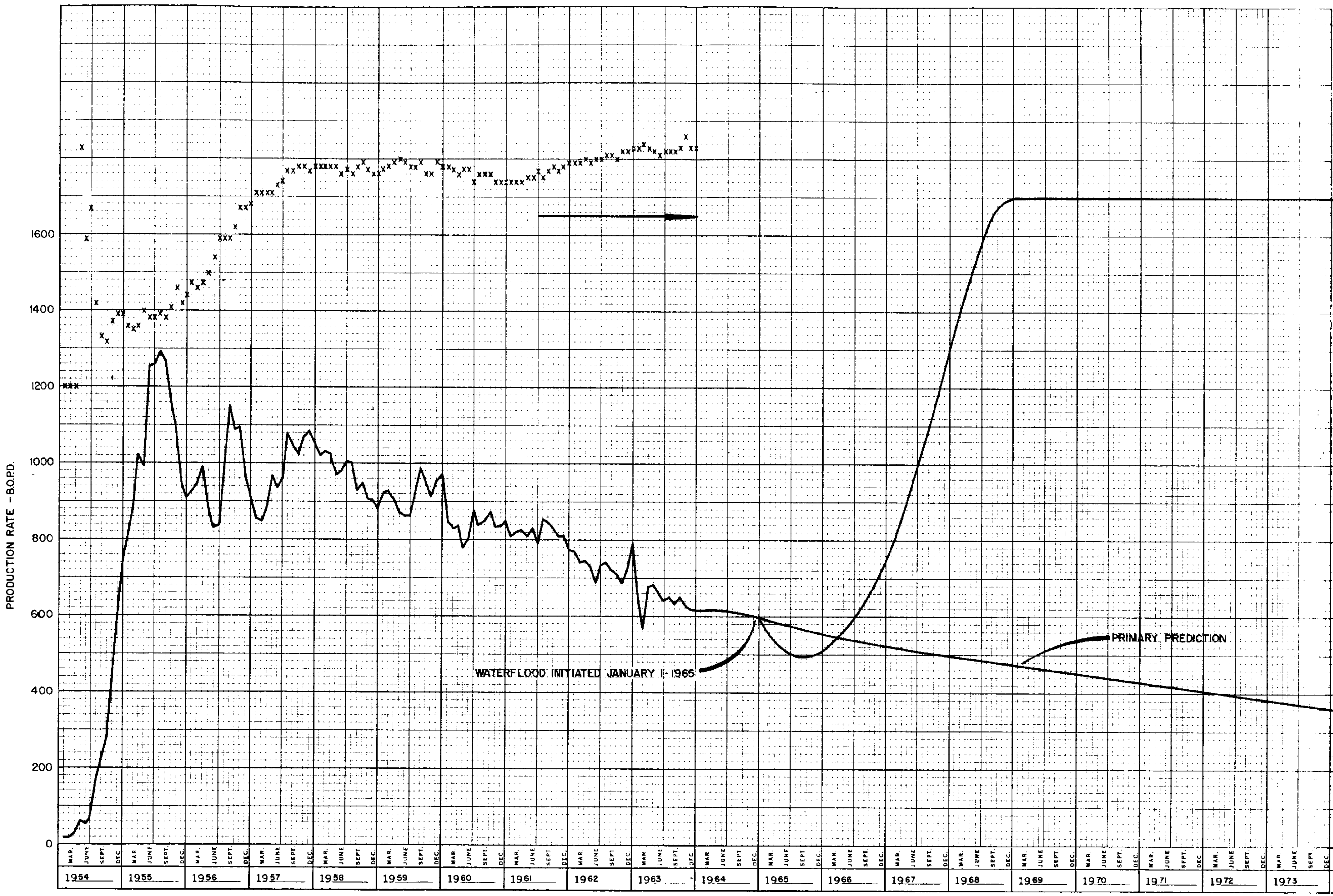
N.E. VIRDEN ROSELEA

ISOPACH OF CRINOIDAL ZONE PERMEABILITY

CONTOUR INTERVAL 5'

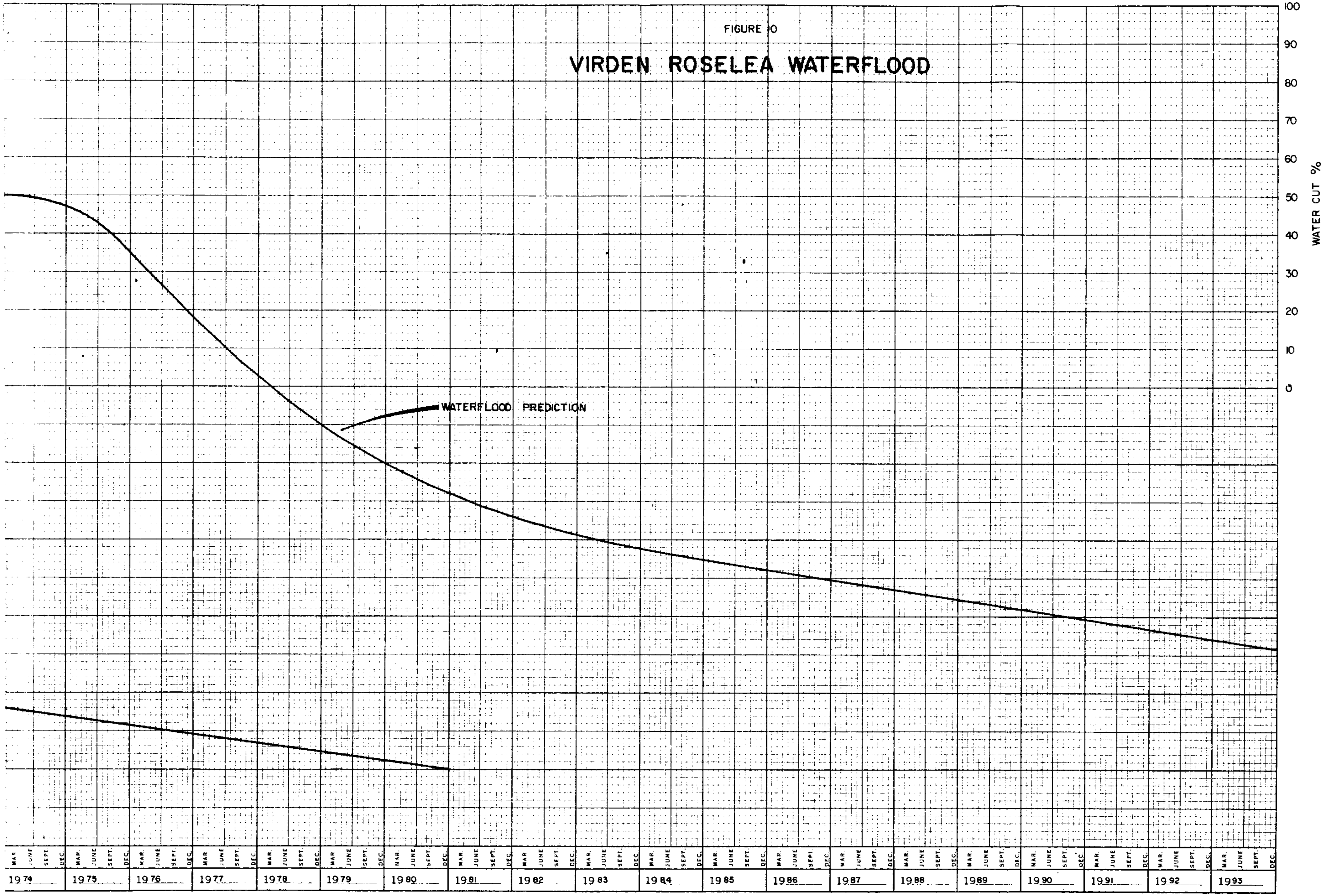
(ALL VALUES FROM CORE ANALYSIS)

FIGURE 9



PRODUCTION RATE - B.O.P.D.
0
200
400
600
800
1000
1200
1400
1600
WATERFLOOD INITIATED JANUARY 1 - 1965
PRIMARY PREDICTION
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
MAR.
JUNE
SEPT.
DEC.

FIGURE 10



VIRDEN ROSELEA WATERFLOOD
WATERFLOOD PREDICTION
WATER CUT %
100
90
80
70
60
50
40
30
20
10
0
MAR. JUNE SEPT. DEC.
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993

Figure 11

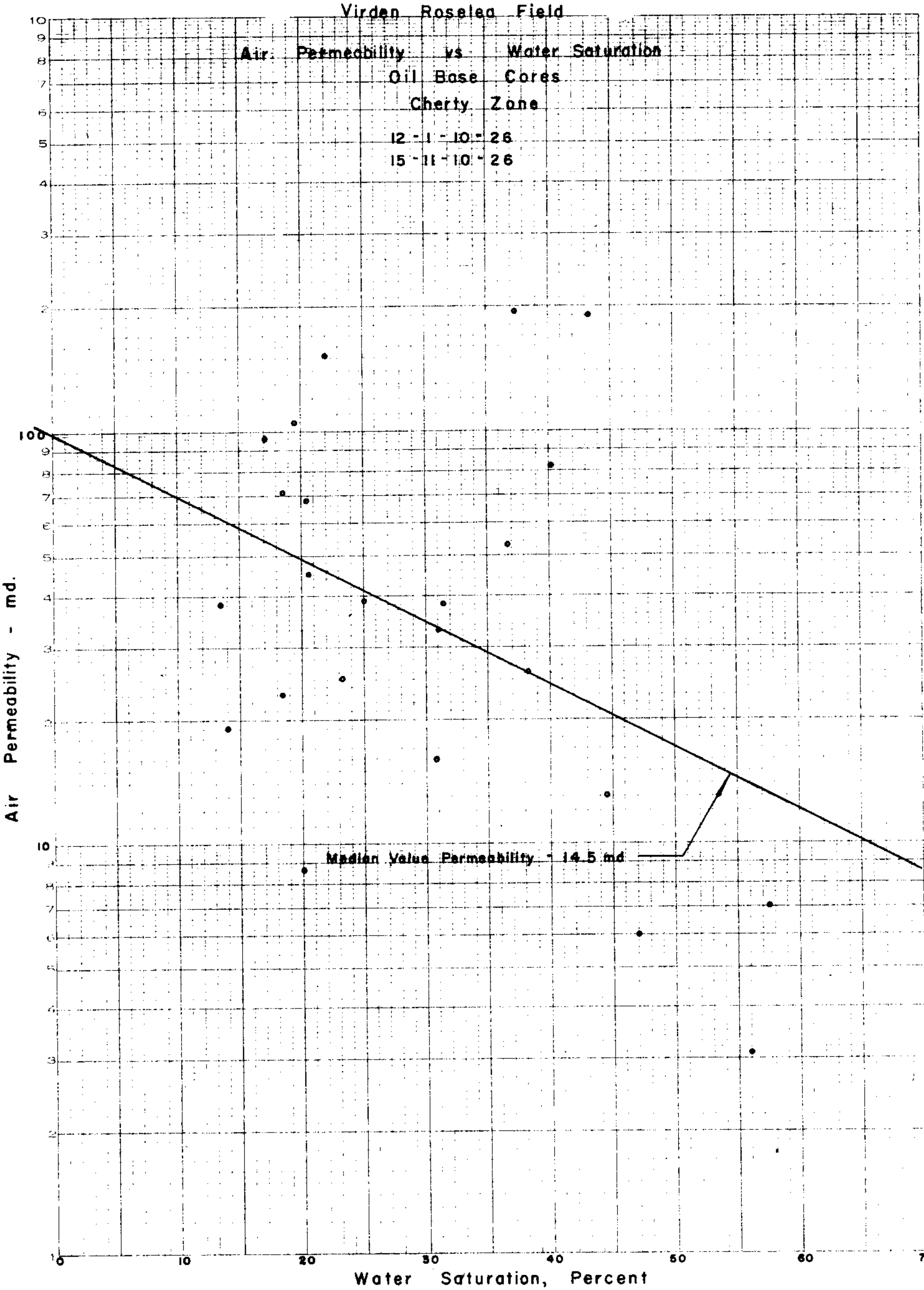

Virden Roselea Field
Air Permeability vs Water Saturation
Oil Base Cores
Cherty Zone
12 - 1 - 10 - 26
15 - 11 - 10 - 26
Median Value Permeability - 14.5 md
Air Permeability - md.
Water Saturation, Percent
0
10
20
30
40
50
60
70
1
10
100

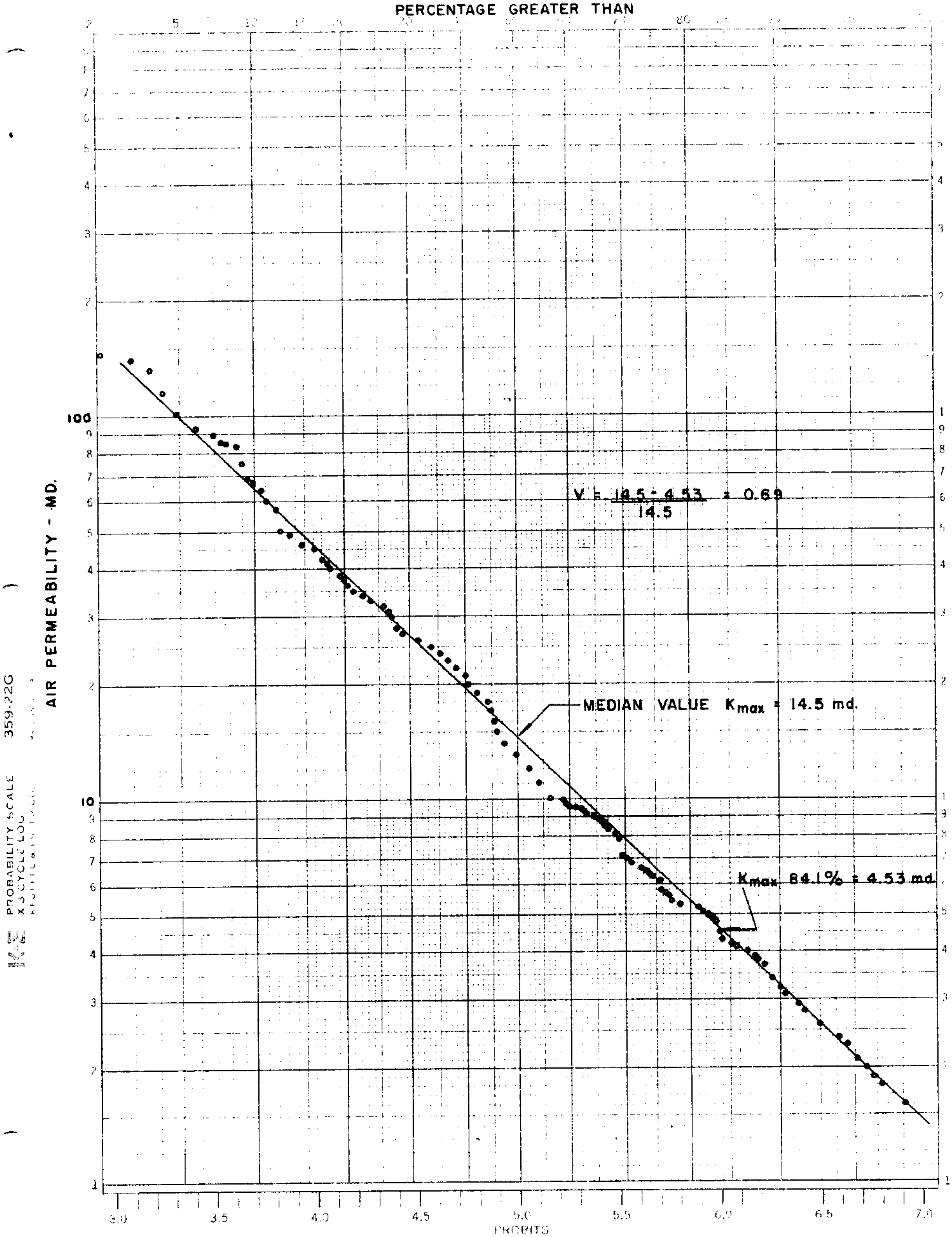
FIGURE 12

PERMEABILITY DISTRIBUTION

RDEN ROSELEA WATERFLOOD AREA

CHERTY ZONE

(14 WELLS)



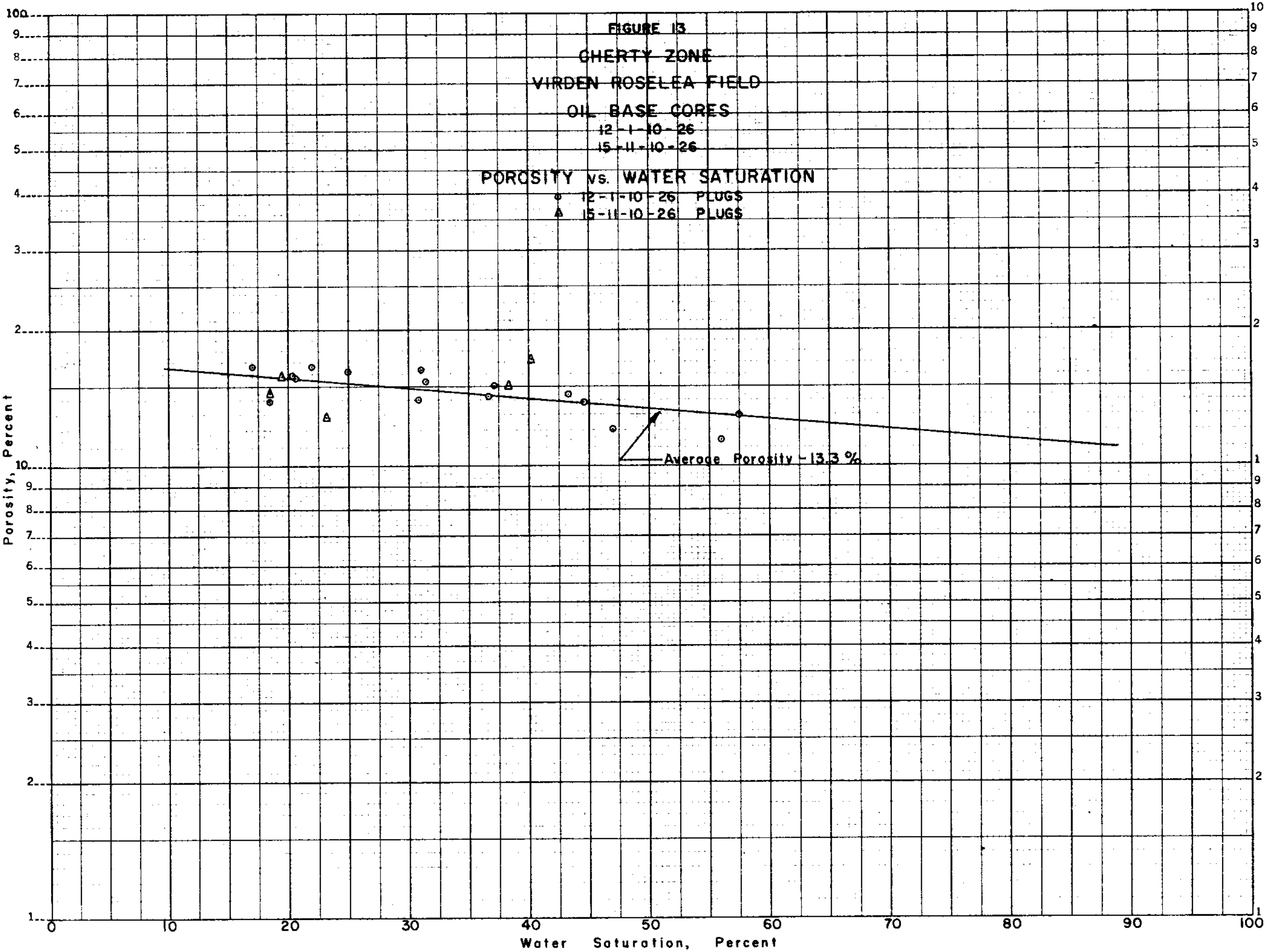


FIGURE 13
CHERTY ZONE
VIRDEN ROSELEA FIELD
OIL BASE CORES
12-1-10-26
15-11-10-26
POROSITY vs. WATER SATURATION
⊙ 12-1-10-26 PLUGS
Δ 15-11-10-26 PLUGS
Average Porosity - 13.3 %
Porosity, Percent
Water Saturation, Percent
0
10
20
30
40
50
60
70
80
90
100

FIGURE 14

PERMEABILITY DISTRIBUTION

VIRDEN ROSELEA WATERFLOOD ARE

OOLITIC ZONE
(16 WELLS)

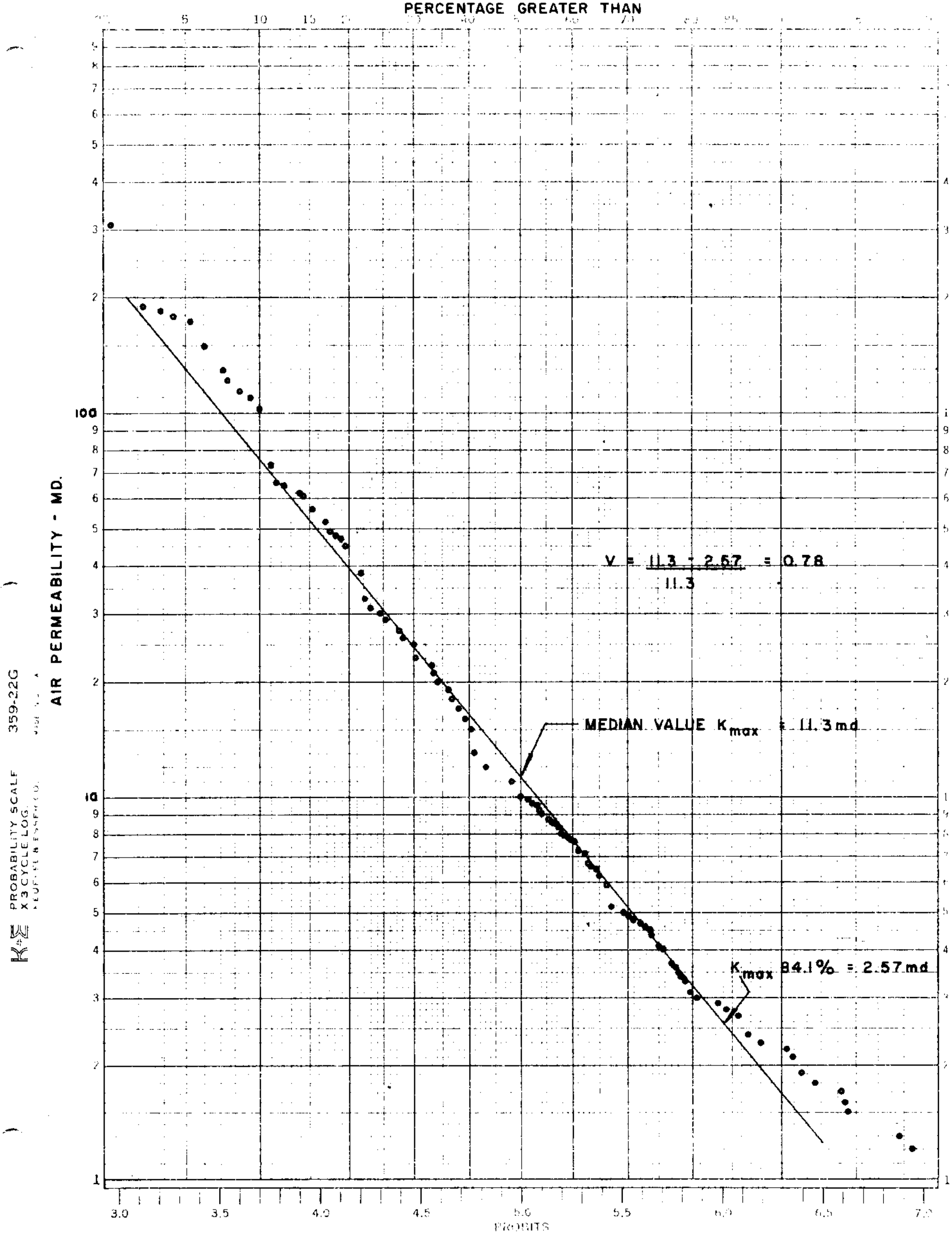
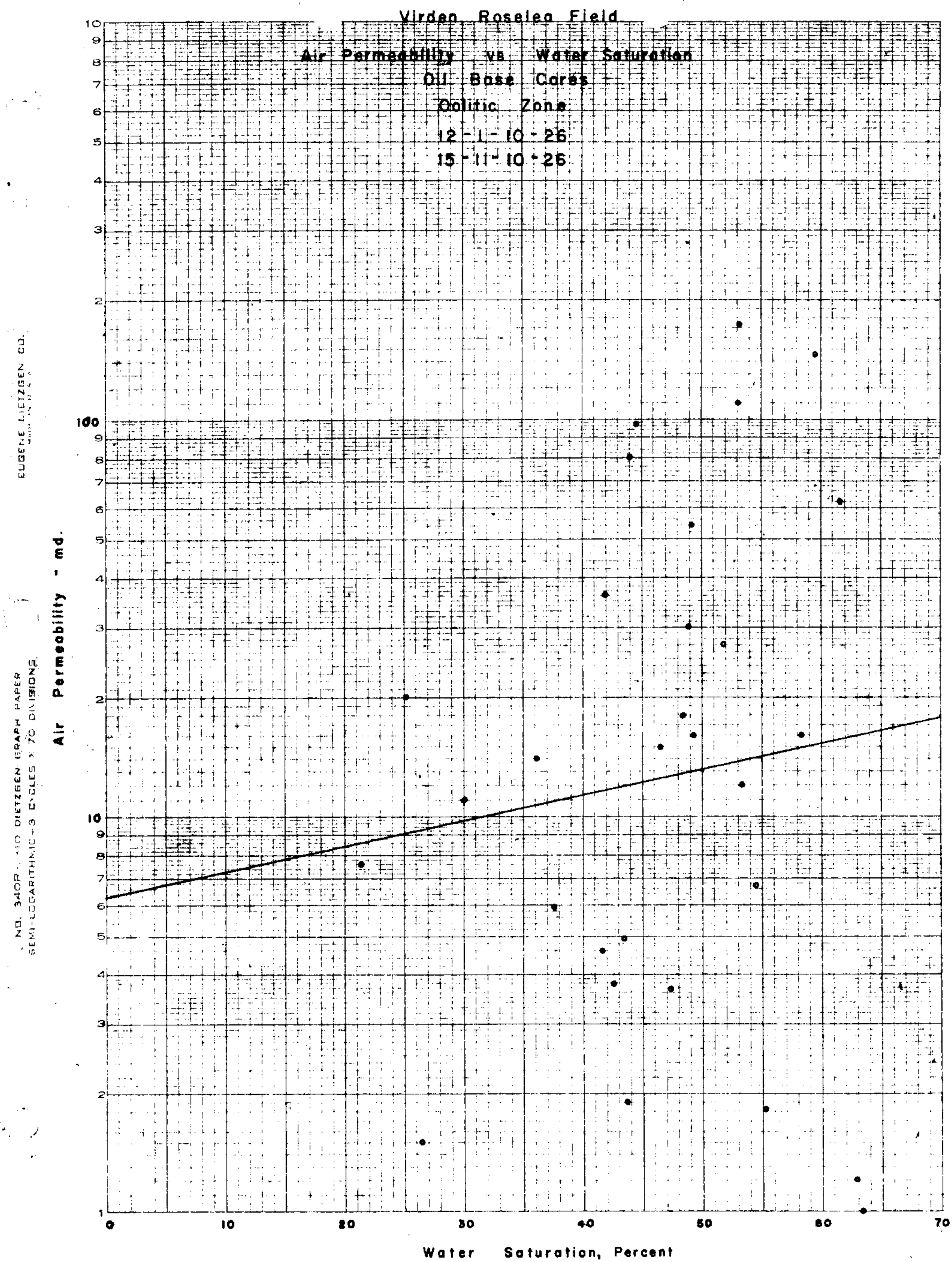
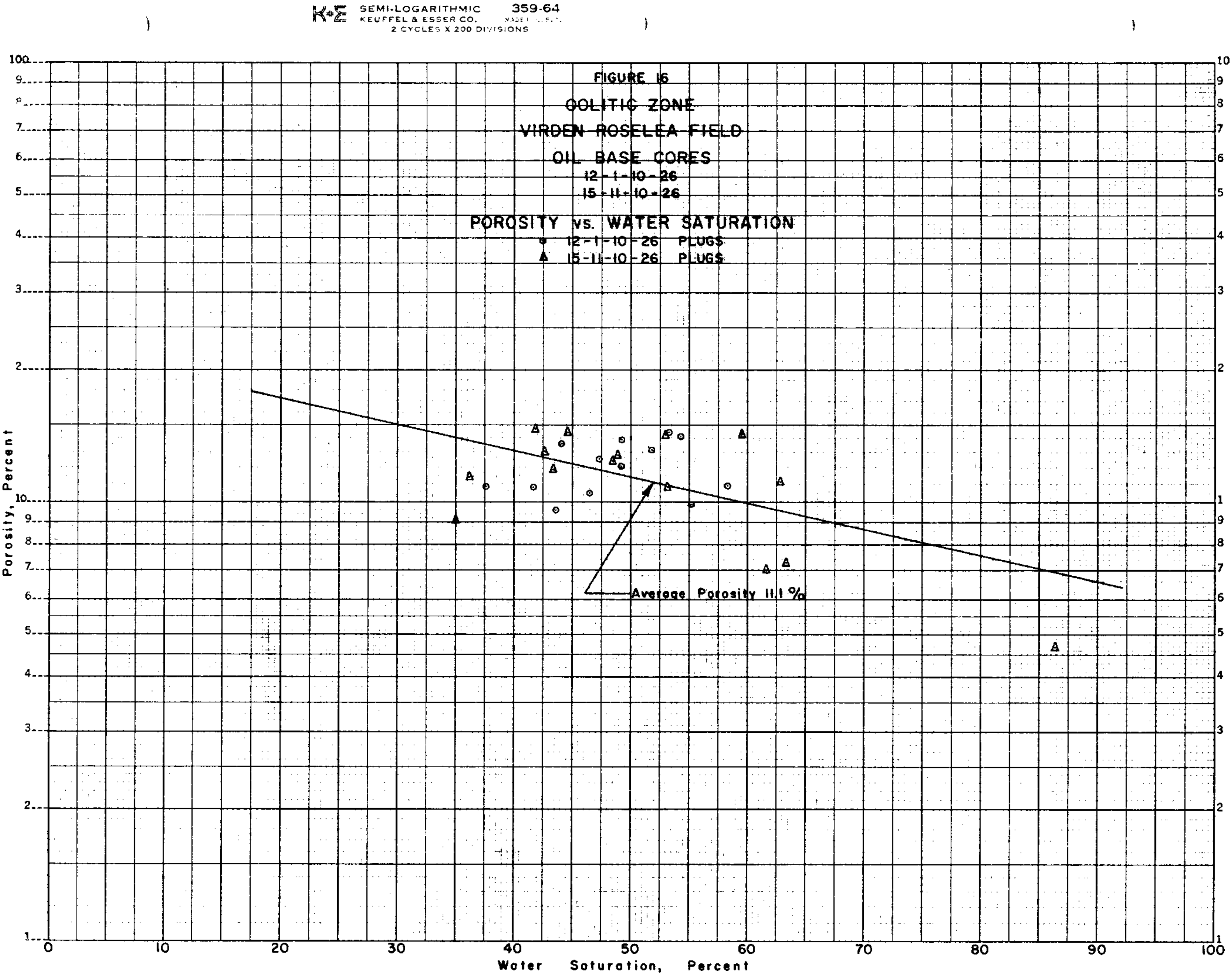


Figure 15



Virden Roselea Field
Air Permeability vs Water Saturation
Oil Base Cores
Oolitic Zone
12 - 1 - 10 - 26
15 - 11 - 10 - 26
Air Permeability - md.
Water Saturation, Percent
0
10
20
30
40
50
60
70
1
2
3
4
5
6
7
8
9
10
100
EUGENE DIETZGEN CO.
NO. 340R-110 DIETZGEN GRAPH PAPER
SEMI-LOGARITHMIC-3 CYCLES X 70 DIVISIONS



K+E SEMI-LOGARITHMIC 359-64
KEUFFEL & ESSER CO.
2 CYCLES X 200 DIVISIONS
FIGURE 16
OOLITIC ZONE
VIRDEN ROSELEA FIELD
OIL BASE CORES
12-1-10-26
15-11-10-26
POROSITY vs. WATER SATURATION
12-1-10-26 PLUGS
15-11-10-26 PLUGS
Average Porosity 11.1 %
Porosity, Percent
Water Saturation, Percent

FIGURE 17

PERMEABILITY DISTRIBUTION

VIRDEN ROSELEA WATERFLOOD AREA

SANDHILL ZONE
(12 WELLS)

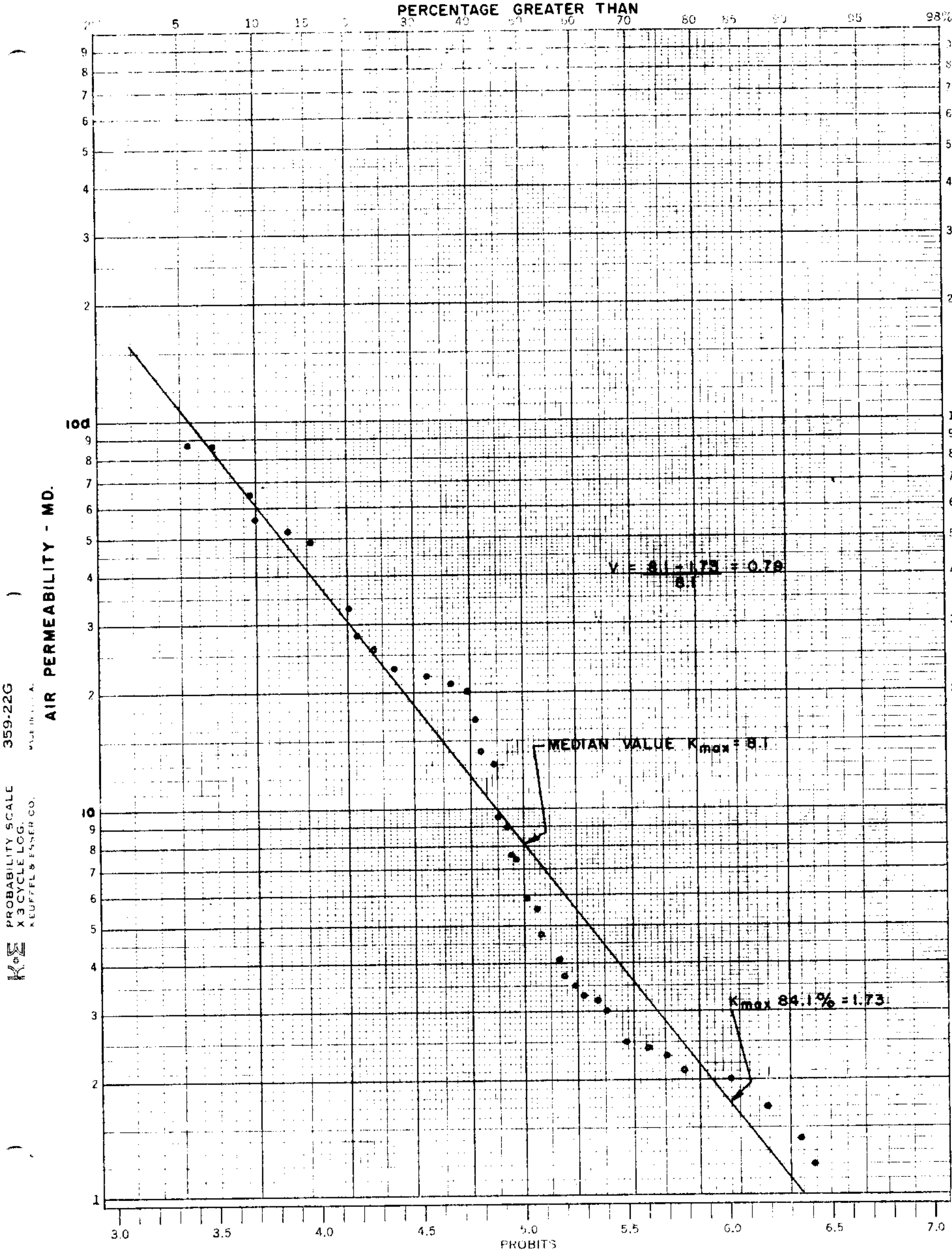


Figure 18

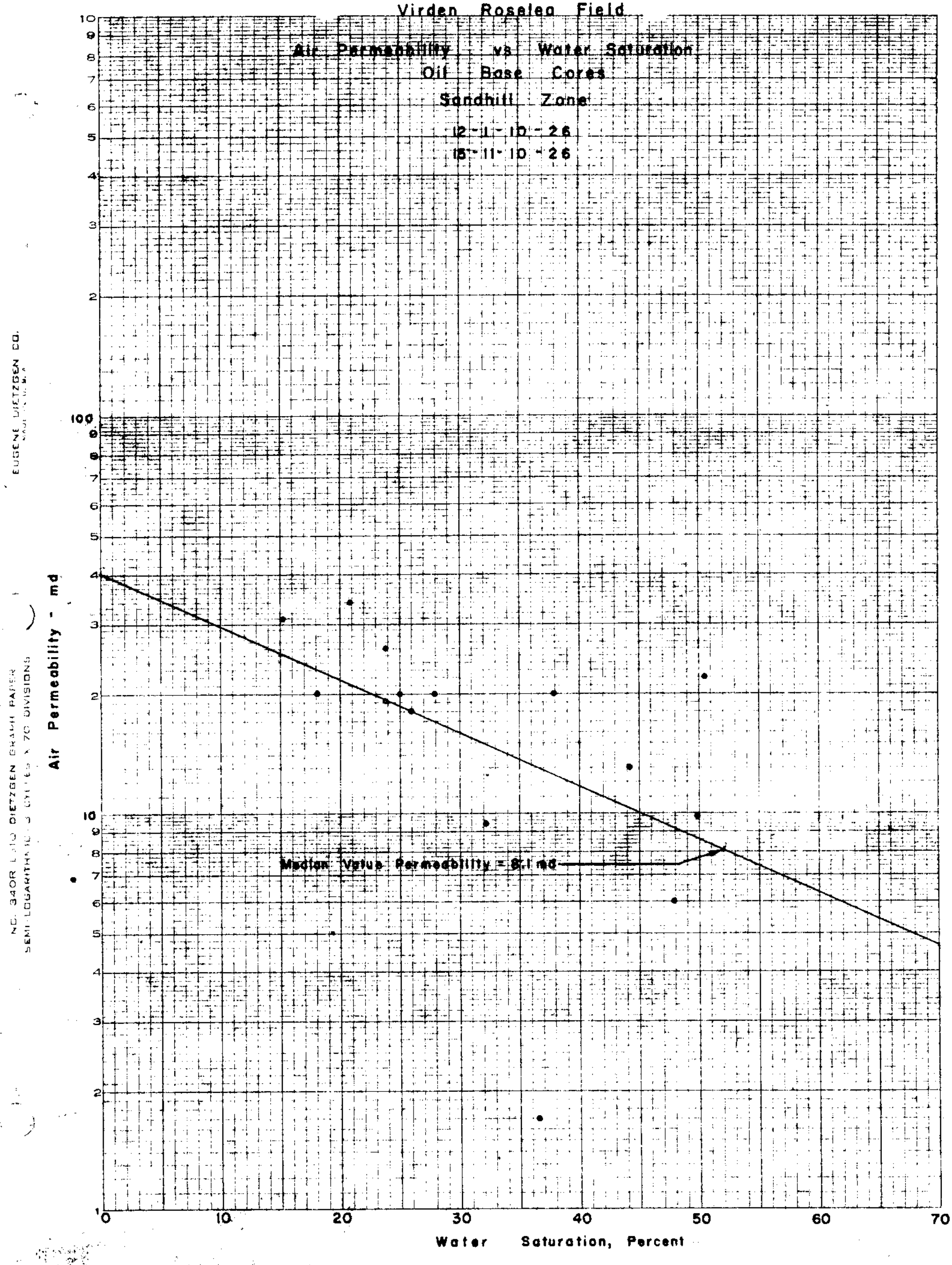
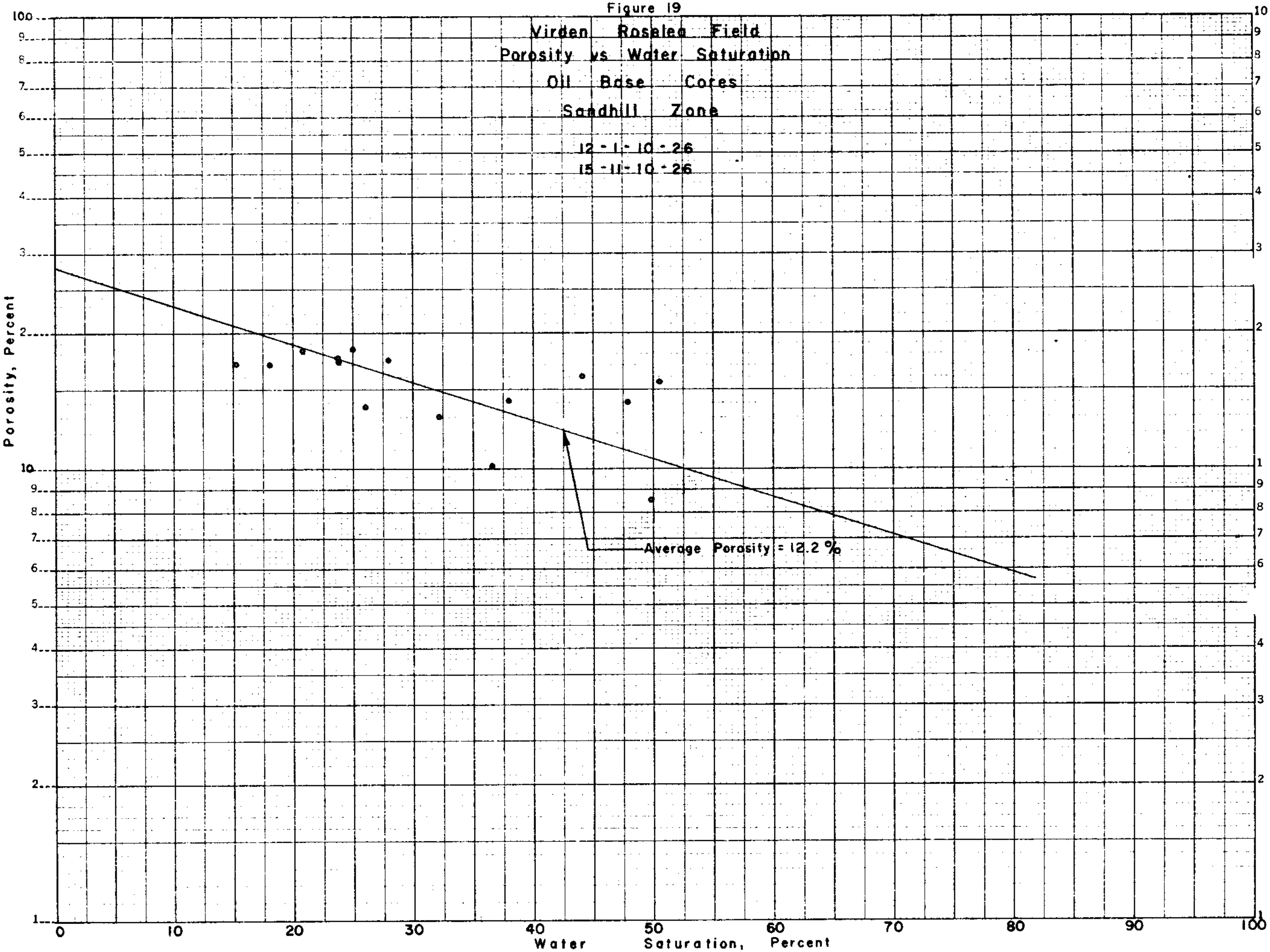

Virden Roselea Field
Air Permeability vs Water Saturation
Oil Base Cores
Sandhill Zone
12 - 11 - 10 - 26
15 - 11 - 10 - 26
Median Value Permeability = 8.1 md
Air Permeability - md
Water Saturation, Percent
0
10
20
30
40
50
60
70
EUGENE DIETZGEN CO.
NO. 340R L-10 DIETZGEN GRAPH PAPER
SEMI-LOGARITHMIC 3 CYCLES X 70 DIVISIONS

Figure 19



Virden Roselea Field
Porosity vs Water Saturation
Oil Base Cores
Sandhill Zone
12 - 1 - 10 - 26
15 - 11 - 10 - 26
Average Porosity = 12.2 %
Porosity, Percent
Water Saturation, Percent
0
10
20
30
40
50
60
70
80
90
100

FIGURE 20
PERMEABILITY DISTRIBUTION
/IRDEN ROSELEA WATERFLOOD ARE
CRINOIDAL ZONE
(13 WELLS)

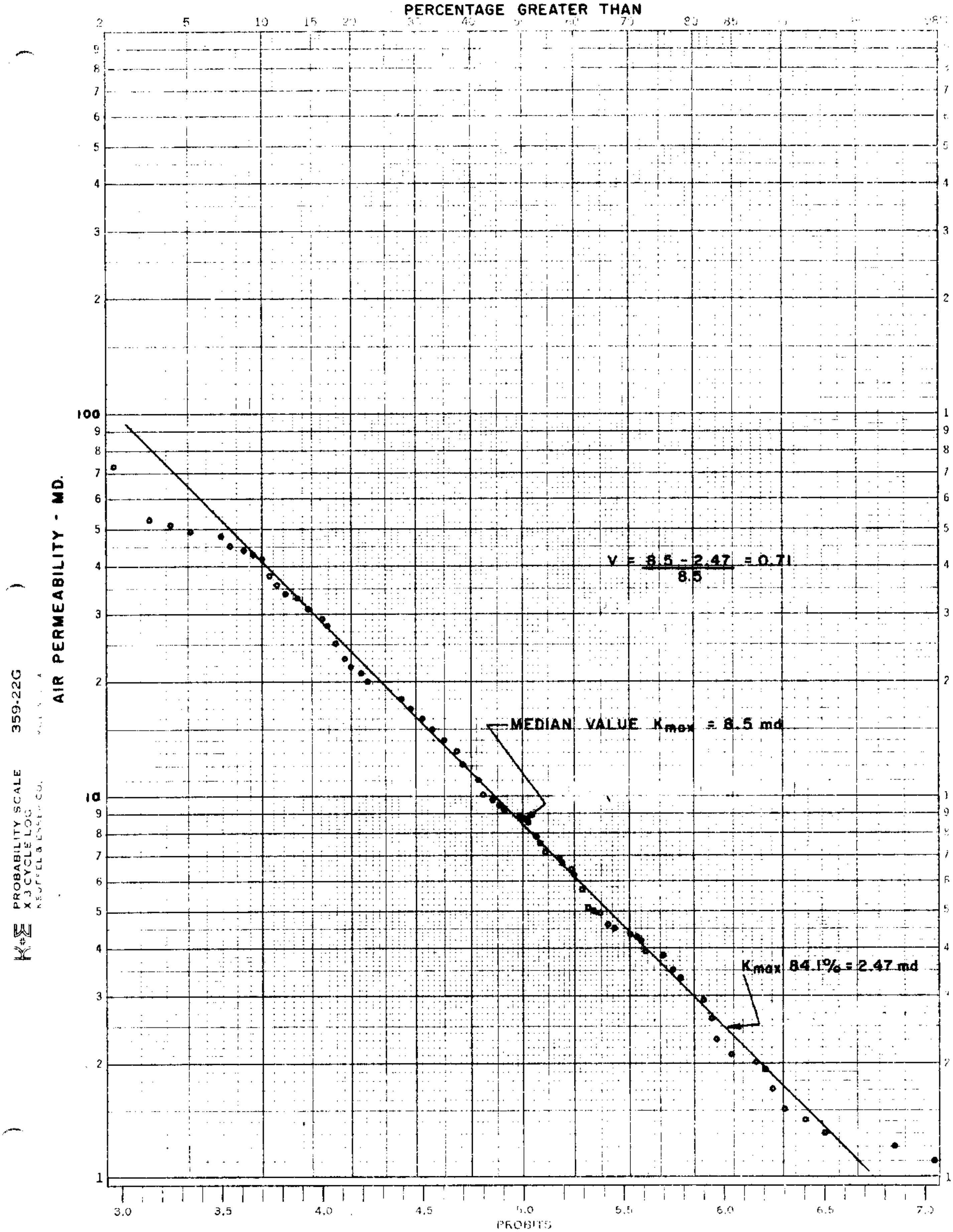
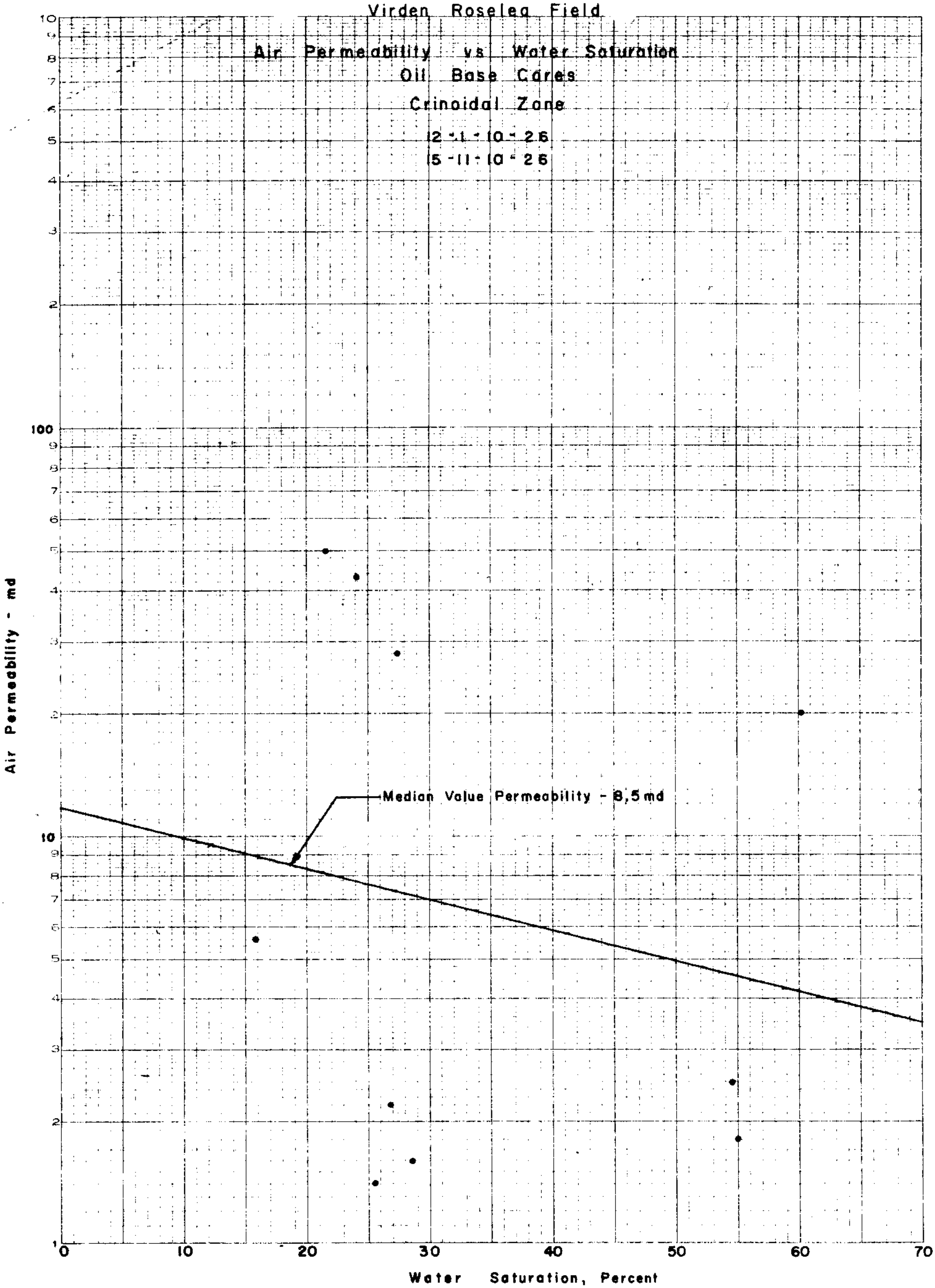


Figure 21



Virden Roselea Field
Air Permeability vs Water Saturation
Oil Base Cores
Crinoidal Zone
12-1-10-26
15-11-10-26
Median Value Permeability - 8,5 md
Air Permeability - md
Water Saturation, Percent

FIGURE 22

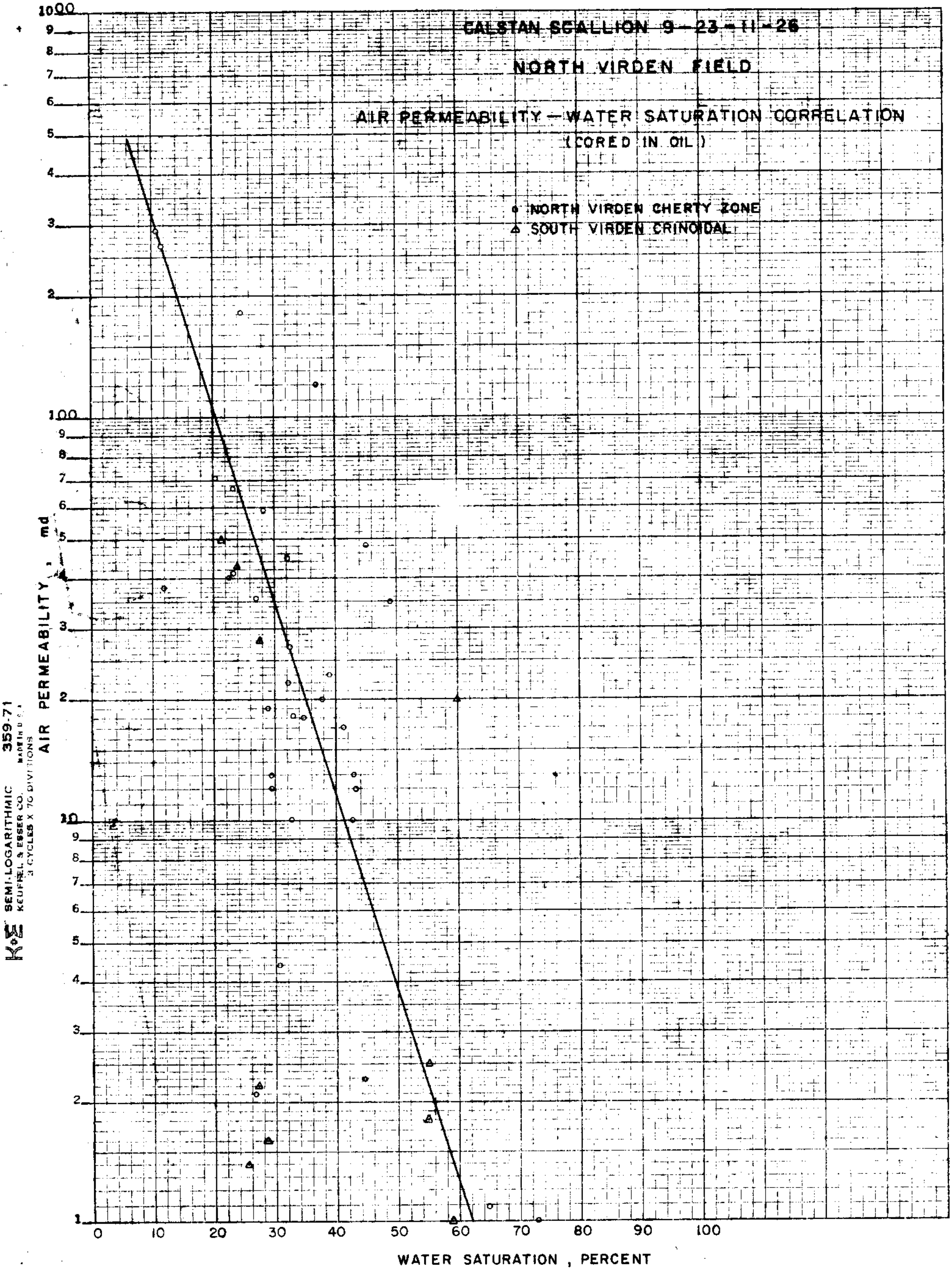
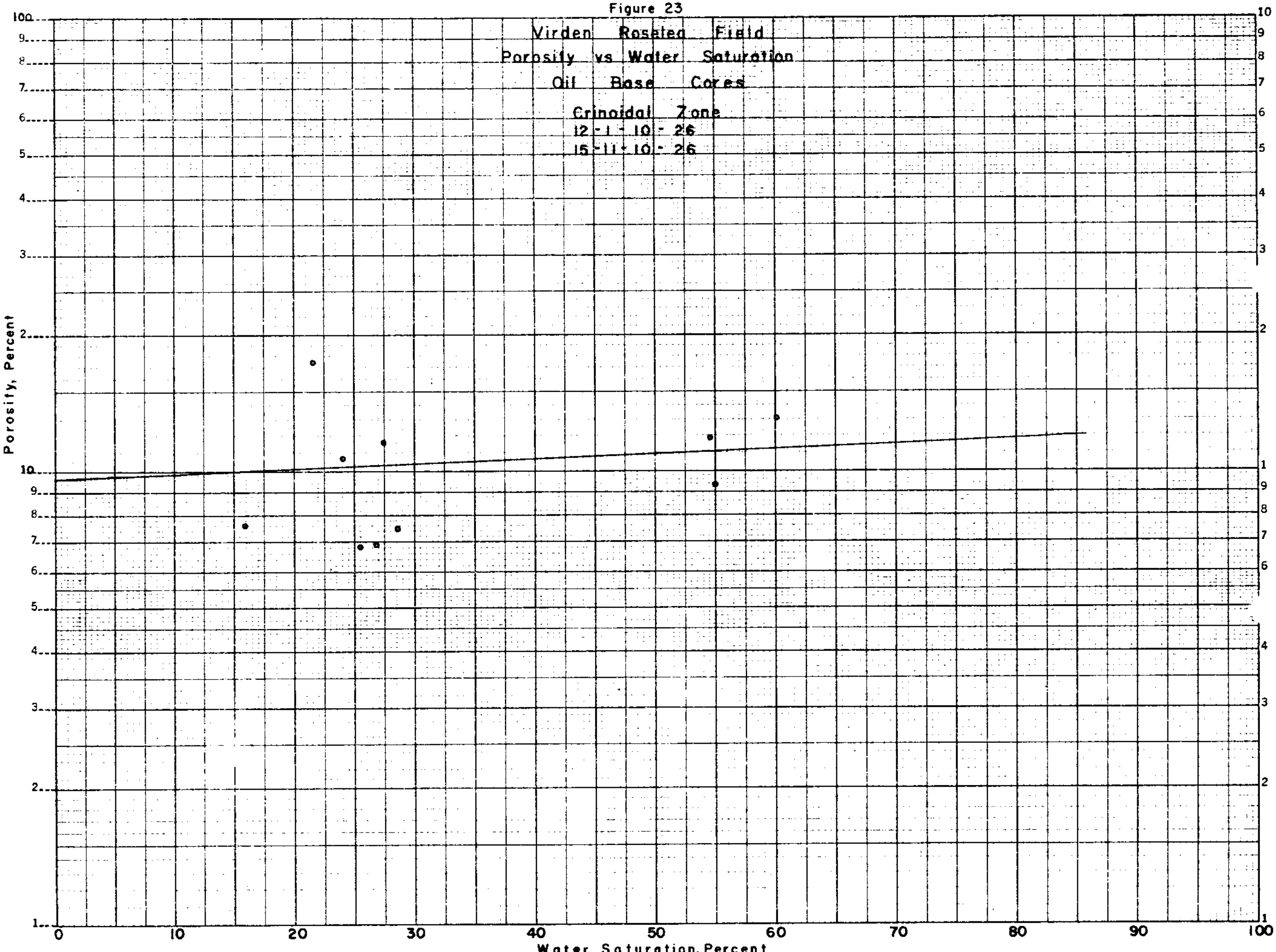

CALSTAN SCALLION 9-23-11-26
NORTH VIRDEN FIELD
AIR PERMEABILITY — WATER SATURATION CORRELATION
(CORED IN OIL)
o NORTH VIRDEN CHERTY ZONE
Δ SOUTH VIRDEN CRINOIDAL
AIR PERMEABILITY , md
WATER SATURATION , PERCENT
1000
100
10
1
0
10
20
30
40
50
60
70
80
90
100
SEMI-LOGARITHMIC 359-71
KEUFFEL & ESSER CO.
3 CYCLES X 70 DIVISIONS

Figure 23


Virden Roselea Field
Porosity vs Water Saturation
Oil Base Cores
Crinoidal Zone
12-1-10-26
15-11-10-26
Porosity, Percent
Water Saturation, Percent

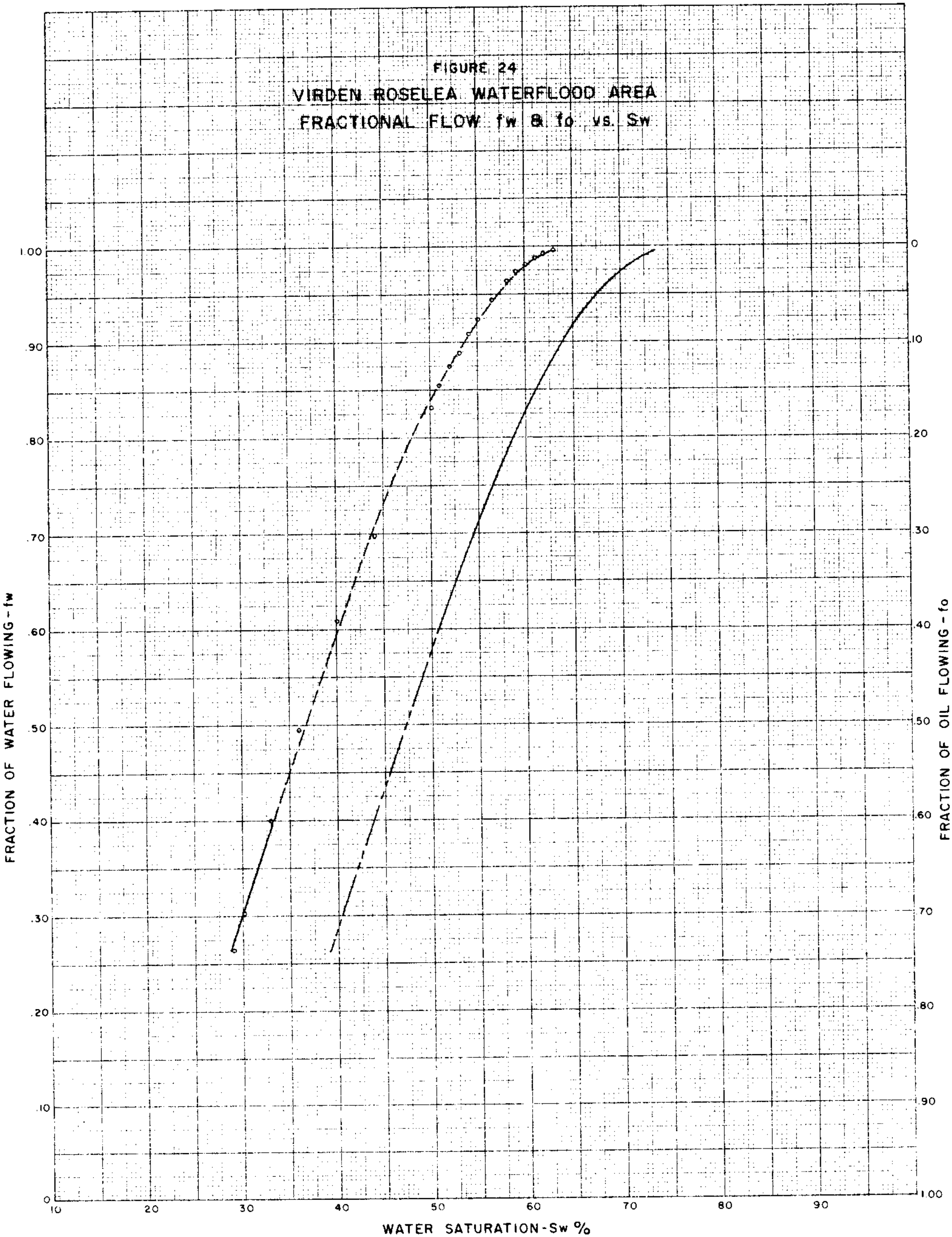


FIGURE 24
VIRDEN ROSELEA WATERFLOOD AREA
FRACTIONAL FLOW fw & fo vs. Sw
FRACTION OF WATER FLOWING - fw
FRACTION OF OIL FLOWING - fo
WATER SATURATION - Sw %
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0
10
20
30
40
50
60
70
80
90
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.00

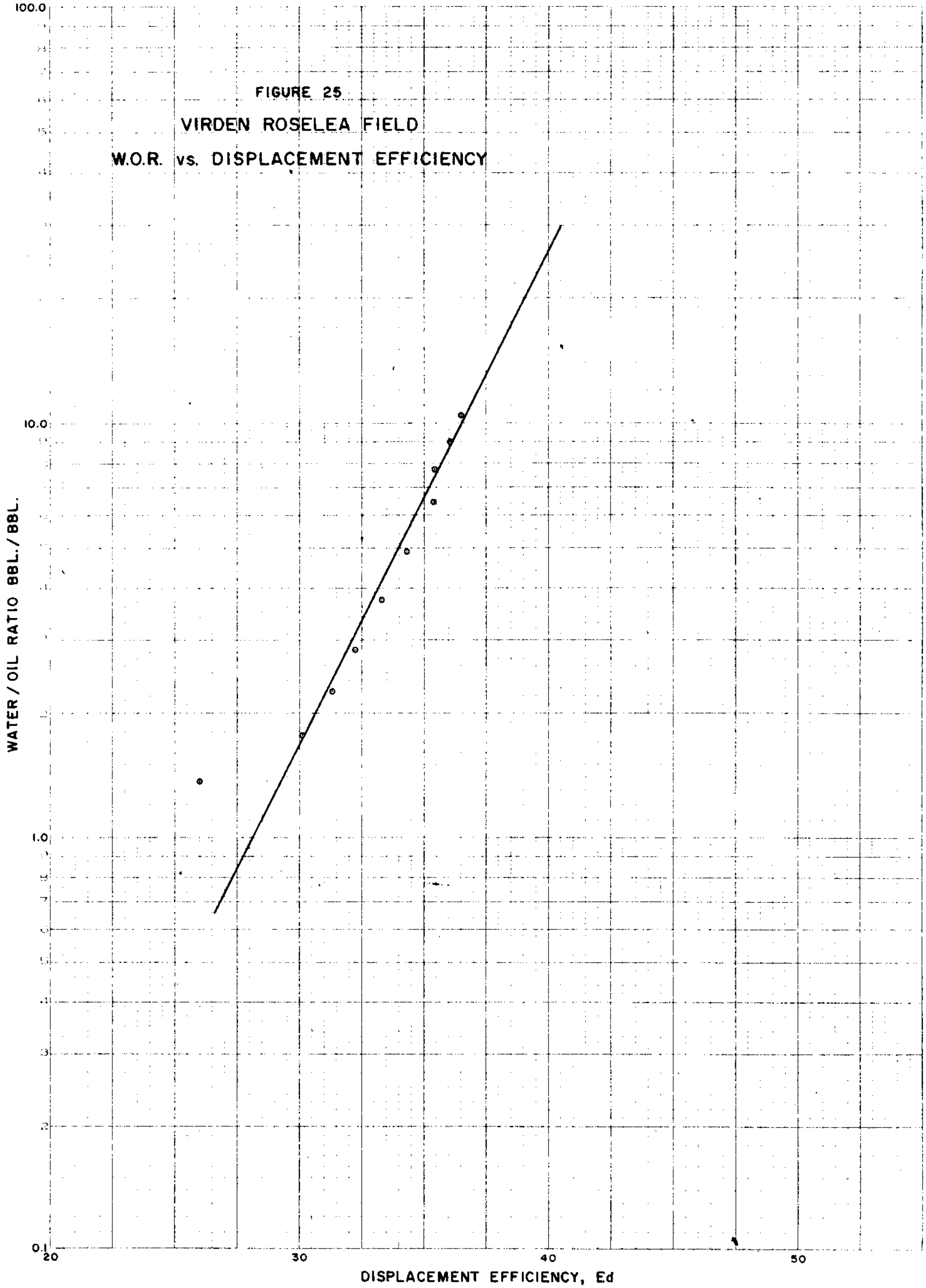
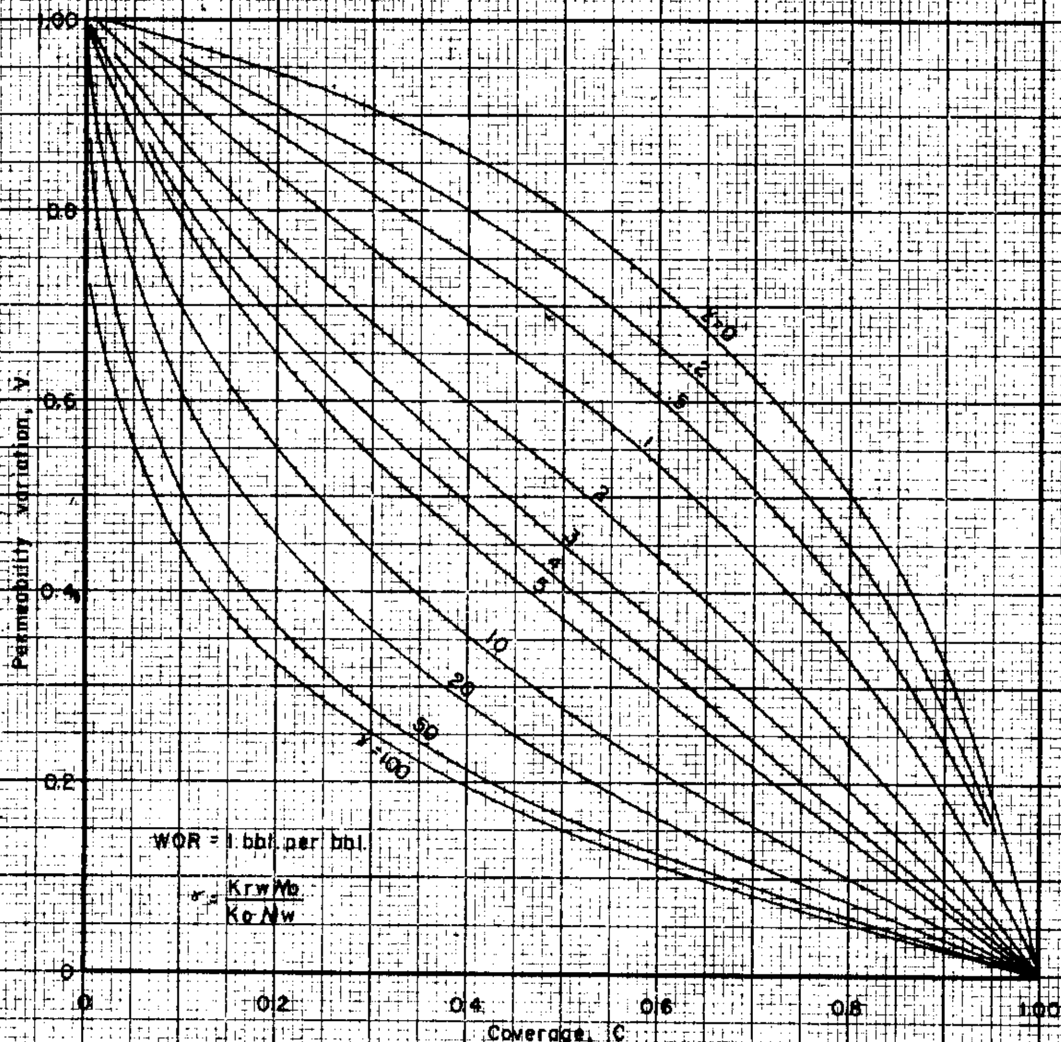


FIGURE 25
VIRDEN ROSELEA FIELD
W.O.R. vs. DISPLACEMENT EFFICIENCY
WATER / OIL RATIO BBL./BBL.
100.0
10.0
1.0
0.1
20
30
40
50
DISPLACEMENT EFFICIENCY, Ed

DYKSTRA AND PARSON'S WATER FLOOD CALCULATIONS

PERMEABILITY VARIATION VS. COVERAGE

FIG. 26

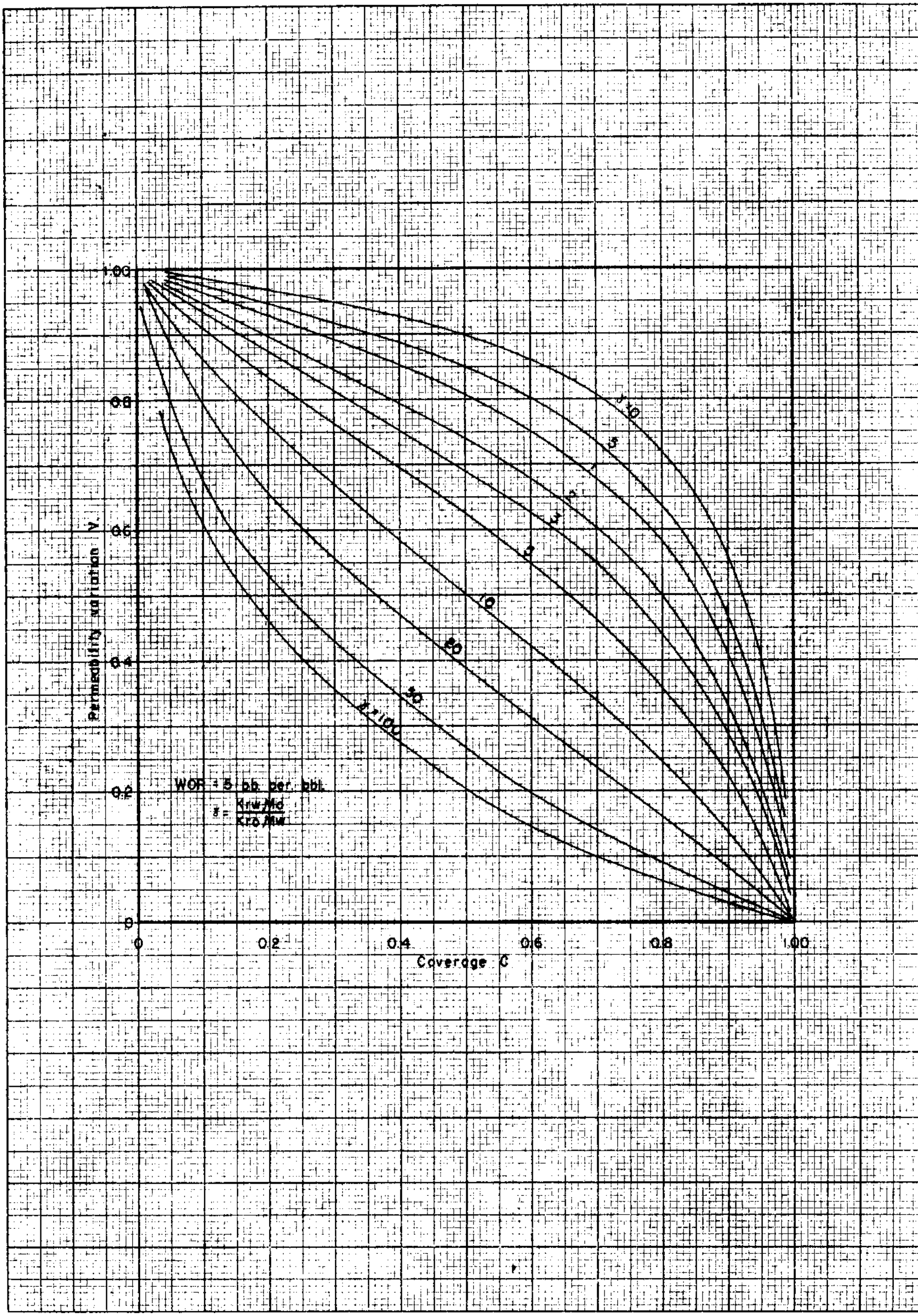


359-11 KEUFFEL & ESSER CO.
10 × 10 to the ½ inch, 5th lines accented.
MADE IN U.S.A.

DYKSTRA AND PARSON'S WATER FLOOD CALCULATIONS

PERMEABILITY VARIATION VS. COVERAGE

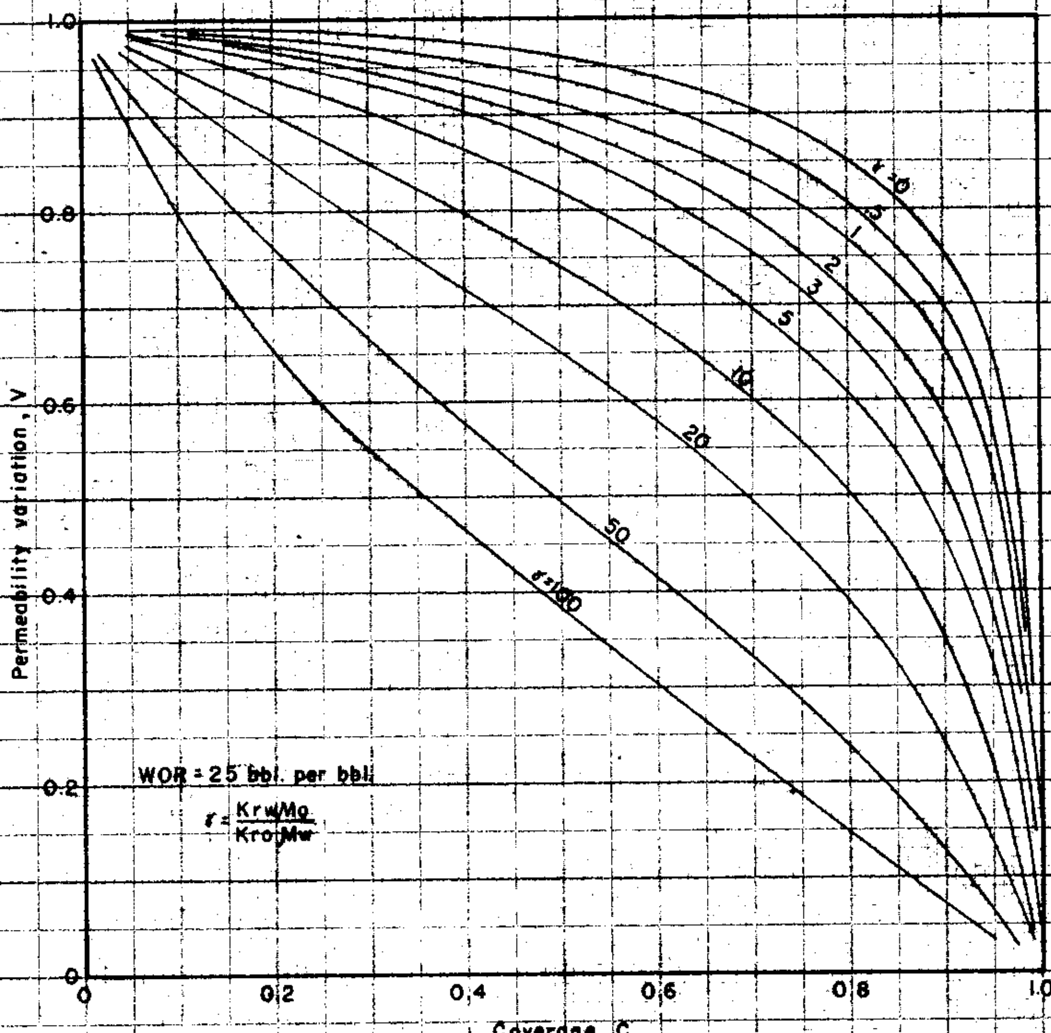
FIG. 27



DYKSTRA AND PARSONS' WATER FLOOD CALCULATIONS

PERMEABILITY VARIATION VS. COVERAGE

FIG. 28



DYKSTRA AND PARSON'S WATER FLOOD CALCULATIONS

FIG. 29

PERMEABILITY VARIATION VS. COVERAGE

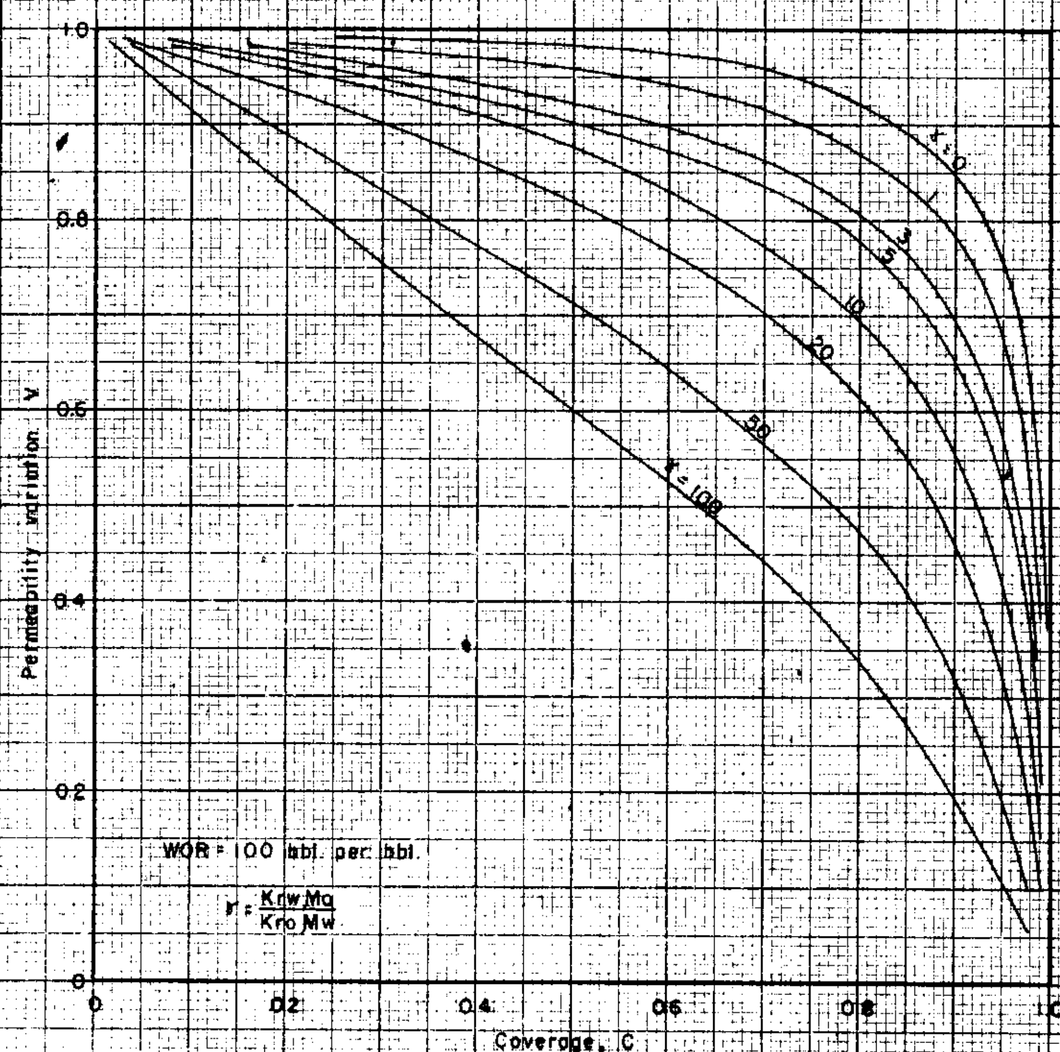


FIGURE 30

NORTH VIRDEN SCALLION

OIL PERMEABILITY vs. AIR PERMEABILITY

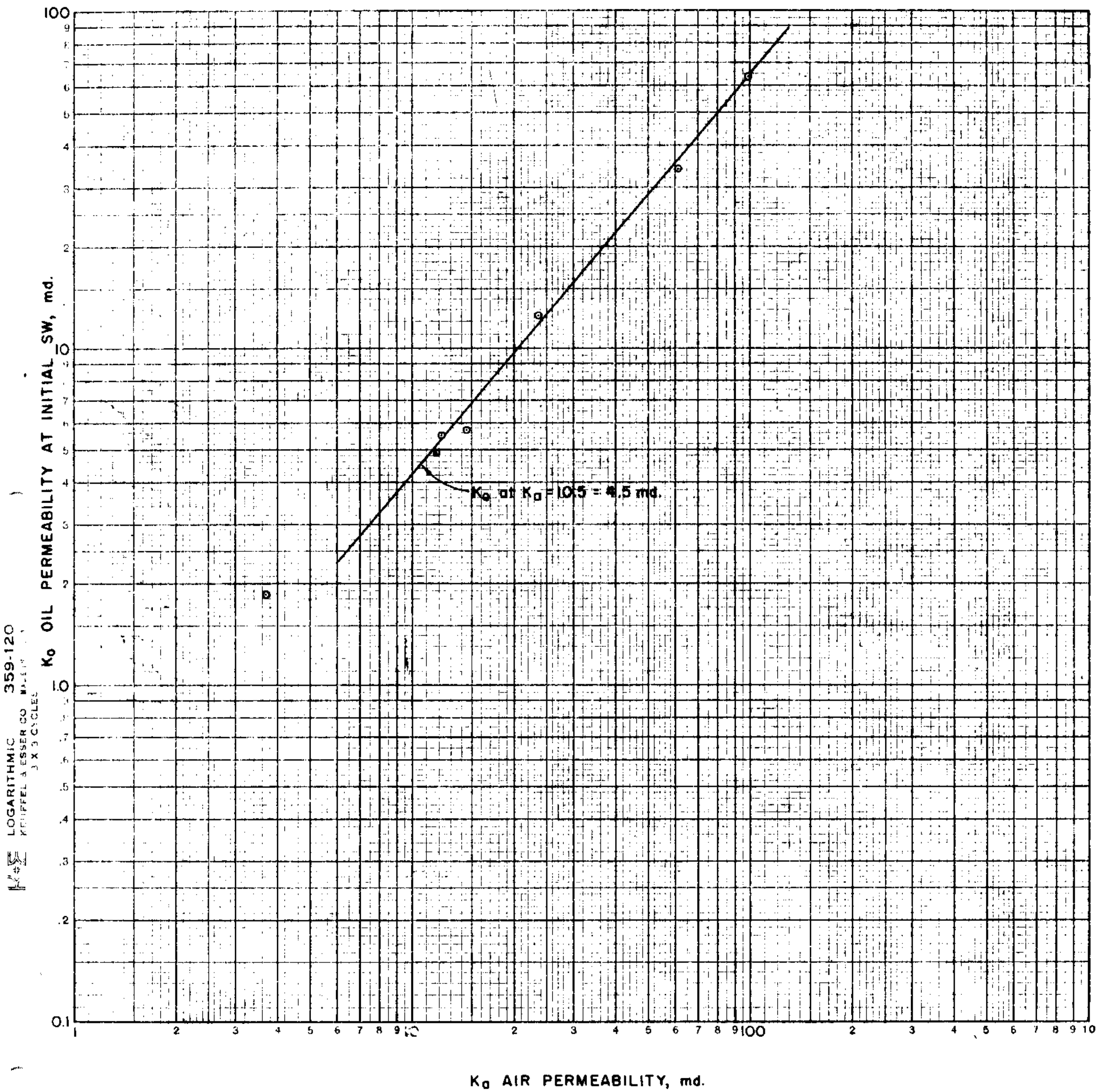
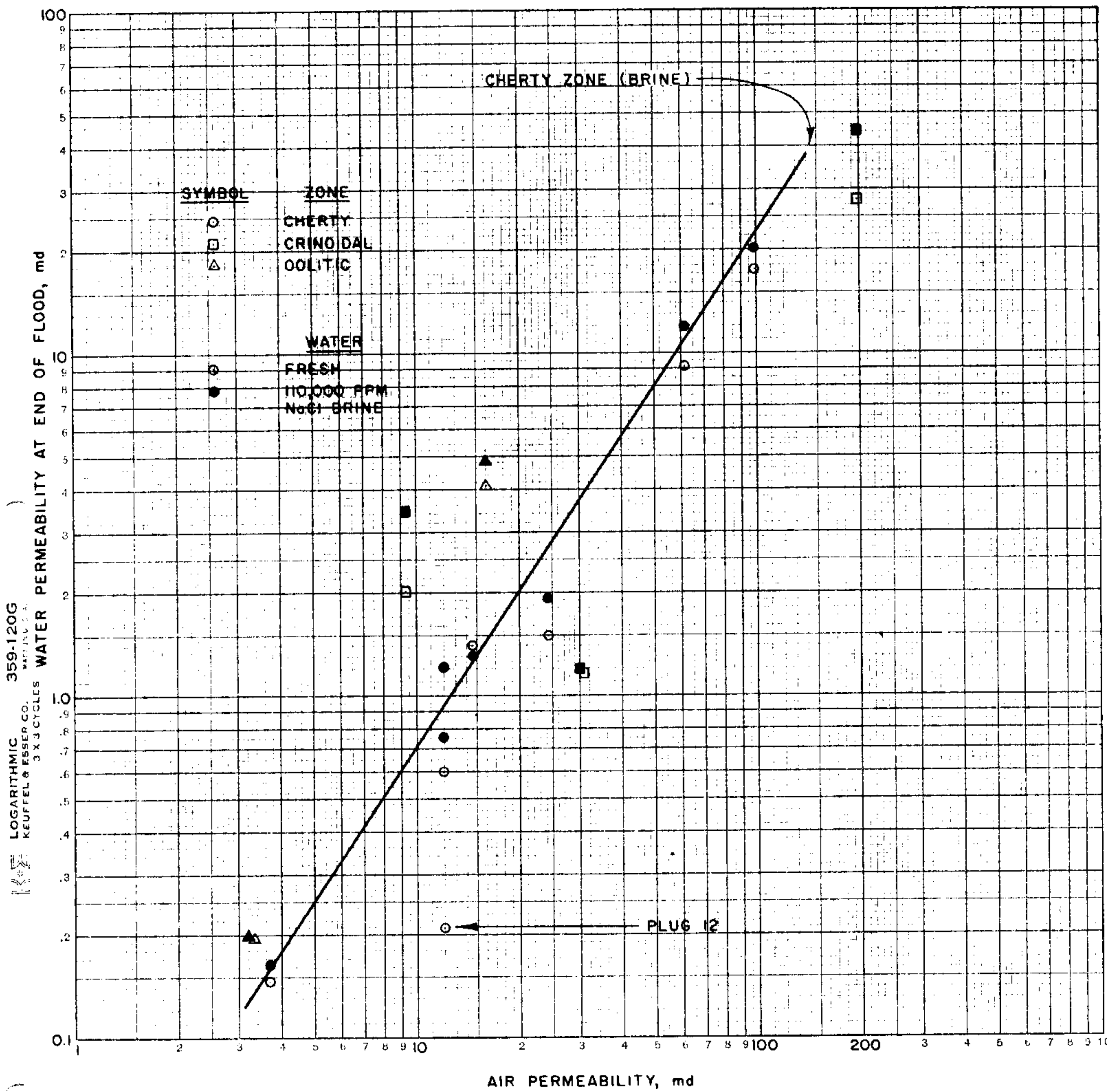


FIGURE 31

NORTH VIRDEN SCALLION

BRINE AND FRESH WATER PERMEABILITIES AT END OF FLOOD vs. AIR PERMEABILITY



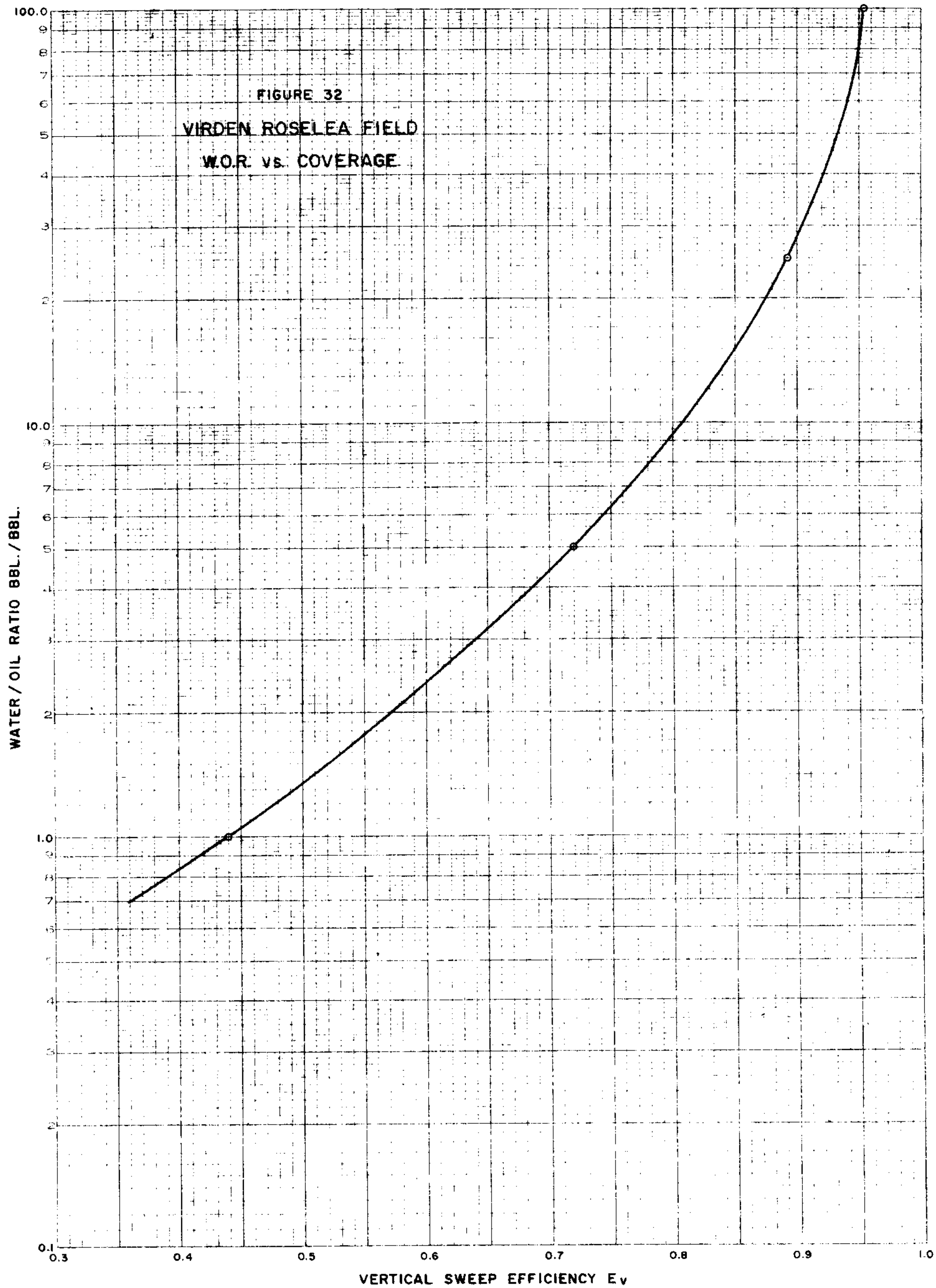


FIGURE 32
VIRDEN ROSELEA FIELD
W.O.R. vs. COVERAGE
WATER / OIL RATIO BBL./BBL.
VERTICAL SWEEP EFFICIENCY Ev
100.0
10.0
1.0
0.1
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

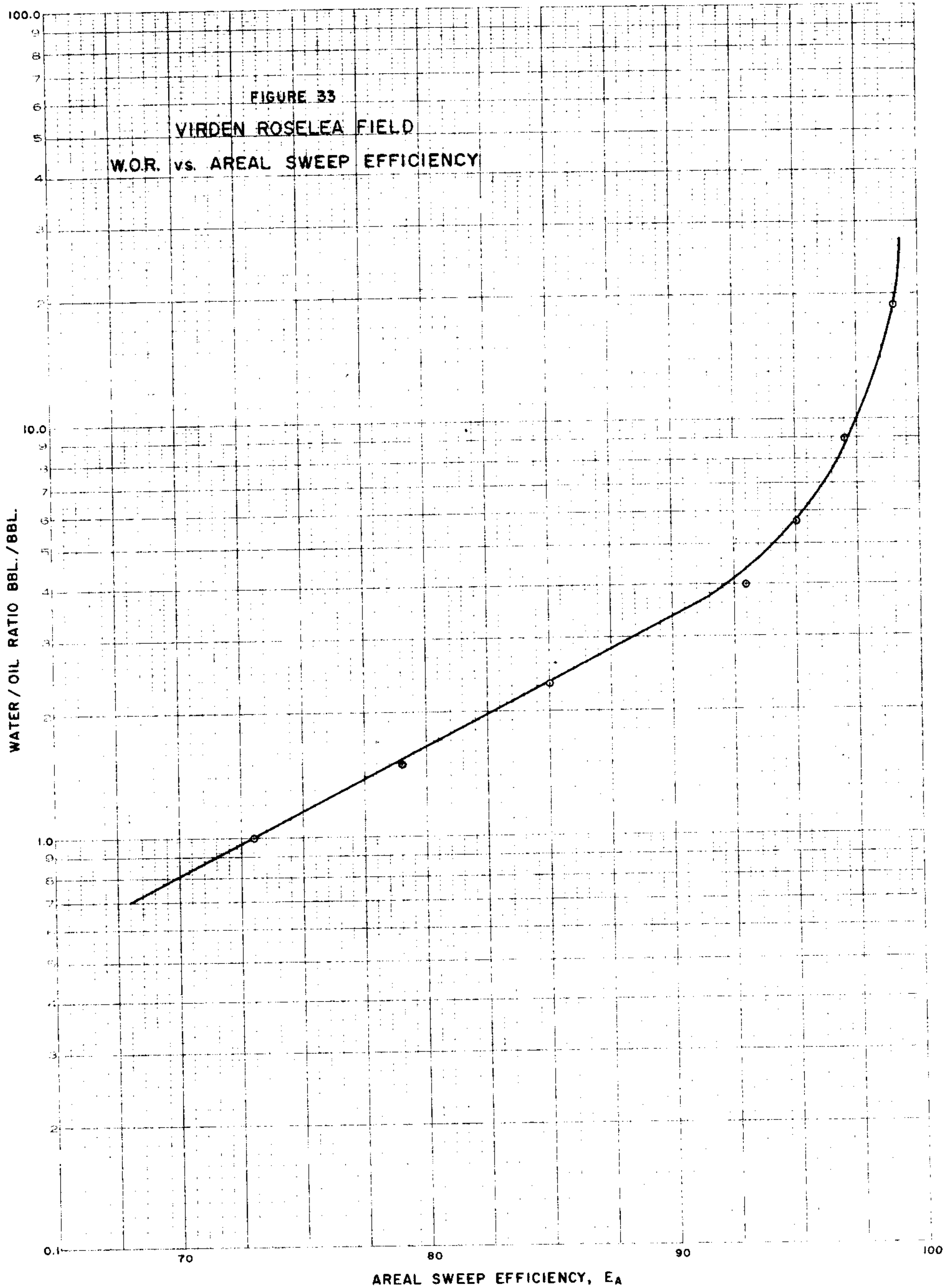


FIGURE 33
VIRDEN ROSELEA FIELD
W.O.R. vs. AREAL SWEEP EFFICIENCY
WATER / OIL RATIO BBL./BBL.
100.0
10.0
1.0
0.1
70
80
90
100
AREAL SWEEP EFFICIENCY, E_A

FIGURE 34

VIRDEN ROSELEA FIELD

WATER FLOOD RECOVERY

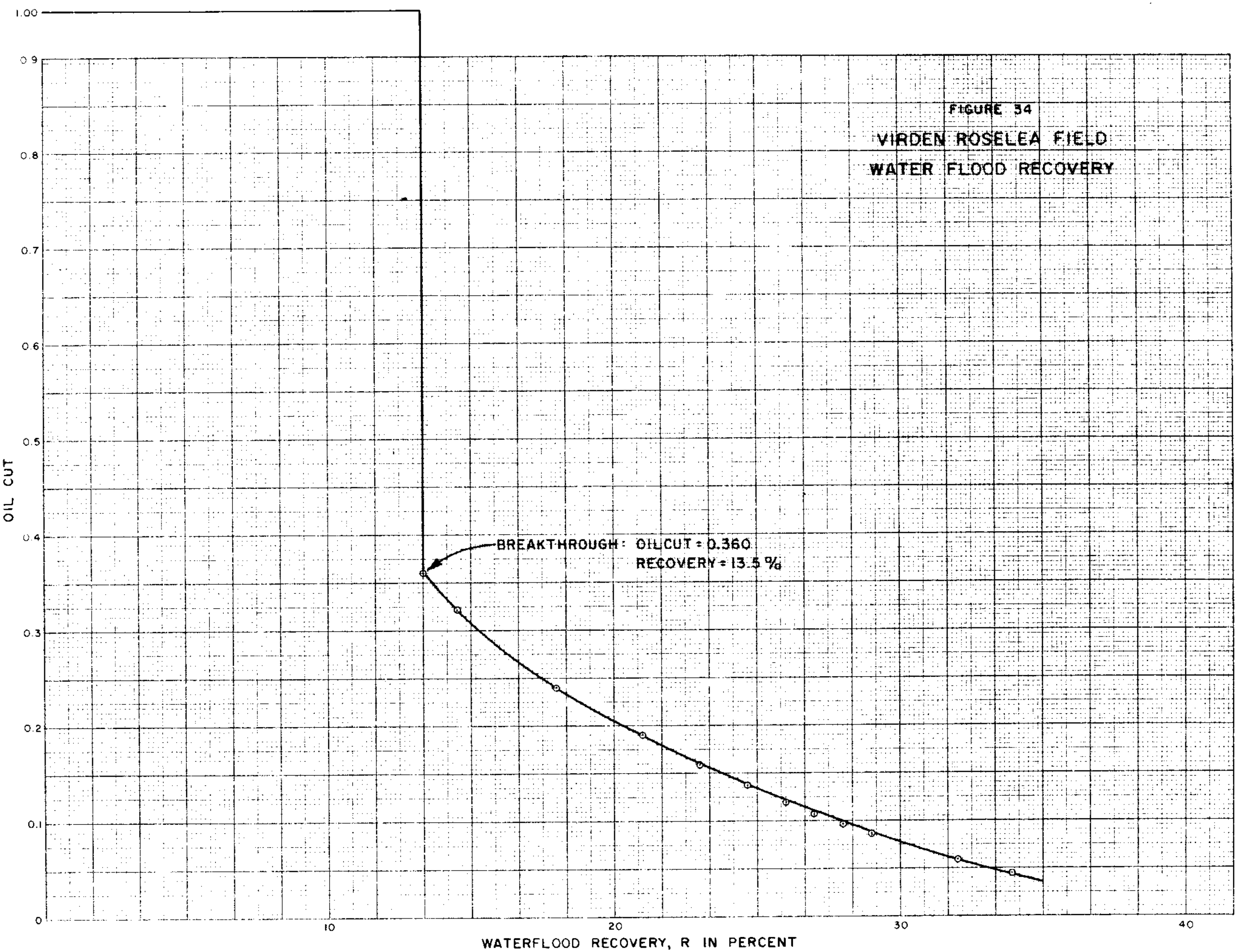


TABLE I

PROPOSED VIRDEN ROSELEA WATERFLOOD
SUMMARY OF
PROPOSED INJECTION WELL INJECTIVITIES

Well	Injectivity (BWPD)
5-28-10-25	108
7-29-10-25	145
5-29-10-25	215
* 7-30-10-25	544
5-30-10-25	278
*13-24-10-26	610
15-24-10-26	307
5-25-10-26	165
7-25-10-26	309
13-25-10-26	225
15-25-10-26	292
*13-20-10-25	190
*15-20-10-25	90
13-21-10-25	102
TOTAL	3580

* Wells with core analysis.

TABLE II

PROPOSED VIRDEN ROSELEA WATERFLOOD
PREDICTION OF WATERFLOOD RECOVERY
IN WELGE'S METHOD
(Soi = 0.480)

Sw	S_{AVG} (From Fig.24)	SoR $SoR=1-S_{AVG}$	E_d $E_d=\frac{Soi-SoR}{Soi}$	fo (From Fig.24)	RES.WOR $=\frac{1-fo}{fo}$
0.50	0.645	0.355	0.260	0.420	1.38
0.52	0.665	0.335	0.302	0.363	1.75
0.54	0.670	0.330	0.313	0.310	2.23
0.56	0.675	0.325	0.323	0.260	2.85
0.58	0.680	0.320	0.333	0.210	3.76
0.60	0.685	0.315	0.344	0.170	4.88
0.62	0.690	0.310	0.354	0.135	6.41
0.64	0.693	0.307	0.360	0.100	9.00
0.645	0.695	0.305	0.365	0.087	10.50

TABLE III

PROPOSED VIRDEN ROSELLA WATERFLOOD
COMBING E_d, E_v and E_a TO PREDICT FLOOD BEHAVIOR

Res. WOR	E_d	E_v	E_a	Recovery	Stock Tank WOR (B x WOR)	Stock Tank Oil Cut $\frac{1}{1 + WOR}$
1.00	0.262	0.440	0.730	0.084	1.05	0.488
1.50	0.295	0.520	0.787	0.121	1.58	0.388
1.75	0.302	0.545	0.808	0.133	1.84	0.360
1.90	0.305	0.563	0.820	0.141	2.00	0.333
2.00	0.307	0.570	0.828	0.145	2.10	0.323
3.00	0.322	0.640	0.884	0.182	3.15	0.241
4.00	0.332	0.685	0.922	0.209	4.20	0.192
5.00	0.340	0.717	0.940	0.229	5.25	0.160
6.00	0.347	0.744	0.953	0.246	6.30	0.137
7.00	0.352	0.765	0.962	0.259	7.35	0.120
8.00	0.357	0.782	0.968	0.270	8.40	0.106
9.00	0.362	0.796	0.972	0.280	9.45	0.096
10.00	0.365	0.815	0.976	0.291	10.50	0.087
15.00	0.380	0.850	0.987	0.319	15.75	0.060
20.00	0.390	0.876	0.992	0.339	21.00	0.045