CHEVRON STANDARD LIMITED

PRODUCING DEPARTMENT

CALGARY DIVISION

FEASIBILITY OF SECONDARY RECOVERY
WEST BUTLER FIELD

December 1971

S. N. Borowski

TABLE OF CONTENTS

LIST OF FIGURES

SUMMARY

1. Purpose

The purpose of this report was to investigate the feasibility of secondary recovery in the West Butler Field.

2. Conclusions

a) The estimated original oil-in-place from volumetric calculations is 2,500,000 barrels within the project area.

b) Primary depletion will recover an estimated 160,000 barrels or 6.4% of the original oil-in-place. To 1972 - 149,08[illegible] bbls

c) A conventional waterflood would realize an ultimate recovery of 809,000 barrels, or 32.4% of the original oil-in-place at the terminal WOR of 25:1.

3. Recommendation

Ultimate recovery can be substantially increased by instituting a waterflood scheme in the West Butler Field.

DEVELOPMENT HISTORY

1. Introduction

The West Butler field is located six miles west of the Daly field and is comprised of portions of Sections 29, 30 and 31 in Township 9, Range 29, WPM (see Figure 1).

The discovery well in the pool was Chevron West Butler 1-31-9-29. This well was drilled in November 1955 to test the upper Lodgepole formation, the producing horizon in the Ebor field, and the Bakken siltstone. The well was subsequently plugged back to 2,940' and completed in the upper Lodgepole formation. Following a 10,000 lb. sand frac., the well flowed 152 barrels in 18 hours, and produced an average 71 BOPD on a five-day test. The production, however, declined to 8 BOPD within two years. Other wells in the pool exhibited similar rapid production declines.

Presently, the field consists of four producing wells, one suspended well and one abandoned previous producer.

2. Geology

The West Butler field produces from the limestones and dolomites in the upper Lodgepole beds of Mississippian age. Dolomitization below the Mississippian erosional surface has occurred in all wells. Anhydrite filled fractures and anhydrite interbeds of 4" to 6" in thickness are found to varying depths in all parts of the reservoir. Completions have been made in both the dolomite and limestone, with no marked difference in the productivity of the wells.

The reservoir is overlain by the Jurassic Watrous series of Red Beds which provide a good seal. Few wells have penetrated sufficiently deep enough to encounter any well-defined marker beds. However, both 1-31-9-29 and 8-31-9-29 tested water approximately 140' below the top of the Mississippian.

3. Production History and Primary Performance

The cumulative production for the project area, to October 31, 1971, was 148,208 barrels. Extrapolation of the rate-time relationship shows an ultimate primary recovery of 160,000 barrels or 6.4% of the estimated original oil-in-place (2,500,000 STB).

The very rapid decline exhibited by all wells suggests that there is little, if any, water drive in this reservoir. Fluid levels were taken on four wells in May 1969, after the wells had been shut in for the winter months. These readings showed a build-up of pressure of less than 100 psi, indicating a very depleted reservoir, with little or no outside drive mechanism.

RESERVOIR ROCK CHARACTERISTICS

1. Permeability and Porosity

A total of 704.4' of core from six wells has been recovered from the upper Lodgepole formation.

In the determination of average porosity and permeability, a one millidarcy (Kmax. Air) cut-off was employed. An added refinement, to eliminate isolated thin stringers of permeability, was to include only intervals of 1.5' of continuous section having permeabilities greater than 1.0 md as effective pay. The amount of section in the project area with permeability greater than 1 md is 259.9' with 122.9' of this amount deemed as being effective pay.

The calculated footage weighted average permeability and porosity, as determined from cored wells using the above cut-off, was 8.2 md and 10.6%.

By plotting permeability versus cumulative pore volumes, a median permeability of 4.6 md was determined (see Figure 2). From this permeability distribution, the permeability variation was 0.73.

2. Net Pay

A map of the net pay is shown on Figure 3. Pay figures were derived from core analysis. Low productivity, rather than structure has limited the development of the field, hence the field boundaries have not been defined.

A rock volume of 5,000 acre-ft. for the project area was established by using the well bore pay figure as the average pay for the 40-acre tract on which the well was drilled.

3. Initial Water Saturation

A connate water saturation of 34.3% was determined by using the restored state method from core samples on 2-31-9-29. Thirteen core samples, with permeabilities ranging from 1.2 to 55 md. were used in determining the average water saturation. The saturation of 34.3% compares favourably with the value of 39.5% which has been established for a similar reservoir in Daly from four different oil-base cores. For calculation purposes, an intial water saturation of 35% was used for West Butler.

4. Fluid Properties

The original bottom-hole pressure was determined to be 1,050 psig from drillstem test data. Reservoir temperature is 82°F.

PVT analyses were not conducted on West Butler fluid samples. Reservoir fluid studies[1] conducted on a subsurface sample of Daly crude from 6-32-9-28 were assumed to be representative of the West Butler reservoir.

The pertinent fluid properties for Chevron Daly 6-32-9-28 and the West Butler field are summarized as follows:

Reservoir Temperature	82°F
Saturation Pressure	220 psig
Initial Formation Volume Factor	1.07 Res. Bbls./STB
Crude Viscosity at 0 psig and 82°F	5.35 cp

Crude Viscosity at average reservoir conditions 600 psig and 82°F	3.48 cp
Gravity of stock tank crude at 60°F	33 API

ORIGINAL OIL-IN-PLACE

The average net pay for the project was calculated by arithmetically averaging the pay figure for the five wells. From this net pay, and other factors listed below, the original oil-in-place was calculated at 2,500,000 STB.

Porosity	10.6%
Initial Water Saturation	35%
Formation Volume Factor	1.07 Res. Bbls./STB
Project Area	200 acres
Average Pay	25 feet

ENHANCED RECOVERY

1. Waterflood Prediction

The enhanced recovery prediction was determined by combining the displacement efficiency Ed, the vertical coverage efficiency Ev, and the area sweep efficiency Ea. It was assumed that the terminal water-oil ratio would be 25:1.

The displacement efficiency, Ed, was calculated by using the Buckley-Leverett method.[2] The Kw/Ko vs. Sw relationship was obtained from relative permeability measurements calculated by Chevron Research Company for Daly 15-1 core[3] (Figure 4). This data was normalized to Swi = 35%, Sor = 28%, μo = 3.48 cp, μw = 0.86 cp. Using the above data, the displacement efficiency was calculated to be 34% at a WOR of 25:1.

The vertical coverage efficiency, Ev, was determined using the standard Dykstra-Parsons method.[4]

From Figure 2, the permeability variation is shown to be .73. No oil permeability to air permeability, or water permeability to air permeability relationships were obtained in laboratory studies using Daly core samples. A study using North Virden Scallion core samples[5] shows the graphical relationship based on Cherty, Oolitic, and Crinoidal core. A relationship representative of West Butler was established by eliminating non-representative data (Figures 5, 6).

At a median air permeability of 5.2 md, the Kw at residual oil saturation was .26 md and Ko at initial water saturation was 2.2 md. The mobility ratio, derived from the relationship $\gamma = \frac{K_w \mu_o}{K_o \mu_w}$ is .50

At the terminal water-oil ratio, the vertical coverage efficiency is 88%.

The areal sweep efficiency, Ea, was determined by inspection (Figure 7). An attempt to determine areal sweep by methods published by Dyes, Caudle and Erickson was not successful, due to the limited size of the pool. For the study, Ea was estimated at 94%.

The waterflood recovery in the project area was determined by combining the three efficiencies as established above.

displ... vert... areal

Waterflood Efficiency = Ed x Ev x Ea = .34 x .88 x .94 = .281

Estimated Original Oil-In-Place	2,500,000 Bbls.
Estimated Cumulative Production to October 31, 1971	148,000 Bbls.
Oil-In-Place at Commencement of Injection	2,352,000 Bbls.
Estimated Recovery Following Commencement of Injection	.281 x 2,352,000 = 661,000 STB
Ultimate Recovery from Pool	809,000 STB or 32.4% of OOIP
Projected Primary Recovery	160,000 STB or 6.4% of OOIP
Incremental Secondary Oil	649,000 STB or 26.0% of OOIP

The predicted secondary production and an extrapolation of the primary reserves are shown in Figure 8.

2. Injectivity and Flood Pattern

Injectivity calculations, using Darcy's radial flow equation, indicate that some difficulty may be anticipated in injecting a sufficient quantity of water into the West Butler reservoir. However, since all wells were hydraulically fractured at the time of completion, the effective permeability and injectivity of the wells will have been improved significantly. A more realistic injectivity of 160 BWPD per well was established for the West Butler field. This estimate was based on a review of injection rates at 21 Daly injection wells at the end of the first year of injection.

[illegible] Two injection wells are required to provide adequate injectivity for the project. Conversion of 16-30-9-29 and 8-31-9-29 to water injection will provide the maximum areal coverage. In the event that injectivity is inadequate, it is likely that high pressure injection will be instigated. 1200 psi — ?

3. Water Supply

The most suitable water supply is the Viking Sand at a depth of 1,870'. Although absent at location 1-31-9-29 WPM, the sand is approximately 40' thick at location 7-31-9-29 WPM and extends over a wide area to the north.

The Jurassic sands over the interval 2,000' to 2500' also present a potential water source, but they are quite thin and appear to be discontinuous. A water source in the Mississippian aquifer at a depth of 2,800' would provide an adequate supply if it should be necessary to go to this depth. Good recoveries and pressures have been recorded on drillstem tests over portions of the Mississippian aquifer.

4. Costs

The following is an estimate of the expenditures for the waterflood project.

Water Supply Well	$39,000
Injection Plant	9,000
Injection Lines	6,000
Well Conversions	12,000
Miscellaneous Equipment	4,500
Miscellaneous Labour	1,500
Supervision and Contingencies	8,000
Total	$80,000

REFERENCES

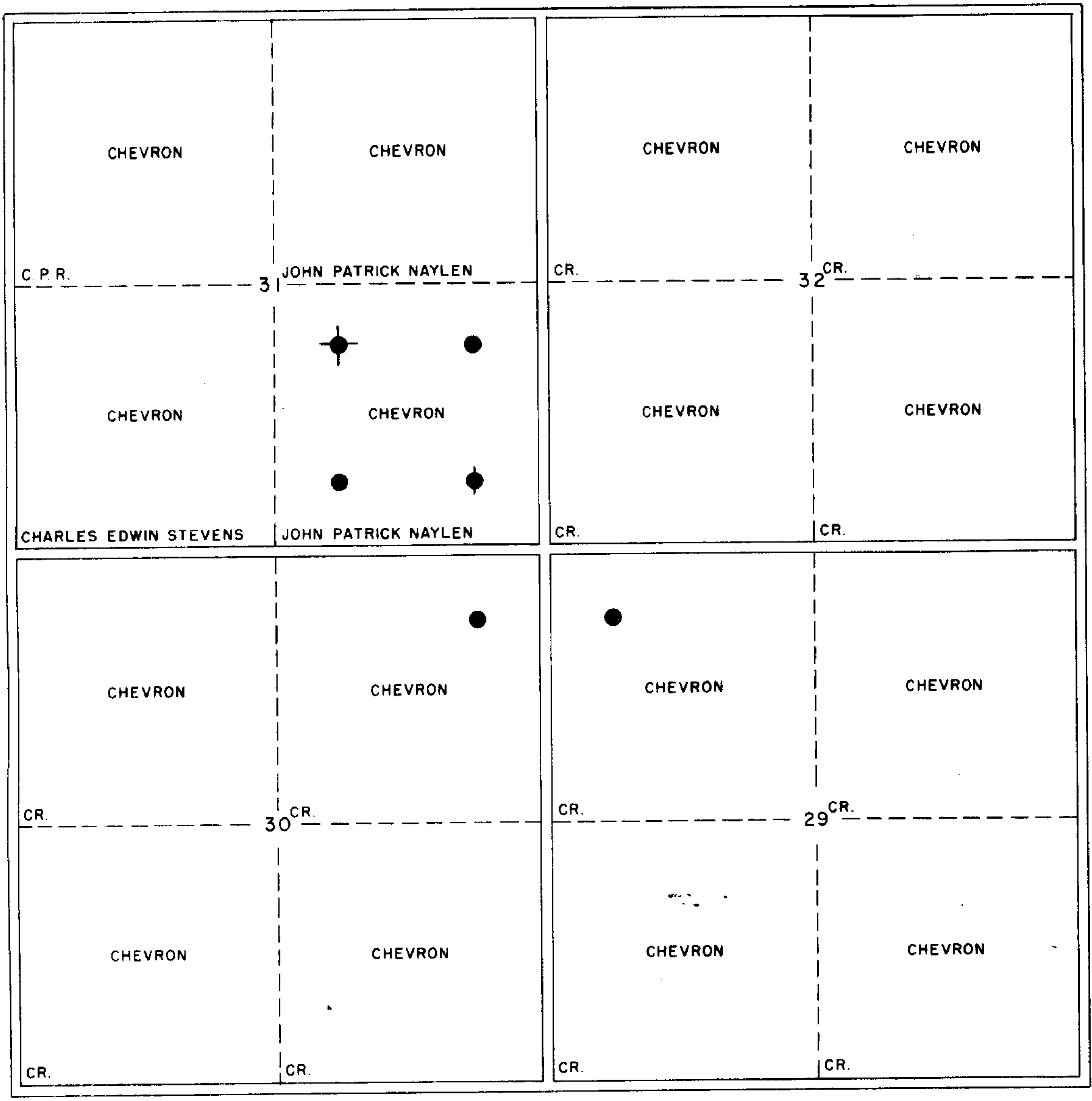
1. Core Laboratories, Inc., "Reservoir Fluid Study, California Standard Daly, No. 6-32 Well," June 2, 1954.

2. Buckley, S. E. and Leverett, M. C., "Mechanism of Fluid Displacement in Sands," Trans. AIME 146, 197, 1942.

3. California Research Corporation, "Water Flood Tests, Well 15-1, Daly Field, Manitoba," Project 8201, March 27, 1953.

4. Dykstra, H. and Parsons, R. L., "The Prediction of Oil Recovery by Waterflood," Recovery of Oil in U.S., A.P.I., 160, 150.

5. California Reserach Corporation, "Water Flood Tests, North Virden Field, Manitoba," Project 24,029, January 30, 1958.



Twp. 9 Rge. 29 WPM

FIGURE 1

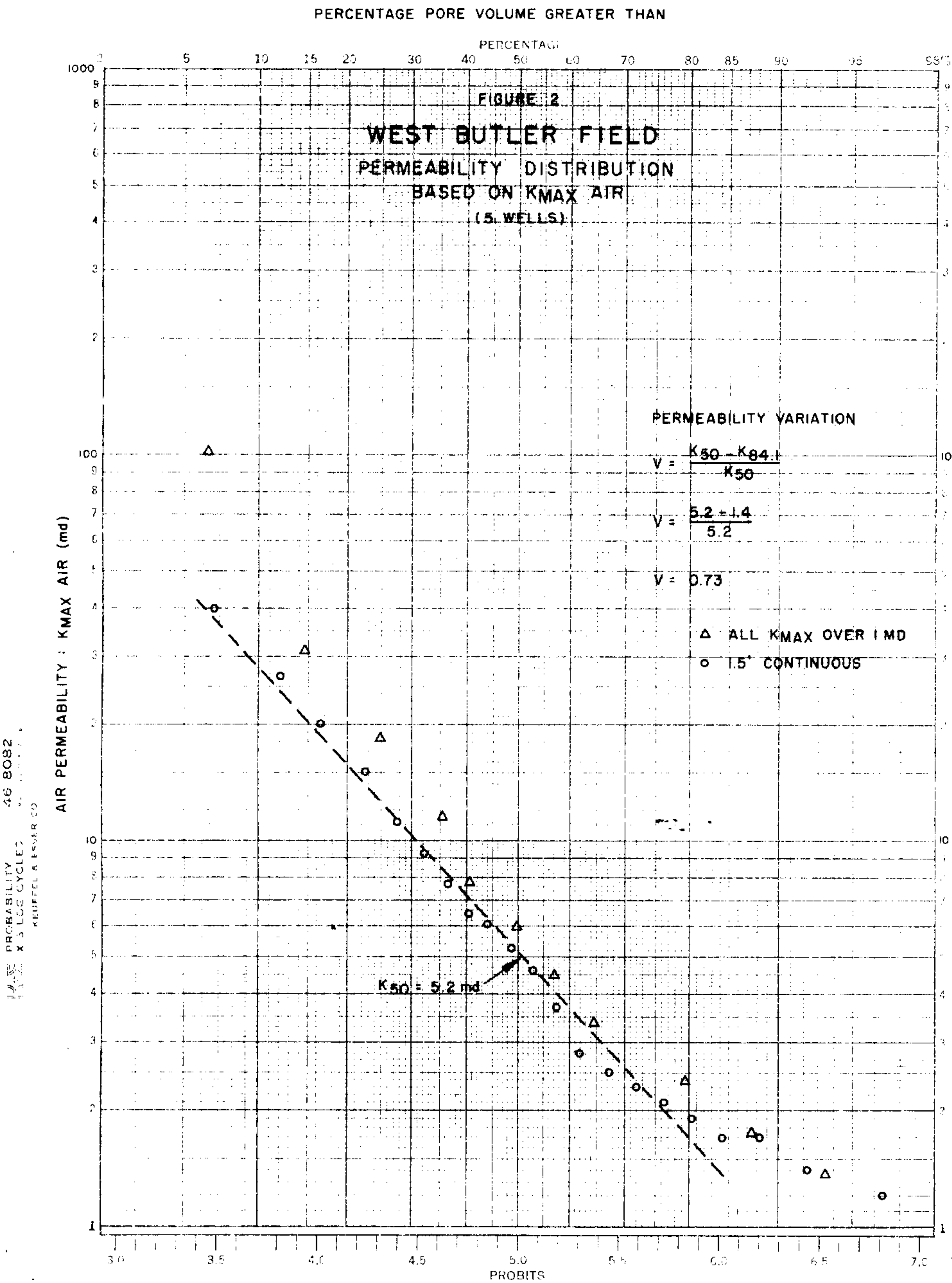
CHEVRON STANDARD LIMITED

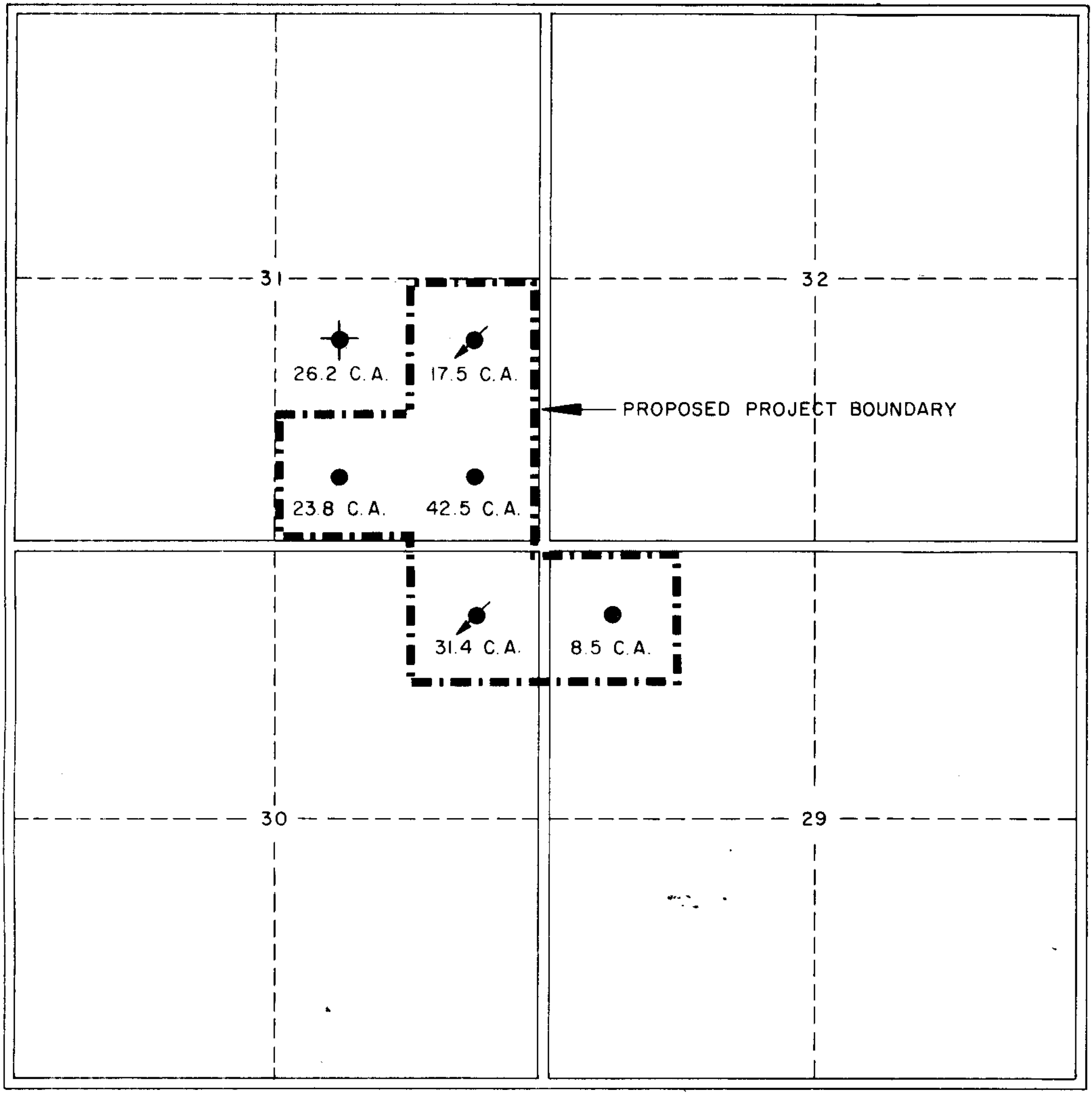
WEST BUTLER FIELD

LAND AND ROYALTY OWNERSHIP

SCALE 4" = 1 MILE

DECEMBER, 1971


PERCENTAGE PORE VOLUME GREATER THAN
FIGURE 2
WEST BUTLER FIELD
PERMEABILITY DISTRIBUTION
BASED ON KMAX AIR
(5 WELLS)
PERMEABILITY VARIATION
V = (K50 - K84.1) / K50
V = (5.2 - 1.4) / 5.2
V = 0.73
ALL KMAX OVER 1 MD
1.5' CONTINUOUS
K50 = 5.2 md
AIR PERMEABILITY : KMAX AIR (md)
PROBITS
46 8082
PROBABILITY X 3 LOG CYCLES
KEUFFEL & ESSER CO.



Twp. 9 Rge. 29 WPM

LEGEND

PROPOSED INJECTION WELL

17.5 C.A PAY THICKNESS CORE ANALYSIS

FIGURE 3

CHEVRON STANDARD LIMITED

WEST BUTLER FIELD

NET PAY MAP

SCALE: 4" = 1 MILE DECEMBER, 1971

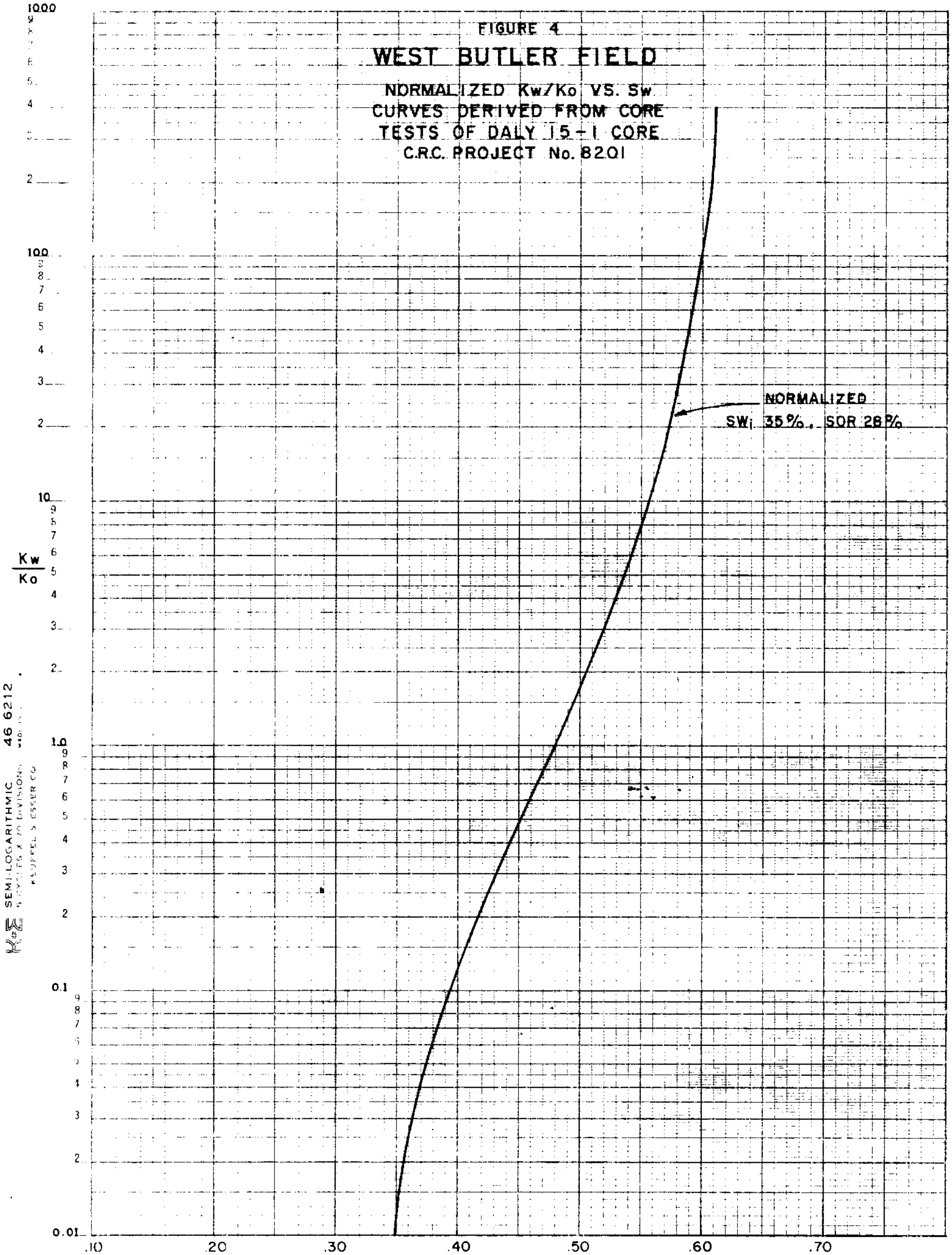


FIGURE 4
WEST BUTLER FIELD
NORMALIZED Kw/Ko VS. Sw
CURVES DERIVED FROM CORE
TESTS OF DALY 15-1 CORE
C.R.C. PROJECT No. 8201
NORMALIZED
SWi 35%, SOR 28%
Kw
Ko
1000
100
10
1.0
0.1
0.01
.10
.20
.30
.40
.50
.60
.70
46 6212
SEMI-LOGARITHMIC
KEUFFEL & ESSER CO.

FIGURE 5

WEST BUTLER FIELD

OIL PERMEABILITY AT INITIAL SW

VS

AIR PERMEABILITY

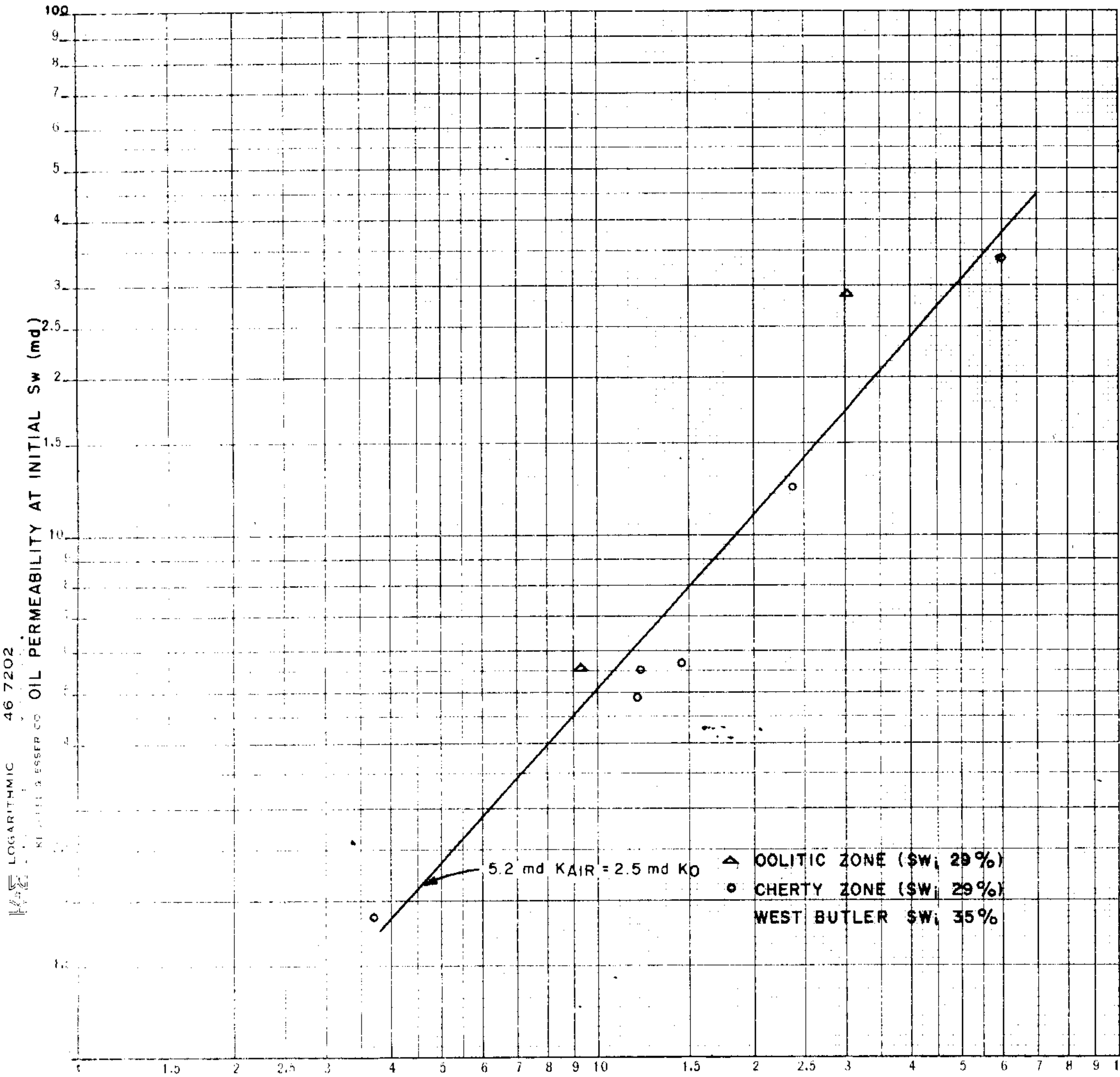
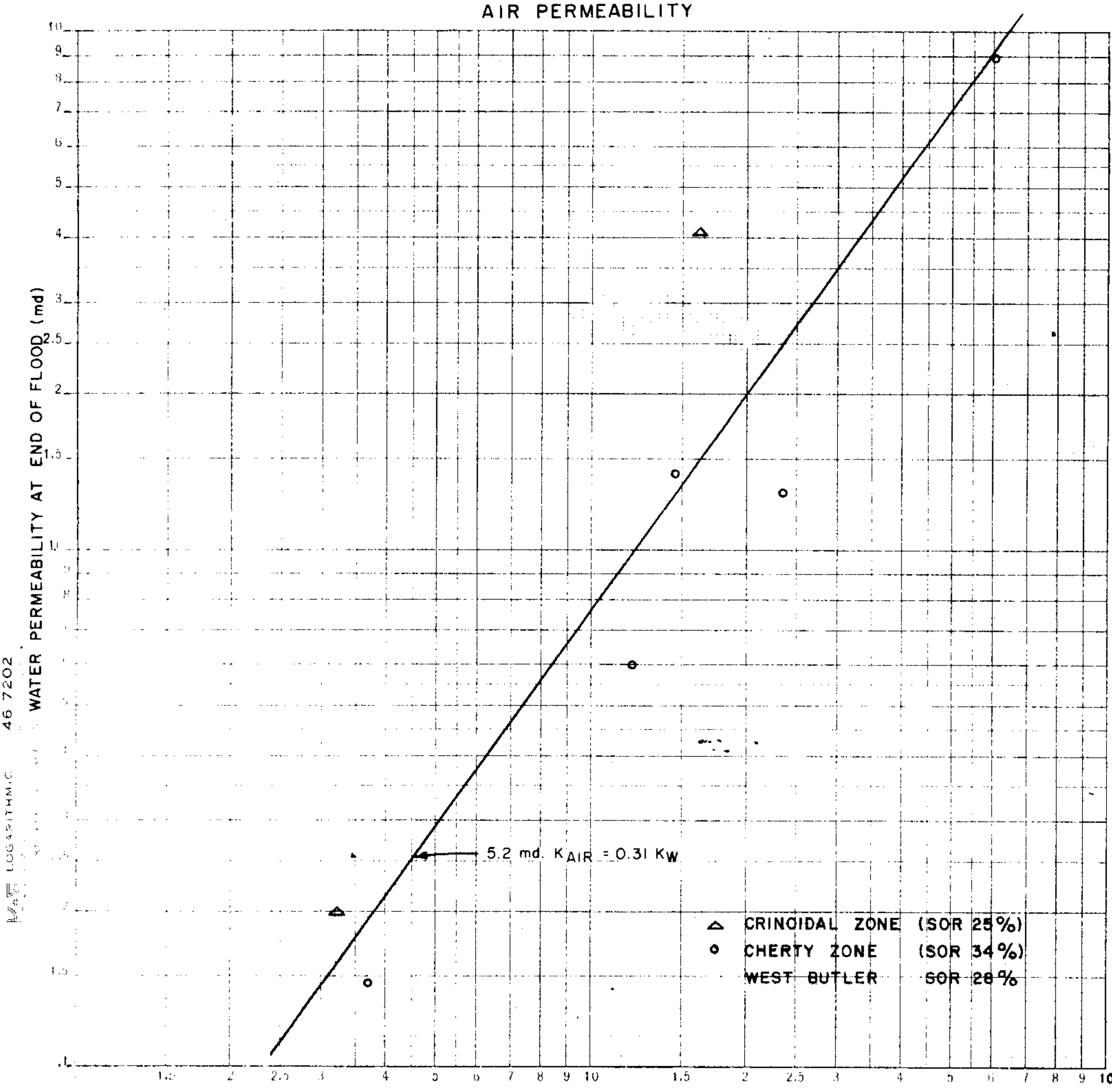
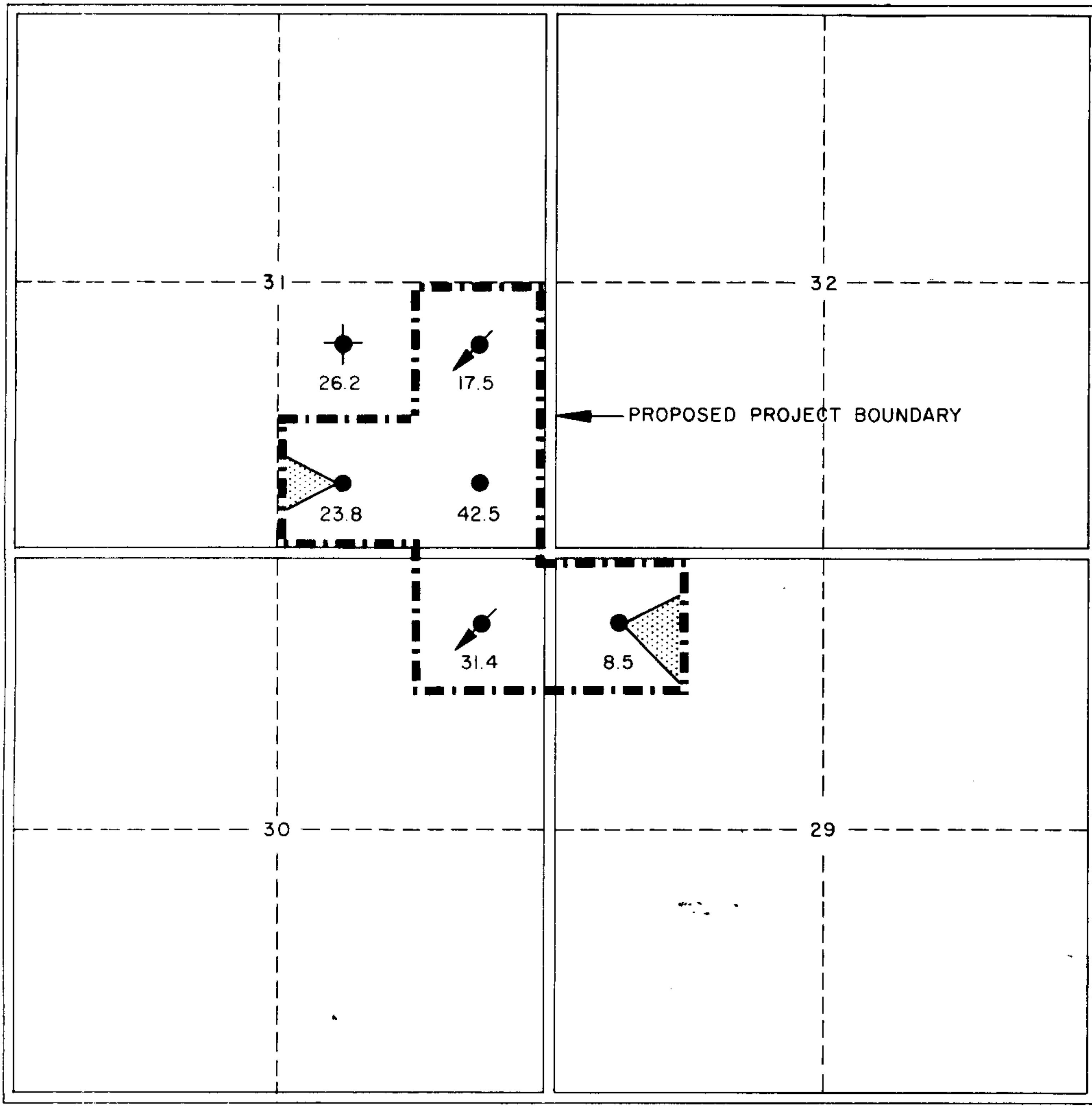


FIGURE 6

WEST BUTLER FIELD

FRESH WATER PERMEABILITY AT END OF FLOOD VS AIR PERMEABILITY





Twp. 9 Rge. 29 WPM

PROPOSED INJECTION WELL

PAY THICKNESS

17.5

AREA NOT SWEPT BY WATERFLOOD

TOTAL AREA NOT SWEPT = 12 ACRES

SWEEP EFFICIENCY $= \frac{188 \times 100}{200}$

$E_A = 94\%$

FIGURE 7

CHEVRON STANDARD LIMITED

WEST BUTLER FIELD

AREAL SWEEP EFFICIENCY

SCALE: 4" = 1 MILE

DECEMBER, 1971

APPLICATION FOR IMPLEMENTATION OF SECONDARY RECOVERY PROPOSED WEST BUTLER UNIT NO. 1

The applicant proposes to unitize the five capable oil wells of the West Butler field (see Figure 1). The primary purpose of unitizing is to facilitate the operation of a waterflood in the subject area. An engineering report entitled "Feasibility of Secondary Recovery - West Butler Field" and dated December 1971 has been included in support of this submission.

The estimated original oil-in-place from volumetric calculations is 2,500,000 barrels. The indicated ultimate primary recovery from the proposed Unit Area is 160,000 barrels. By comparison, the waterflood calculation indicates an estimated ultimate primary plus secondary recovery of 809,000 barrels or an incremental 649,000 barrels of secondary oil from the same area.

Appendix I contains a summary of the investigation of the feasibility of waterflooding. Due to low injectivities, the recommended waterflood program proposes that two wells be converted to water injection. A detailed outline of the proposed waterflood program is presented in Appendix II.

Unitization of the area under application would enable all royalty interest in the area to be merged so that the productive portion of the reservoir may be operated as a single property. Maximum operating flexibility and maximum recovery efficiency may be obtained under Unit operation.

Two of the five wells in the proposed waterflood scheme are required for conversion to water injection. The royalty owners must be insured of a continued income from currently producing wells, including those that would be converted to water injection. Additional production is expected to be obtained from the waterflood project and the Unit Operator must provide a fair and equitable basis for sharing this benefit. The applicant submits that the proposed participation formula provides a fair and equitable basis for sharing the unitized production.

All the capable oil wells in the West Butler field have been included in the proposed Unit Area. Low productivity rather than structure has limited the development of the field, hence the field boundaries have not been defined (Figure 1). A successful waterflood may encourage development of lands currently excluded from the present Unit. Should any outside acreage be subsequently developed and proven productive, it could enter the Unit under provisions of Section 79 of the Mines Act.

APPENDIX I

INVESTIGATION OF THE FEASIBILITY OF WATERFLOODING

The wells in the proposed West Butler Unit No. 1 were drilled in 1955 and 1956. The very rapid production decline exhibited by all wells suggests that there is little, if any, water drive in this reservoir. Since primary recovery for the field is very low, geological and reservoir studies were therefore initiated to study the feasibility of waterflooding the reservoir.

Flood tests have not been conducted on cores from the West Butler field, however, it is believed that the results of waterflood tests conducted on Daly and North Virden Scallion cores would be reasonably representative. These tests indicated that substantial additional oil could be recovered by waterflooding.

The report "Feasibility of Secondary Recovery, West Butler Field," dated December 1971 may be briefly summarized as follows:

(a) The size and structure of the reservoir and the properties of the reservoir rock were determined to obtain an estimated original oil-in-place of 2,500,000 barrels.

(b) An estimate of the ultimate primary oil reserves as a percentage of the estimated original oil-in-place was determined from the pool decline curve to be 6.4% (160,000 barrels).

(c) An ultimate recovery by waterflood of 809,000 barrels at a terminal W.O.R. of 25:1 was calculated by using laboratory waterflood test data with consideration given to displacement, vertical sweep efficiency and areal sweep efficiency.

(d) An estimate of possible gain, which may result from waterflooding was calculated to be approximately 649,000 barrels.

SUMMARY

PRIMARY RESERVE ESTIMATE

Surface Area	200 Acres
Rock Volume	5,000 Acre ft.
Average Pay Thickness	25 Feet
Footage Weighted Porosity	10.6%
Initial Water Saturation	35%
Initial Formation Volume Factor	1.07 Res. Bbls./STB
Original Oil-In-Place	500 Bbls./Acre ft.
Original Oil-In-Place	2,500,000 Barrels
Primary Recovery	160,000 Barrels
Primary Recovery	6.4%

WATERFLOOD RESERVES ESTIMATE

Initial Water Saturation	35%
Residual Oil Saturation	28%
Footage Weighted Permeability to Air	8.2 md.
Median Permeability to Air	5.2 md.
Mobility Ratio	.50
Waterflood Efficiency	.281
Ultimate Recovery	809,000 Barrels
Incremental Secondary Oil	649,000 Barrels

APPENDIX II

DETAILS OF OPERATION TO BE CONDUCTED IN PROPOSED UNIT AREA

The basic objective of the waterflood proposal is to recover the greatest amount of oil economically. Conversion of two wells, located on Lsds. 16-30-9-29 WPM and 8-31-9-29 WPM should provide maximum areal sweep efficiency in addition to adequate injection rates. A review of injectivity in the Daly Waterflood Area indicates that an injection rate of approximately 160 BWPD might be expected in each of the proposed injection wells.

A. SOURCE WATER FOR INJECTION

The most suitable water supply appears to be the Viking Sand at a depth of 1870'. It is proposed that a water supply well be drilled on Lsd. 7-31-9-29 WPM to test the productivity of the Viking Sand. It may also be possible to reenter the abandoned well located on Lsd. 7-31-9-29 WPM to conduct a test to establish water well productivity. Other potential sources of water include the Mississippian aquifer, and the Devonian formation. The possibility of developing a surface water supply appears remote.

B. INJECTION PLANT

It is tentatively proposed that the water injection plant be located on Lsd. 1-31-9-29 WPM. The plant will consist of water storage facilities and a reciprocating injection pump. It is anticipated that produced water will initially be disposed of until the produced water volume will adequately supply a segment of requirements of the injection system, at which time the injection system will be converted to accommodate the produced Mississippian water. The water is presently disposed at Chevron Daly SWD 5-29-9-28.

C. HIGH PRESSURE SYSTEM

It is proposed that the injection lines be 2-3/8" cement-lined Grade A line pipe, wrapped and tested to a pressure greater than the anticipated injection pressure. Figure 1 shows the proposed West Butler Unit No. 1 injection system.

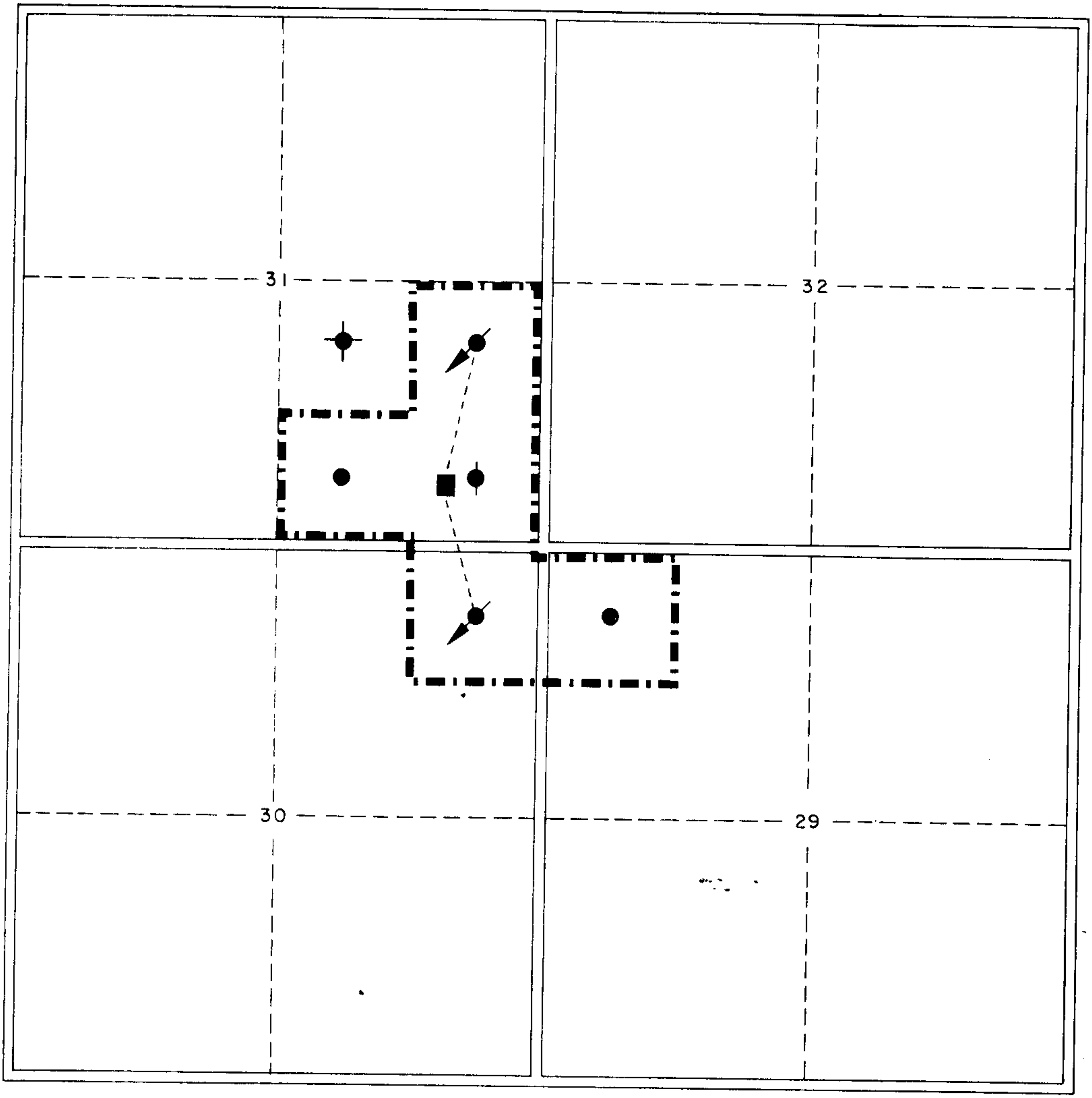
D. CONVERSION OF WELLS TO WATER INJECTION

It is the applicants intention to flood the oil bearing portion of the Lodgepole formation. A schematic diagram of a typical injection well is shown in Figure 2. The following procedure outlines the program to be carried out in converting the wells to water injection:

(a) Pull pump, rods, and tubing
(b) Run casing scraper
(c) Perforate the oil stained portion of the Lodgepole formation.
(d) Acidize well bore and perform a water injection test
(e) Pull tubing and place well on injection down casing until such time as well is pressured up.
(f) Run 2-3/8" cement-lined tubing for injection string.
(g) Fill casing annulus with oil
(h) Place well back on injection.

E. PROJECT COST ESTIMATES

Water Supply Well		$39,000
Injection Plant		9,000
Injection Lines		6,000
Well Conversions		12,000
Miscellaneous Equipment		4,500
Miscellaneous Labor		1,500
Supervision and Contingencies		8,000
	Total	$80,000



Twp. 9 Rge. 29 WPM

INJECTION WELL

INJECTION PLANT

FIGURE I

CHEVRON STANDARD LIMITED

PROPOSED

WEST BUTLER UNIT

INJECTION SYSTEM

SCALE: 4" = 1 MILE

DECEMBER, 1971

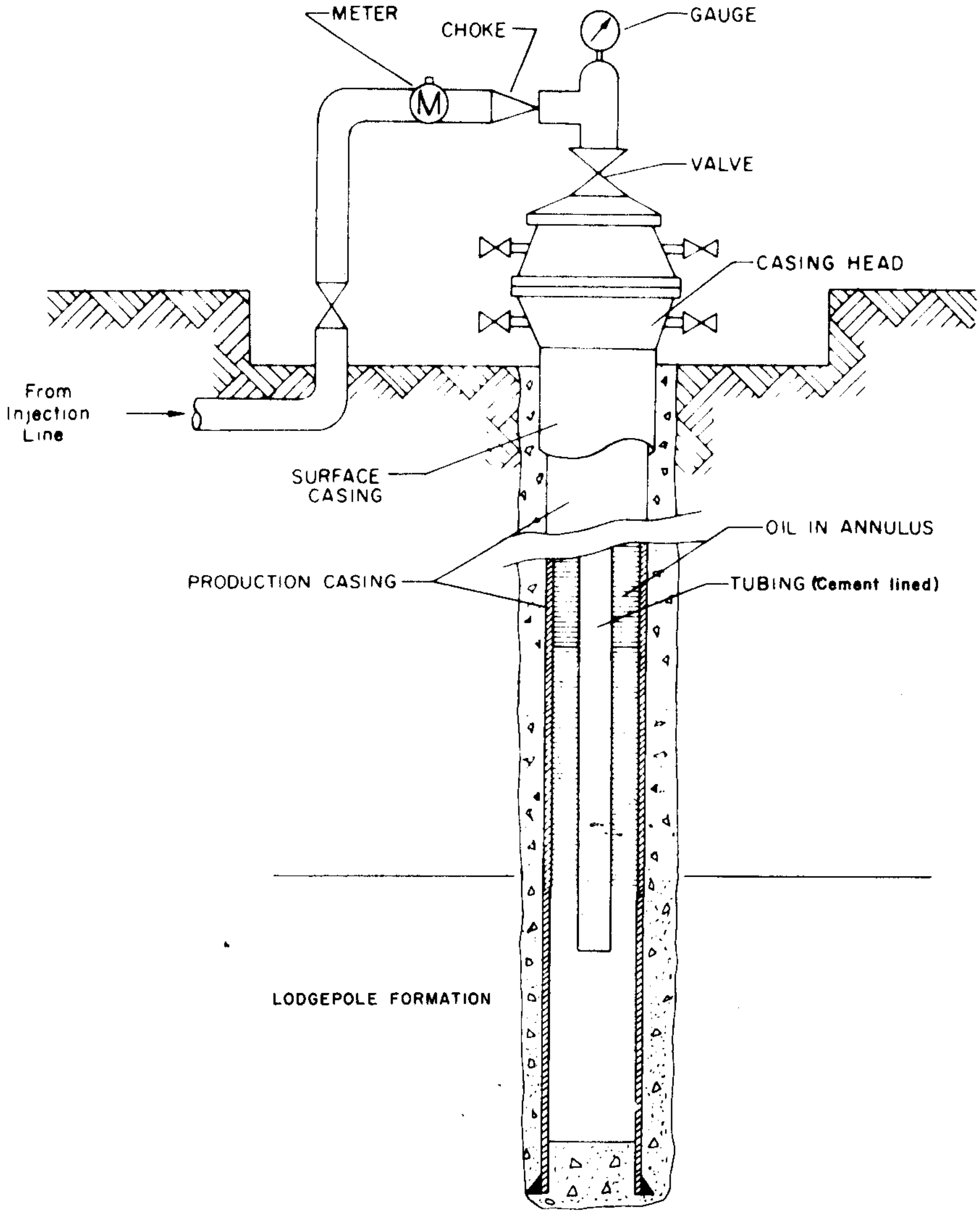
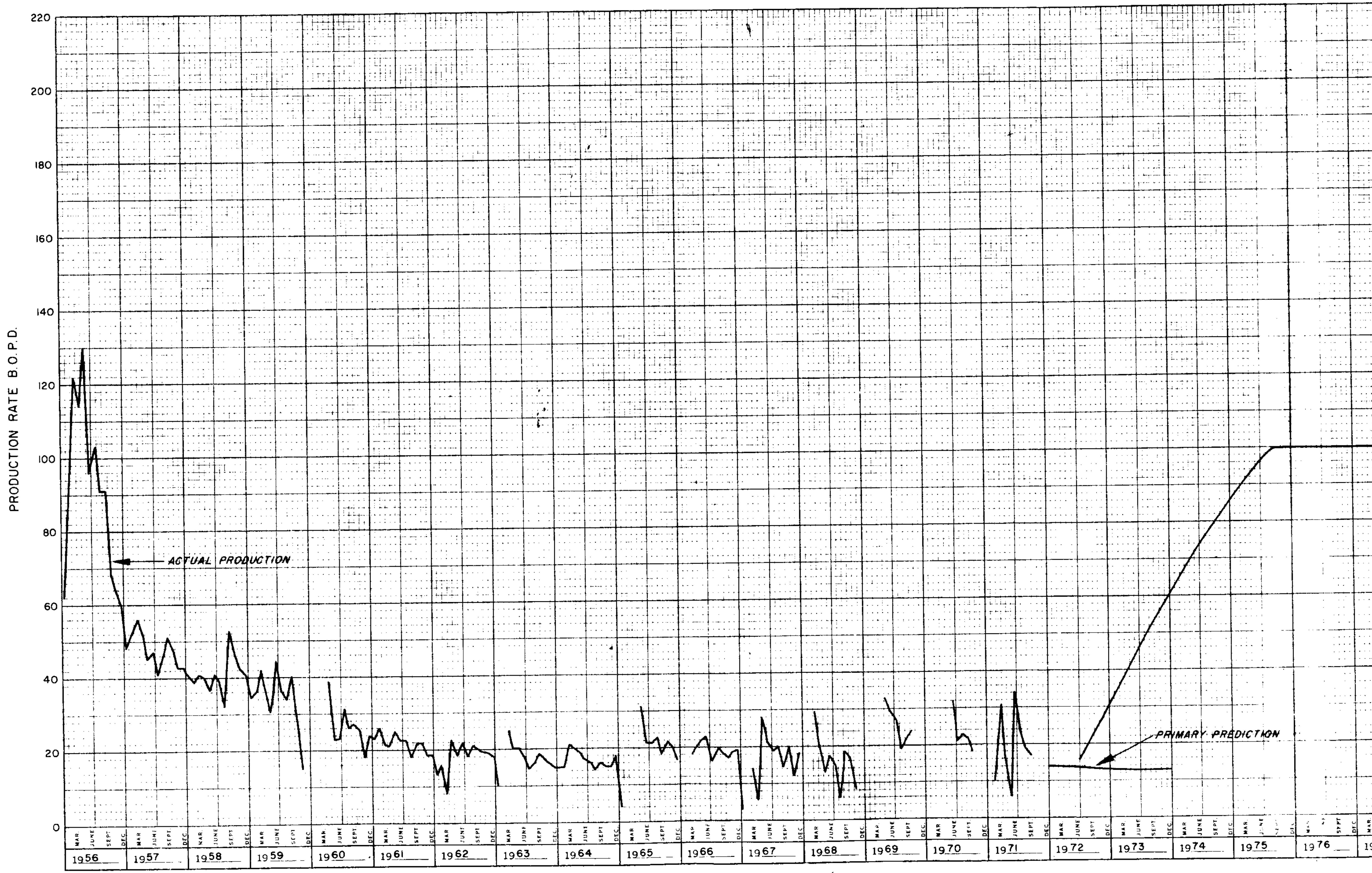


FIGURE 2

PROPOSED WEST BUTLER UNIT No. 1
TYPICAL INJECTION WELL

FIGURE 8

WEST BUTLER PRODUCTION PREDICTION A



20 YEARS BY MONTHS X 110 DIVISIONS 47 3853
KEUFFEL & ESSER CO.

ICTION AND HISTORY