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NSEP-111

A/S NORSKE SHELL

PRODUCTION LICENCE 054

BLOCK 31/2

RESERVOIR ENGINEERING
OIL ZONE WELL MODELS
WELLS 31/2-2 AND 31/2-5

By

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CONTENTS

1. SUMMARY AND CONCLUSIONS

Well 31/2-2 was drilled and tested during the spring/summer 1980. It penetrated an oil column approximately 12 metres thick, in unconsolidated highly permeable sand, sandwiched between gas and water bearing intervals. The production test in the oil zone (gravel packed) was dominated by severe skin. However, after several stimulations and with gas lift a maximum gross liquid rate of 2500 B/D including 25% water (partly spent acid) was obtained for a few hours followed by a rapid decline in rate and water cut. In view of these inconclusive test results a 12 layer radial well model of well 31/2-2 was constructed to predict the unimpaired well performance. With this model a match of the water cut behaviour during the gas lift phase of the oil zone production test in well 31/2-2 was obtained. Long term prediction runs were then made with the matched model. Sensitivity runs were made to demonstrate the effects of changes in important reservoir parameters. The following conclusions can be drawn from the study:

1. A liquid rate of some 800 B/D is the maximum which can be sustained for a long period of time without unacceptable increase in gas production. (GOR less than 3000 SCF/B).

2. At a liquid rate of 800 B/D the water cut would be in the order of 15% for long term production.

3. The development of gas coning is sensitive to the oil withdrawal rate from the reservoir, while the water cut remains essentially unchanged at various rate levels.

4. The unexpected low water cut during the production test is attributed to:
   a) A tight layer (5 mD) 6 metres below the OWC. This layer to a large extent controls the performance of the well.
   b) The presence of a residual oil saturation below the OWC which is believed to cause a significant reduction in water relative permeability.

5. The production periods during the oil zone production test were not sufficiently long to develop significant gas and water coning.

6. The performance match indicates that the core derived permeability of some 8.1D in the completed interval is in the right order of magnitude. This invalidates the value of 800 mD estimated from the skin and afterflow dominated buildups during the production test.

2. RECOMMENDATIONS

After this initial 31/2-2 well model study the following recommendations are made:

1. The experience gained by the development of the 31/2-2 well model should be used in the design and application of a well 31/2-5 model.

2. This model work should form the basis for forthcoming studies of sophisticated coning restrained completion configurations.

3. INTRODUCTION

Well 31/2-2 was drilled during the spring of 1980. It was located in the south-eastern part of block 31/2 in the Norwegian Sector of the North Sea in approximately 300 metres water depth. Fig. I.1 shows the location of the block and Fig. I.2 the locations of the wells drilled as well as the probable extension of the reservoir(s) into the neighbouring blocks. The well penetrated a 35 metre gas reservoir overlying an approximately 12 metres thick oil bearing section. Below the hydrocarbon bearing sands is an extensive aquifer with an estimated thickness of some 400 metres. The reservoir sands which are of Jurassic age basically consists of two types; unconsolidated highly permeable clean sands and micaceous less permeable sands. The oil layer in well 31/2-2 was found in the former. However, a tight micaceous sand was found just below the OWC. The reservoir pressure is hydrostatic with a reservoir pressure at the GOC (1554 metres sub sea) of 2290 psig. Although interrupted by a strike on the platform, the well was tested during the period from June through September 1980. The test in the oil zone (gravel packed) was dominated by severe skin. To improve productivity several acid/de-emulsifier stimulations were performed and internal gas lift was used to improve the poor vertical lift due to the low GOR. Eventually a maximum gross liquid rate of 2500 B/D including 25% water was obtained for a few hours, declining rapidly towards the end of the test when the gross rate was down to 1350 B/D with a water cut of 5%. The produced oil had an API gravity of 25. With these relatively inconclusive test results and realizing the extreme importance of this oil zone to any future development plans, it was decided to develop a single well simulation model for the oil zone in well 31/2-2.

4. OBJECTIVES

The main objectives for the simulation of well 31/2-2 were:

1. To match the performance observed during the oil zone production test.

2. To predict gas and water coning effects at different rates.

3. To study the impact of the restrictions to flow below the OWC.

4. To establish the maximum gross offtake rate at which low GOR production could be sustained.

5. To use the experiences from the 31/2-2 model in the contruction and application of a well model of well 31/2-5 which will be tested during the summer of 1981.

5. MODEL CONSTRUCTION

5.1 Model Type

The simulation program employed in the study was the current version of Implicit COMSIM. The solution method in the program is implicit with respect to both pressure and saturation. The model was a 3 phase radial well model with the dimentions 10-1-12 indicating that the reservoir was split into 10 blocks in the radial direction and 12 layers in the vertical direction.

5.2 Layers - Permeability/Porosity Data

Both log and core data were used to describe the reservoir. On the basis of these data the model was set up with 12 layers. Permeability and porosity data used in the model were based on the GECO core analysis for the well. Porosities were corrected for stress using the correlation of Fig. I.3. The permeabilities were corrected for stress and connate water applying a statistical method developed by Shell in the U.S. The correlation is shown in Fig. I.4. In intervals where no core data were available, porosity was estimated from logs and permeability from zones with similar lithology and porosity.

Enclosure 1 and Table I.1 illustrate the layering and the permeability/porosity data used in each layer.

In all model runs the production was withdrawn from layer seven which has approximately the same elevation above the OWC as the test completion interval.

5.3 Relative Permeabilities

Very limited relative permeability data were available for the study. The data used in the model are based on measurements on 31/2-1 core plugs. Two sets of relative permeability curves were used. Type 1 represents clean highly permeable formation (exceeding 500 mD) while type 2 data represents tighter formation (less than 500 mD).

Based on the core data, average block relative permeabilities were estimated as a function of average block saturations for the oil/water and gas/liquid systems. Because of the very high permeabilities capillary forces were neglected and oil and water were assumed to be flowing in segregated flow regions without interferring with each other in reducing relative permeabilities. For this system the oil/water relative permeabilities are reduced to stright lines joining the end points of the rock relative permeability curves. The resulting curves are shown in Fig. I.5.

The log interpretation indicates a residual oil saturation below the OWC. The k_{rw} curve for $S_o < S_{orw}$ describes the assumed reduction in water relative permeability caused by the presence of this oil. (Fig. I.5).

In the gas/liquid system some curvature was used between the endpoints in order to prevent model unstability at inital development of gas saturation.

From the oil/water and gas/liquid system relative permeabilites the simulation program computes three phase grid block relative permeabilitis based on average grid block saturation. The resulting three phase oil relative permeability plots for the two rock types are illustrated in Fig. I.6.

5.4 PVT Data

The oil properties were based on preliminary laboratory analysis by Statoil on a bottom hole sample from well 31/2-3. No differential vaporization data were available from the analysis. Only measurements of oil formation volume factor and solution gas/oil ratio only at initial conditions were available. Straight line relationships between the initial pressure and stock tank conditions were therefore assumed for B_o and R_s. The oil viscosity at initial conditions was increased with lower pressures in accordance with the decreased amount of gas in solution. The error introduced by using these linear relationships is negligible because of the small changes in pressure in the model. The oil PVT data are illustrated in Fig. I.7.

The gas properties are based on samples taken during the clean sand gas test in well 31/2-3. The data can be found in Fig. I.8.

6. PRODUCTION TEST MATCH

6.1 Match of Base Model

To test the validity of the model, an attempt was made to match the actual well performance observed during the gas lift phase of the 31/2-2 oil zone production test. This was done by imposing on the model liquid rates similar to those observed during the test. The shut-in periods experienced for various reasons during the test, were also included in the history match. The buildup of skin during the test is believed to be a near wellbore effect and was not considered other than through lower imposed rates. Initially the layers below the OWC were assumed to be 100% saturated with water. However, with this assumption the model gave water cuts much higher than those observed during the test. To correct this, oil saturations of 15-25% as indicated by log interpretation were introduced in the first 15 metres below the OWC. This reduced the water relative permeability and thus the water influx. Under these conditions a reasonable match was obtained with the water cuts observed during the test. The results of this run are plotted together with test data in Fig. I.9.

In the model run the GOR increased marginally towards the end of the test. With the internal gas lift arrangement applied during the actual test it was difficult to differentiate between the gas that came from the producing interval and the gas lift gas. Thus the small increase in model GOR could not be confirmed by test data. On the assumption of a constant rate through the gas lift mandrel (critical flow), it would appear that the producing interval GOR did increase towards the end of the test. The validity of this observation is however questionable, since the nozzle in the gas lift mandrel was found to be cut by sand production. Hence the apparent increase in test GOR was probably caused by increasing amounts of gas lift gas.

With the match of the water cut and a credible model GOR behaviour confidence was gained that the model gave an acceptable representation of observed well behaviour.

6.2 Effect of Critical Reservoir Parameters

To confirm the validity of the model and demonstrate model sensitivity to changes in reservoir parameters, three parameters were varied:

1) presence of tight layers below the OWC
2) presence of residual oil below the OWC
3) permeability in completion interval.

The same producing and shut in sequence used in the test history match was incorporated in these sensitivity runs.

Firstly the impact of the tighter layers (139 and 5 mD) some 1.5 metres below the oil/water contact was tested. The permeability in these layers, was increased to the 1000 mD of the underlying layer. This resulted in a significant increase in water cut from 10% to 25% at the end of the test duration. This demonstrated that the low water cut observed during the test was to a great extent caused by the presence of these tight layers. The performance of this run is compared with the base case in Fig. I.10.

The second sensitivity run was made to demonstrate the effect of the residual oil saturation (15-25%) indicated by logs below the OWC. Oil was also observed bleeding from the fresh cores recovered from this interval. This oil saturation is believed to considerably reduce the water relative permeability. In the sensitivity run 100% water saturation was assumed below the OWC. This caused a strong increase in water cut from 10% to 27% at the end of the test duration and indicates that the presence of the oil below the OWC significantly modified well performance. The resulting GOR's and water cuts from this run are shown in Fig. I.10.

The third sensitivity was made with reduced permeability in the completion interval.In the interpretation of production test pressure build-ups, which were heavily dominated by skin and after-flow effects, a permeability of about 800 mD in the completion interval had been estimated. Detailed studies of core and log data as described in chapter 3.2, indicated that this interpretation was probably erroneous. The logs indicated that the completion interval belongs to a layer for which a permeability of 8150 mD was estimated from actual core data. This means that the Horner lines used in the buildup analyses must have been influenced by skin and/or afterflow effects. With a permeability of 8150 mD in the completion interval the kh would be so large that any buildup subsequent to the skin/afterflow dominated period would not be noticeable. Furthermore the buildup would probably be affected by the high transmissibility in the gas zone. Hence this part of the test buildups could not be observed. The sensitivity run was made to test the model performance assuming the value of 800 mD instead of 8150 mD in the completion interval. Both the GOR and the water cut showed significant increases as compared with the base case. In particular the very high GOR towards the end of the test duration was not observed during the actual test. (See Fig. I.10). This observation supported the use of the high core derived permeability of 8150 mD in the completion interval in the base model.

7. PREDICTION RUNS

7.1 Performance of Base Model.

After confirming the validity of the original model as described in chapter 6, long term prediction runs were made.

The model was run at liquid rate levels of 500, 800 and 1000 B/D and the performance observed. Reliable runs at higher rates were not possible because of very quick gas break throughs and subsequent GOR's in excess of 10,000 SCF/B. Model results in terms of GOR and water cut at the various rate levels are compared in Fig. I.11.

Conditions at 10 days and 1 year of production are tabulated below:

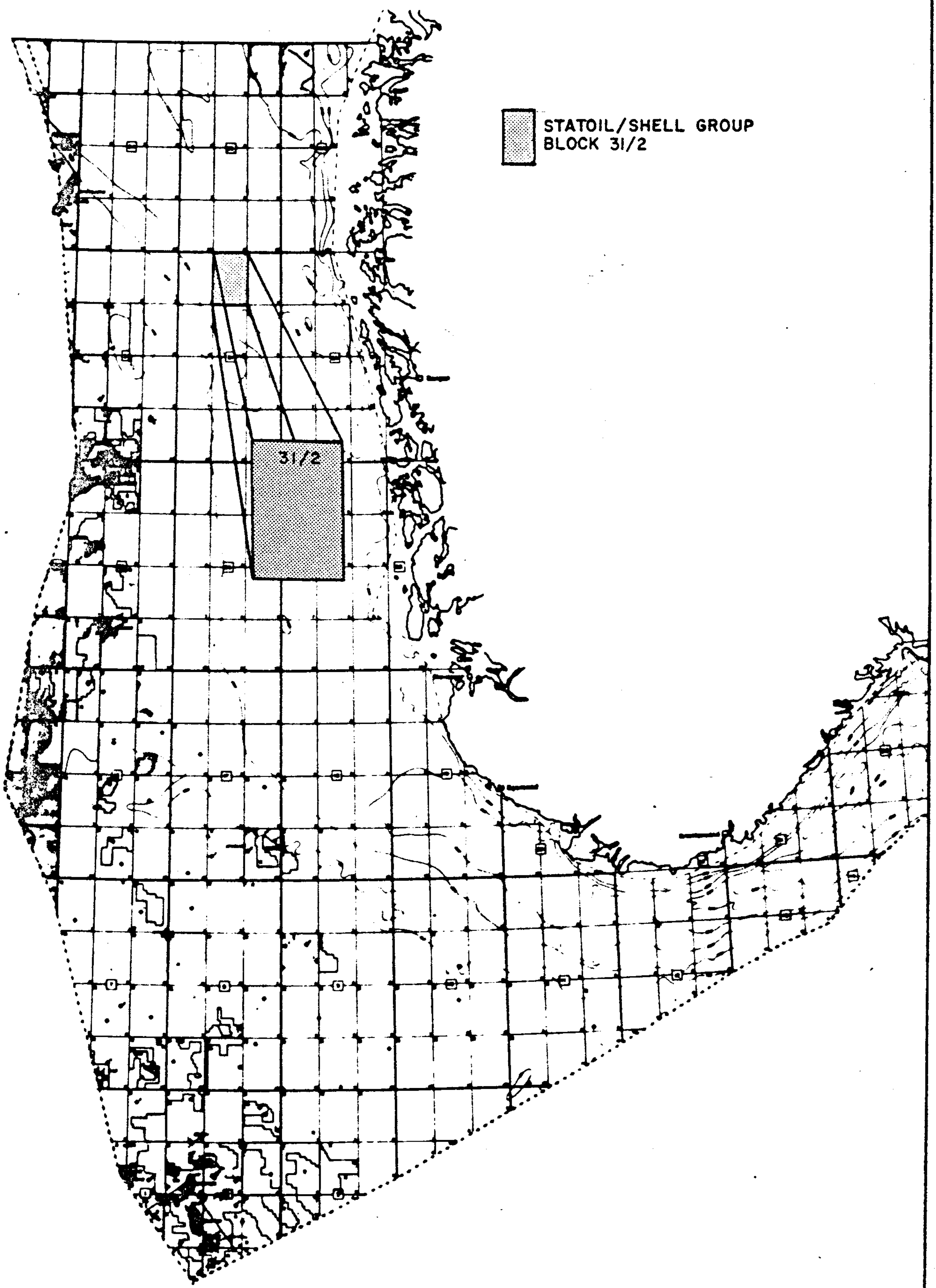
Liquid Rate (B/D)	GOR (SCF/STB)		Water Cut (%)	
	10 days	365 days	10 days	365 days
1000	330	3500	11.0	14.8
800	322	1400	10.2	14.0
500	322	322	9.5	12.5

As can be appreciated, the GOR performance is sensitive to rate, whereas the water cut remains more or less unaffected. The results indicate that a gross liquid rate of some 800 B/D is the maximum sustained rate without excessive gas production.

7.2 Restrictions to Flow below the OWC

The effect of removing the tight zone below the OWC was investigated in the run described in section 6.2. To further study long term effects a prediction run was made applying a liquid rate of 800 B/D. The performance is compared with the original model in Fig. I.12. As expected, the tight zone has a pronounced effect on both GOR and water cut. Without the tight zone the water cut would reach 24% at 10 days and 55% at 365 days. On the other hand the development of the gas cone was delayed because of lower oil production when the tight zone was removed. It is apparent that the performance of this well is to a large extent controlled by the presence of the tight layers below the OWC. Therefore the well with its favourable layering is believed to represent a special case which cannot be expected in other wells in the area.

Another restriction to water influx was caused by the presence of a residual oil saturation below the OWC. The effect of this during the test was studied in chapter 6.2. A further sensitivity run assuming 100% water below the OWC was made to study the long term effects of this phenomenon. The results are shown in Fig. I.12. Without the oil saturation below the OWC the water cut approximately doubled and the GOR showed some reduction. This confirmed that the presence of this oil saturation is essential to match the observed well behaviour.



0 50 100 Km

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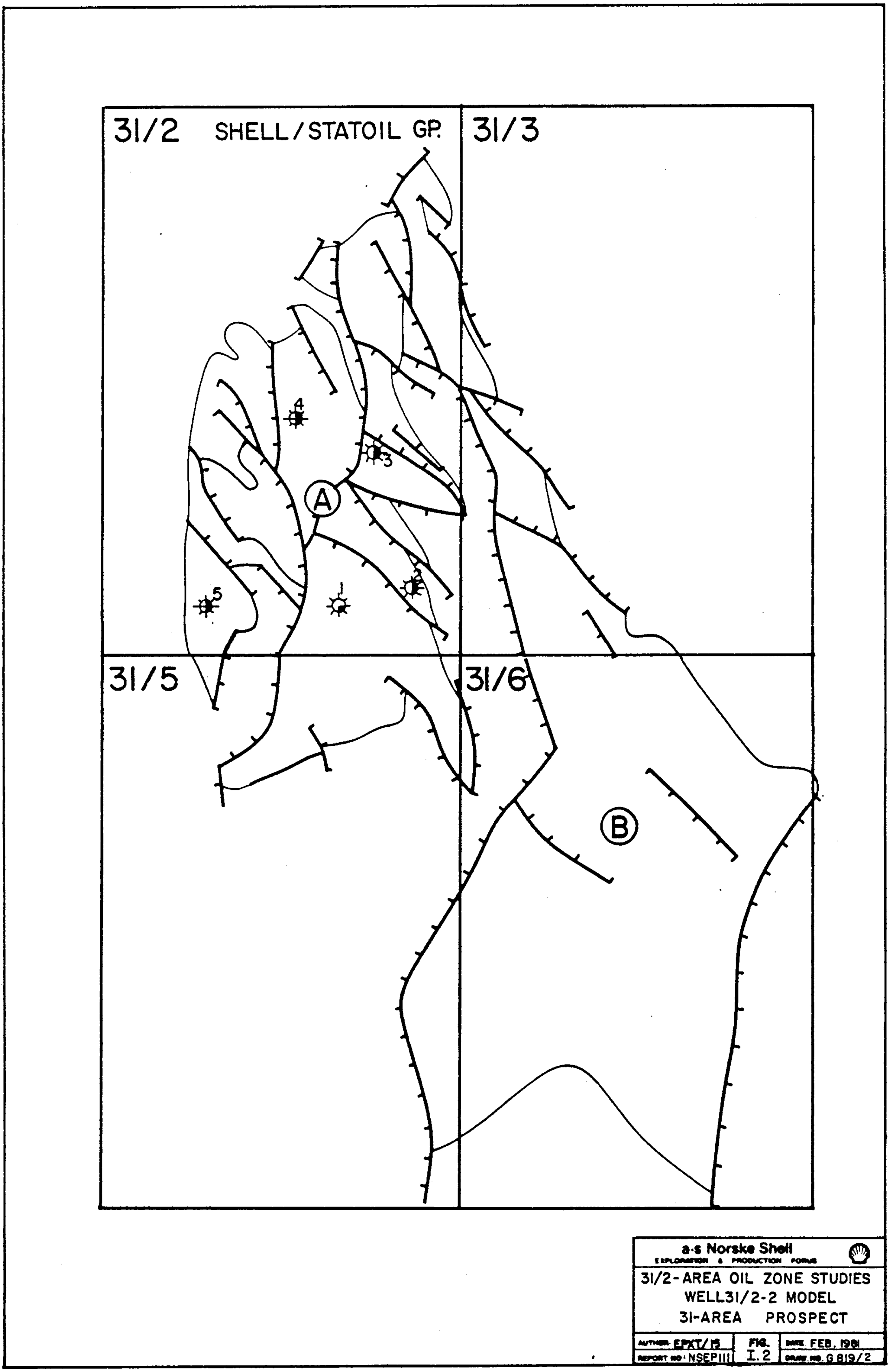
31/2-AREA OIL ZONE STUDIES
WELL 31/2-2 MODEL
LOCATION MAP BLOCK 31/2

AUTHOR EPXV/2	FIG. I.1	DATE January '80
RPT No NSEP 111		DRAW. No 8197/1


31/2
SHELL/STATOIL GP.
31/3
31/5
31/6
A
B
1
2
3
4
5
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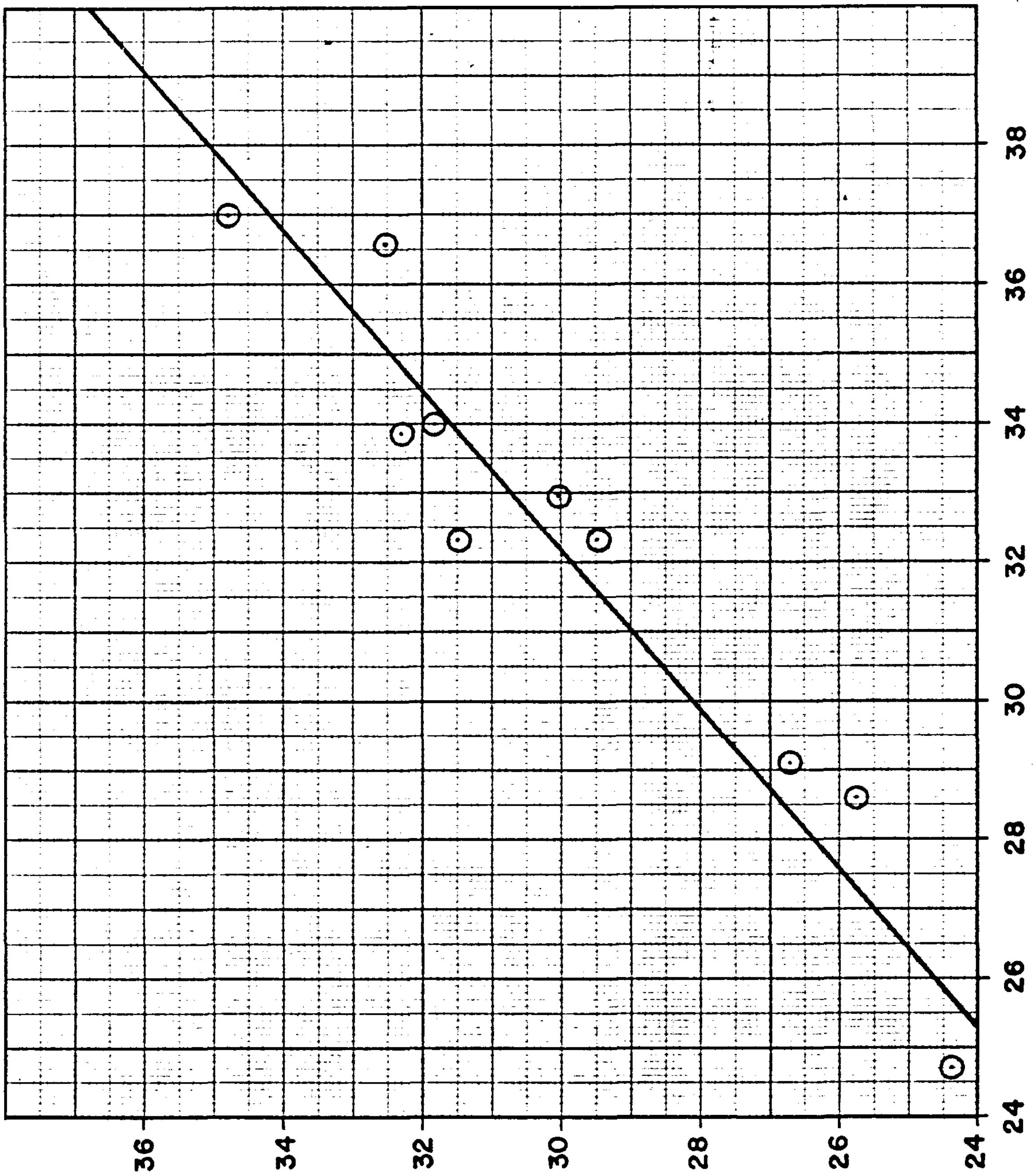
31/2-AREA OIL ZONE STUDIES
WELL31/2-2 MODEL
31-AREA PROSPECT
AUTHOR EPXT/15
REPORT NO NSEP111
FIG. I.2
DATE FEB. 1981
DRAW. NO. G 819/2

IN SITU VERSUS ATMOSPHERIC POROSITY
31/2-1 CORE SAMPLES



IN SITU POROSITY - %

(AT 150 kg/cm^2 EFFECTIVE STRESS)

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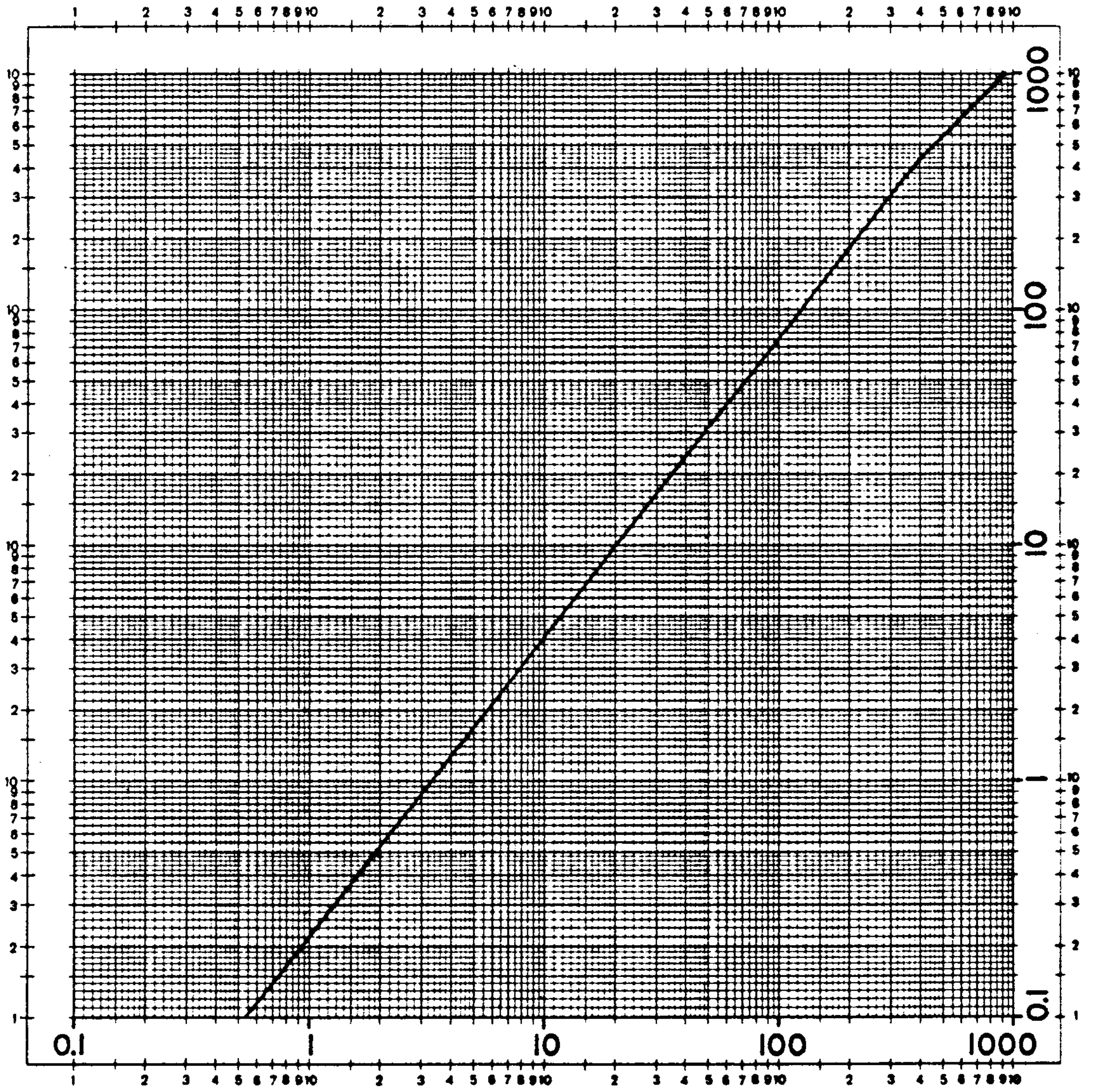
31/2-AREA OIL ZONE STUDIES WELL 31/2-2 MODEL POROSITY CORRECTION		
AUTHOR EPXT/11	FIG: I.3	DATE Feb. 1981
REPORT NO. NSEP111		DRAW. NO. G 819/3

EFFECT OF STRESS AND CONNATE WATER ON ROUTINE AIR PERMEABILITIES



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31/2-AREA OIL ZONE STUDIES WELL 31/2-2 MODEL PERMEABILITY CORRECTION		
AUTHOR EPXT/11	FIG. I. 4	DATE Feb. 1981
REPORT NO. NSEP111		DRAW. NO. G819/4

WELL 31/2-2 MODEL, LAYERING

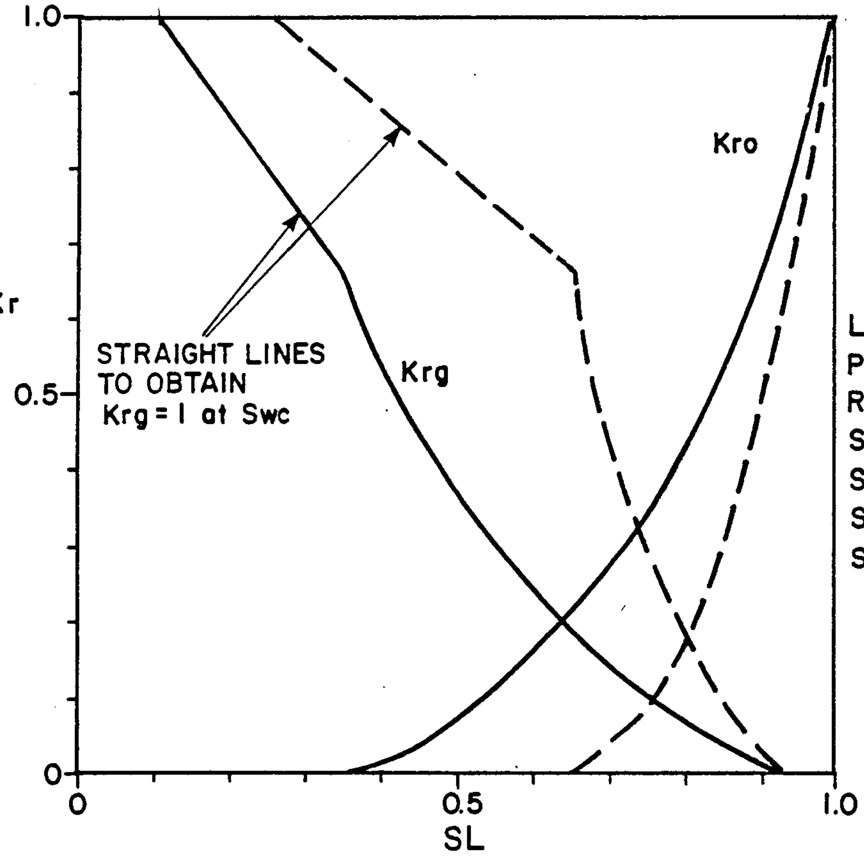
LAYER NO.	LAYER DEPTH TOP-BASE (m BDF)	LAYER THICKNESS (m)	POROSITY 0/0	PERMEABILITY mD		REL.PERM. CURVE	PORE FILL	SATURATIONS 0/0			REMARKS
				K_h	K_v			GAS	OIL	WATER	
1	1544.11-1547.16	3.05	32	400	175	2	GAS	75	0	25	
2	1547.16-1552.04	4.88	28	90	32	2	-"-	75	0	25	
3	1552.04-1562.10	10.06	32	4000	2500	1	-"-	90	0	10	
4	1562.10-1579.16	17.07	31	700	392	1	-"-	90	0	10	
5	1579.16-1584.04	4.88	32	3600	2250	1	OIL	0	90	10	
6	1584.04-1587.09	3.05	30	405	175	2	-"-	0	75	25	
7	1587.09-1589.22	2.13	32	8150	6000	1	-"-	0	90	10	Completion interval
8	1589.22-1591.36	2.13	32	8150	6000	1	-"-	0	90	10	
9	1591.36-1592.88	1.52	32	1760	900	1	WATER	0	18	82	
10	1592.88-1597.45	4.57	31	139	82	2	-"-	0	20	80	
11	1597.45-1606.60	9.14	25	5	1.4	2	-"-	0	15	85	
12	1606.60-1791.31	184.71	30	1000	600	1	-"-	0	0	100	

GRID MESH IN R - DIRECTION (m):

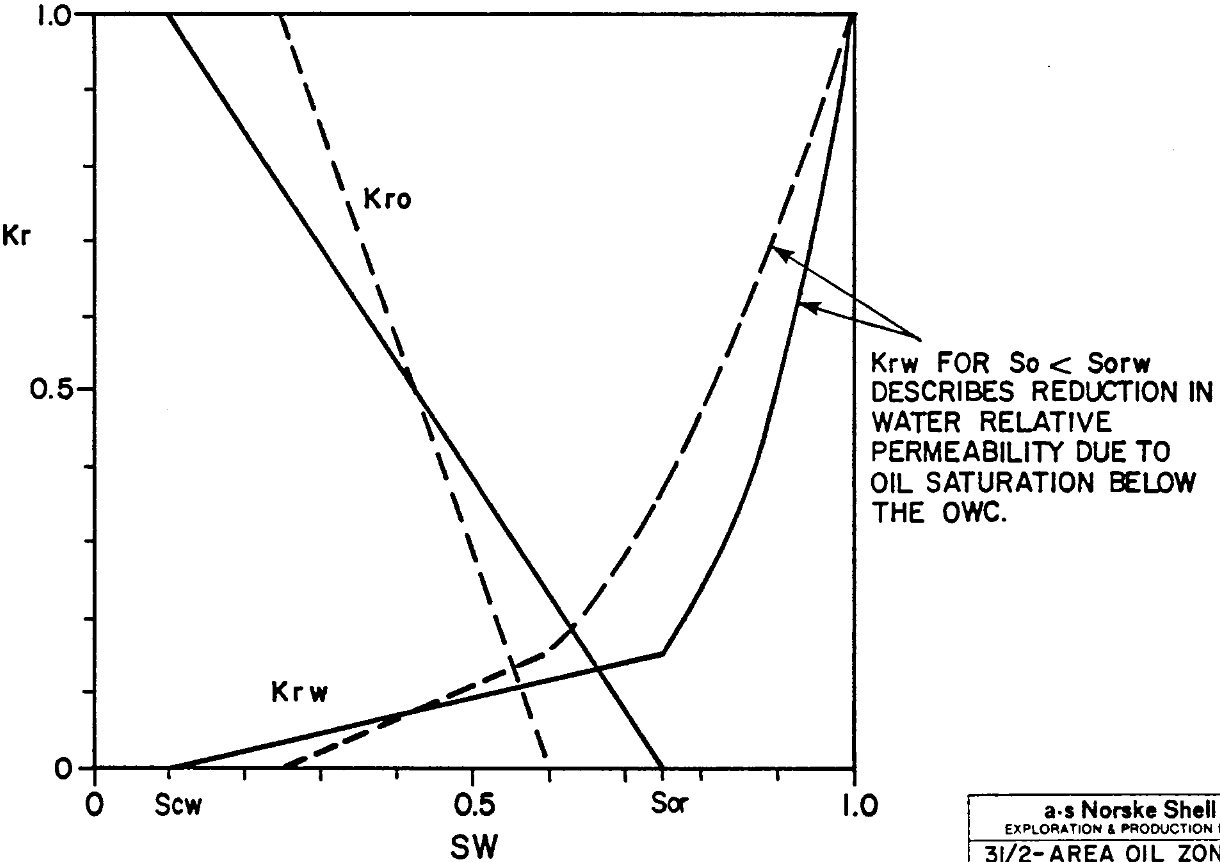
I=1	I=2	I=3	I=4	I=5	I=6	I=7	I=8	I=9	I=10
2	4	8	16	32	64	128	256	512	1416

Table I.1

RELATIVE PERMEABILITIES



	TYPE I	TYPE 2
LEGEND :	———	----
Perm. Range(mD)	>500	<500
Sorw:	.25	.40
Sorg:	.25	.40
Scw:	.10	.25
Sgcrit:	.03	.05



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31/2-AREA OIL ZONE STUDIES
WELL 31/2-2 MODEL
REL. PERM.

AUTHOR EPPP/22	FIG.	DATE MARCH 1981
REPORT NO NSEP III	I.5	DRAW NO G 819/5

THREE PHASE OIL RELATIVE PERMEABILITIES

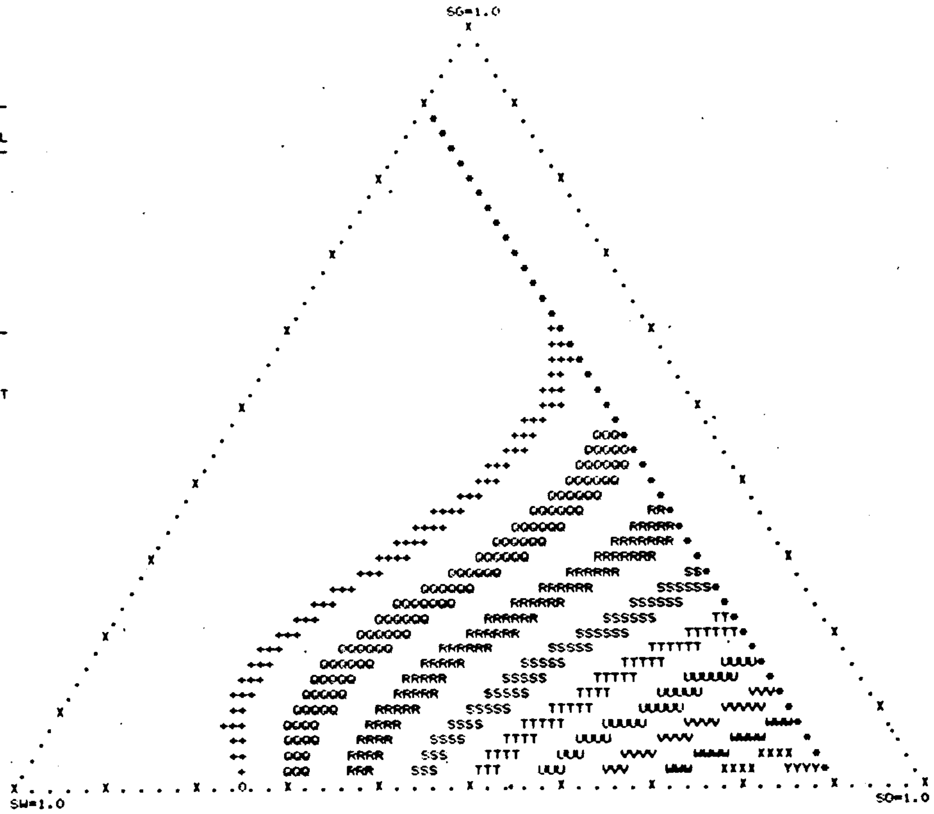
THREE PHASE OIL RELATIVE PERMEABILITY PLOT

SATURATION TABLE NUMBER 1

OIL RELATIVE PERMEABILITY	PLOT SYMBOL
.000 TO .025	+
.075 TO .125	Q
.175 TO .225	R
.275 TO .325	S
.375 TO .425	T
.475 TO .525	U
.575 TO .625	V
.675 TO .725	W
.775 TO .825	X
.875 TO .925	Y
.975 TO 1.000	Z

* DENOTES CONNATE WATER

O DENOTES TWO PHASE ENDPOINT



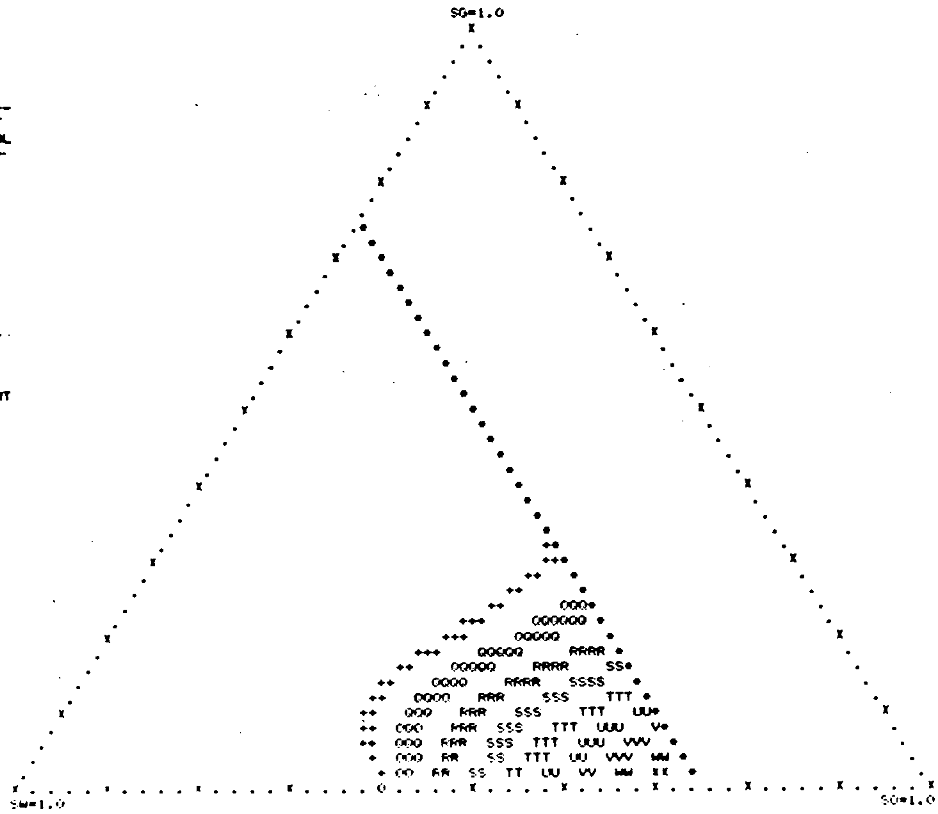
THREE PHASE OIL RELATIVE PERMEABILITY PLOT

SATURATION TABLE NUMBER 2

OIL RELATIVE PERMEABILITY	PLOT SYMBOL
.000 TO .025	+
.075 TO .125	Q
.175 TO .225	R
.275 TO .325	S
.375 TO .425	T
.475 TO .525	U
.575 TO .625	V
.675 TO .725	W
.775 TO .825	X
.875 TO .925	Y
.975 TO 1.000	Z

* DENOTES CONNATE WATER

O DENOTES TWO PHASE ENDPOINT



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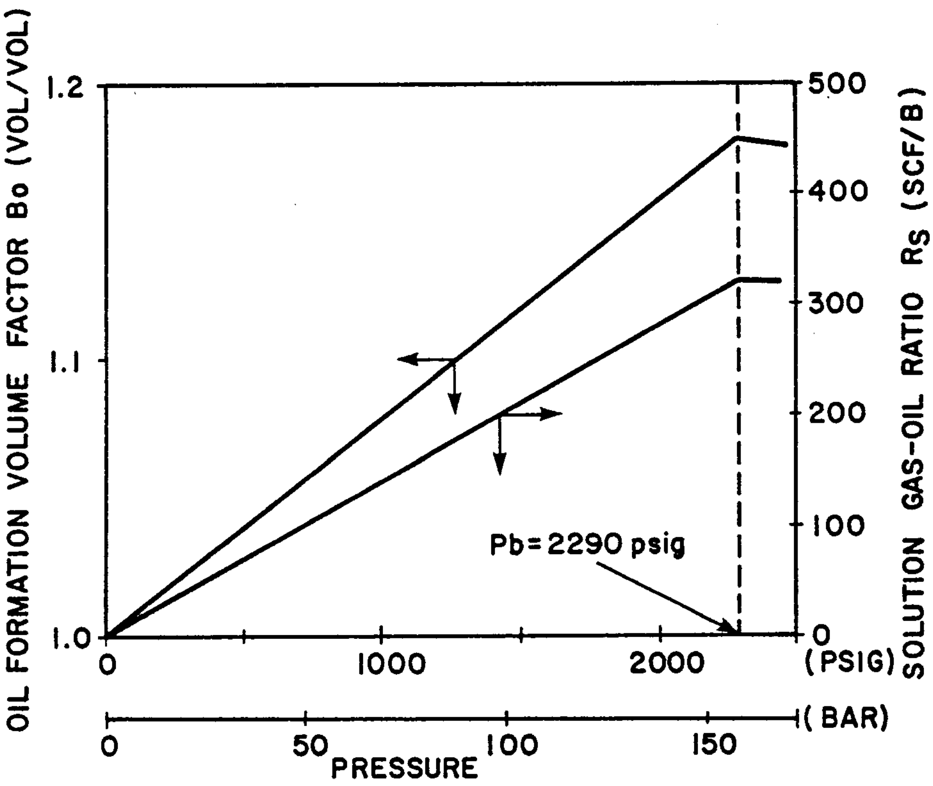
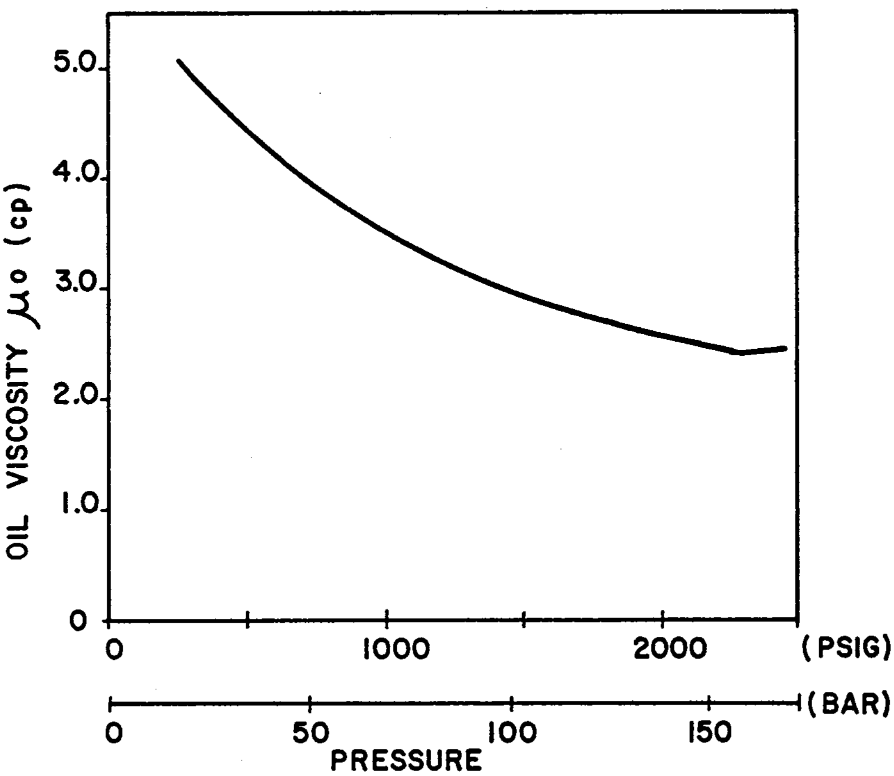
31/2 AREA OIL ZONE STUDIES
WELL 31/2-2 MODEL
THREE PHASE OIL REL. PERM.

AUTHOR: EPPP/22	FIG.	DATE: APRIL 1981
REPORT NO. NSEP III	I. 6	DRAW. NO.: G 819/6

OIL PROPERTIES USED IN THE 31/2-2 STUDY





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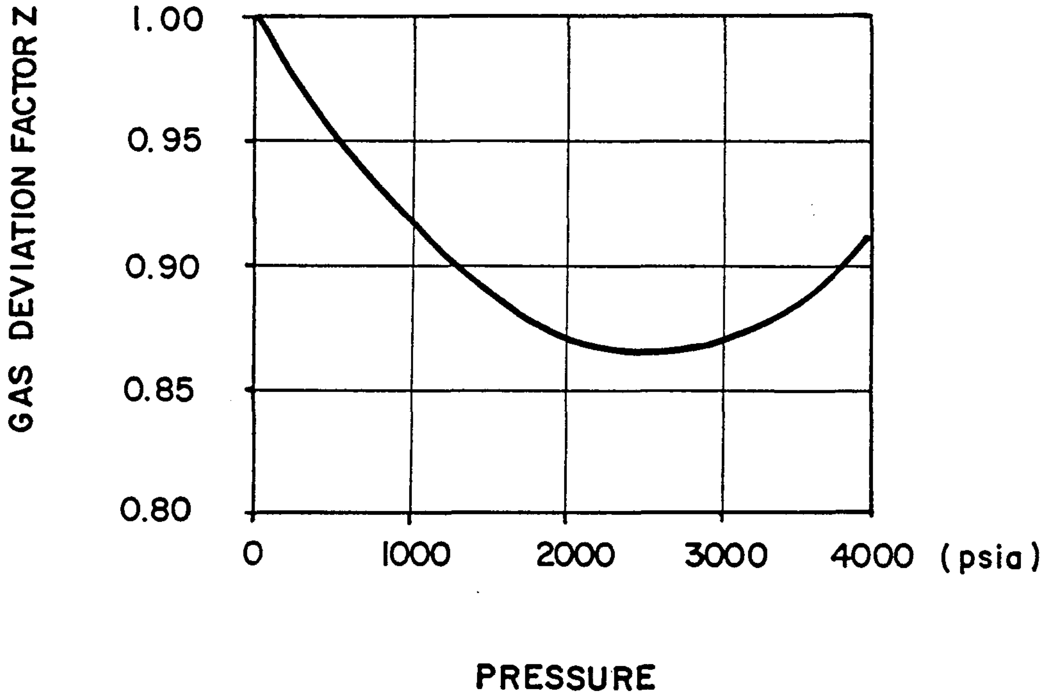
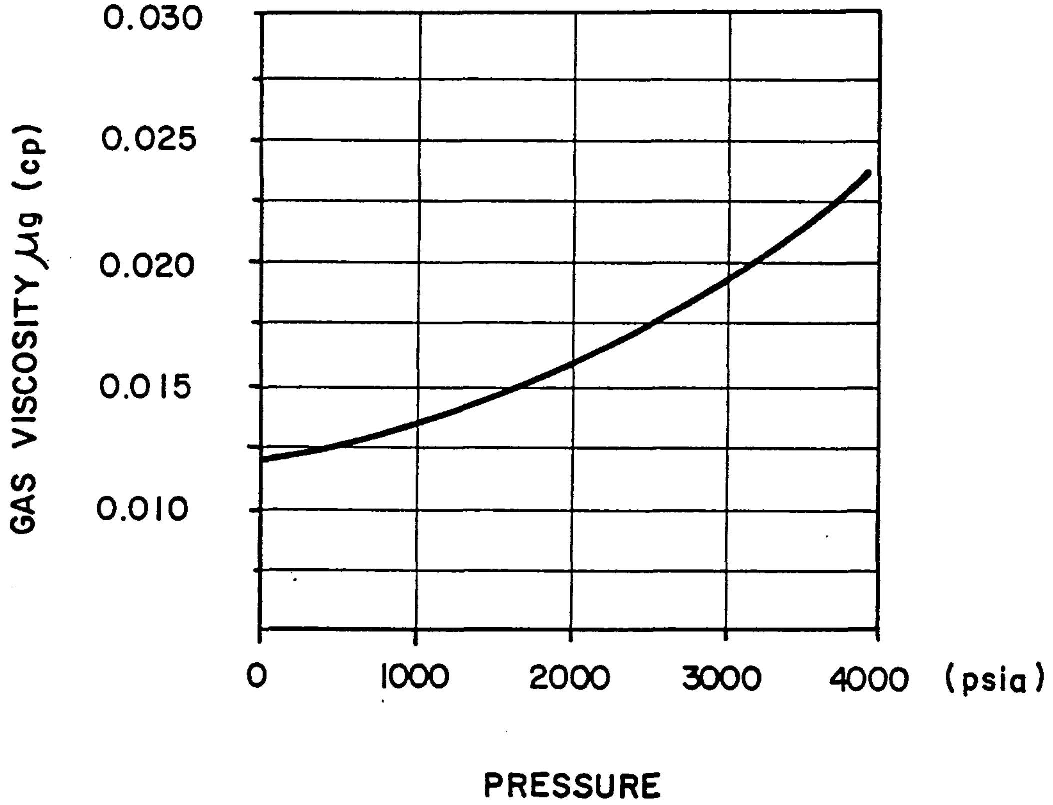
31/2-AREA OIL ZONE STUDIES
WELL 31/2-2 MODEL
OIL PROPERTIES

AUTHOR EPPP/22	FIG. I7	DATE MARCH 1981
REPORT NO NSEP III		DRAW NO G 819/7

GAS PROPERTIES USED IN THE 31/2-2 STUDY





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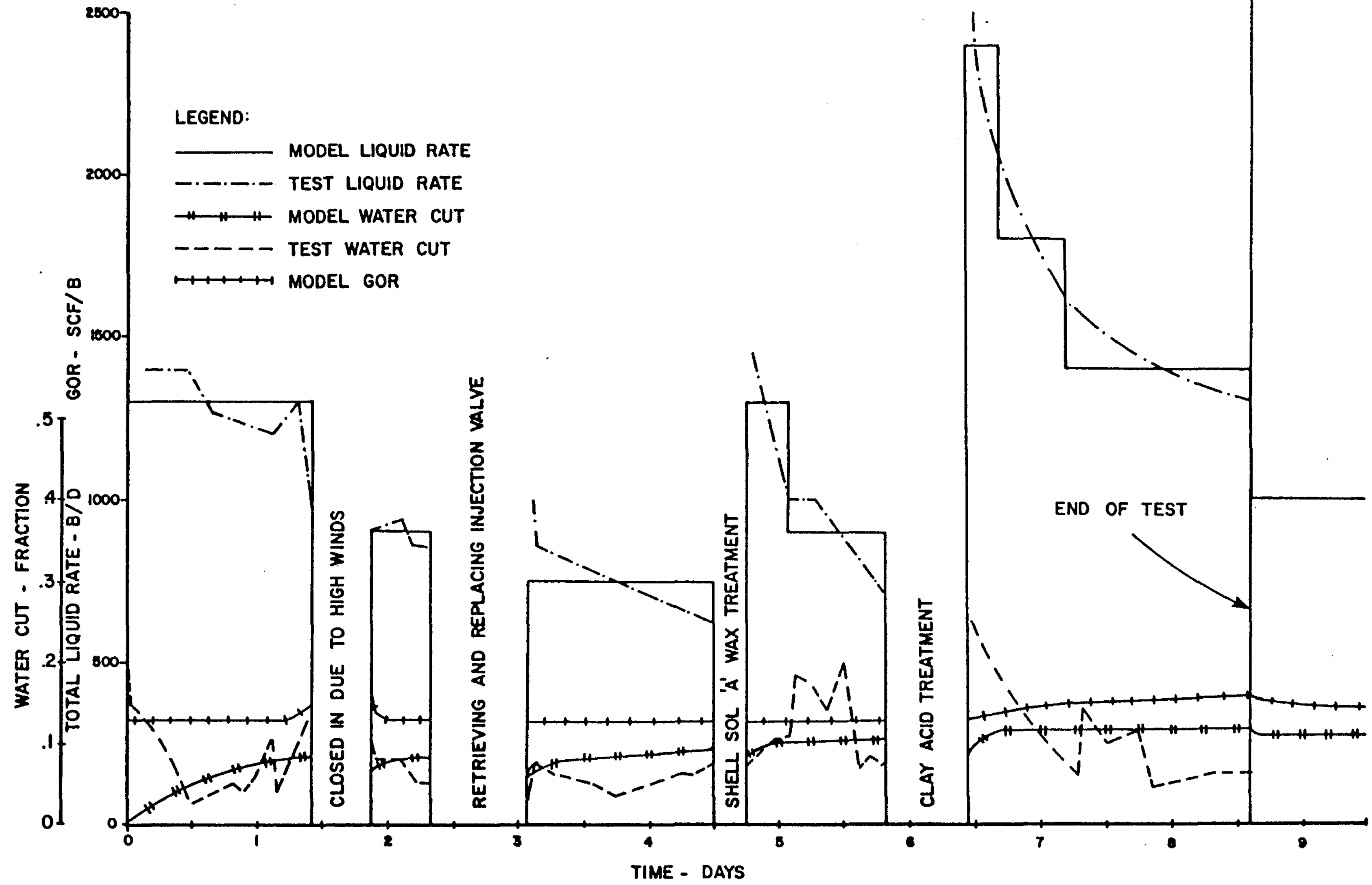
31/2 - AREA OIL ZONE STUDIES WELL 31/2-2 MODEL GAS PROPERTIES		
AUTHOR EPPP/22	FIG.	DATE MARCH 1981
REPORT NO NSEP III	I. 8	DRAW NO 819/ 8

TEST MATCH WELL 31/2 - 2

GAS LIFT PHASE



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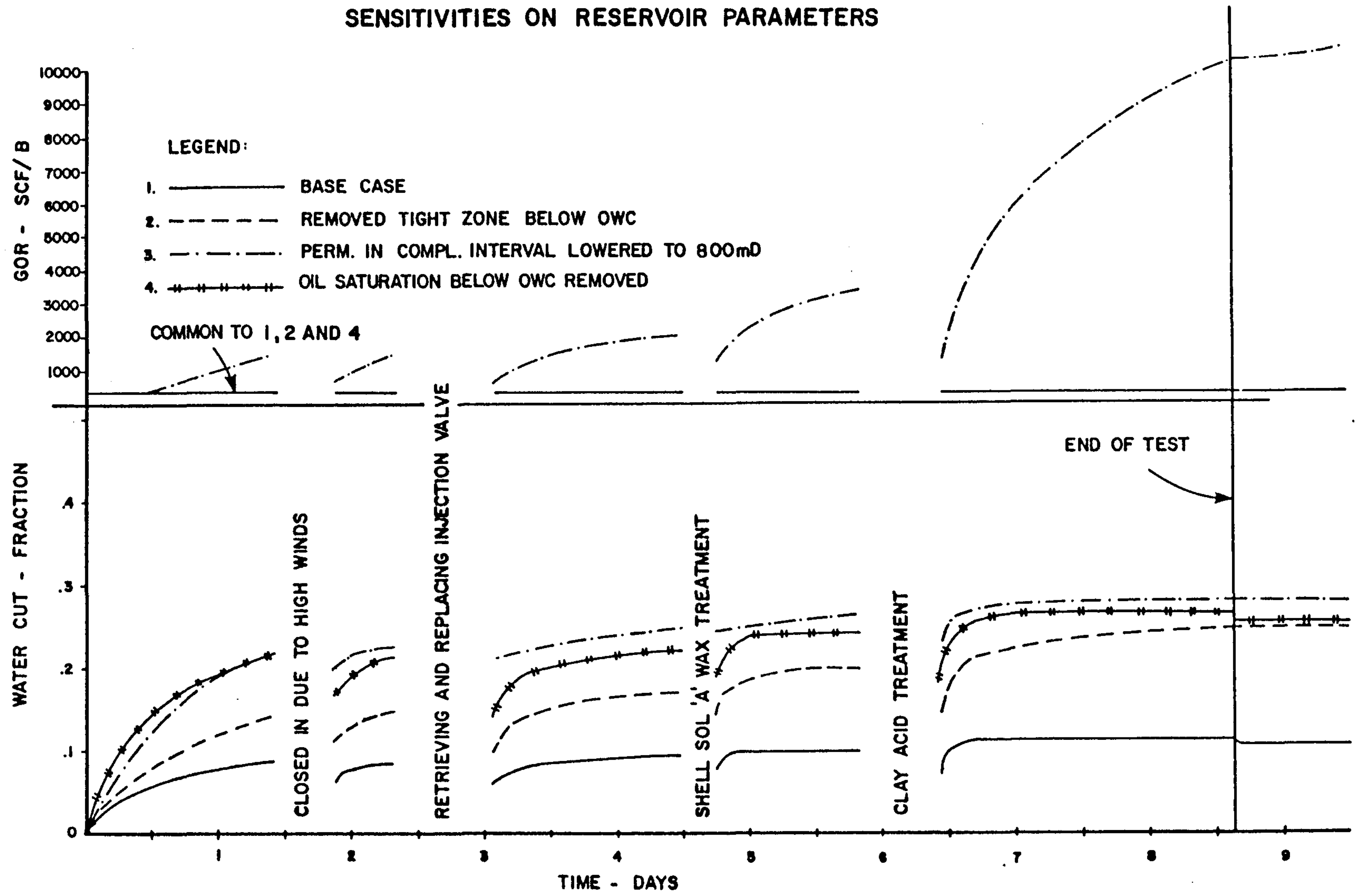
31/2-AREA OIL ZONE STUDIES
WELL 31/2-2 MODEL
TEST MATCH

AUTHOR: EPPP/22	FIG.	DATE: MARCH 1981
REPORT NO.: NSEP 111	I.9	DRAW. NO. 819/ 9

31/2-2 TEST MATCH

SENSITIVITIES ON RESERVOIR PARAMETERS



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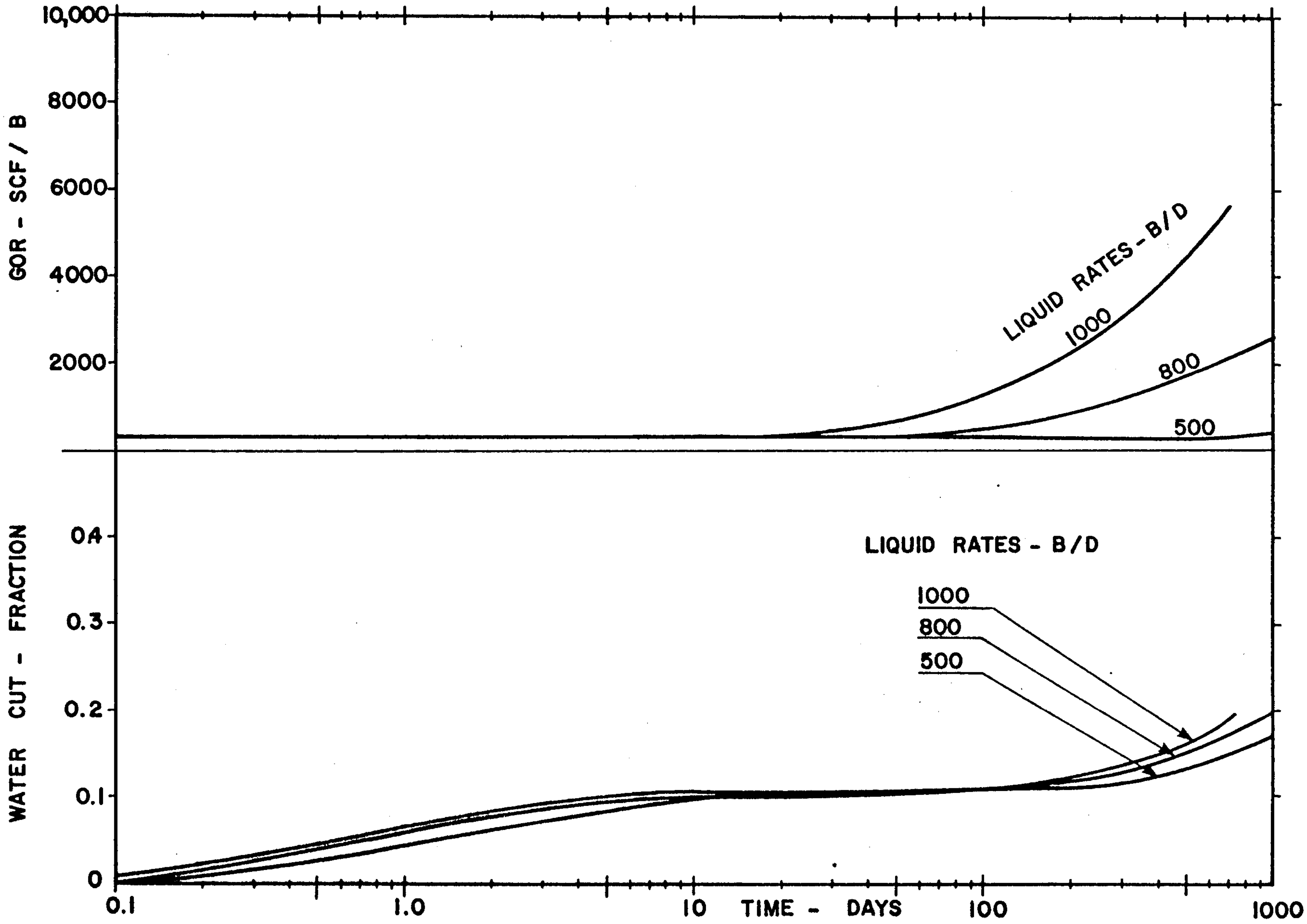
31/2-AREA OIL ZONE STUDIES WELL 31/2-2 MODEL TEST MATCH SENSITIVITIES		
AUTHOR: EPPP/22	FIG.	DATE: MARCH 1981
REPORT NO.: NSEP 111	I 10	DRAW. NO.: 819/10

WELL 31/2-2
PERFORMANCE AT VARIOUS RATE LEVELS



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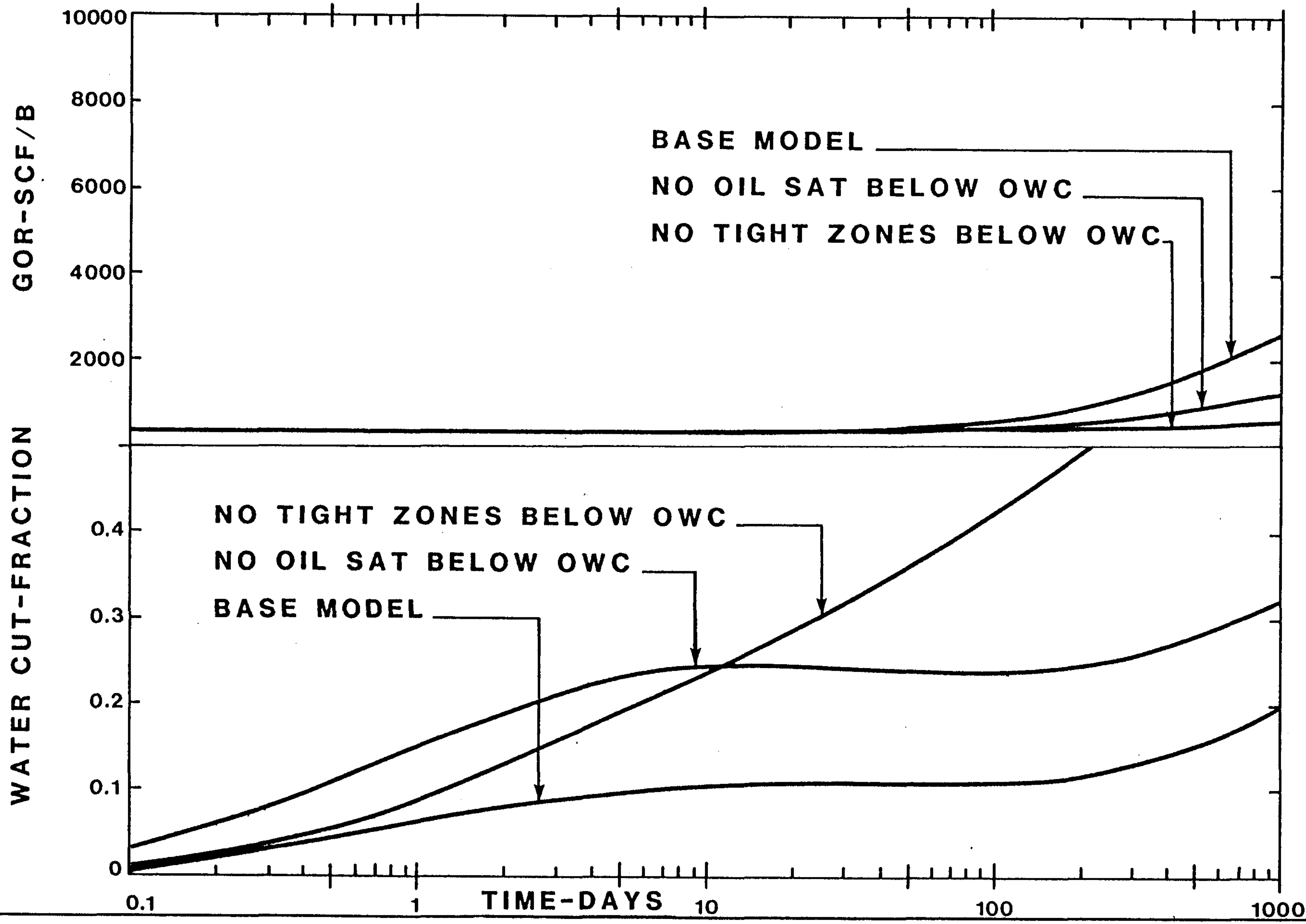
31/2-AREA OIL ZONE STUDIES
WELL 31/2-2 MODEL
PREDICTION RUNS

AUTHOR: EPPP/22	FIG. I.11	DATE MARCH 1981
REPORT NO. NSEP III		DRAW.NO. 819/11

WELL 31/2-2
EFFECTS OF RESTRICTIONS BELOW THE OWC
800 B/D LIQUID RATE



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31/2 AREA OIL ZONE STUDIES WELL 31/2-5 MODEL EFFECT OF TIGHT ZONE BELOW OWC		
AUTHOR: EPPP/22 REPORT NO. NSEP 111	FIG I 12	DATE: MARCH 1981 DRAW. NO. G 819/12

CONTENTS

1. SUMMARY AND CONCLUSIONS

Well 31/2-5 was drilled during the autumn of 1980 and suspended for testing during the 1981 season. It tested a fault block in the south-western part of block 31/2. The well penetrated an oil rim approximately 22 metres thick in unconsolidated highly permeable sands sandwiched between gas and water bearing zones. The oil rim in this well is considerably thicker than the 12 meters observed in wells further to the east in block 31/2. The 30^0 API oil gravity of an RFT sample from 31/2-5 is also different from the 25^0 API found in wells 31/2-2 and 3.

A radial model based on preliminary core data and logs was constructed for use in planning the forthcoming oil zone production test. The permeabilites in the oil zone and the adjacent parts of the water and gas bearing zones were estimated at the high value of 9.6 D. In the model 100% water saturation was assumed below the OWC. Runs with various completion intervals (all with 5 metres of perforations) indicate producing conditions after 10 days and 1 year of production as follows:

Base of Completion	Gross Liq Rate B/D	GOR SCF/D		Water Cut %	
		10 days	365 days	10 days	365 days
8 metres above OWC	2000 5000 10000	370 1600 7200	380 7000* >>10000*	2 11 23	10 35* >40*
5 metres above OWC	2000 5000 10000	370 400 3000	380 1800 9000*	7 18 30	18 37 45*
2 metres above OWC	2000 5000 10000	370 370 1000	380 450 5000*	20 30 38	30 42 48*

* Approximate values obtained by extrapolating plots.

However, in view of results from the 31/2-2 model, runs were also made including the log indicated residual oil saturation (about 25%) below the OWC. These runs show considerable reductions in water cuts and thus increases in GOR's because of higher oil rates. The results for a completion 5 metres above the OWC (base case) is summarized in the following table:

Gross Liquid Rate B/D	GOR SCF/B		Water Cut %	
	10 days	365 days	10 days	365 days
2000	370	370	2	8
5000	420	3400	6	15
10000	4000	>10000*	10	>15*

* Approximate values obtained by extrapolating plots

The following conclusions can be drawn from the model results:

1. Development of water and gas coning in this well requires rates which are in the order of 5-10 times higher than in well 31/2-2.

2. The GOR behaviour is very sensitive to liquid withdrawal and location of the completion. The water cut is significantly less affected.

3. With the base of the completion (5 m opened) located 5 metres above the OWC a gross liquid rate of some 5000 B/D can be sustained for about one year with GOR's lower than about 3000 SCF/B.

4. The oil saturation indicated by the logs below the OWC may have an appreciable effect on well performance in reducing water cuts.

5. The well performance is only marginally affected by the tight streaks above and below the oil bearing interal. The high permeabilities immediately above and below the oil zone appear to be controlling.

6. With the high expected PI (greater than 10 B/D/psi) and 5 inch tubing a liquid rate in excess of 5000 B/D should be achievable during the production test.

7. To avoid the risk of early excessive gas production during the test the completion should not be higher than 5 metres above the OWC. The base of the test completion is recommended to be located between 2 and 5 metres above the OWC.

2. RECOMMENDATIONS AND FUTURE WORK

Based on the results of the 31/2-5 well model runs, the following recommendations are made:

1. The 31/2-5 oil zone test completion should be located rather low in the oil column, preferably 2-5 metres above the OWC.

2. Test equipment should be sized to handle liquid rates up to 10,000 B/D.

3. 5 inch tubing should be applied in the test since it is preferable to the 3 1/2 inch string for essentially all producing conditions.

4. After the oil zone production test in 31/2-5 (Summer 1981) a comparison should be made between test results and model predictions. The model should then be calibrated to include the test results. With this updated model the feasibility of oil rim production, with low and high GOR and low and high water cuts should be further investigated, incorporating the effects of pressure depletion and aquifer behaviour.

3. INTRODUCTION

Well 31/2-5 was drilled during autumn 1980 in the south-western corner of block 31/2 in the Norwegian Sector of the North Sea. Due to expected weather problems and expiration of the rig lease contract the well was suspended for subsequent testing during the 1981 season. The objective of the well was to test whether the reservoir accumulation appraised by other wells in the main 'A' compartment in block 31/2, extended into the fault block in the south-western part of the block. (See Fig. II.1). Seismic had shown a possible "flatspot" across this fault block, indicating the potential existence of a gas-liquid contact. The well proved this interpretation to be correct as it penetrated 42 metres of gas bearing sands overlaying an approximately 22 metre oil column underlain by some 350 m of water bearing sands. The oil layer in this well was found to be considerably thicker than the 12 metres observed in wells 31/2-2, 3 and 4 in the 'A' compartment further to the east. Furthermore, on an RFT oil sample from 31/2-5 gave a gravity of 30^0 API as compared with 25^0 API in wells 31/2-2 and 3.

The hydrocarbon bearing part of the reservoir was found to be of exceptionally good quality. In particular the oil leg appears to be very homogeneous with an estimated permeability of 9.6 D. The reservoir pressure was found to be hydrostatic with a value of 2280 psig at the gas/oil contact (1554 metres sub sea). The depth of the GOC and the pressure regime appear to be approximately the same as in other wells in block 31/2.

With a thickness of 22 metres in very permeable sands the oil zone in this well is of particular interest. Hence, in order to plan the forthcoming production test, a simulation model of the well was developed.

4. OBJECTIVES

The 31/2-5 oil zone model study was undertaken with two main objectives:

1) To describe the expected oil production performance of well 31/2-5 with respect to water and gas coning, as a function of the position and length of the completion interval.

2) To recommend the optimum completion interval for the forthcoming oil zone production test in well 31/2-5.

5. MODEL CONSTRUCTION

5.1 Model Type

A three phase two dimensional radial model was used in the study. The model dimensions were 10-1-12 indicating that the reservoir was split into 10 blocks in the radial direction and 12 layers in the vertical direction. The solution method in the simulation program (IMPSIM19) was implicit with respect to pressures and saturations.

5.2 Layers - Permeability/Porosity Data

The permeability and porosity values applied in the model are based on preliminary GECO core analysis results combined with log interpretation. The permeabilities are generally very high, being in the order of several Darcies in the hydrocarbon bearing parts of the reservoir and in the top 17 meters of the water leg. These highly permeable sands are interrupted by a few tight streaks in the gas and water bearing parts, while the oil zone appears to be quite uniform. The properties of the individual model layers are summarized in Table II.1 and are illustrated together with log data in Enclosure 2.

At the time of data collection core data were available only down to 15 metres below the OWC. Permeabilities below this point were estimated by correlation with other layers above, which appeared similar from the logs.

5.3 Relative Permeabilities

The relative permeability data from the 31/2-2 model were also applied in the 31/2-5 model. The description can be found in the 31/2-2 model writeup (chapter 5.3 and Figs. I.5 and I.6). Capillary pressure effects were neglected in the model.

5.4 PVT Data

The gas data (viscosity and Z-factor) used in the 31/2-2 model were also applied in the 31/2-5 model (Fig. I.8 of the 31/2-2 model description)

Preliminary tests of a RFT segregation sample had indicated an oil gravity of about 30^0 API compared to about 25^0 API in wells 31/2-2 and 31/2-3. A later check of the RFT sample by Core Lab confirmed the higher API gravity. On this basis oil PVT data for the 31/2-5 model were estimated from correlations. The following values were used at initial reservoir conditions (Pi=Pb=2280 psig, T=160^0 F):

Solution gas-oil ratio	R_{si}	= 370 SCF/B
Oil form. vol. factor	B_{oi}	= 1.16 B/B
Oil viscosity	μ_{oi}	= 1.6 cp

The gas-oil ratio and the formation volume factor were assumed to be linear with pressure. The oil viscosity was varied according to the amount of gas assumed in solution at various pressures. The error introduced by using these linear relationships is believed to be negligible because of the small changes in pressure in the model. The oil PVT relationships applied are presented in Fig. II.2.

6. PREDICTION RUNS

6.1 Performance of Various Completion Intervals

Model prediction runs were made in order to determine expected well performance under various producing conditions. Three different completion intervals, all with a length of 5 metres, and elevations of 8,5 and 2 metres above OWC were studied. The base case was defined with the base of the completion at an elevation of 5 metres above the OWC. The runs used liquid withdrawal rates ranging from 2000 to 10 000 B/D. No vertical lift calculations were included in these runs in order to concentrate on reservoir performance aspects only. The performance appeared to be rather sensitive to both withdrawal rate and completion position. The gas-oil ratio, however, seems to be more affected than does the water cut. The results of the runs have been plotted in Figs. II.3 through II.5.

For the sake of completeness, completions lower than 2 meters above OWC were also tested. Runs were made with completions immediately above and immediately below the OWC. In order to observe changes in GOR for these completions a high gross liquid rate of 10 000 B/D was chosen. The results are compared with results from higher completions in Fig. II.6. It is interesting to note that the water cuts for the three lowest completions appear to be essentially identical from about 20 days production time and onwards. However, the GOR's are different. The early time 'hump' in the water cut profile for the completion immediately above the OWC is hard to explain physically, but it is consistent with grid block saturations given by the model.

6.2 Effect of Critical Reservoir Parameters

The importance of various reservoir parameters was investigated in model sensitivity runs.

The permeability in the major part of the oil leg (upper 18 metres) is uncertain. No cores were recovered from this interval because of the very friable formation. However, from logs it appears very similar to the interval consisting of the lower 5 meters of the oil zone and the upper 15 meters of the water zone. An average zone and the upper 15 meters of the water zone. An average permeability of 9615 mD was estimated from 12 core plug measurements. This high permeability value was used in the base model for the entire oil zone and also for the lower 4 meters of the gas zone. A sensitivity to this major assumption was made by replacing the 9615 mD with 4445 mD except within 5 meters of the OWC where core plug measurements are available. The lower permeability is the average value estimated for the upper part of the gas zone, which from logs appears to be less uniform than the oil zone. The reduced permeability causes a considerable increase in both GOR and water cut. The result of this sensitivity is compared with the base case in Fig. II.7.

Further sensitivity runs were made by removing the tight zones above the GOC and below the OWC respectively. Although the tight zone is only 5 meters above the GOC, removing it has only a marginal impact on the GOR behaviour and no impact on the water cut. (See Fig. II.7) The reason is the high transmissibility in the gas zone immediately above the GOC. Removing the two tight zones below the OWC (6 and 15 m below OWC) causes only a modest increase in water cut and a slight decrease in GOR. (See Fig. II.7)

The model permeabilities below the top 15 metres of the water leg were estimated by correlation with other layers above, which appeared similar from logs. Additional core data received subsequent to the data collection for this study indicate that these permeabilities were somewhat overestimated. Therefore, after the runs for this study were finalized, a sensitivity run was made using the new core permeabilities to investigate the possible error due to use of too high permeabilites in the aquifer. The run gave essentially identical results to the corresponding run presented in this study. It appears that the water influx is controlled by the high transmissibility immediately below the OWC.

6.3 Impact of Oil Saturations below OWC

During the attempts to match the 31/2-2 production test performance, it was realized that the presence of residual oil saturations below the OWC probably has a strong effect on water coning behaviour. Logs from well 31/2-5 indicate that these oil saturations are also present in this well. The phenomenon extends at least 25 metres into the aquifer with an oil saturation level of about 25%.

In order to investigate the effect of these oil saturations, they were included in a modified version of the model. The inclusion of the oil saturations in the water zone approximately halves the predicted water cut and accelerates the development of gas coning. The results of model runs are shown in Figs. II.8 through II.10. A comparison with a case where the oil saturation below the OWC was neglected is shown in Fig. II.11. It will be appreciated that with the base of the completion 5 metres above the OWC and a maximum liquid rate of 5000 B/D, it may become difficult to obtain appreciable increases in water or gas production within a testing time frame of 10-20 days.

In order to improve the chances of obtaining a high rate and noticeable coning during the test, runs were made by extending the length of the completion interval by 3 metres both upwards and downwards respectively. The results in Fig. II.12 show only small effects for a liquid rate of 5000 B/D within the time frame of a test. Considerable differences in the GOR are however apparent for long term production. Only if a higher rate of some 10,000 B/D is achieved will the differences become appreciable within the testing time frame (See Fig. II.13). However, at 10,000 B/D a rapid increase in GOR is predicted in all cases, independent of the length and position of the perforated interval.

7. SELECTION OF TEST INTERVAL

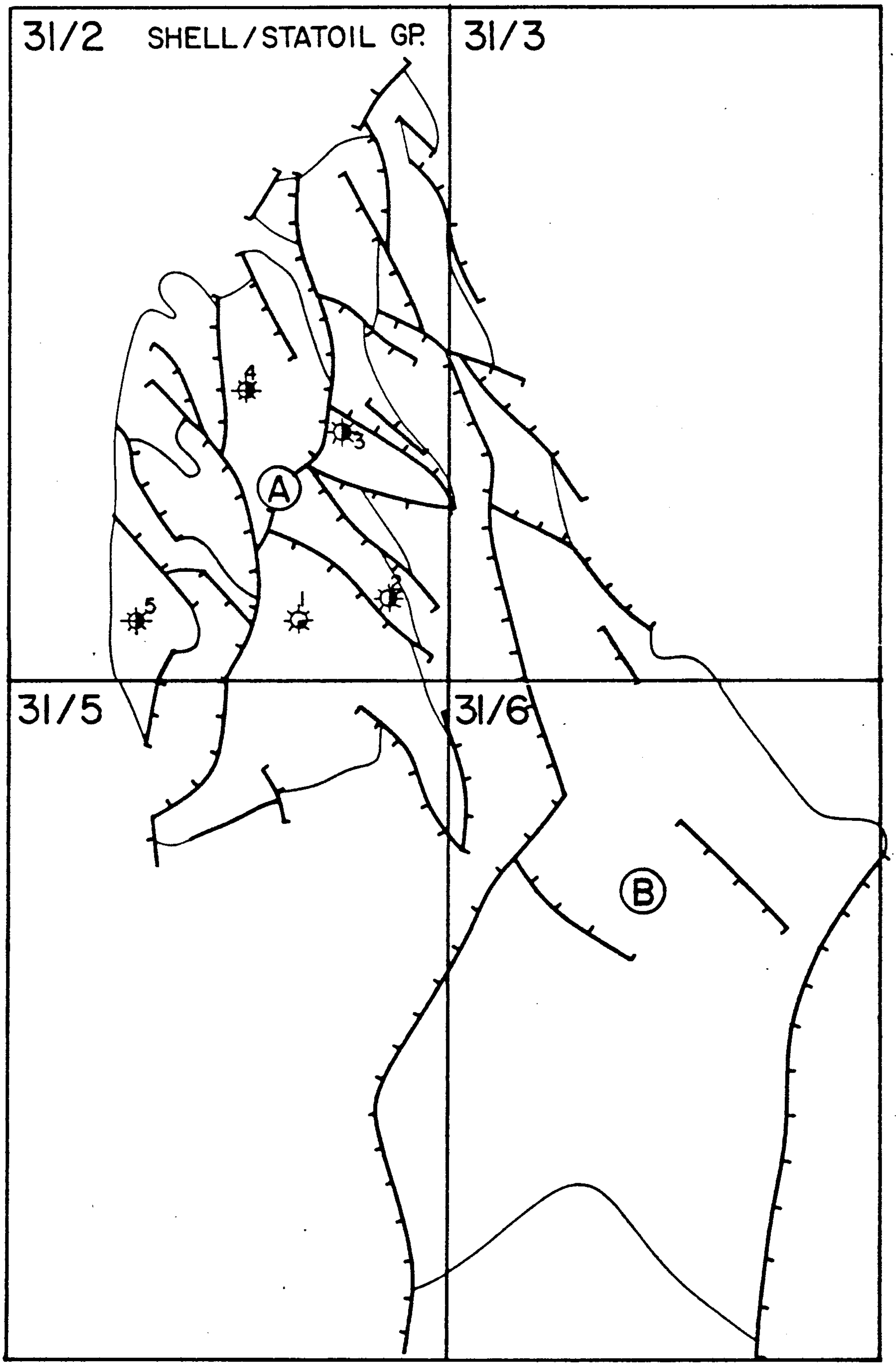
7.1 Reservoir Performance

With the high permeability and a completion without excessive skin, the productivity index of a completion in the oil zone should be very high. Consequently a high rate can be expected. For planning purposes a liquid rate in the order of 5000 B/D has been assumed, although the possibility of achieving a higher liquid rate than 5000 B/D is recognised. With this rate the performance plots of the various completion intervals in Figs. II.3 through II.5 indicate that for the highest completion (8 m above OWC) the GOR exceeds 2000 SCF/B within a reasonable test period of 10-20 days. It should be noted that the low permeability sensitivity in Fig. II.7 and the cases including a residual oil saturation below the OWC (Figs. II.8 through II.10) show an accelerated development of gas coning. With this background it is felt that the test completion interval should be relatively low in the oil column to make sure that excessive gas production is avoided at an early stage of the test. As the completion interval approaches the OWC water production increases. But the increase is not dramatic, as illustrated in Fig. II.6, until the completion gets as close as 2 metres above the OWC. Hence the best chance of a conclusive test is believed to be with the base of the completion located some 2-5 metres above the OWC.

7.2 Tubing Size - Lift Performance

Selection of the optimum tubing size is an important part of test planning. The sizes available for the test in well 31/2-5 are 3-1/2 inch and 5 inch. Preliminary vertical lift runs has been made for these two tubing sizes using Shell's WIPCO program. GOR's ranging from solution GOR (370 SCF/B) to 10 000 SCF/B and water cuts of 0% and 50% were studied. The tubing head pressure was varied from 250 psi for production at the solution gas oil ratio to 750 psi at the highest rates and GOR's. The maximum liquid rates for the two tubing sizes were then estimated under the various flow conditions using liquid PI's ranging from 2 to 50 B/D/psi. The results are shown in Table II.2, which indicate that the 5 inch tubing is preferable to the 3 1/2" for essentially all conditions.

Only for 50% water cut and solution GOR combined with a PI value of less than 10 B/D/psi is the 3 1/2 inch better. However, as stated in section 7.1 a high productivity is expected. A value in the order of 10-20 B/D/psi is expected. With this assumption the 5 inch tubing is always preferable to the 3 1/2 inch.



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EXPLORATION & PRODUCTION FORMS

31/2-AREA OIL ZONE STUDIES
WELL31/2-5 MODEL
31-AREA PROSPECT

AUTHOR EPXT/15	FIG.	DATE FEB. 1981
REPORT NO· NSEP111	II.1	DRAW. NO. G 819/13

31/2-5 MODEL DATA

Interval No.	Interval	Thickness		Ø - %		K_H - mD		K_V - mD	
	Log Depth*-MBDF	m	ft	Lab	Corrected	Lab	Corrected	Lab	Corrected
1	1536.5 - 1573	36.5	120	35.1 (3)	32.5	4445 (25)	4445	1925 (7)	1925
2	1573 - 1574.5 a)	1.5	5	1.17	1.17	0.032 (3)	0.003	0.006 d)	0.0003
3	1574.5 - 1579	4.5	15						
4	1579 - 1586	7	23						
5	1586 - 1591	5	16						
6	1591 - 1596	5	16	32.3 (17)	29.9	9615 (12)	9615	6500 d)	6500
7	1596 - 1601	5	17						
8	1601 - 1605.5	4.5	15						
10	1608 - 1615	7	23						
9	1605.5 - 1608	2.5	8	25.7 (1)	24.4	23 (1)	23 e)	8.5 d)	8.5 e)
11	1615 - 1618 b)	3	10	25.7 c)	24.4	23 c)	23 e)	8.5 d)	8.5 e)
12	1618 - 1818 b)	200	656	35.2	32.6	511 (5) b)	511	115 (1)	80

* Assumed to be the same as drillers depth. Investigations subesequent to this study indicate very minor corrections.

a) Used plugs at core depths 1555.9, 1555.6, and 1566.9 as typical

b) From Gamma Ray assumed similar to 1562 - 1564 m

c) Assumed same as layer 9

d) From K_V - K_H correlation Well 31/2-2

e) No correction was applied in order not to be optimistic with respect to water production

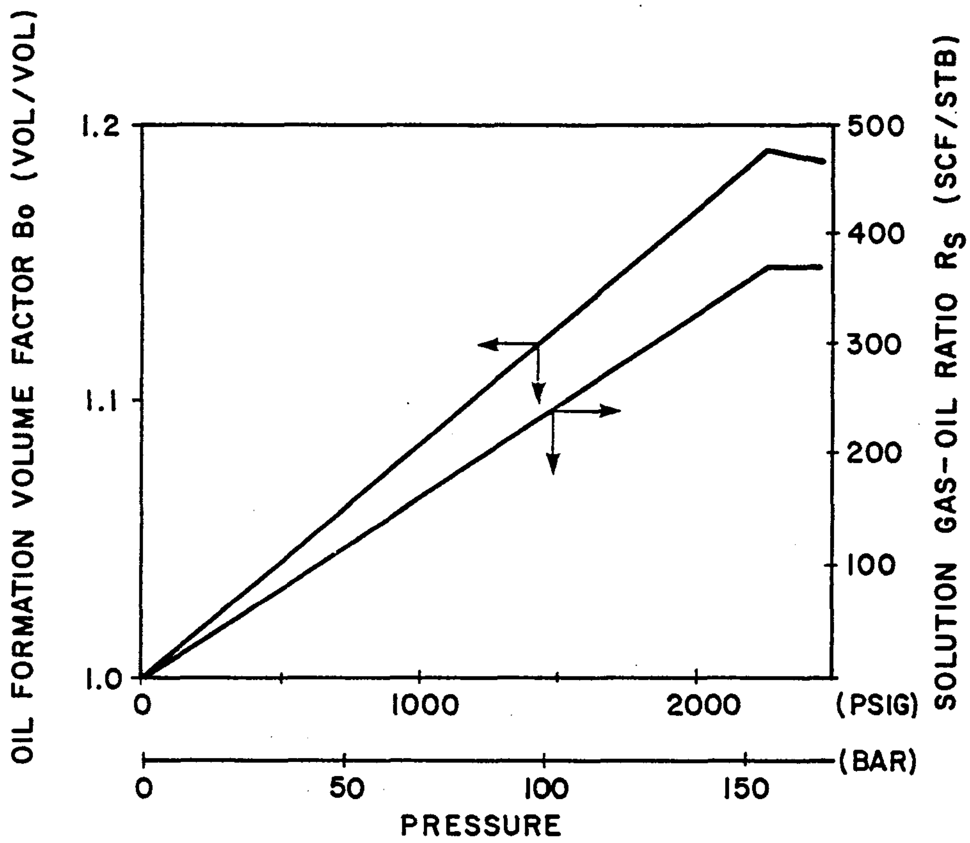
( ) Number in parenthesis is number of core plug measurements used

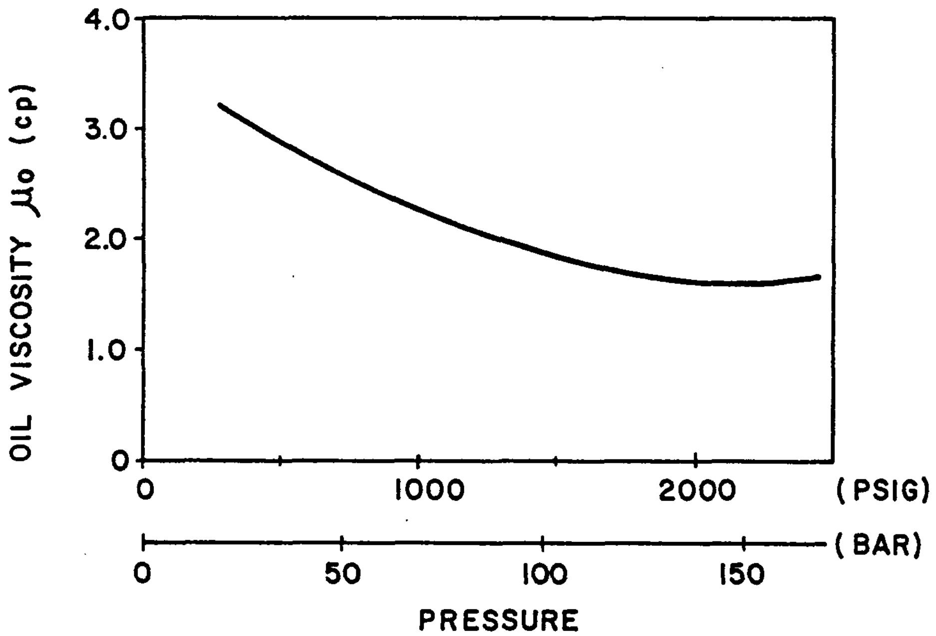
GRID MESH IN R-DIRECTION (m):

I=1	I=2	I=3	I=4	I=5	I=6	I=7	I=8	I=9	I=10
2	4	8	16	32	64	128	256	512	1416

Table II.1.

OIL PROPERTIES USED IN THE 31/2-5 STUDY





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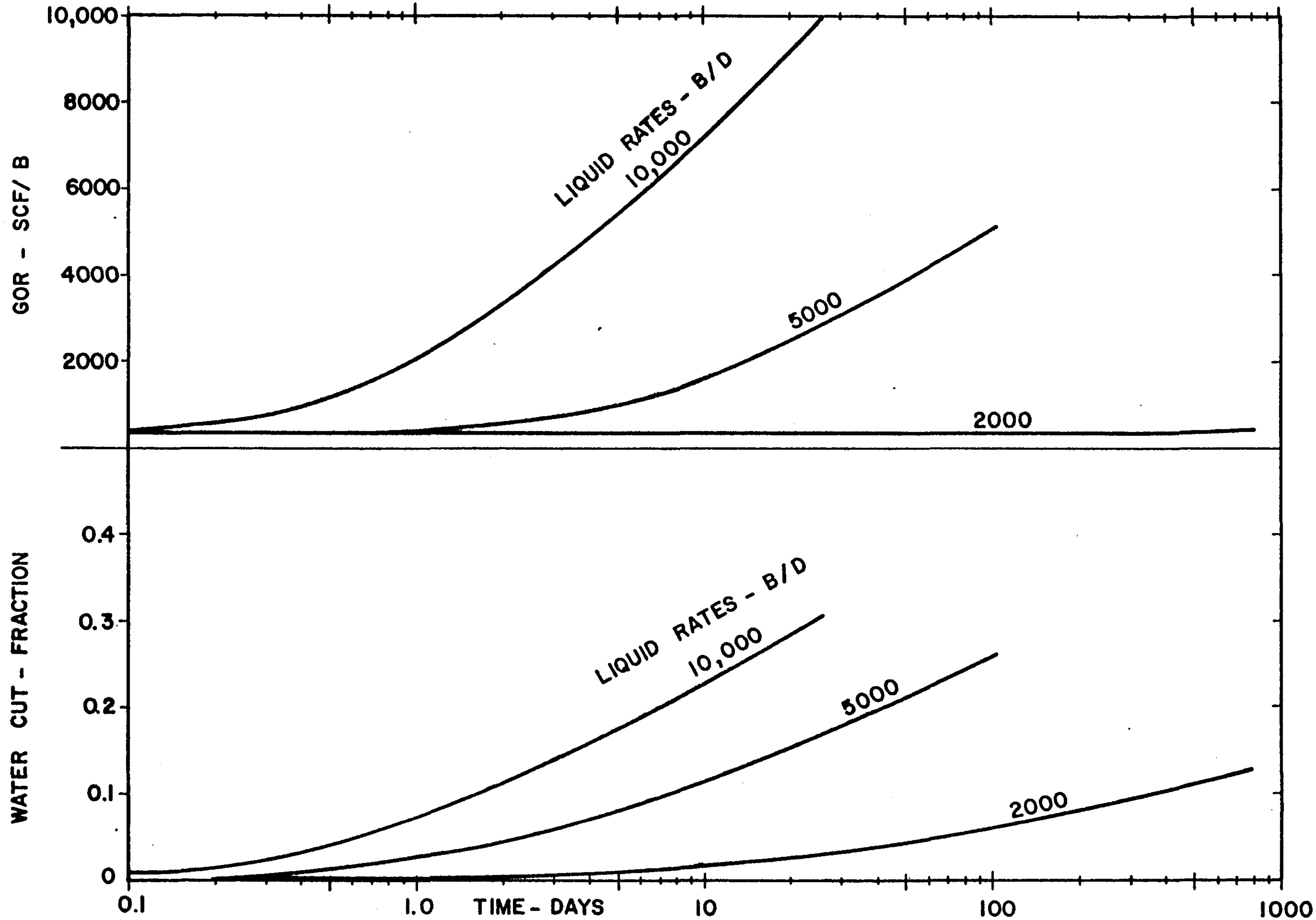
EXPLORATION & PRODUCTION FORUS

31/2-AREA OIL ZONE STUDIES
WELL 31/2-5 MODEL
OIL PROPERTIES

AUTHOR EPPP/22	FIG.	DATE MARCH 1981
REPORT NO NSEP/III	II.2	DRAW NO G819/14

WELL 31/2-5
PERFORMANCE AT VARIOUS RATE LEVELS
COMPLETION 8 m ABOVE OWC



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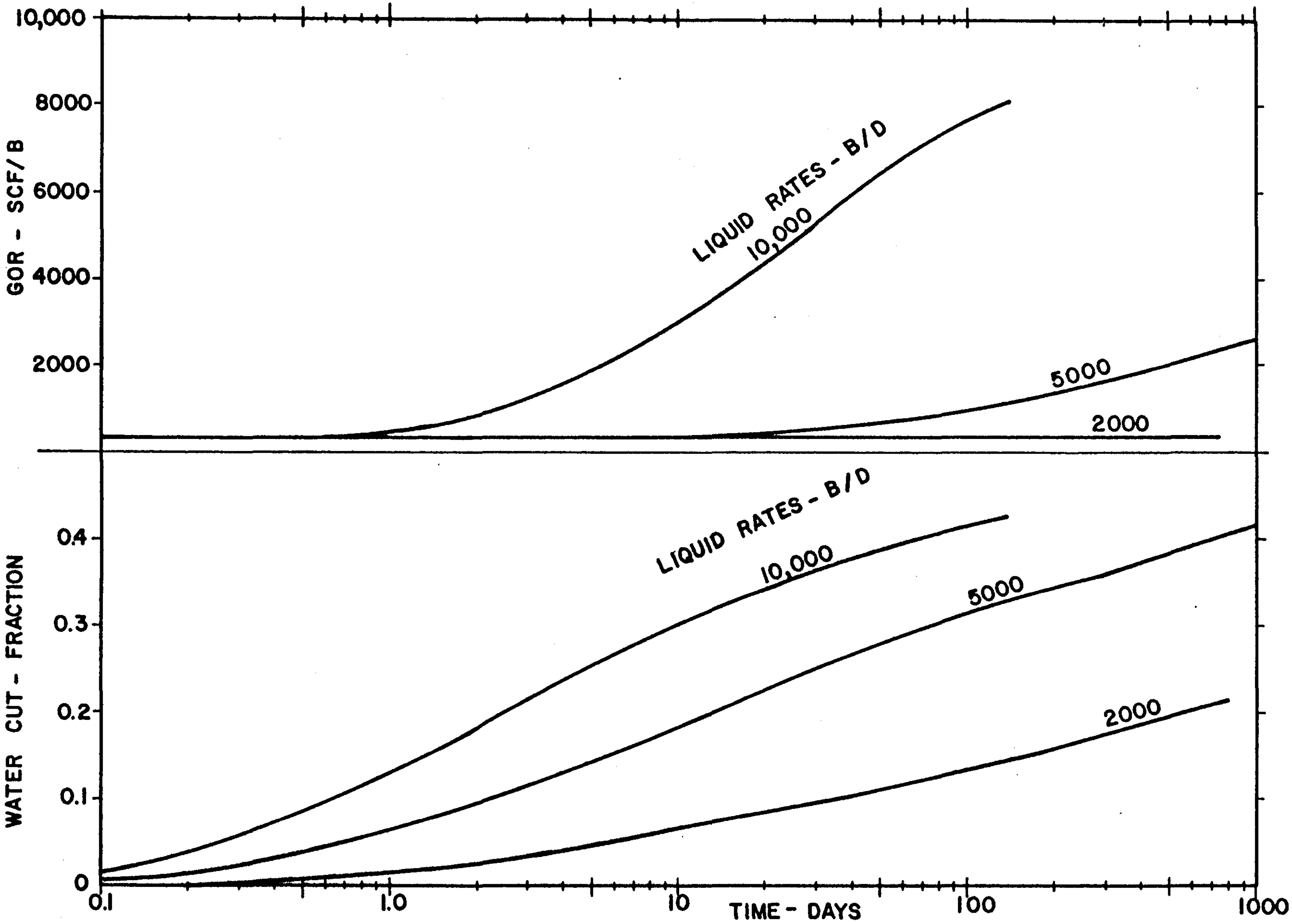
EXPLORATION & PRODUCTION FORUS

31/2 AREA OIL ZONE STUDIES
WELL 31/2-5 MODEL
COMPLETION 8 m ABOVE OWC

AUTHOR EPPP/22	FIG.	DATE MARCH 1981
REPORT NO. NSEP/III	II.3	DRAW. NO. G 819/15

WELL 31/2-5
PERFORMANCE AT VARIOUS RATE LEVELS
COMPLETION 5 m ABOVE OWC



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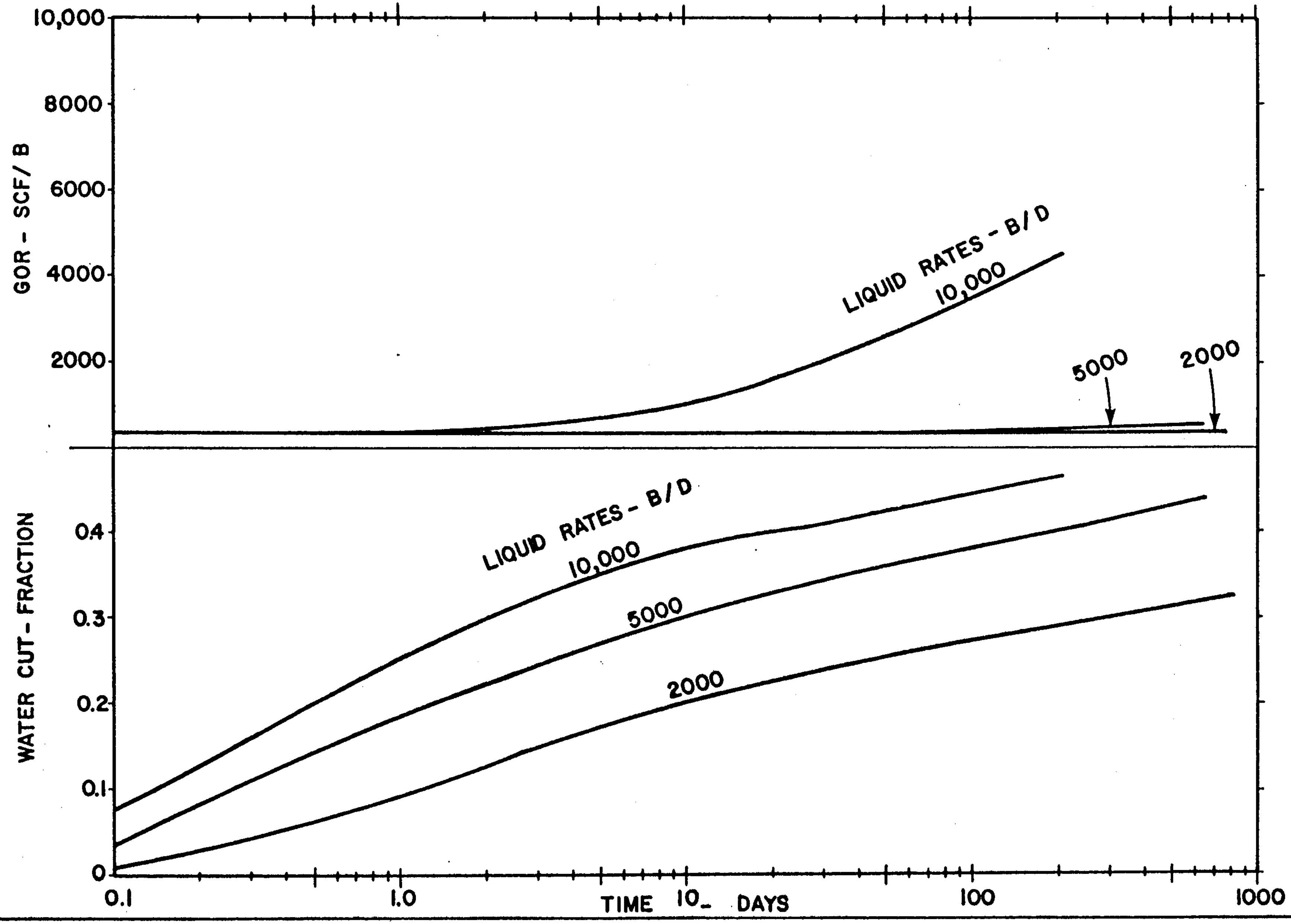
EXPLORATION & PRODUCTION FORUS

31/2 AREA OIL ZONE STUDIES
WELL 31/2-5 MODEL
COMPLETION 5 m ABOVE OWC

AUTHOR: EPPP/22	FIG.	DATE: MARCH 1981
REPORT NO.: NSEP/11	II.4	DRAW. NO. G 619/16

WELL 31/2-5
PERFORMANCE AT VARIOUS RATE LEVELS
COMPLETION 2 m ABOVE OWC



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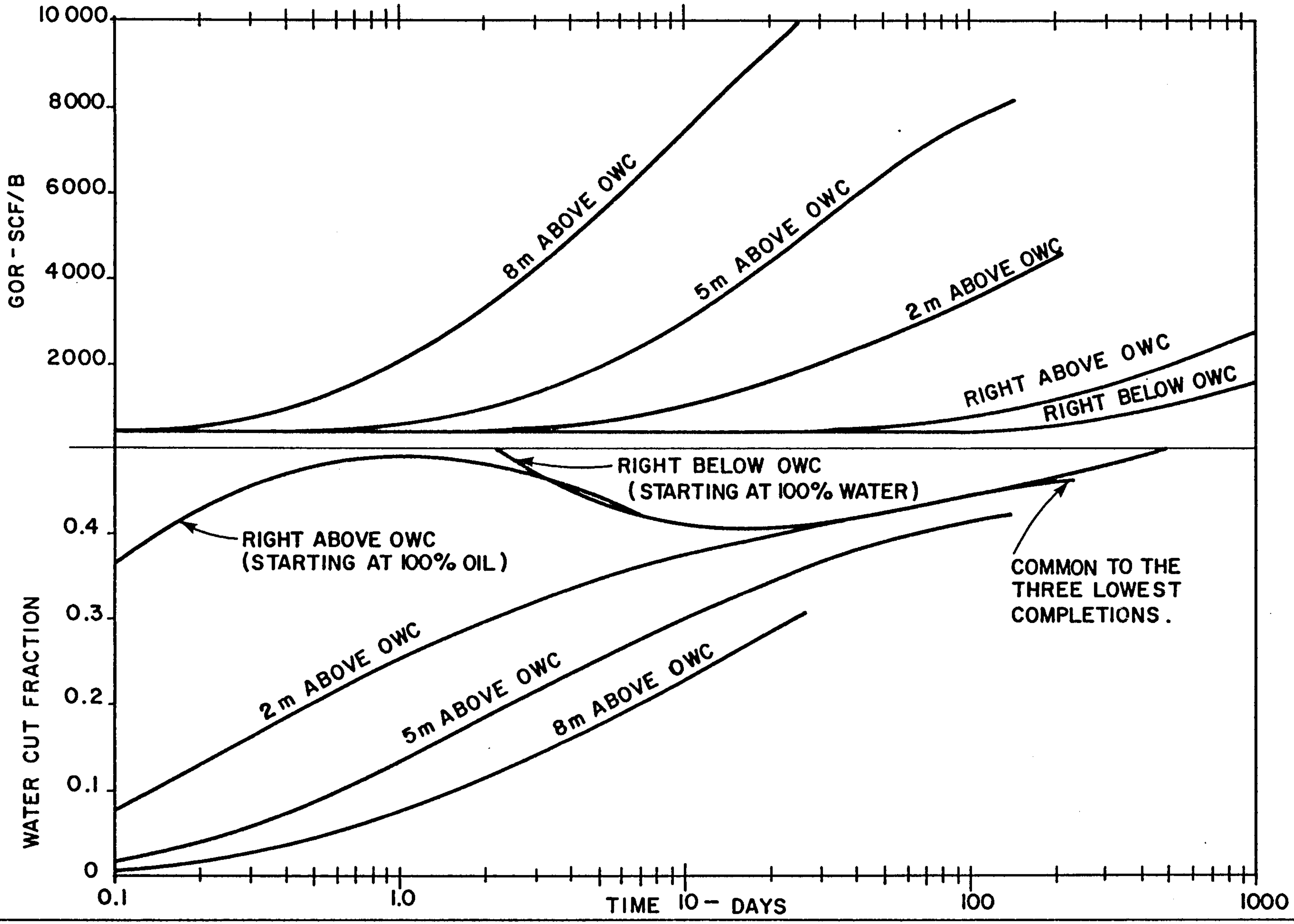
EXPLORATION & PRODUCTION FORUS

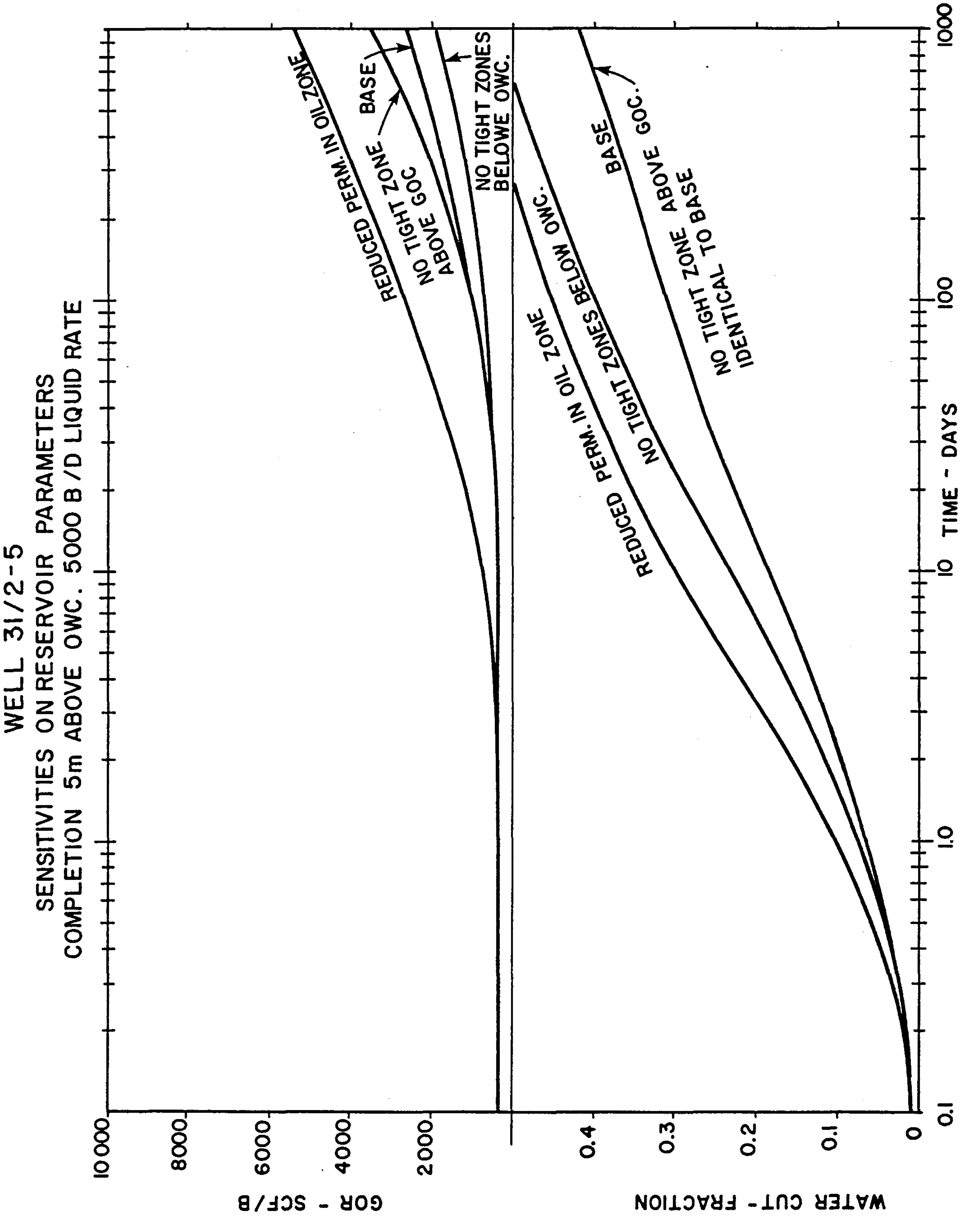
31/2 AREA OIL ZONE STUDIES
WELL 31/2-5 MODEL
COMPLETION 2 m ABOVE OWC

AUTHOR: EPPP/22	FIG.	DATE: MARCH 1981
REPORT NO.: NSEP/111	II.5	DRAW. NO. G 819/17

WELL 31/2-5
PERFORMANCE OF VARIOUS COMPLETION INTERVALS
10000 B/D LIQUID RATE



a·s Norske Shell EXPLORATION & PRODUCTION FORUS		
31/2-AREA OIL ZONE STUDIES WELL 31/2-5 MODEL PERFORMANCE OF VARIOUS COMPLETION INTERVALS		
AUTHOR EPPP/22	FIG.	DATE MARCH 1981
REPORT NO NSEP/111	II.6	DRAW NO G 819/18



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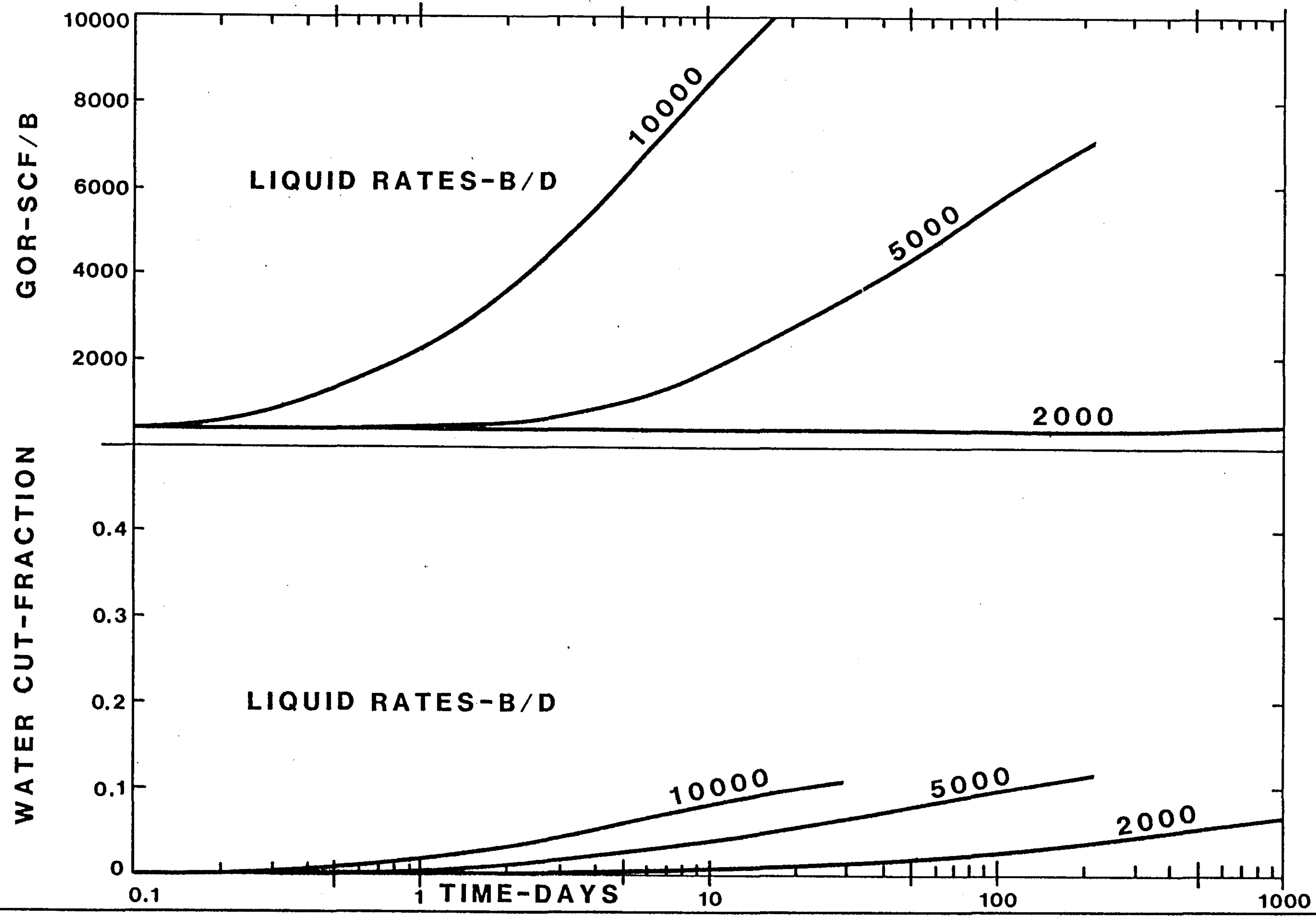
EXPLORATION & PRODUCTION FORUS

31/2-AREA OIL ZONE STUDIES
WELL 31/2-5 MODEL
SENSITIVITIESON RESERVOIR PARAMETERS

AUTHOR EPPP/22	FIG.	DATE MARCH 1981
REPORT NO NSEP/111	II.7	DRAW NO G 819/19

WELL 31/2-5
COMPLETION 8M ABOVE OWC
RESIDUAL OIL BELOW OWC INCLUDED
PERFORMANCE AT VARIOUS RATE LEVELS



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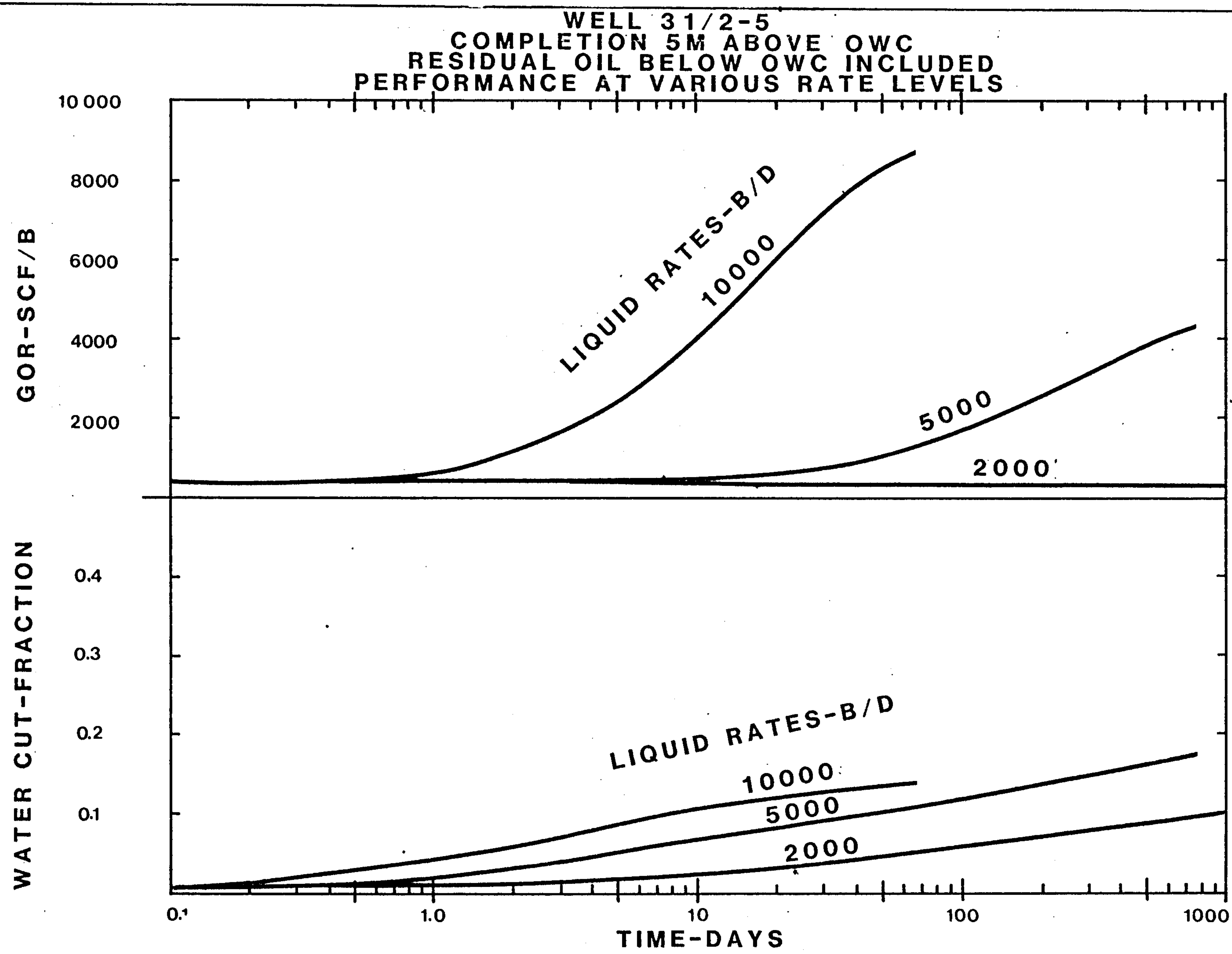
EXPLORATION & PRODUCTION FORUS

31/2 AREA OIL ZONE STUDIES
WELL 31/2-5 MODEL
RESID. OIL BELOW OWC INCL.
COMPLETION 8m ABOVE OWC

AUTHOR: EPPP/22	FIG.:	DATE: MARCH 1981
REPORT NO. NSEP III	II.8	DRAW. NO.: G 819/20



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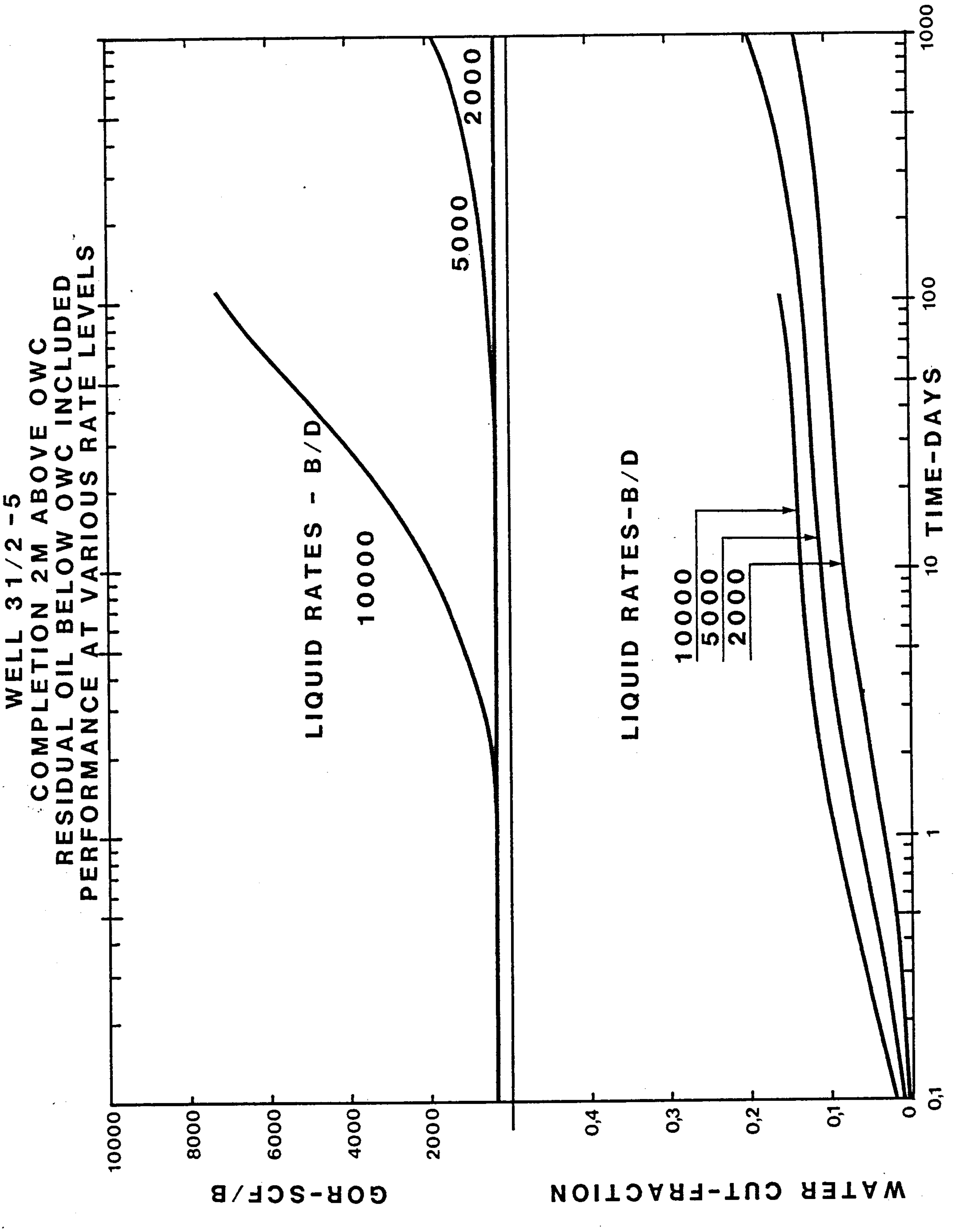
EXPLORATION & PRODUCTION FORUS

31/2 AREA OIL ZONE STUDIES
WELL 31/2-5 MODEL
RESID. OIL BELOW OWC. INCL.
COMPLETION 5m ABOVE OWC.

AUTHOR: EPPP/22	FIG:	DATE: MARCH 1981
REPORT NO. NSEP/111	II.9	DRAW. NO.: G 819/21



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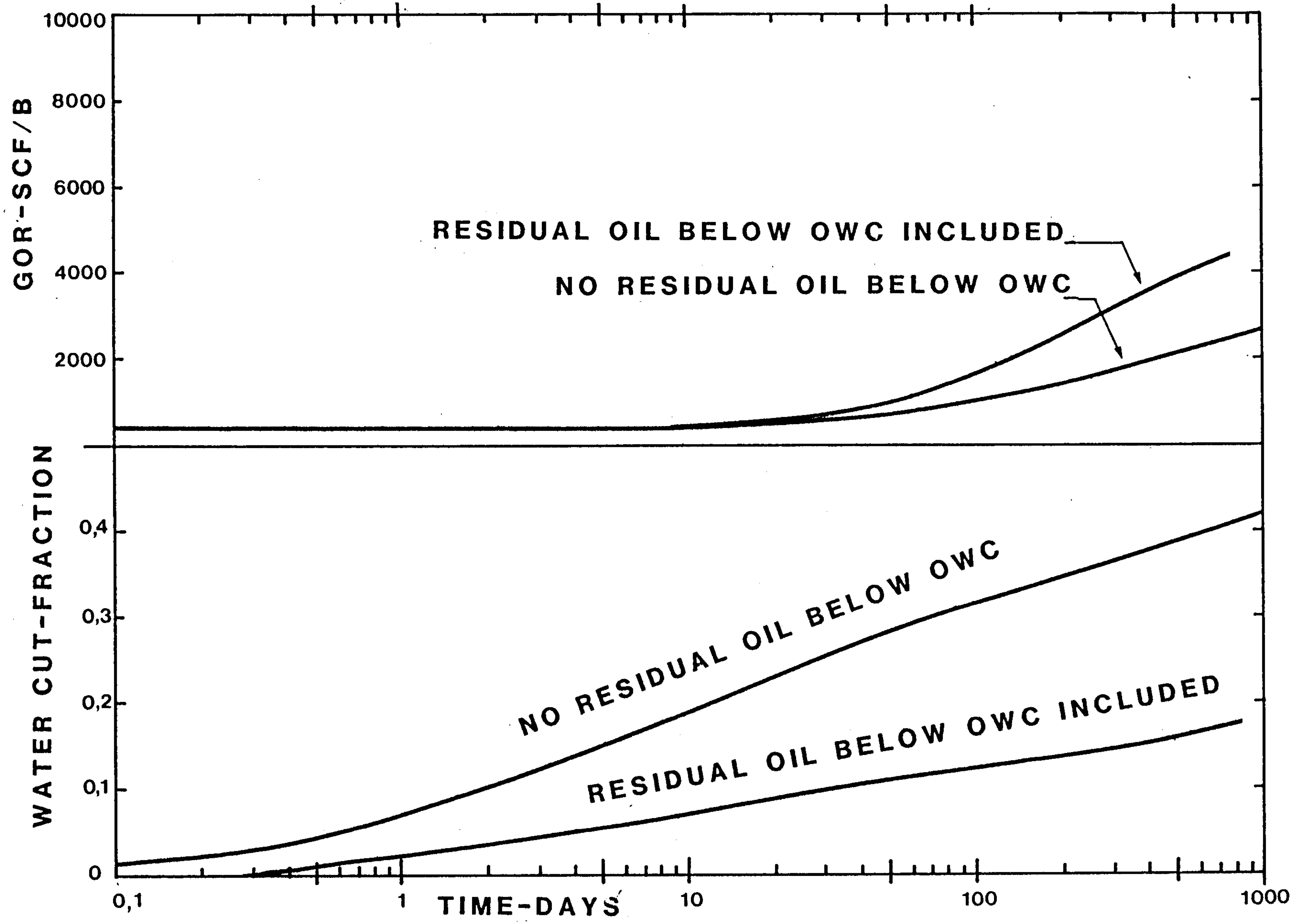
EXPLORATION & PRODUCTION FORUS

31/2 AREA OIL ZONE STUDIES
WELL 31/2-5 MODEL
RESID. OIL BELOW OWC. INCL.
COMPLETION 2 m ABOVE OWC.

AUTHOR: EPPP/22	FIG:	DATE: MARCH 1981
REPORT NO.: NSEP III	II.10	DRAW. NO.: G819/22

WELL 31/2-5
COMPLETION 5M ABOVE OWC
EFFECT OF RESIDUAL OIL BELOW OWC
5000 B/D LIQUID RATE



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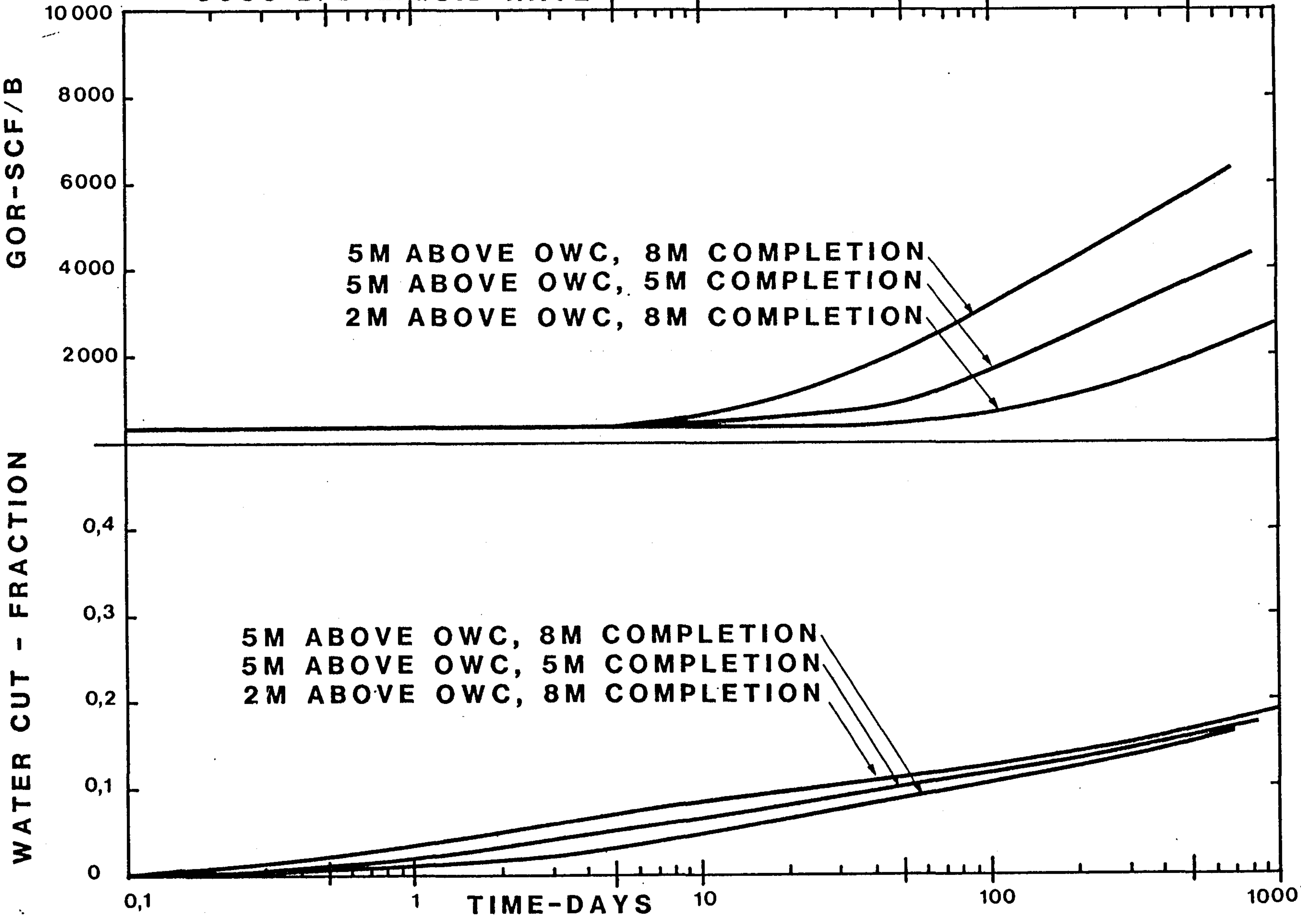
EXPLORATION & PRODUCTION FORUS

31/2 AREA OIL ZONE STUDIES
WELL 31/2-5 MODEL
EFFECT OF RESID. OIL BELOW OWC

AUTHOR: EPPP/22	FIG:	DATE: MARCH 1981
REPORT NO. NSEP/111	II.11	DRAW. NO. G 819/23

WELL 31/2-5
EFFECT OF COMPLETION LENGTH
RESIDUAL OIL BELOW OWC INCLUDED
5000 B/D-LIQUID RATE



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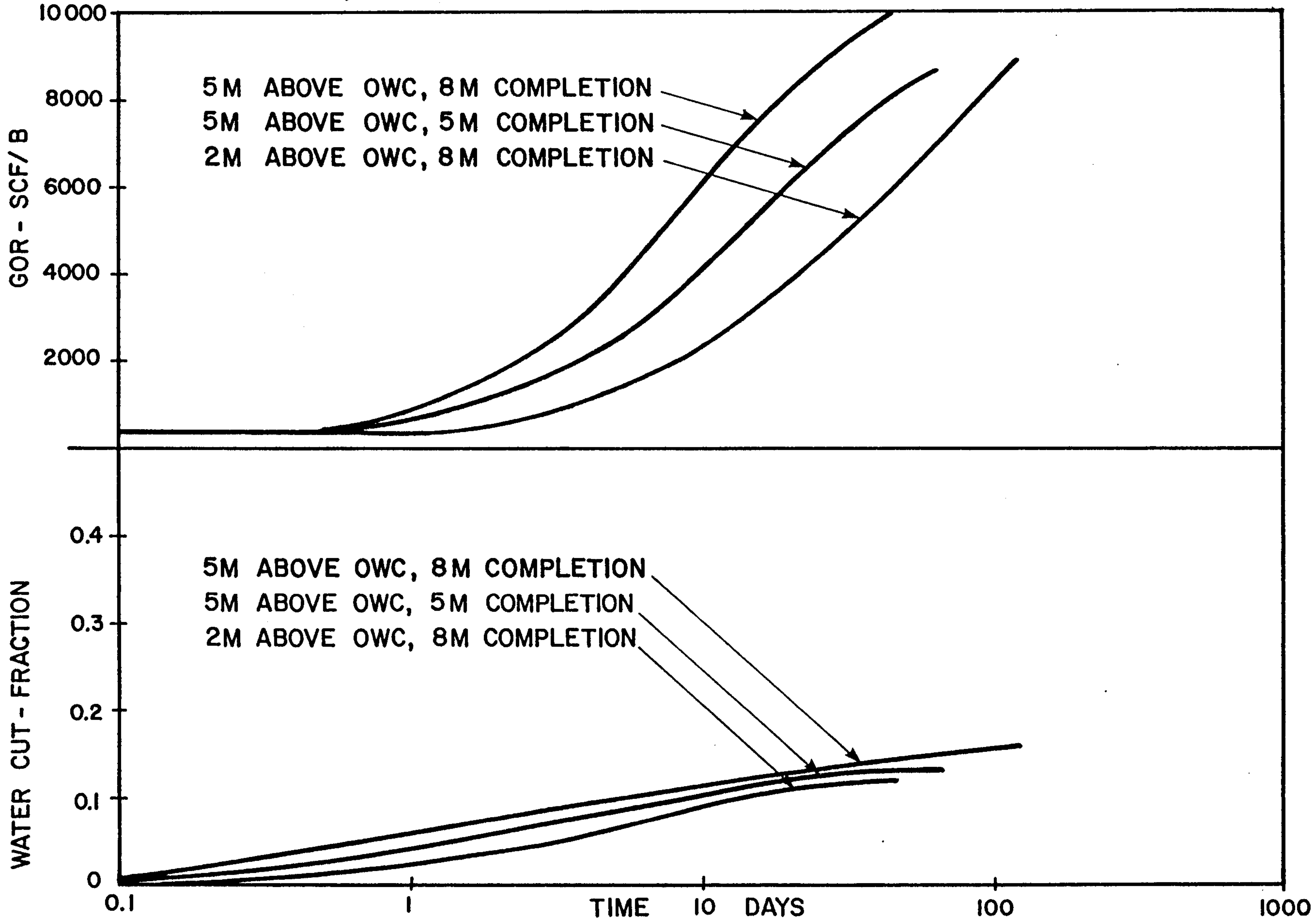
31/2 AREA OIL ZONE STUDIES
WELL 31/2-5 MODEL
EFFECT OF COMPL. LENGTH
AT 5000 B/D

AUTHOR: EPPP/22	FIG: II.12	DATE: MARCH 1981
REPORT NO. NSEP/111		DRAW. NO. G 819/24

WELL 31/2-5
EFFECT OF COMPLETION LENGTH
RESIDUAL OIL BELOW OWC INCLUDED
10,000 B/D LIQUID RATE



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31/2 AREA OIL ZONE STUDIES
WELL 31/2-5 MODEL
EFFECT OF COMPL. LENGTH
AT 10 000 B/D

AUTHOR EPPP/22	ENCL.	DATE MAY 1981
REPORT NO NSEP/111	II.13	DRAW NO 819/25

VERTICAL FLOW CALCULATIONS

APPROXIMATE LIQUID RATES

0% WATER CUT

GOR	TUBING SIZE	PI				
		2	5	10	20	50
370	3-1/2"	1600	3050	4300	5300	6250
	5"	1600	4150	7200	10500	>13000
2000	3-1/2"	2300	3700	4600	5300	5800
	5"	2800	6000	9300	12500	>13000
6000	3-1/2"	2490	3000	3550	3900	4150
	5"	2600	5300	7800	10200	12000
1000	3-1/2"	1850	2700	3250	3500	3700
	5"	2500	4900	6700	8500	10200

50% WATER CUT

GOR	TUBING SIZE	PI				
		2	5	10	20	50
370	3-1/2"	700	1600	2650	3600	4700
	5"	400	1350	3100	5700	9700
2000	3-1/2"	2100	3700	4900	5750	6400
	5"	2800	5500	9300	12800	>13000
6000	3-1/2"	1900	3100	3800	4300	4800
	5"	2800	5000	7800	10500	12800
10000	3-1/2"	1900	2900	3450	3800	4050
	5"	2400	5000	6800	9000	10900

Table II.2.