DOE/BC/14990--3

APPLICATION OF RESERVOIR CHARACTERIZATION AND ADVANCED TECHNOLOGY TO IMPROVE RECOVERY AND ECONOMIC IN A LOWER QUALITY SHALLOW SHELF CARBONATE RESERVOIR

Cooperative Agreement Number - DE - FC22 - 94BC 14990

Participant Organization - Oxy USA, Inc.

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Anticipated Completion Date - 6/14/96 - Budget Period 1

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Principal Investigator - Oxy USA, Inc.

Contracting Officer's Representative (COR) - Augustine, John

Reporting Period - First Quarter 1995

I. OVERVIEW

The focus of the project is to show that the use of advanced technology can improve the economics of CO_2 projects in low permeability reservoirs. The approach involves the use of tomography, 3-D seismic and detailed petrophysical descriptions to enhance reservoir characterization. Cyclic CO_2 stimulations and model designed frac treatments will be used to increase and facilitate oil recovery to improve project economics. The detailed reservoir characterization will be used to create a geological model for use in simulation to arrive at an optimum operating plan to be instituted during the second budget period. The official start-up of the project was August 3, 1994, so the three-month period ending March 31, 1995 represents the end of the third quarter.

Objectives to be accomplished during the third quarter include:

(1) Complete petrophysical description on cores from observation wells.

(2) Apply petrophysical data to geologic model.

(3) Conduct additional laboratory analysis on cores and fluids.

(4) Refine 3-D seismic interpretations.

(5) Complete tomography surveys.

(6) Process tomography data.

(7) Establish relationship between seismic and tomography interpretations.

(8) Conduct preliminary simulator runs with improved geologic model.

(9) Evaluate results of cyclic CO_2 stimulation treatments.

(10) Design frac treatment for linear flood fronts.

All of the above objectives were worked on during the current quarter and the overall project is fairly well on schedule. The area of greatest concern time-wise is reservoir simulation. The simulator depends on the geologic model, which in turn depends on the petrophysical, 3-D seismic and tomography interpretations. Hence, the final geologic model won't be available until all of the reservoir characterization work is completed.

II. TECHNICAL PROGRESS

1.5 Reservoir Characterization

1.5.1 - Update existing characterization

The final results of the petrophysical study performed by D. K. Davies and Associates, on cores from the two observation wells was available during this quarter. The study incorporated detailed depositional environments with lateral and vertical facies distribution. Thin section and SEM analysis of 84 samples, plus pore casts and pore geometry analysis of 59 samples were used to generate synthetic capillary pressure data. This data was used to distinguish four separate rock types that should have similar production characteristics. The general characteristics of the rock types are as follows:

Rock Type 1 - large crystal size
2 - intermediate crystal size
3 - finely crystalline dolostones
4 - less than 1 md

Capillary pressure data was used to develop a relationship between porosity, pore entry radius and permeability. The slope of the line through these points should give the Kozeny constant with the intercept going through the origin. The plot of this data is attached (Exhibit 1). Rock types 2 and 3 appear to give straight lines through all 3 samples. Rock type 1 appears to have 2 straight lines. This suggests that type 1 rock may need to be divided into two separate rock types. Additional capillary pressure measurements are being obtained to determine if this is the situation.

Sequence stratigraphy, based on the petrophysical studies, has been applied to the geological model to determine facies continuity between wells. Although sequence stratigraphy can define the pinch-out of zones between wells, it does not indicate where the pinch-out occurs. It is anticipated that 3-D seismic interpretations will help approximate the pinch-outs and the tomography data will further the refine the inter-well character of the reservoir.

1.5.3 - Perform Baseline Tomography Survey

Fifteen of the sixteen wellbore seismic/tomography surveys have been acquired (Exhibits 2 and 3). Line 4852-4843 was deferred since well 4843 was scheduled to be treated with the cyclic CO_2 injection stimulation. It is hoped that the CO_2 injection into the formation will be detectable by the tomography survey. The quality of the data has been very good on the shorter tomography lines and ranges from fair to good on the longer lines as anticipated.

Preprocessing of the tomography data is done by hand, hence it is labor intensive. Preprocessing of the P wave data (compression) is well along. The set up required to preprocess the P wave data will make the preprocessing for the Shear wave and cross well VSP go much faster. A preliminary tomogram on 50-foot spacing has been completed and the results look good. All tomograms will be processed on 5-foot spacing for additional detail.

1.5.5 - 3-D Seismic Interpretation

The 3-D seismic structural and stratigraphic interpretations have been refined. Five seismic horizons relevant to the main pay zone were tied to 5 log markers (N, M, M3, M5 and Z6) and correlated throughout the 3-D seismic volume. These time structure horizons were each converted to depth using average velocity and gradient method. The differences between the horizons create the isopachs. Subsea structure value for the M1, M3 and M5 markers and isopach value for the M1-M5, M1-M3 and M3-M5 intervals were established at each seismic bin location. These seismic bins are spaced 110 ft. N-S and 165 ft. E-W across the DOE study area. The investigation into using seismic attributes to estimate petrophysical (log) properties revealed that there are several correlations between seismic attributes and pore volume that might be useful. Correlations between seismic structure and pore volume and the seismic-derived isopachs and pore volume were excellent as shown by the Kendall's Tau indicators (Exhibit 4). The relative amplitude of the M3 horizon had excellent correlation with pore volume across the total main pay (M1-M5) interval. The inverted seismic velocity correlation varied from fair to very good with pore volume. The instantaneous amplitude, instantaneous frequency, instantaneous phase did not correlate with pore volume distribution for any of the reservoir intervals.

The reservoir thickness (isopach) and the interval velocity were selected for the initial transformation to the pore volume values. Representative cross plots are attached (Exhibits 5 and 6). The transformation of thickness and velocity attributes to pore volume were successfully applied to all three reservoir intervals (M1-M5, M1-M3 and M3-M5). The log data are currently being reviewed and updated and a final seismic attribute to porosity transformation will be produced.

A detailed base map of the tomographic bin locations has been developed. The process of transferring tomography data to the Stacked Curves (SCPC) system to integrate with well log data and 3-D seismic data has been initiated. A technique developed to tie 2-D seismic line to 3-D interpretations will be utilized to integrate the tomography interpretations with the 3-D seismic interpretations.

1.5.6 - Determine Saturation Distributions

Prior to the start of the current DOE project, the geologic model for a 60-acre area in the West Welch Unit was upgraded to a 19 layer model utilizing sequence stratigraphy which results in the pinch-out of some layers between wells. The resulting production and injection history match was much improved over what had been obtained from the simpler geologic model. The model has been further adjusted for the results of injectivity surveys.

During the current quarter, induction of a new equation of state has given more realistic residual oil saturations. Also, additional water/oil and gas/water relative permeability data has been obtained that will be used for simulating CO_2 WAG injection. Significant advances in the simulation project, however, depend upon further refinement of the geologic model. Because of geologic model's dependency upon the 3-D seismic and tomography interpretations, the simulation effort will continue to lag behind the original schedule.

1.5.7 - Fracture Geometry

Core analysis was performed on selected samples from the 4852 observation well for use in the 3-D fracture simulation model. Insitu stress data from full wave sonic logs were incorporated into the model and the initial results indicate that the fracture would grow down out of zone. However, long term injection experience surrounding the test well (4807) and a post fracture treatment evaluation log on 3811 suggest containment of the fracture within the main pay. The lower boundary zone properties are being modified in the model to limit fracture growth. A cross section showing the containment zones is attached (Exhibit 7). The orientation and extent of the actual induced fracture wing will be traced using passive seismic triangulation.

1.5.8 - Laboratory Testing Requirements

Calculations for determining the diffusion constant from laboratory resistivity measurements were completed during the quarter. The value for diffusion in a straight tube was found to be .00511CM^2/sec. This value is found from measurements of the change in water resistivity measured as a CO_2 diffused through an oil column overlying the water. Plots showing the CO_2 concentration and resistivity versus time are attached as Exhibits 8, 9 and 10.

Additional mercury injecting capillary pressure data were obtained on 10 of the core samples from the observation wells that represented Davies' rock types 1, 2 and 3. Since rock type 1 appeared to have two separate trends, additional samples will be chosen for its capillary pressure measurements.

Seven of these ten samples were aged in crude oil and had steady state water relative permeability tests performed. The tests showed mixed wet ability which appears to vary with pore size. Additional end point water/gas relativity permeability are being obtained for use with relative permeability hysterises curves.

The relative permeability tests were followed by flooding the core with a slim-tube developed miscible bank. The slim-tube fluid was followed by injecting alternating cycles of water and CO_2 to endpoint saturations. Following the WAG cycles, the residual oil to CO_2 was extracted for compositional analysis. The SCAL results are given on Exhibit 11. The fluid equation of slate has been modified to reflect the residual saturation from slim-tube experiments.

1.6 Reservoir Management Plan Development

1.6.2 - Cyclic CO_2 Stimulation Evaluation

The fifth and final well (4845) scheduled for cyclic CO_2 stimulation treatment was injected with 15 MMCF of CO_2 during the current quarter. After a soak period, the well was placed back on production. Oil has increased from a baseline of 12 BOPD to 19-20 BOPD with a significant reduction in the watercut (Exhibit 12). Recently, the well inexplicably fell off to less then 12 BOPD. The situation is being further investigated to determine if it is some mechanical malfunction or actual reservoir conditions.

In summary, five wells have been treated with volumes of CO_2 ranging from 5 MMCF to 15 MMCF. To date, only one well has experienced a significantly sustained production increase. Two wells have experienced a slight production increase. One well appears to receive no benefit from the treatment and one well is still being evaluated. The complete evaluation of the cyclic CO_2 treatments must account for the increased value of producing gas and the effect on operating costs due to lower water production. Performance of all 5 wells will continue to be monitored (Exhibits 13-16).

III. TECHNOLOGY TRANSFER

Mr. George Watt presented a paper at the 3-D seismic symposium sponsored by the Rocky Mountain Association of Geophysics and the Denver Geophysical Society entitled "3-D Seismic Predication of Reservoir Properties - West Moose Queen Field, Ector County, Texas." Although the actual field example was not in the West Welch demonstration area, it involved the technique for using seismic-guided estimates of log properties that was developed for the West Welch DOE demonstration project. Mr. Watt will also make an informal presentation of some of the aspects of the West Welch demonstration project to the West Texas Geophysical Society during the last week in May.

Mr. Jim Justice will make a presentation concerning the tomography aspect of the project to a joint SEG/AAPC/SPE meeting in San Francisco, California May 3/5, 1995. In addition, Mr. Justice will include some aspects of the demonstration project in a SEG short course entitled "Reservoir Geophysics" in Lafayette, Louisiana April 19/20, 1995.

An informal data exchange with Texaco concerning the results of cyclic CO_2 stimulation injection is being carried on.

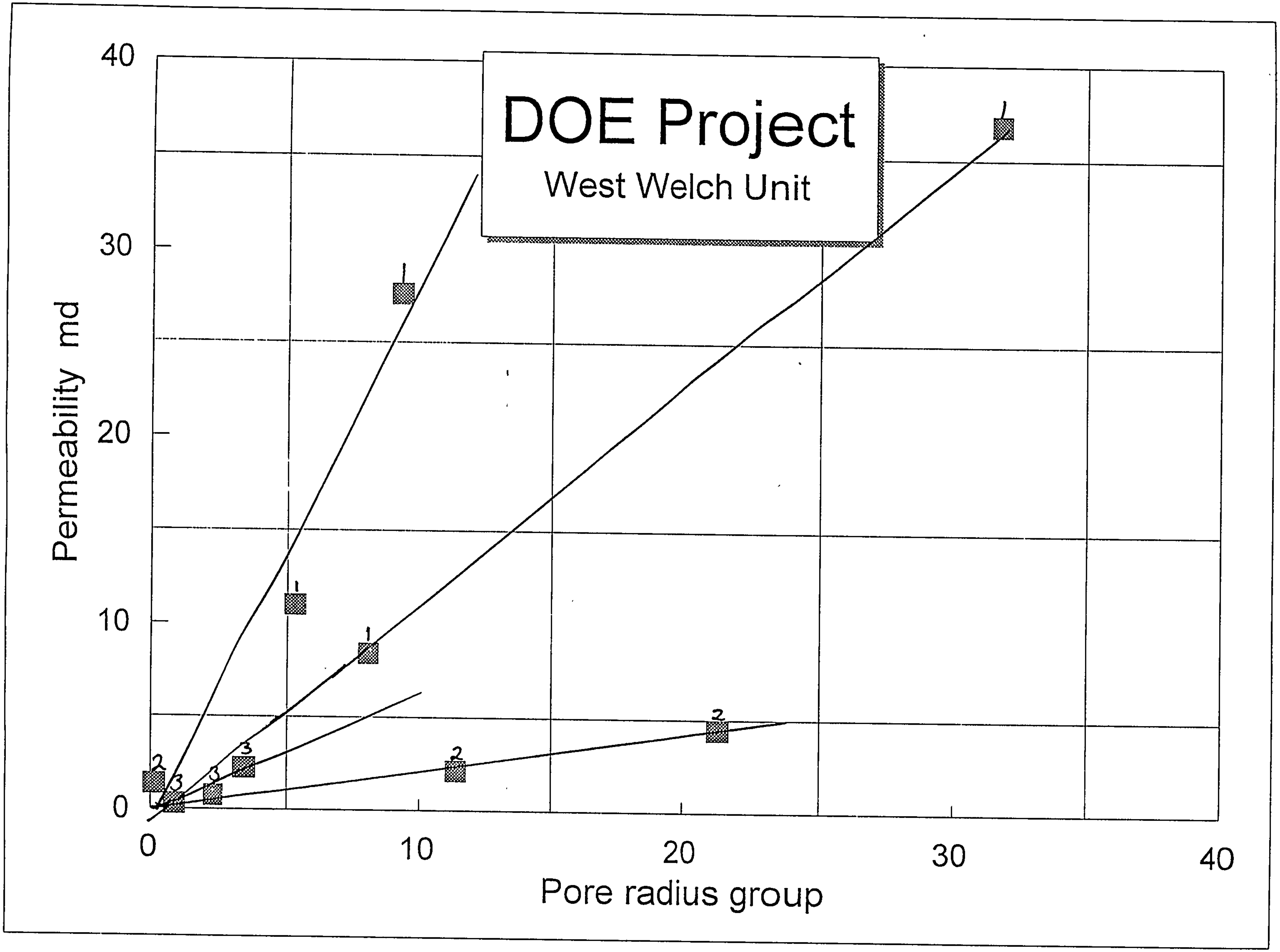

DOE Project
West Welch Unit
Permeability md
Pore radius group
0
10
20
30
40
0
10
20
30
40
1
1
1
1
2
2
2
3
3
3

EXHIBIT I

CROSSHOLE SEISMIC SURVEYS
PHASE I

LINES ACQUIRED

7916 - 3206
7916 - 4825
7916 - 3203
7916 - 4832
7916 - 7914
7916 - 4827
7916 - 4824
4852 - 4827
4852 - 4828
4852 - 4822

7916 - 7901
4852 - 4841
4852 - 4809
4852 - 4808
7916 - 4852

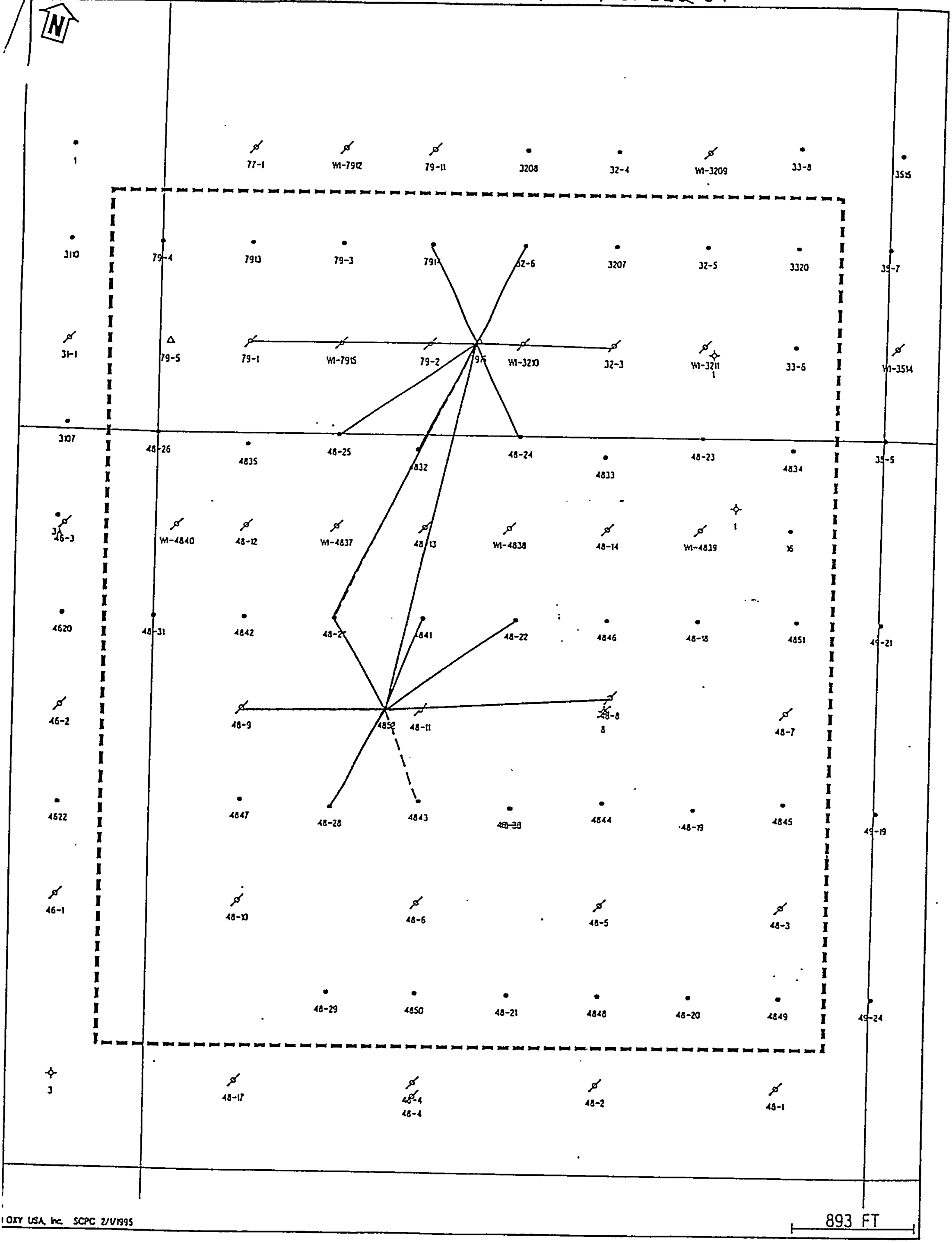
LINE REMAINING

4852 - 4843

EXHIBIT 2

MAR 95

ACQUIRED TOMOGRAPHY (SOLID) 31 DEC 94



QUALITY MATRIX: Pore Volume versus Seismic Attributes
Kendall's Tau Indicator Calculations

Reservoir Interval	Reservoir Structure	Reservoir Thickness	Internal Velocity	Relative Amplitude	Instantaneous		
					Amplitude	Frequency	Phase
Total Main Pay	100.0	100.0	90.2	96.6	39.9	19.8	6.5
Upper Main Pay	100.0	100.0	80.4	-	34.5	2.3	11.1
Lower Main Pay	100.0	100.0	64.0	-	6.5	32.2	9.3

EXHIBIT 4

M1 to M5 PHIH vs M1 to M5 ISOPACH

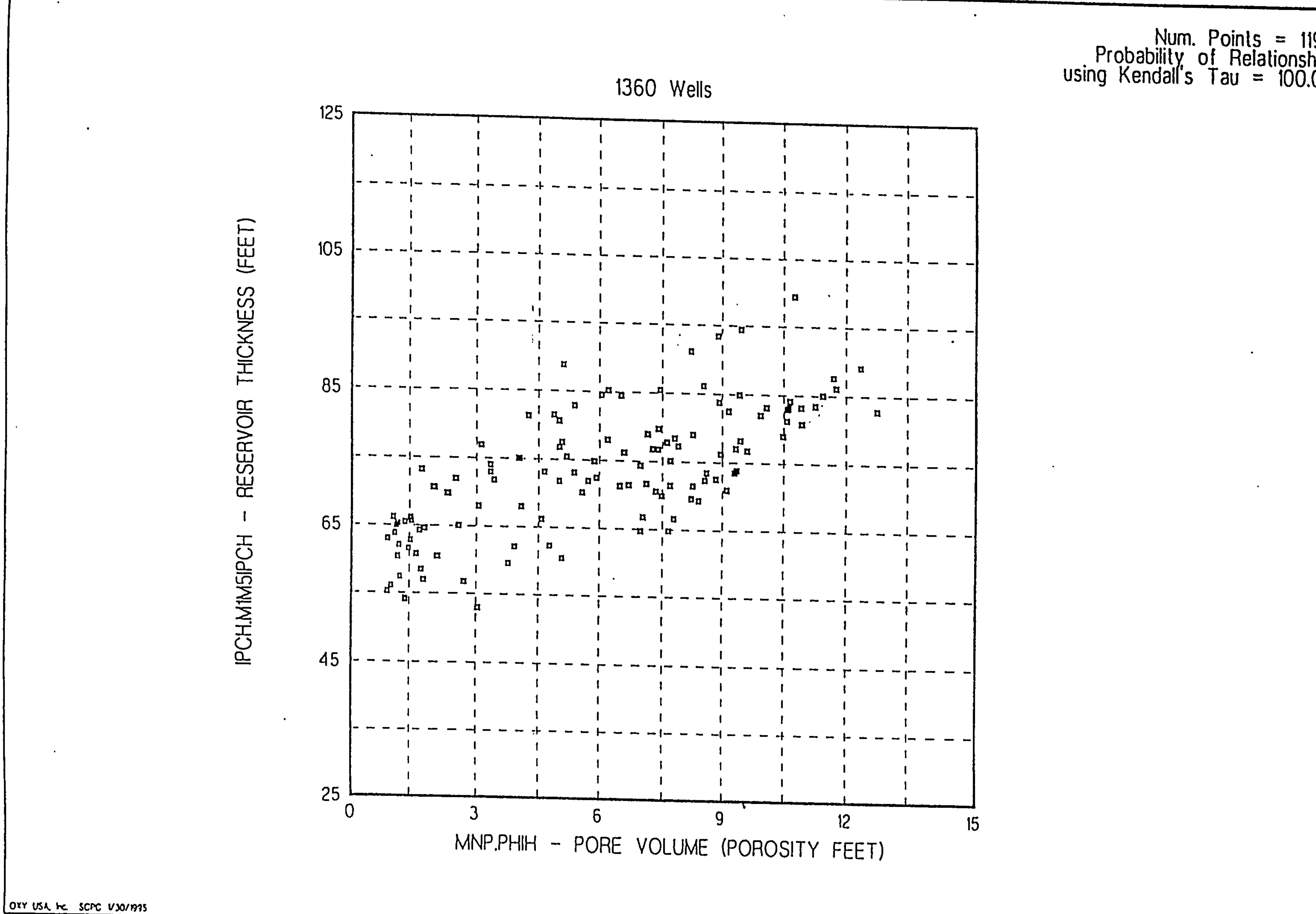


EXHIBIT 5

M1 to M5 PHIH vs M1 to M5 VELOCITY

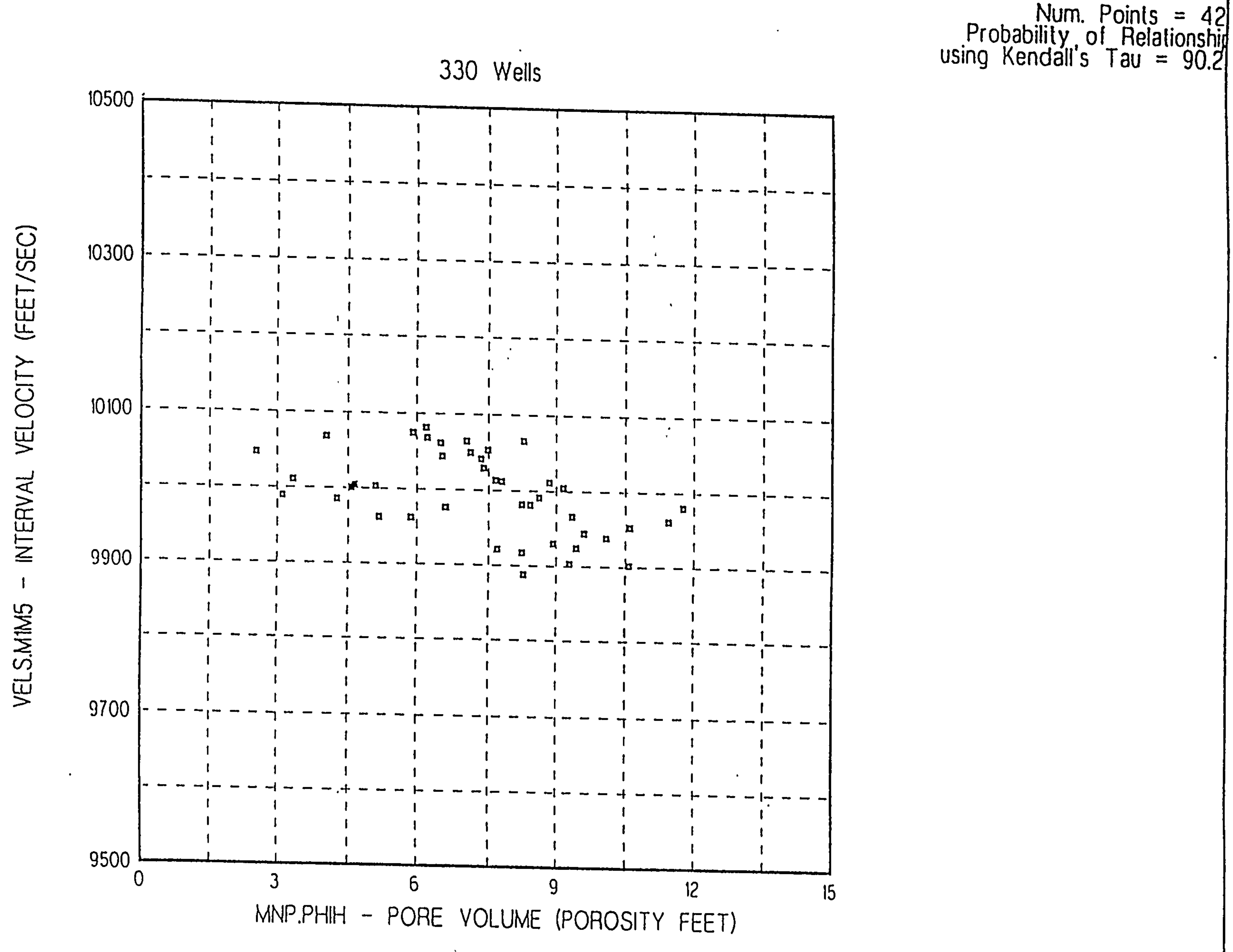


EXHIBIT 6

West Welch Area: Dawson Co., TX

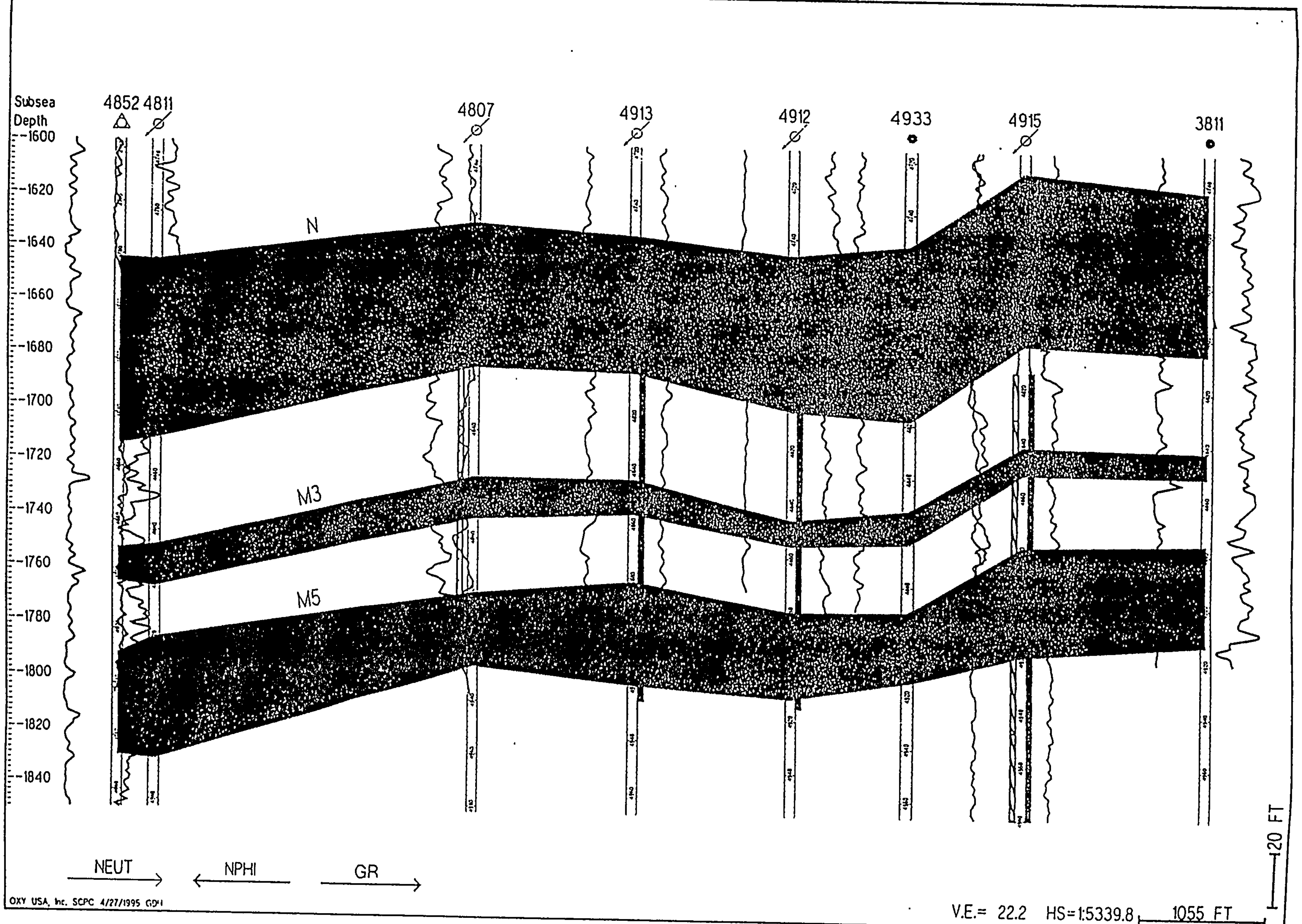
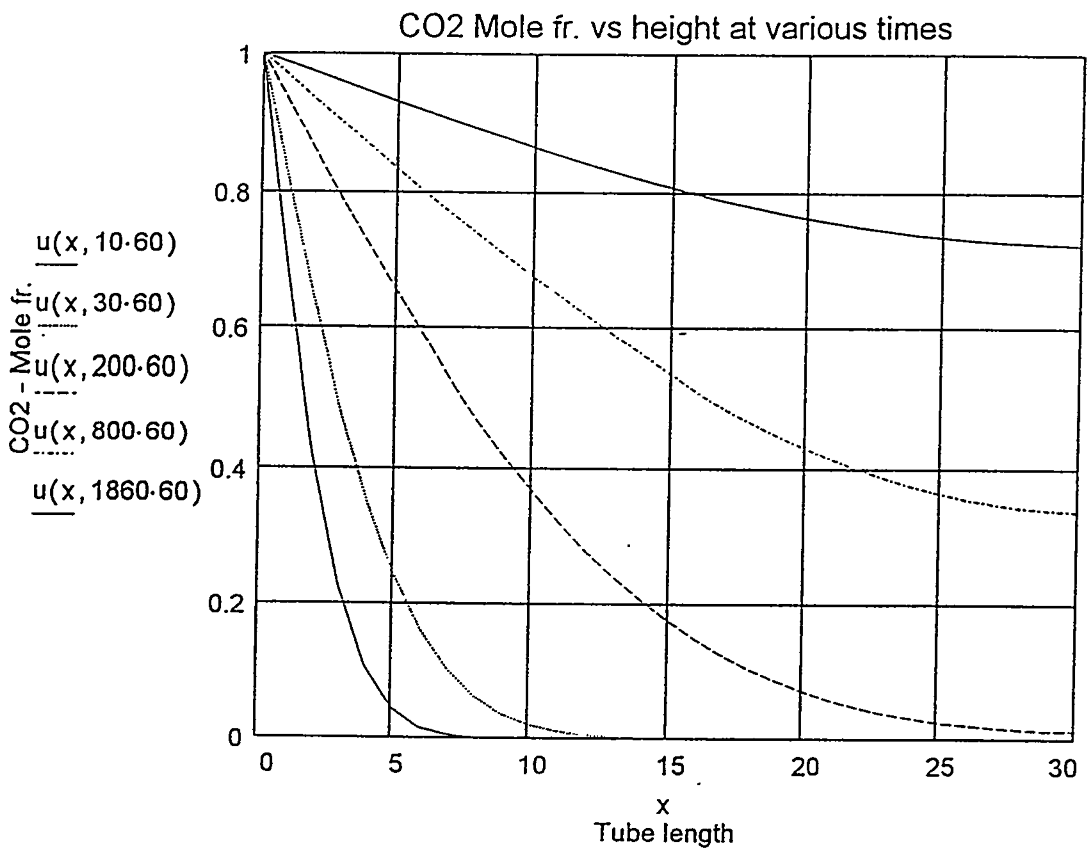
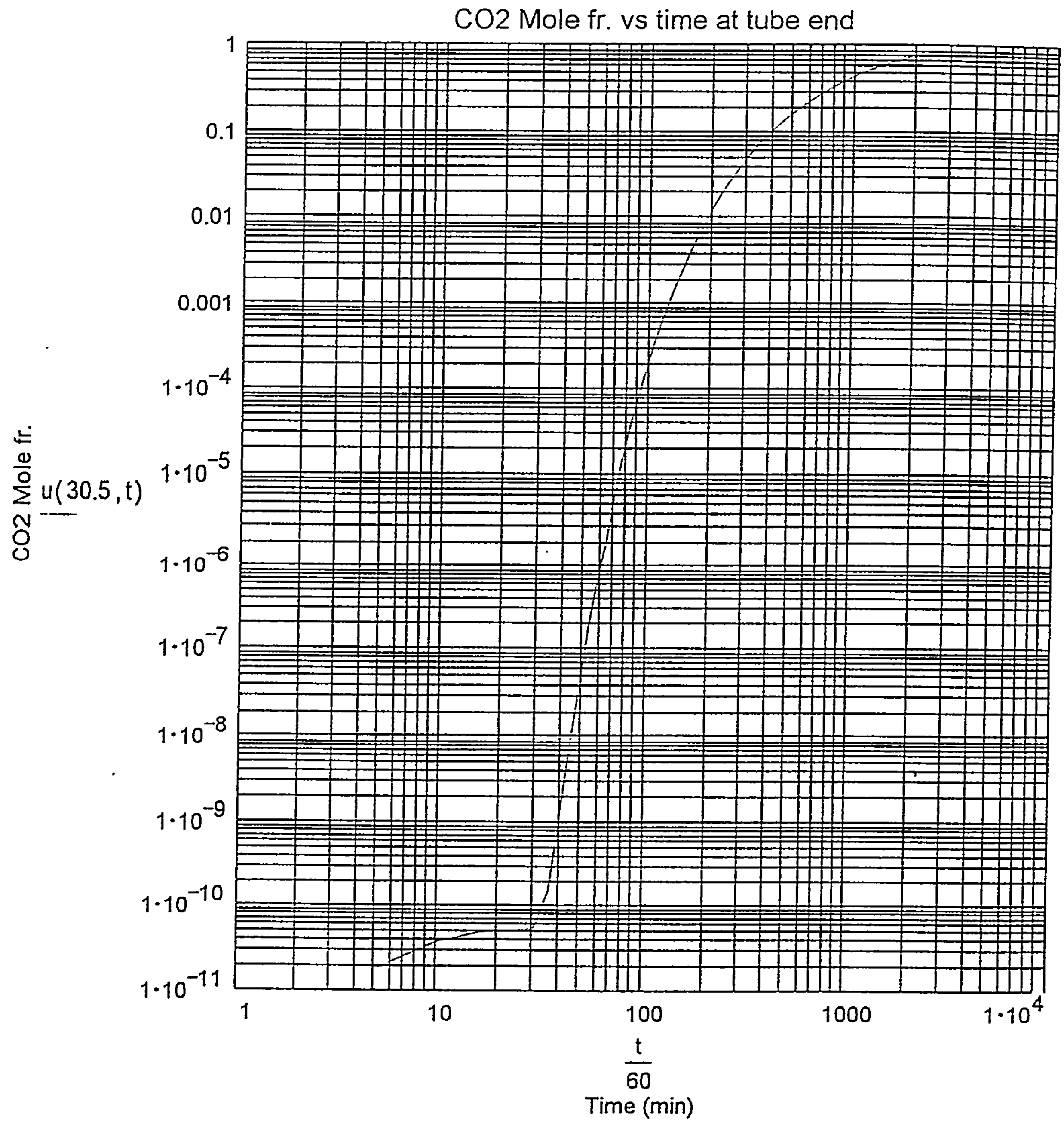


EXHIBIT 7

$x := 0 .. 12 \cdot 2.54$



For time ranging from 5 to 1850 minutes (test times) $t := 5 \cdot 60, 10 \cdot 60 .. 1860 \cdot 60$



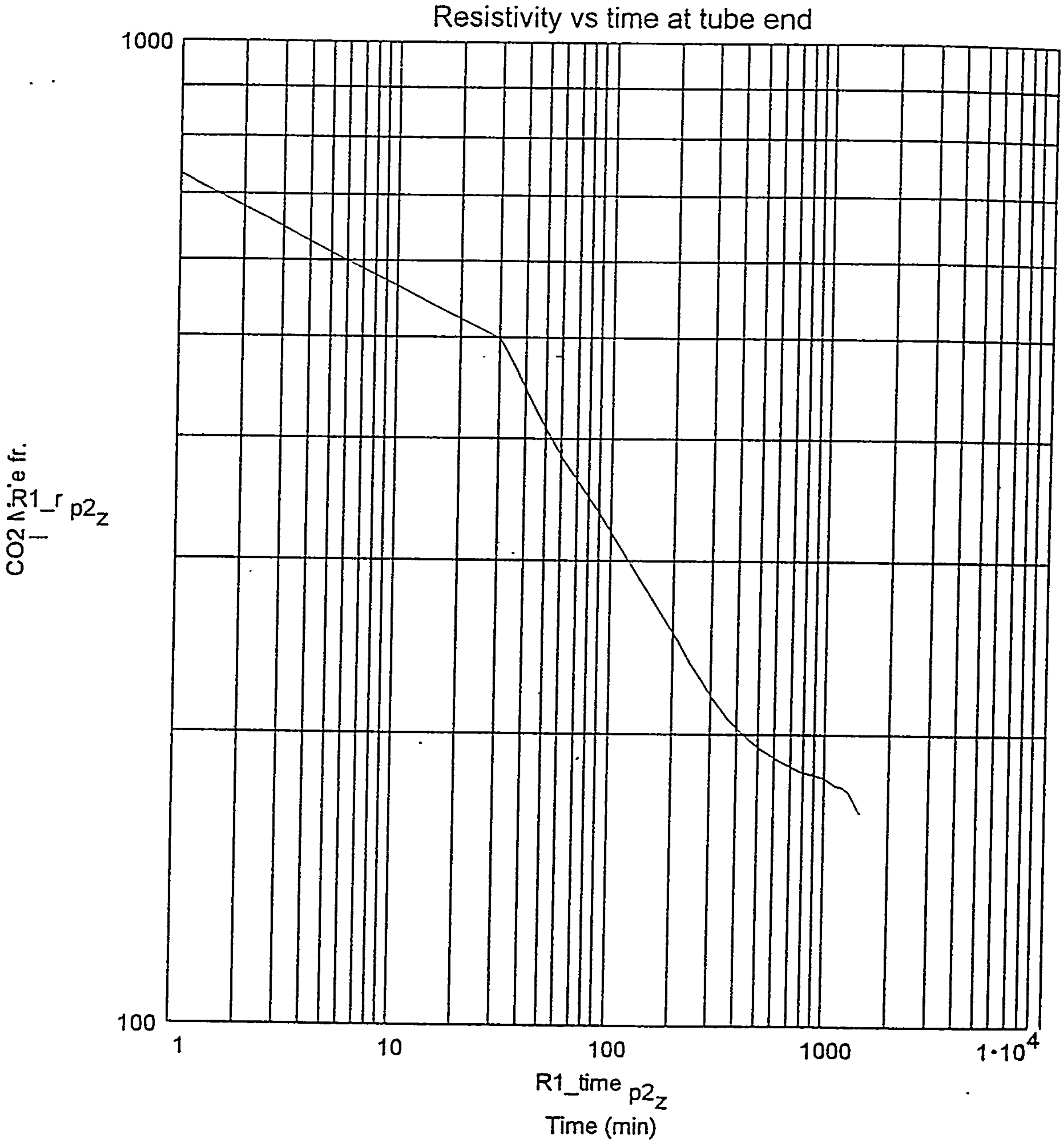

Resistivity vs time at tube end
1000
100
1
10
100
1000
1·10^4
R1_time p2z
Time (min)

EXHIBIT 10

Carbon Dioxide Core Floods

Company : OXY U.S.A. Inc.
West Welch Field

Sample Number	Well	Depth		Ksair	Porosity	Grain Density	Sro	Keo Live oil	Kew	Keco2 First	Kew	Kco2 Second	Kew	Kco2 Third	Kew	Sorm
		ft	in	mD	%	g/cc	%	mD	mD	mD	mD	mD	mD	mD	mD	%
1	7916	4,812	8	1.36	12.47	2.85	35.10	0.660	0.184	0.147	0.675	0.095	0.650	0.116	0.675	6,73
3	7916	4,822	3	2.23	17.70	2.83	35.90	0.886	0.130	0.260	0.681	0.103	0.686	0.086	0.729	8.04
4	7916	4,826	2	4.42	16.13	2.83	24.40	2.26	0.530	0.703	2.30	0.336	2.28	0.405	3.46	7.83
5	7916	4,856	8	.308	9.49	2.83	41.20	0.156	0.051	0.021	0.056	0.024	0.056	0.030	0.057	13.82
6	7916	4,859	3	8.38	14.30	2.82	27.70	3.74	0.976	0.614	3.59	0.578	3.65	0.567	3.41	7.38
8	4852	4,899	3	36.8	18.81	2.81	44.60	14.13	3.95	1.72	12.76	1.01	12.25	1.12	11.34	8.96
		Average:		8.92	14.82	2.83	34.82	3.64	.970	.577	3.34	.357	3.26	.388	3.28	8.79

EXHIBIT 11

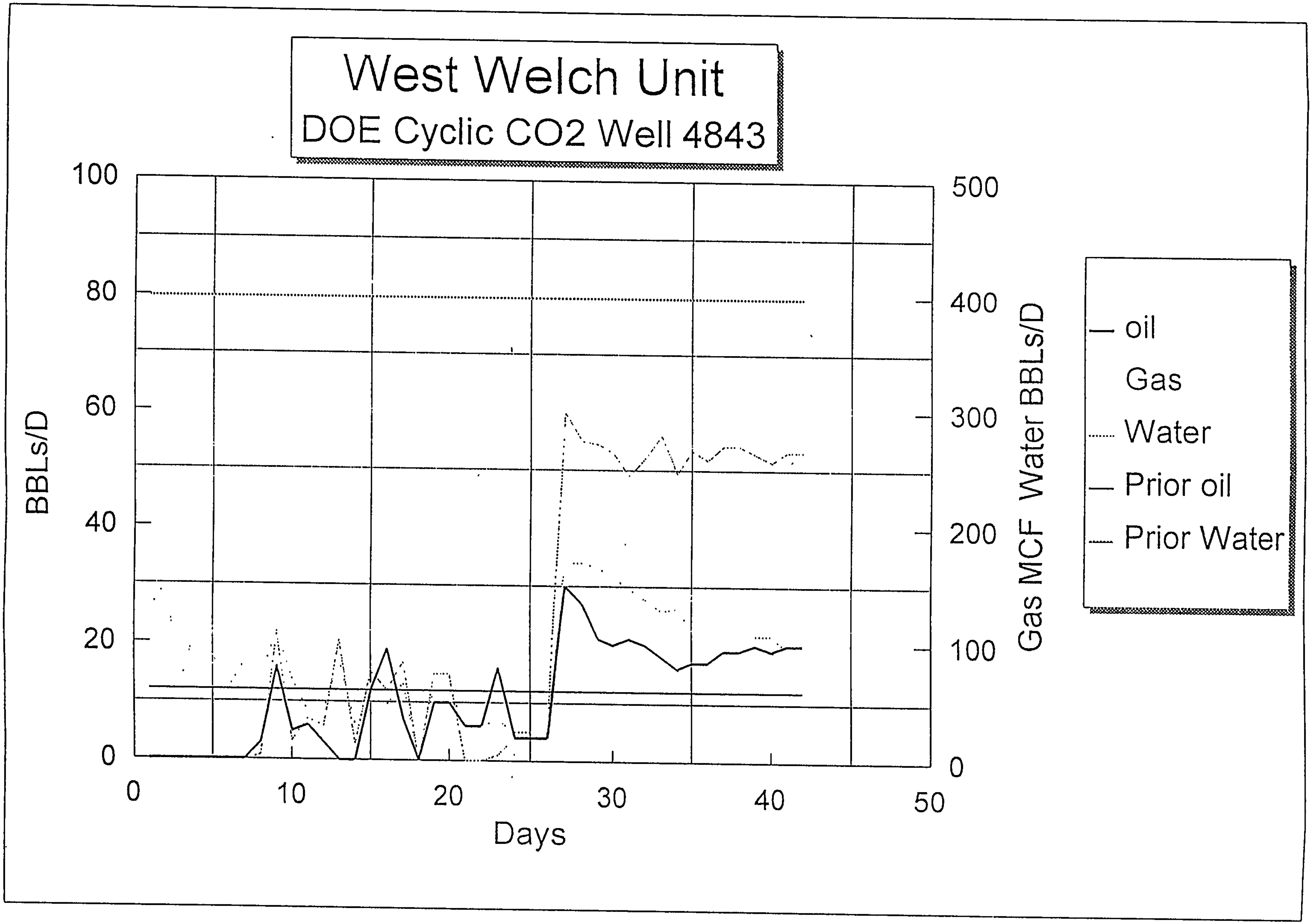

West Welch Unit
DOE Cyclic CO2 Well 4843
BBLs/D
100
80
60
40
20
0
10
20
30
40
50
Days
500
400
300
200
100
Gas MCF Water BBLs/D
oil
Gas
Water
Prior oil
Prior Water

EXHIBIT 12

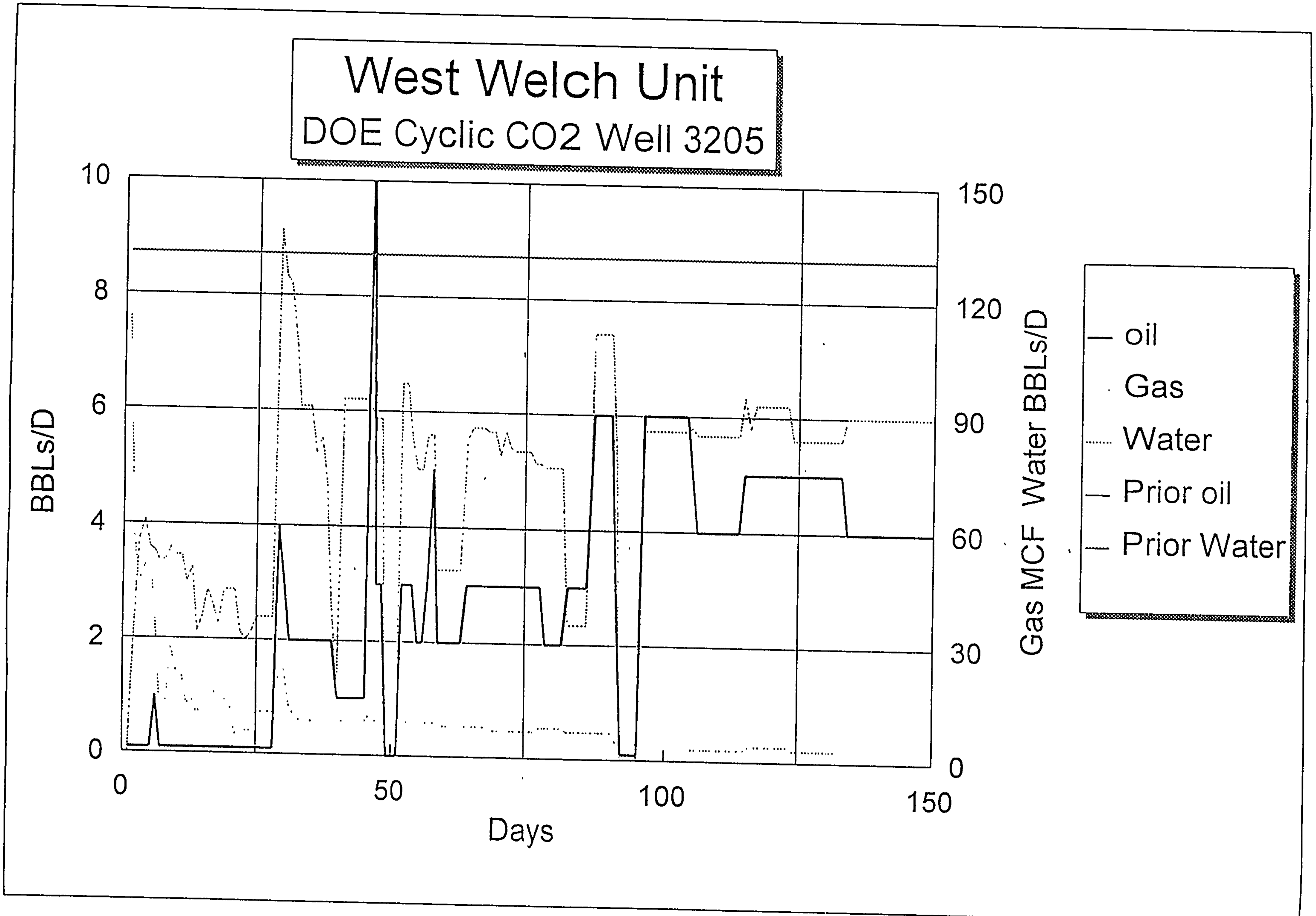

West Welch Unit
DOE Cyclic CO2 Well 3205
BBLs/D
Gas MCF Water BBLs/D
Days
oil
Gas
Water
Prior oil
Prior Water
0
2
4
6
8
10
0
30
60
90
120
150
0
50
100
150

EXHIBIT 13

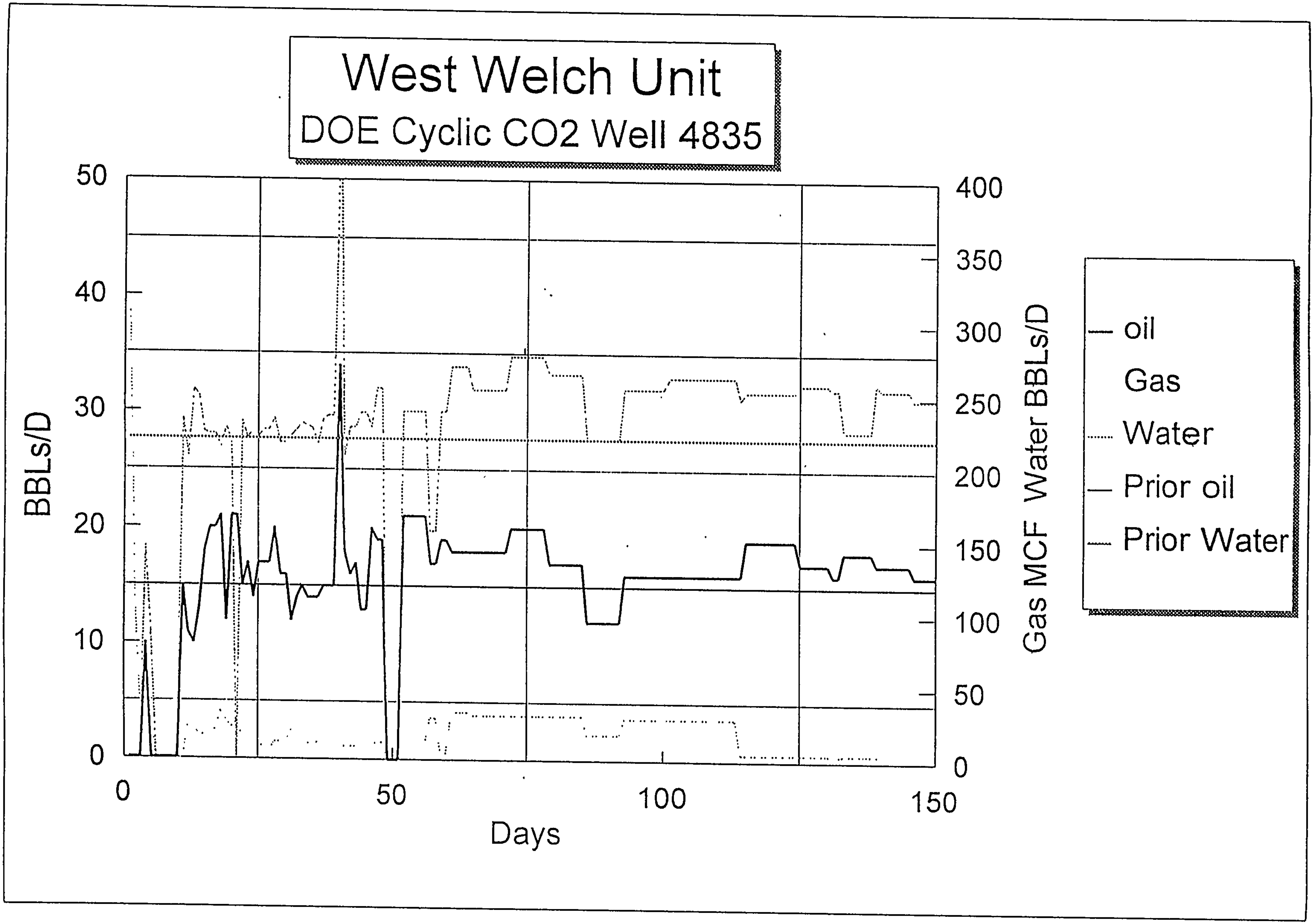

West Welch Unit
DOE Cyclic CO2 Well 4835
BBLs/D
50
40
30
20
10
0
0
50
100
150
Days
400
350
300
250
200
150
100
50
0
Gas MCF Water BBLs/D
oil
Gas
Water
Prior oil
Prior Water

EXHIBIT 14

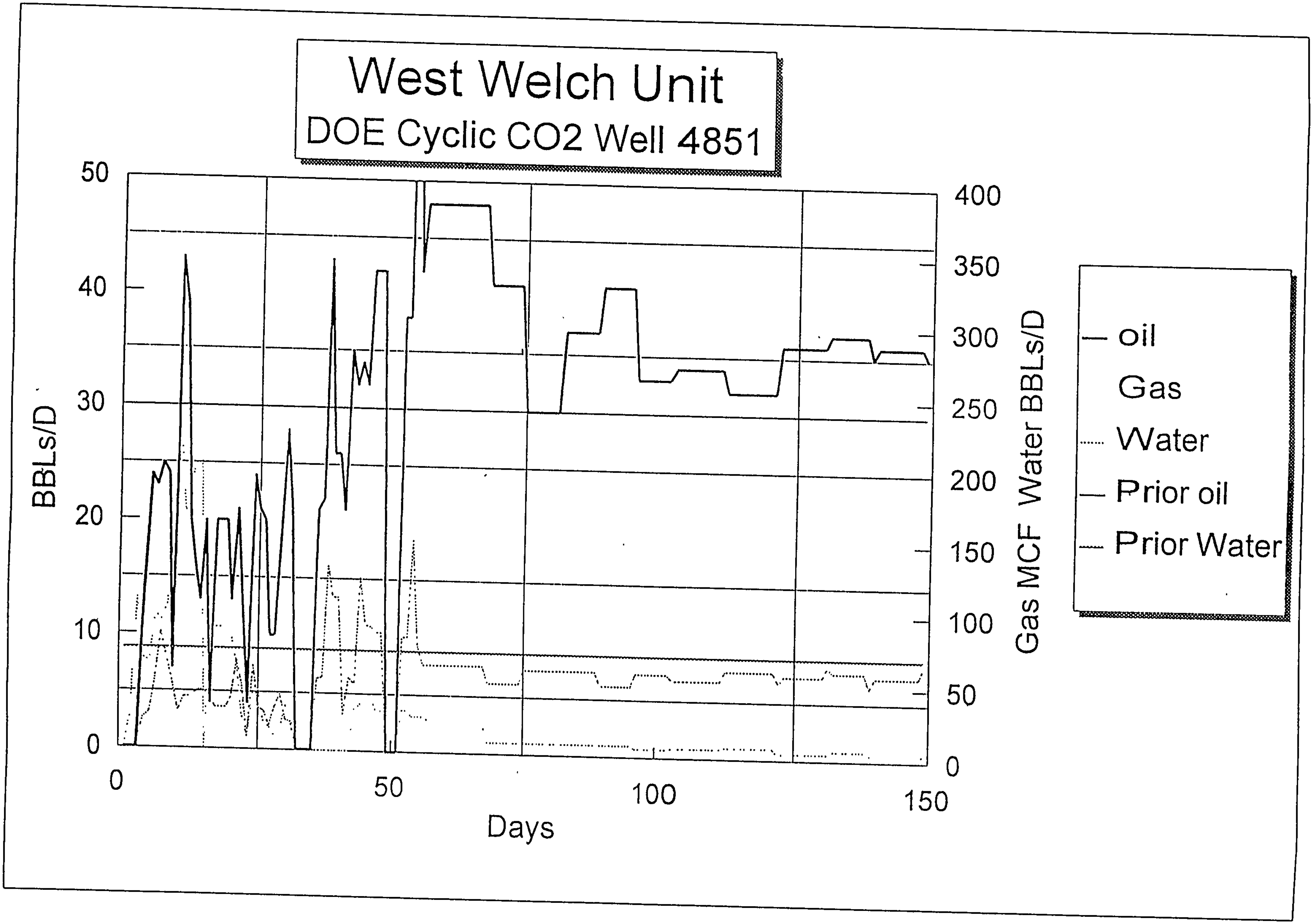

West Welch Unit
DOE Cyclic CO2 Well 4851
BBLs/D
50
40
30
20
10
0
0
50
100
150
Days
400
350
300
250
200
150
100
50
0
Gas MCF Water BBLs/D
oil
Gas
Water
Prior oil
Prior Water

EXHIBIT 15

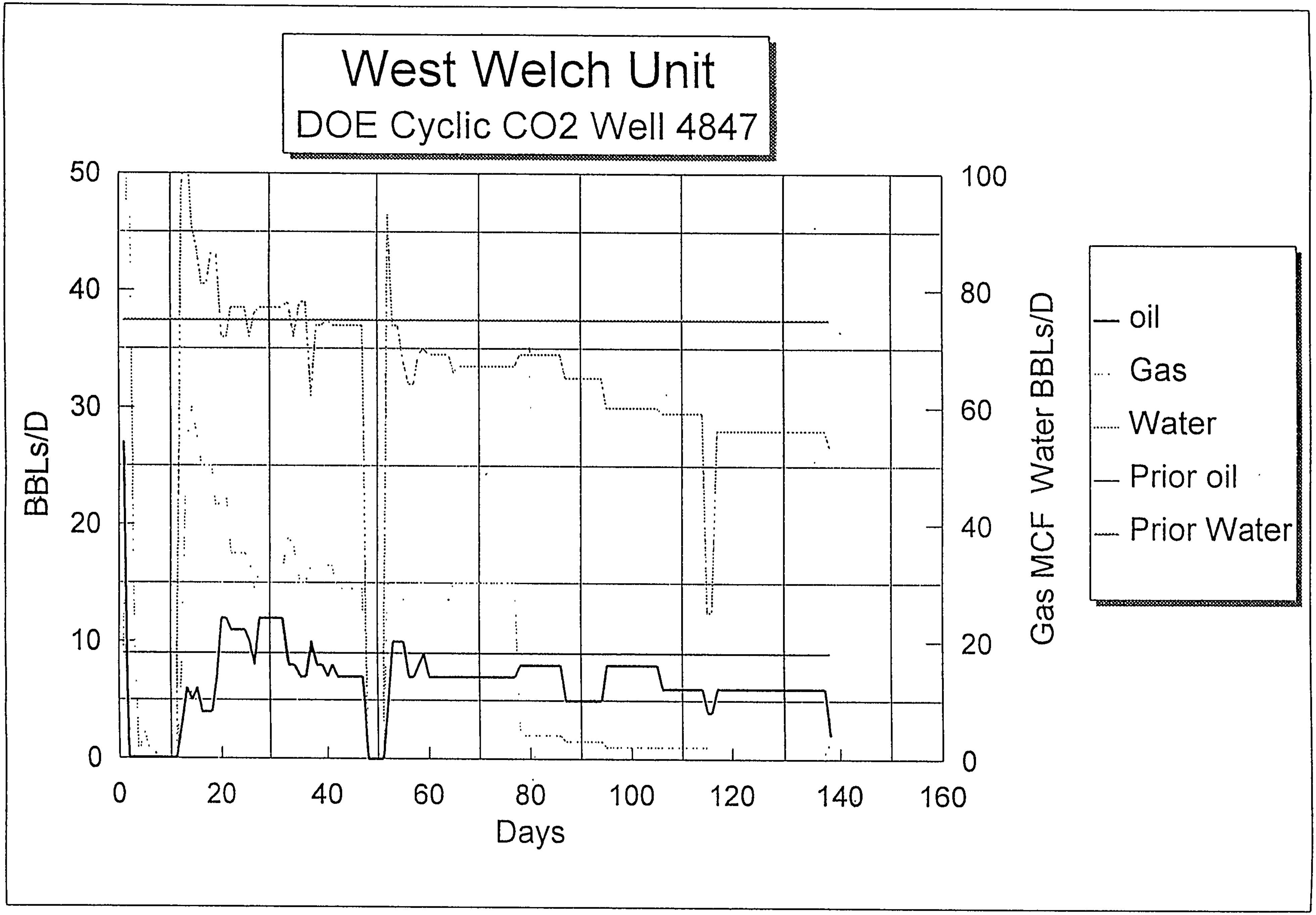

West Welch Unit
DOE Cyclic CO2 Well 4847
BBLs/D
50
40
30
20
10
0
0
20
40
60
80
100
120
140
160
Days
100
80
60
40
20
0
Gas MCF Water BBLs/D
oil
Gas
Water
Prior oil
Prior Water

EXHIBIT 16