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ESTIMATES OF INCREMENTAL OIL RECOVERABLE BY CARBON DIOXIDE FLOODING AND RELATED CARBON DIOXIDE SUPPLY REQUIREMENTS FOR FLOODING MAJOR CARBONATE RESERVOIRS IN THE PERMIAN, WILLISTON, AND OTHER ROCKY MOUNTAIN BASINS

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ESTIMATES OF INCREMENTAL OIL RECOVERABLE BY CARBON DIOXIDE FLOODING AND RELATED CARBON DIOXIDE SUPPLY REQUIREMENTS FOR FLOODING MAJOR CARBONATE RESERVOIRS IN THE PERMIAN, WILLISTON, AND OTHER ROCKY MOUNTAIN BASINS

EXECUTIVE SUMMARY

This report was prepared to fulfill the work requirements of the United States Department of Energy (DOE) Contract Numbers DE-AC21-82MC19393 and DE-AC21-79MC08341. The objective of the work was ". . . to build a solid engineering foundation (in) . . . carbonate reservoirs for the purpose of extending the technology base in carbon dioxide miscible flooding." This report presents estimates of incremental oil recovery and related carbon dioxide supply requirements for selected carbonate reservoirs in the Permian, Williston, and Rocky Mountain Basins.

The estimates presented here are based on calculations using a volumetric model derived and described in this report. The calculations utilized data developed in previous work (1,2,3)* performed in fulfillment of Contract No. DE-AC21-79MC08341.

Calculations were made for a total of 279 reservoirs in the Permian, Williston, and several smaller Rocky Mountain Basins. In summary, these results show estimated incremental oil and carbon dioxide supply requirements as follows:

Basin	No. Res.	ISTOIP MMBbls	Inc. Oil From CO_2 MMBbls	CO_2 Req. BCF	Avg. CO_2/ Oil Ratio Mcf/Bbl
Permian	188	56,526	10,557	57,157	5.4
Williston	68	3,336	767	4,415	5.7
Rocky Mountain	23	2,279	498	2,328	4.7
Totals	279	62,141	11,822	63,900	5.4

It is obvious that the carbonate reservoirs of the Permian Basin constitute an order of magnitude larger target for carbon dioxide flooding than do all the carbonate reservoirs of the Williston and Rocky Mountain intermontane basins combined.

*References (including those referenced in Appendices) are listed, following the text of the report, on page 54.

It should be noted that the calculation procedure assumed 100-percent recycling of produced carbon dioxide and that the carbon dioxide volumes and ratios listed above refer to supply volumes only. Estimated total injection volumes, including recycle, would approximately double the figures given above to some 128 trillion cubic feet of carbon dioxide for a carbon dioxide to incremental oil ratio of approximately 11 Mscf/Bbl.

Review of the calculated data in comparison with information from earlier work (1) indicates that the figures given here are probably optimistic in that incremental oil volumes may be biased toward the high side while carbon dioxide supply requirements may be biased toward the low side. However, the information available would not permit further practical refinement of the calculations.

Use of the incremental oil figures given for individual reservoirs as an "official estimate" is not recommended because of various uncertainties in individual field data. Further study and compilation of data for field projects as they develop appears warranted to better calibrate the calculation procedures and thus to develop more refined estimates of incremental oil potential and carbon dioxide supply requirements.

INTRODUCTION

Enhanced oil recovery is a term coined in recent years to encompass various techniques for recovering oil left underground as residual from application of more conventional practices such as displacement by gas or water. Injection of a fluid miscible with the residual oil is one such enhanced recovery technique.

BACKGROUND

The use of carbon dioxide as a miscible fluid for enhanced oil recovery has been the subject of research and field trials by many investigators and operators for more than 20 years. Work continues on both fundamental research levels and on more pragmatic field application levels of effort. Work accomplished to date, as reported and summarized elsewhere (1), has shown that carbon dioxide is technically capable of displacing otherwise unrecoverable oil from reservoir rocks over a wide range of geological and physical conditions. Hence, it presently appears that the limitations on widespread application of carbon dioxide flooding are more economic than technical.

PURPOSE AND SCOPE OF THIS REPORT

This report is part of the work required to fulfill Contracts No. DE-AC21-82MC19393 and No. DE-AC21-79MC08341. The latter contract was awarded to Gruy Federal, Inc. by the United States Department of Energy (DOE) on February 12, 1979 and administered by DOE's Morgantown Energy Technology Center, Morgantown, West Virginia. The requirements of the original contract are summarized on Enclosure One. It may be noted that Gruy's efforts were directed (Scope of Work, 2.2) toward studies of "carbonate reservoirs located in west Texas, southeast New Mexico, and the Rocky Mountain states. . ." as target reservoirs for carbon dioxide miscible flooding.

Specifically, this report is directed toward the requirements of Task Three (Scope of Work, 2.3). To accomplish this, basic information about the carbon dioxide flooding process compiled in Gruy's Task One work (1) and geologic and reservoir data compiled in work accomplished under Task Two (2,3) were used to calculate incremental oil and carbon dioxide requirements on a site-specific reservoir-by-reservoir basis using a volumetric model the derivation of which is discussed in this report.

ENCLOSURE ONE

"TARGET RESERVOIRS FOR
CARBON DIOXIDE MISCIBLE FLOODING"

Contract No. DE-AC21-79MCO8341

APPENDIX A
STATEMENT OF WORK

1.0 OBJECTIVE

1.1 The objective is to build a solid engineering foundation upon which field mini- and pilot tests may be conducted in both high and low oil saturation carbonate reservoirs for the purpose of extending the technology base in carbon dioxide miscible flooding.

2.0 SCOPE OF WORK

2.1 Summary of Available CO_2 field Test Data

Data will be collected, categorized and interpreted from all significant past and on-going CO_2 field operations in order to evaluate the relative success of each test. This information will include oil gravity, reservoir pressure, depth, temperature, porosity, permeability, and net/gross pay. Also, these data must include pattern size, estimated incremental oil production due to CO_2 injection, CO_2 concentration and slug size, CO_2 injection rates and sequencing, CO_2 breakthrough and production rates, and any indications of formation damage or corrosion.

2.2 Summary of Existing Reservoir and Geological Data

The following reservoir geology will be determined on carbonate reservoirs located in west Texas, southeast New Mexico, and the Rocky Mountain states: stratigraphy, structure, mineralogy, porosity, permeability, gross and net thickness, and any other geological properties deemed significant regarding CO_2 injection. Reservoir data will be collected on hydrocarbon content, composition and distribution; connate water content and composition; pressure and production data from primary and/or secondary recovery operations; PVT analysis; and well test data and analysis. Guidelines for selecting reservoirs to be included are as follows:

Average formation permeability -	$\geqq$ 5 md
Average current oil saturation -	$\geqq$ 38%
Oil gravity ----------	$\geqq$ 36 deg API
Oil viscosity ----------	$\geqq$ 10 cp

In addition, no extremely high-permeability, stratigraphic, thief zones should exist. However, no consideration should be given to the proximity of CO_2 sources at this point. The objective here is to "characterize the resource" for possible future CO_2 injection.

2.3 Selection of Target Reservoirs

By analyzing available reservoir and geological data, and comparing the results of various CO_2 field tests, a priority list will be developed based primarily on potential incremental oil recovery and the projected CO_2 requirements and availability. CO_2 requirements can be based on estimates from data collecteds in Task 1 and CO_2 supply data can be obtained from existing public documents on the subject (e.g. "The Supply of Carbon Dioxide for Enhanced Oil Recovery: by Pullman Kellogg, September, 1977).

2.4 Selection of Specific Reservoirs for CO_2 Injection Tests

A selection will be made from the priority list based on demonstrating the technology in those reservoirs with the greatest potential influence toward stimulating new projects capable of meeting the 1985 incremental oil production of 124,000 barrels per day stated in the Technical Implementation Plan for reservoirs in these target areas. For the reservoirs selected, the owners and operators will be identified. Also, company officials who have the authority or influence to bring about commercialization of CO_2 recovery processes will be contacted. This is absolutely necessary since it is these companies which must eventually initiate and carry out commerical demonstrations of CO_2 injection if the full potential of the target reservoirs is realized.

2.5 Selection of Specific Sites for Test Wells (Carbonate Reservoirs)

Using all useful available knowledge from previous CO_2 field tests, reservoir and geological compilations, conventional production data, PVT analysis, log analysis, core analysis and well test analysis, specific sites will be selected for drilling test wells for further delineation and substantiation of the reservoir properties prior to conducting CO_2 injection tests. These sites must be in the Rocky Mountain and west Texas-southeast New Mexico areas. A minimum of eight and a maximum of twelve sites are to be selected.

2.6 Drilling and Coring Activities

Depending on the availability of data at each site selected, test wells will be drilled, cored, logged, tested and analyzed to confirm initial oil saturation parameters and to design mini-test CO_2 injection programs. It is expected that one test well will be drilled at each site selected. However, the exact number and location of wells to be drilled will be negotiated to be consistent with the amount of additional engineering and geological information required, drilling costs in the area at the time of execution, and any other economic and engineering factors that may arise.

METHODOLOGY - TECHNICAL CONCEPTS OF CARBON DIOXIDE FLOODING

Potential incremental oil recovery and projected carbon dioxide requirements for carbon dioxide injection projects in various reservoirs are site-specific and should be expected to vary from reservoir to reservoir as a function of such factors as geologic stratification, porosity magnitude and distribution, remaining oil saturation, etc. Hence, a method by which calculations can be made on a reservoir-by-reservoir basis is needed.

A simple volumetric model can be used both to illustrate the key concepts involved in carbon dioxide flooding and to calculate expected incremental oil recovery and carbon dioxide requirements utilizing reservoir-specific data. The mathematical and physical reasoning necessary to develop a volumetric model is presented in detail in Appendix A. The following section summarizes the rationale that guided development of the model.

VOLUMETRIC EQUATIONS

The key concepts for developing a volumetric balance equation involve a swept zone or volume invaded by injection fluid, a resaturated zone or oil bank volume, and an undisturbed volume not (as yet) invaded by either oil bank or injection fluid. Fractional resaturation (f_{rs}) is defined as the ratio of the volume of the oil bank to the volume of the entire unswept zone. These concepts apply to any displacement project in which an injected fluid banks and moves oil. However, the nomenclature and development given here are specifically directed toward a carbon dioxide displacement.

Saturation distributions are based on the concepts that:

(1) Carbon dioxide displaces oil in the swept zone from an in-place beginning saturation ($\overline{S}_o$) to a residual oil saturation (S_{or}),

(2) The oil displaced forms an oil bank of higher oil saturation ($S_{ob} = 1-S_{wr}-S_{gr}$) by displacing mobile gas and water as it encroaches into the undisturbed zone.

The carbon dioxide bank contains the only free carbon dioxide saturation. However, residual oil, oil-bank oil, and residual water are all assumed to be saturated with carbon dioxide by the displacement process.

A volumetric balance applicable at any given point in time can be constructed from the concepts:

Oil Recovered = Original oil in place - Oil left in swept volume

- Oil left in unswept volume

The oil left in the unswept volume is the sum of the oil left in the resaturated zone and the oil left in the undisturbed zone. On this basis, an equation can be written:

$$N_p = 7758Ah\phi \left[E_s(\bar{S}_o/\bar{B}_o - S_{or}/B_{or}) - (1 - E_s)f_{rs}(S_{ob}/B_{ob} - \bar{S}_o/\bar{B}_o)\right]. \quad (1)$$

This equation utilizes volumetric notation* coupled with the concepts of sweep efficiency (Es) and fractional resaturation (f_{rs}). It is important to note that negative incremental production can result from a combination of low sweep efficiency and large fractional resaturation.

Fractional resaturation is an important factor in displacement projects that use small volumes of injectant. At any given sweep efficiency, the fraction of the unswept area that is invaded by oil bank or resaturated (fr_s) is related to the relative growth of the oil bank with respect to the growth of the carbon dioxide bank. The ratio of relative oil bank growth, termed the displacement factor (9), is obtained by comparing the volume of oil displaced from a given bulk volume invaded by carbon dioxide to the bulk volume of displaceable space into which the oil bank can accumulate.

Based on the same volumetric concepts, a companion equation for estimating carbon dioxide requirements can be developed. Volumetric balance requires that:

CO_2 required = free CO_2 in swept zone + solution CO_2 in swept zone + solution CO_2 in resaturated zone + produced CO_2.

In the equivalent symbols and notations as those used above, this relationship can be expressed as

CO_2 required (Mcf) =

$$I_{CO_2} = 43.560Ah\phi/B_{CO_2} \; E_s(1 - S_{wr} - S_{or})$$

$$+ 7758Ah\phi\left[E_s(R_{so}S_{or}/B_r + R_{sw}\, S_{wr}/B_w) + (1-E_s)f_{rs}R_{so}(S_{ob}/B_{ob})\right] \quad (2)$$

$$+ N_pR_{sp}$$

Equation (2) thus allows calculation of the carbon dioxide required to displace the oil calculated by Equation (1).

Where the basic data contain uncertainties, these relationships can be used with a Monte Carlo computer program model to calculate a range of values for expected incremental oil and carbon dioxide requirements.

*See Symbols List in Appendix A - page A-13 for Nomenclature and Units.

APPLICATION

Illustrative calculations utilizing equations (1) and (2) are presented in detail in Appendix B. These calculations were designed to demonstrate that the model can quantify differences in performance that might be expected between two reservoirs that (superficially) might be considered similar in that they each contained the same oil content per acre foot and the same "target" oil in place.

Calculations were performed for a high porosity, low residual oil saturation reservoir typical of a Gulf Coast water-driven reservoir and for a lower porosity, higher residual oil saturation reservoir more typical of a West Texas depletion reservoir, each containing 450 barrels per acre foot with a total target oil content of 3 million barrels. For the same sweep efficiencies, comparative results were:

	High Porosity Reservoir		Low Porosity Reservoir	
E_S	Oil Recovery M Bbls	CO_2/Oil Ratio Mcf/Bbl	Oil Recovery M Bbls	CO_2/Oil Ratio Mcf/Bbl
0.40	659	11.5	1,609	3.1
0.60	1,186	9.4	2,012	2.8

These comparative calculations, admittedly idealized, indicate the capability of the model in distinguishing between better and poorer candidate reservoirs.

Calculations utilizing equations (1) and (2) were performed on a reservoir-by-reservoir basis for most of the reservoirs listed in references two and three. Details of the methods used to set up these calculations and of the results are presented in the following sections.

PERMIAN BASIN CALCULATIONS AND ESTIMATES

Geological and reservoir data compiled and reported earlier (2) for selected carbonate reservoirs in the Permian Basin were used to calculate estimates of incremental oil recoverable and related carbon dioxide requirements. The basic data used are summarized for reference in Table C-1 of Appendix C.

DATA AND ASSUMPTIONS USED IN CALCULATIONS

It was assumed in all calculations that pure carbon dioxide would be the injection fluid. Volumetric properties (i.e., B_{CO_2}) of this fluid as a function of pressure and temperature were obtained from data contained in an earlier (Task One) report (1). It was further assumed that injection would be performed at minimum miscibility pressure, determined as a function of reservoir temperature from the correlation on Yellig and Metcalfe (10), shown for reference on Figure 1. Carbon dioxide solubility in the reservoir oil was estimated from data previously reported (1). Carbon dioxide solubility in reservoir water was considered negligible as compared to other required quantities and, thus, was not included in the calculations. Complete (100-percent) recycling of produced carbon dioxide was also assumed (i.e., R_{sp} = O in Equation 2).

In performing the calculations, it was assumed that sufficient carbon dioxide would be injected to achieve 50-percent lateral sweep of the most permeable layer and that vertical sweep would be a function of formation thickness. Overall sweep efficiency is considered the product of lateral times vertical sweep. An estimated vertical sweep function for the Permian Basin is shown on Figure 2. This empirical curve is based on a very limited amount of proprietary field data and may be the weakest element of the calculation procedure. Use of this curve has the obvious effect of assigning higher vertical sweep efficiencies to thinner reservoirs. This makes physical sense on a qualitative basis. The effect, however, is extremely difficult to quantify from the limited data available.

In an effort to focus better on the proper value for oil saturation at the beginning of carbon dioxide flooding, a series of calculations were performed on 25 Permian Guadalupe reservoirs using cumulative production through 1979 as a measure of remaining oil saturation, calculated as follows:

$$\bar{S}_o = (N-N_p)\, B_o \,/\, 7758\, Ah\phi \qquad (3)$$

in which N_p is the cumulative production reported through 1979, N is Gruy's calculated value for original oil in place (Table C-1) and B_o is

the original formation volume factor. Other assumptions were:

Residual oil saturation (S_{or}): 5%

Oil bank saturation (S_{ob}): $(1-S_{wc}-.05)$

The results of these calculations are shown on Table 1.

It is evident that this procedure generated optimistic forecasts of carbon dioxide flooding potential and related CO_2/oil ratios, because:

(1) oil recoverable in the future by continuation of present methods is included as carbon dioxide floodable incremental oil;

(2) carbon dioxide is injected at minimum miscibility pressure, which may reduce the standard volumes required to fill a given reservoir volume as compared to actual project operation;

(3) complete recycling allows no loss of source carbon dioxide; and

(4) no provision is made for shrinkage of the in-place oil due to pressure depletion during primary production. This effect would be represented by a reduced value for B_o, thus decreasing $\overline{S}_o$ and the CO_2 floodable oil in place.

Field results reviewed in Gruy's work (1) and other industry data indicate that source CO_2/oil ratios ranging from 6 Mcf/Bbl on up are more reasonable than the values shown on Table 1.

In an attempt to develop more realistic assumptions for calculations of incremental oil and carbon dioxide requirements, a revised series of calculations were performed for the same group of reservoirs. To perform these calculations, it was assumed that continuation of present practices would recover 30 percent of original oil in place, and that residual oil saturation after carbon dioxide flooding would be 10 percent of pore space.

A comparison of key changes in the assumptions used is given below:

Quantity	Table 1 Assumptions	Table 2 Assumptions
Average oil saturation ($\overline{S}o$)	Remaining as of 1/01/80	Remaining after 30% recovery
Residual oil saturation (S_{or})	5%	10%
Oil bank saturation (S_{ob})	$(1-S_{wc}-.05)$	$1-S_{wc}$

Assumptions regarding miscibility pressure, sweep efficiency, and produced carbon dioxide recycling were the same.

TABLE 1 Estimated Incremental Oil and CO_2 Requirements -
Permian Guadalupe Fields - Central Basin Platform, West Texas and Eastern New Mexico

Field	Est. Orig. Oil in Place 1000 bbl	Cum.Prod. Thru 1979 1000 bbl	Estimated S_o	Estimated S_{ob}	Calculated E_s	Calculated F	CO_2 Flood Oil 1000 bbl	Total Ult. Rec. 1000 bbl	Recovery Percent Orig. Oil in Place Total	Recovery Percent Orig. Oil in Place CO_2	CO_2 Required MMcf	CO_2/Inc. Oil Ratio Mcf/bbl
Arrowhead (NM)	238,325	27,162	0.71	0.75	0.435	17.5	103,972	131,134	55.0	43.6	268,649	2.58
Block 31	9,143	3,500	0.49	0.75	0.500	2.7	1,938	5,438	59.5	21.1	10,799	5.57
C-Bar	55,043	15,455	0.39	0.60	0.485	2.6	14,828	30,283	55.0	26.9	66,165	4.46
Corazon	30,995	3,739	0.48	0.51	0.500	15.3	15,384	19,123	61.7	49.6	31,900	2.07
Cowden, North	1,863,310	314,161	0.59	0.66	0.325	8.7	544,300	858,461	46.1	29.2	1,753,433	3.22
Cowden, South	1,886,565	121,676	0.75	0.75	0.325	inf.	1,082,033	1,203,709	63.8	57.3	1,473,714	1.36
Donnelly	15,846	7,513	0.36	0.64	0.500	2.1	2,476	9.989	63.0	15.6	16,267	6.56
Dune	1,251,689	141,820	0.61	0.64	0.380	19.7	547,997	689,817	55.0	43.7	1,217,220	2.22
Edwards	53,402	7,495	0.51	0.55	0.435	12.5	20,707	28,202	52.8	38.7	60,991	2.95
Emma	40,590	17,602	0.33	0.55	0.465	2.3	6,524	24,126	58.9	16.1	39,603	6.07
Emperor Deep	164,930	22,799	0.47	0.50	0.410	15.0	71,350	94,149	57.1	43.3	168,900	2.37
Emperor Holt	35,005	6,367	0.53	0.62	0.500	6.3	11,678	18,045	51.5	33.3	38,686	3.31
Eunice (NM)	- No Data -											
Eunice-Monument (NM)	2,367,980	334,553	0.68	0.75	0.225	10.0	716,106	1,050,659	44.3	30.2	2,328,644	3.25
Foster	1,148,140	206,783	0.53	0.60	0.360	7.9	406,629	613,412	53.4	35.4	1,170,393	2.88
Fullerton	124,826	8,584	0.57	0.57	0.445	inf.	65,264	73,848	59.2	59.1	138,958	2.13
Goldsmith	682,704	205,989	0.60	0.81	0.440	3.7	206,843	412,832	60.4	30.2	781,800	3.78
Goldsmith East	92,500	7,323	0.74	0.75	0.360	70.0	44,269	51,592	55.7	47.8	113,218	2.56
Goldsmith North	561,440	11,432	0.78	0.78	0.44	inf.	324,355	335,787	59.8	57.7	725,964	2.24
Goldsmith West	41,249	5,476	0.69	0.75	0.50	10.7	20,778	26,254	63.6	50.4	51,615	2.48
Harper	232,133	38,945	0.67	0.75	0.47	7.8	105,660	144,605	62.2	45.5	280,629	2.66
Hobbs (NM)	925,231	242,420	0.63	0.80	0.35	4.4	266,738	509,158	55.0	28.8	1,001,974	3.76
Johnson	145,440	21,914	0.68	0.75	0.42	10.0	64,152	86,066	59.1	44.1	176,788	2.76
Jordan	828,543	74,007	0.64	0.65	0.43	60.0	414,077	488,084	58.9	49.9	961,201	2.32
Keystone Holt	228,795	39,542	0.62	0.70	0.43	8.1	92,803	132,345	57.8	40.6	267,304	2.88

Results of these calculations are shown on Table 2. From comparison with Table 1, it can be seen that incremental oil volumes are markedly reduced with relatively minor changes in carbon dioxide requirements. Hence, CO_2/oil ratios are higher and appear more realistic (considering 100-percent recycling) than the earlier values. This procedure was followed for calculations performed for the remainder of the Permian Basin reservoirs listed on Table C-1 of Appendix C.

PERMIAN BASIN ESTIMATES OF INCREMENTAL OIL RECOVERY AND CARBON DIOXIDE REQUIREMENTS

As discussed above, a series of test calculations indicated that reasonable values for incremental oil from carbon dioxide flooding and related carbon dioxide requirements would generally result from calculations using the assumption that present practices would recover 30 percent of original oil in place and that residual oil saturation in the swept volume of a carbon dioxide flood would be 10 percent. Results of calculations for 188 selected Permian Basin carbonate reservoirs in west Texas and eastern New Mexico are given on Table 3. Each entry in this table shows information on two pages. The first page contains data and results of calculations of incremental oil recovery while the second (following) page lists data and results of calculations of carbon dioxide requirements. It may be noted that cumulative production from a number of reservoirs as of January 1, 1980, exceeded 30 percent of calculated initial stock-tank oil. Calculations for these reservoirs used average oil saturation values calculated from cumulative production using Equation (3).

DISCUSSION AND SUMMARY OF RESULTS

In summary, these calculations yielded results as follows:

Geol. Age	No. Res.	Inc. Oil MMBbls	CO_2 Required BCF
Permian	120	9,152	48,352
Pennsylanian	35	749	5,543
Mississippian	1	61	282
Devonian	20	491	2,371
Silurian	6	42	276
Ordovician	6	62	333
Totals	188	10,557	57,157

These statistics are obviously dominated by Permian Age reservoirs. This principally reflects the large San Andres reservoirs, many of which are now being pilot tested for carbon dioxide flooding potential and for which large scale projects by major operators such as ARCO, Amoco, and Shell are planned.

Valid calculations could not be performed for 31 reservoirs because of various inconsistencies in basic data. Table 4 lists the reservoirs (from Table C-1) for which no calculations were made and identifies reasons why no calculations were performed.

TABLE 2

ESTIMATED INCREMENTAL OIL AND CO_2 REQUIREMENTS
(ASSUMING 30 PERCENT RECOVERY BY PRESENT PRACTICES)
PERMIAN GUADALUPE FIELDS-CENTRAL BASIN PLATFORM-WEST TEXAS AND EASTERN NEW MEXICO

Field	Est. Orig. Oil In Place 1000 Bbl	Cum. Prod. Thru 1979 1000 Bbl	Est. Rec. @ 30% 1000 Bbl	Estimated		Calculated		CO_2 Flood Rec. Oil 1000 Bbl	Total Ult. Rec. 1000 Bbl	Recovery-Frac. of OOIP		CO_2 Required Mmcf	CO_2/Inc. Oil Ratio Mcf/Bbl
				S_o	S_{oB}	E_s	F			Total	CO_2		
Arrowhead (NM)	238,325	27,162	71,497	0.56	0.80	0.435	2.9	48,378	119,875	0.502	0.202	276,163	5.7
Block 31	9,143	3,500	2,743	0.49	0.80	0.500	2.5	1,470	4,970	0.543	0.161	11,079	7.5
C-Bar	55,043	15,455	16,513	0.38	0.65	0.485	2.0	10,333	26,846	0.488	0.188	70,696	6.8
Corazon	30,995	3,739	9,298	0.39	0.56	0.500	2.7	8,182	17,480	0.564	0.264	32,365	3.9
Cowden, North	1,863,310	314,161	558,993	0.50	0.71	0.325	2.9	273,753	832,746	0.447	0.147	1,741,357	6.4
Cowden, South	1,886,565	121,676	565,969	0.56	0.80	0.325	2.9	327,527	893,496	0.473	0.174	1,582,112	4.8
Donnelly	15,846	7,513	4,754	0.36	0.69	0.500	1.8	1,641	9,154	0.577	0.104	16,865	10.3
Dune	1,251,689	141,820	375,507	0.48	0.69	0.380	2.8	243,732	619,239	0.495	0.195	1,235,379	5.1
Edwards	53,402	7,495	16,021	0.42	0.60	0.435	2.8	8,880	24,901	0.466	0.166	62,394	7.0
Emma	40,590	17,602	12,177	0.33	0.60	0.465	1.9	5,051	22,653	0.558	0.124	40,473	8.0
Emperor Deep	164,930	22,799	49,479	0.38	0.55	0.410	2.6	32,467	81,946	0.497	0.197	156,057	4.8
Emperor Holt	35,005	6,367	10,501	0.45	0.67	0.50	1.6	9,351	19,852	0.567	0.267	40,021	4.3
Eunice (NM)	No Data			No Data					No Data				
Eunice-Monument (NM)	2,367,980	334,553	710,394	0.56	0.80	0.225	2.9	252,901	963,295	0.407	0.107	2,126,468	8.4
Foster	1,148,140	206,783	344,442	0.46	0.65	0.36	2.9	219,460	563,902	0.491	0.191	1,110,035	5.1
Fullerton	124,826	8,584	37,448	0.43	0.615	0.445	2.8	29,311	66,759	0.535	0.235	124,641	4.2
Goldsmith	682,704	205,929	204,811	0.60	0.857	0.44	2.9	180,876	385,687	0.565	0.265	788,139	4.3
Goldsmith-East	92,500	7,323	27,750	0.56	0.80	0.36	2.9	19,500	47,250	0.511	0.211	99,349	5.1
Goldsmith-North	561,440	11,432	168,432	0.56	0.80	0.44	2.9	146,446	314,878	0.561	0.261	634,435	4.3
Goldsmith-West	41,249	5,476	12,375	0.56	0.80	0.50	2.9	12,294	24,669	0.598	0.298	48,312	3.9
Harper	232,133	38,945	69,640	0.56	0.80	0.47	2.9	64,303	133,943	0.577	0.277	264,961	4.1
Hobbs (NM)	925,231	242,420	277,569	0.60	0.85	0.35	3.0	196,026	473,595	0.512	0.212	987,748	5.0
Johnson	145,440	21,914	43,632	0.56	0.80	0.42	2.9	36,089	79,721	0.548	0.248	113,436	3.1
Jordan	828,543	74,007	248,563	0.49	0.70	0.43	2.9	192,691	441,254	0.533	0.233	876,669	4.5
Keystone Holt	228,795	39,542	68,638	0.52	0.75	0.43	2.8	51,750	120,388	0.526	0.226	165,771	3.2

TABLE 3

ESTIMATED CARBON DIOXIDE FLOODABLE OIL AND CARBON DIOXIDE REQUIREMENTS
FOR SELECTED CARBONATE RESERVOIRS IN THE PERMIAN BASIN
ASSUMING 30 PERCENT RECOVERY BY PRESENT PRACTICES

TEXAS AND NEW MEXICO

Field	County	Zone	Pore Volume MBbls	Est. Orig. Oil In Place MBbls	Rec. @ 30% Efficiency MBbls	Est. Avg. Oil Sat. (frac)	Sweep Efficiency (frac)	Displace. Factor	CO_2 Flood Oil Recovery MBbls	CO_2 Flood Oil Recovery frac OOIP	Total Oil Recovery MBbls	Total Oil Recovery frac OOIP
PERMIAN GUADALUPE - CENTRAL BASIN PLATFORM												
ARROWHEAD	Lea	Grayburg	387,279	238,325	71,498	0.56	.435	2.9	48,378	0.202	119,876	0.502
BLOCK 31	Crane	Grayburg	14,858	9,143	2,743	0.49*	.500	2.5	1,470	0.161	4,970	0.543
C-BAR	Crane	San Andres	121,645	55,043	16,513	0.38	.485	2.0	10,333	0.188	26,846	0.488
CORAZON	Scurry	San Andres	67,624	30,995	9,299	0.39	.500	2.7	8,182	0.264	17,481	0.564
COWDEN, N.	Ector	Gry/SanAn.	3,292,805	1,863,310	558,993	0.50	.325	2.9	273,753	0.147	832,746	0.447
COWDEN, S.	Ector	Gry/SanAn.	2,594,026	1,886,565	565,970	0.56	.325	2.9	327,527	0.174	893,497	0.473
DONNELLY	Ector	San Andres	28,790	15,846	4,754	0.36*	.500	1.8	1,641	0.104	9,154	0.577
DUNE	Crane	San Andres	2,031,727	1,251,689	375,507	0.48	.380	2.8	243,732	0.195	619,239	0.495
EDWARDS	Crane	Gry/SanAn.	116,091	53,402	16,021	0.42	.435	2.8	8,880	0.166	24,901	0.466
EMMA	Andrews	San Andres	79,441	40,590	12,177	0.33*	.465	1.9	5,051	0.124	22,653	0.558
EMPEROR	Winkler	Deep	302,872	164,930	49,479	0.38	.410	2.6	32,467	0.197	81,946	0.497
EMPEROR	Winkler	Holt	65,306	35,005	10,502	0.45	.50	1.6	9,351	0.267	19,853	0.567
EUNICE-MONUMENT	Lea	Gry/SanAn.	3,847,968	2,367,980	710,394	0.56	.225	2.9	252,901	0.107	963,295	0.407
FOSTER	Ector	Grayburg	2,188,532	1,148,140	344,442	0.46	.36	2.9	219,460	0.191	563,902	0.491
FULLERTON	Andrews	San Andres	243,562	124,826	37,448	0.43	.445	2.8	29,311	0.235	66,759	0.535
GOLDSMITH	Ector	San Andres	1,083,405	682,704	204,811	0.60	.44	2.9	180,876	0.265	385,687	0.565
GOLDSMITH, E.	Ector	San Andres	150,312	92,500	27,750	0.56	.36	2.9	19,500	0.211	47,250	0.511
GOLDSMITH, N.	Ector/And.	San Andres	912,341	561,440	168,432	0.56	.44	2.9	146,446	0.261	314,878	0.561
GOLDSMITH, W.	Ector	San Andres	67,029	41,249	12,375	0.56	.50	2.9	12,294	0.298	24,669	0.598
HARPER	Ector	San Andres	373,967	232,133	69,640	0.56	.47	2.9	64,303	0.277	133,943	0.577
HOBBS	Lea	Gry/SanAn.	1,415,059	925,231	277,569	0.60	.35	3.0	196,026	0.212	473,595	0.512
JOHNSON	Ector	Grayburg	236,340	145,440	43,632	0.56	.42	2.9	36,089	0.248	79,721	0.548
JORDAN	Crane	San Andres	1,420,359	828,543	248,563	0.49	.43	2.9	192,691	0.233	441,254	0.533
KEYSTONE	Winkler	Holt	454,541	228,795	68,639	0.52	.43	2.8	51,750	0.226	120,389	0.526
LAWSON	Ector	San Andres	122,887	75,355	22,607	0.45	.49	2.8	20,762	0.276	43,369	0.576
LEA	Crane	San Andres	60,745	41,220	12,366	0.53	.50	2.9	11,447	0.278	23,813	0.578
McCAMEY	Upton	Grayburg	1,629,180	1,002,572	300,772	0.56	.385	2.9	210,732	0.210	511,504	0.510
McELROY	Crane	Grayburg	3,728,681	2,593,865	778,160	0.56	.315	2.9	446,921	0.172	1,225,081	0.472
McFARLAND	Andrews	Queen	227,899	136,739	41,022	0.52	.50	2.8	39,459	0.288	80,481	0.588
MEANS	Andrews	San Andres	635,448	397,155	119,147	0.44*	.42	2.6	83,945	0.211	150,088	0.378
PENWELL	Ector	San Andres	614,961	378,050	113,415	0.53	.415	3.0	62,061	0.164	175,476	0.464
SCARBOROUGH	Lea	Yates	310,661	127,132	38,140	0.30	.350	1.9	23,172	0.182	61,312	0.482
SEMINOLE	Gaines	San Andres	2,220,281	1,328,951	398,685	0.58	.320	3.0	253,709	0.191	652,394	0.491
SEMINOLE, E.	Gaines	San Andres	39,308	24,190	7,257	0.56	.435	2.9	6,404	0.265	13,661	0.565
SEMINOLE, W.	Gaines	San Andres	319,195	167,450	50,235	0.51	.350	2.9	34,065	0.203	84,300	0.503
SHAFTER LAKE	Andrews	San Andres	387,440	235,833	70,750	0.49	.44	2.9	61,448	0.260	132,198	0.560
SKAGGS	Lea	Grayburg	35,609	22,406	6,722	0.48*	.44	2.1	3,198	0.143	11,915	0.532
WADDELL	Crane	San Andres	1,124,910	442,878	132,863	0.35	.30	2.7	63,872	0.144	196,735	0.444
YATES	Pecos	Yates Lm.	2,459,596	1,513,598	454,079	0.39*	.325	1.9	83,916	0.055	537,995	0.355
				21,511,218	6,453,371				3,777,523		10,188,826	

* $\bar{S}_o$ calculated from 1/1/80 cum. production, greater than 30% ISTOIP

TABLE 3 (con't.)

Field	County	CO_2 Properties MMP psia	CO_2 Properties CO_2 Form. Vol. Fac.	Free CO_2 In Swept Zone MMcf	Solution CO_2 MMcf	Total CO_2 MMcf	CO_2/Oil Ratio Mcf/Bbl
PERMIAN GUADALUPE - CENTRAL BASIN PLATFORM							
ARROWHEAD	Lea	1100	.0042	180,172	118,512	298,684	6.2
BLOCK 31	Crane	1100	.0042	7,945	4,129	12,074	8.2
C-BAR	Crane	1100	.0042	51,268	27,277	78,545	7.6
CORAZON	Scurry	1115	.0047	22,620	13,784	36,404	4.4
COWDEN, N.	Ector	1115	.0047	907,736	961,471	1,869,207	6.8
COWDEN, S.	Ector	1200	.0050	757,406	919,382	1,676,788	5.1
DONNELLY	Ector	1150	.0048	11,619	6,933	18,552	11.3
DUNE	Crane	1100	.0042	712,194	626,404	1,338,598	5.5
EDWARDS	Crane	1100	.0042	40,507	28,640	69,147	7.8
EMMA	Andrews	1125	.0048	25,929	18,865	44,794	8.9
EMPEROR	Winkler	1100	.0042	91,306	81,352	172,658	5.3
EMPEROR	Winkler	1250	.0042	29,248	15,138	44,386	4.7
EUNICE-MONUMENT	Lea	1115	.0047	827,476	1,404,726	2,232,202	8.8
FOSTER	Ector	1115	.0047	611,815	592,345	1,204,160	5.5
FULLERTON	Andrews	1125	.0047	79,633	58,007	137,640	4.7
GOLDSMITH	Ector	1300	.0045	509,645	337,975	847,620	4.7
GOLDSMITH, E.	Ector	1300	.0045	54,016	52,085	106,101	5.4
GOLDSMITH, N.	Ector/And.	1300	.0045	400,716	283,808	684,524	4.7
GOLDSMITH, W.	Ector	1300	.0045	33,454	19,036	52,490	4.3
HARPER	Ector	1300	.0045	175,449	111,442	286,891	4.5
HOBBS	Lea	1275	.0045	715,104	525,138	1,240,242	6.3
JOHNSON	Ector	1350	.0044	101,338	75,436	176,774	4.9
JORDAN	Crane	1100	.0042	571,564	386,758	958,322	5.0
KEYSTONE	Winkler	1115	.0048	171,479	106,220	277,699	5.4
LAWSON	Ector	1300	.0044	49,946	36,111	86,057	4.1
LEA	Crane	1100	.0042	30,859	17,291	48,150	4.2
McCAMEY	Upton	1100	.0042	670,842	491,271	1,162,113	5.5
McELROY	Crane	1175	.0048	1,099,166	1,267,200	2,366,366	5.3
McFARLAND	Andrews	1300	.0045	106,637	63,681	170,318	4.3
MEANS	Andrews	1200	.0044	187,320	203,334	390,654	4.6
PENWELL	Ector	1300	.0045	207,180	235,770	442,950	7.1
SCARBOROUGH	Lea	1100	.0042	62,715	26,909	89,624	3.9
SEMINOLE	Gaines	1300	.0045	642,733	781,438	1,424,171	5.6
SEMINOLE, E.	Gaines	1300	.0045	14,909	12,105	27,014	4.2
SEMINOLE, W.	Gaines	1250	.0042	93,455	94,192	187,647	5.5
SHAFTER LAKE	Andrews	1275	.0043	133,565	119,179	252,744	4.1
SKAGGS	Lea	1100	.0042	15,087	9,066	24,153	7.6
WADDELL	Crane	1100	.0042	180,468	183,209	363,677	5.7
YATES	Pecos	1100	.0042	746,430	369,917	1,116,347	13.3
				11,330,951	10,685,536	22,016,487	

TABLE 3 (con't.)

Field	County	Zone	Pore Volume MBbls	Est. Orig. Oil In Place MBbls	Rec. @ 30% Efficiency MBbls	Est. Avg. Oil Sat. (frac)	Sweep Efficiency (frac)	Displace. Factor	CO_2 Flood Oil Recovery MBbls	CO_2 Flood Oil Recovery frac OOIP	Total Oil Recovery MBbls	Total Oil Recovery frac OOIP
PERMIAN GUADALUPE - MIDLAND BASIN												
ADAIR	Gaines	San Andres	300,238	174,245	52,274	0.45	.44	2.8	41,600	0.239	93,874	0.539
AZALEA	Midland	Grayburg	6,703	4,125	1,238	0.56	.50	2.9	1,230	0.298	2,468	0.598
CEDAR LAKE	Gaines	San Andres	424,332	281,325	84,398	0.50	.43	2.8	67,103	0.238	151,501	0.538
G-M-K	Gaines	San Andres	95,648	46,446	13,934	0.40	.37	2.8	9,461	0.204	23,395	0.504
MABEE	Andrews	San Andres	46,423	28,359	8,508	0.56						
MIDLAND FARMS	Andrews	Grayburg	1,062,225	774,640	232,392	0.56	.42	2.9	188,329	0.243	420,721	0.543
MOORE	Howard	Gry/SanAn.	52,646	34,441	10,332	0.49	.50	2.9	8,209	0.238	18,541	0.538
REEVES	Yoakum	San Andres	279,385	167,154	50,146	0.49	.45	2.9	34,384	0.206	84,530	0.506
SUNILAND	Lynn	San Andres	19,115	10,115	3,035	0.44	.34	2.7	1,135	0.112	4,170	0.412
WELCH	Dawson	San Andres	660,089	491,796	147,539	0.58	.45	2.9	98,105	0.199	245,644	0.499
				2,012,646	603,796				449,556		1,044,844	
PERMIAN GUADALUPE - REAGAN UPLIFT												
BIG LAKE	Reagan	Gry/SanAn.	253,221	155,628	46,748	0.56						
FARMER	Crockett	San Andres	212,258	138,322	41,497	0.55	.47	3.0	37,697	0.272	79,194	0.572
HALFF	Crockett	Grayburg	71,094	38,230	11,469	0.40	.50	2.8	8,208	0.215	19,677	0.515
				332,380	99,714				45,905		98,871	
PERMIAN GUADALUPE - EASTERN SHELF												
GARZA	Garza	San Andres	816,917	289,063	86,719	0.32	.43	2.6	58,616	0.203	145,335	0.503
HOWARD	Glasscock	Gry/SanAn.	1,522,084	702,501	210,750	0.322*	.39	2.8	28,222	0.040	238,972	0.340
HUNTLEY	Garza	"3400"	5,560	4,044	1,213	0.56						
HUNTLEY, E.	Garza	San Andres	27,432	14,312	4,293	0.42	.50	3.7	4,532	0.317	8,825	0.617
HUNTLEY	Garza	Glorieta	5,560	3,422	1,027	0.56						
P.H.D.	Garza	Glorieta	86,095	47,999	14,400	0.47	.50	2.9	13,990	0.291	28,390	0.591
ROCKER A	Garza	Glorieta	45,878	15,227	4,568	0.27	.47	2.4	(515)			
ROCKER A	Garza	San Andres	68,266	32,935	9,881	0.38	.50	2.6	8,623	0.262	18,504	0.562
				1,109,503	332,851				113,468		440,026	
PERMIAN GUADALUPE - NORTH BASIN												
BRAHANEY	Yoakum	San Andres	325,836	200,309	60,093	0.525	.48	2.8	56,756	0.283	116,849	0.583
BUCKSHOT	Cochran	San Andres	185,695	111,983	33,595	0.526	.50	10.7	32,971	0.294	66,566	0.594
LANDON	Yoakum	San Andres	67,029	41,248	12,374	0.560	---	---	11,011	0.267	23,385	0.567
LEVELLAND	Hockley	San Andres	3,118,250	1,712,587	513,776	0.465	.47	4.8	471,490	0.275	985,266	0.575
OWNBY	Yoakum	San Andres	69,263	31,716	9,515	0.434	.50	3.1	9,077	0.286	18,592	0.586
RUSSELL	Gaines	Clear Fork	293,485	174,852	52,456	0.533	.39	2.1				
RUSSELL	Gaines	Glorieta	27,929	17,612	5,284	0.525*	.45	2.4	4,547	0.258	9,831	0.558
SABLE	Yoakum	San Andres	33,402	18,093	5,428	0.447*	.45	2.7	3,346	0.185	8,774	0.485
SLAUGHTER	Cochran	San Andres	3,634,158	2,068,220	620,466	0.430*	.45	2.2	367,190	0.177	987,656	0.477
WASSON	Yoakum	San Andres	7,488,021	4,233,427	1,270,028	0.519	.29	3.1	681,139	0.161	1,951,167	0.461
				8,610,047	2,583,015				1,637,527		4,168,086	

* $\bar{S}_o$ calculated from 1/1/80 cum. production, greater than 30% ISTOIP

TABLE 3 (con't.)

Field	County	CO_2 Properties MMP psia	CO_2 Properties CO_2 Form. Vol. Fac.	Free CO_2 In Swept Zone MMcf	Solution CO_2 MMcf	Total CO_2 MMcf	CO_2/Oil Ratio Mcf/Bbl
PERMIAN GUADALUPE - MIDLAND BASIN							
ADAIR	Gaines	1250	.0042	97,134	86,933	184,067	4.4
AZALEA	Midland	1275	.0045	2,924	1,905	4,829	3.9
CEDAR LAKE	Gaines	1250	.0042	151,465	141,087	292,552	4.3
G-M-K	Gaines	1300	.0045	20,767	26,405	47,172	5.0
MABEE	Andrews						
MIDLAND FARMS	Andrews	1250	.0042	417,508	397,810	815,318	4.3
MOORE	Howard	1250	.0042	21,114	15,912	37,026	4.5
REEVES	Yoakum	1300	.0045	94,122	84,241	178,363	5.2
SUNILAND	Lynn	1700	.0040	4,936	6,158	11,094	9.8
WELCH	Dawson	1100	.0042	290,334	222,170	512,504	5.2
				1,100,304	982,621	2,082,925	
PERMIAN GUADALUPE - REAGAN UPLIFT							
BIG LAKE	Reagan	1250	.0042				
FARMER	Crockett	1150	.0048	79,205	62,966	142,171	3.8
HALFF	Crockett	--	---	18,762	17,822	36,584	4.4
				97,967	80,788	178,755	
PERMIAN GUADALUPE - EASTERN SHELF							
GARZA	Garza	1125	.0048	148,122	142,470	290,592	4.9
HOWARD	Glasscock	1100	.0042	396,802	350,252	747,054	26.4
HUNTLEY	Garza	1100	.0042				
HUNTLEY, E.	Garza	1250	.0042	8,067	6,172	14,239	3.1
HUNTLEY	Garza	1350	.0044				
P.H.D.	Garza	1300	.0045	30,615	22,670	53,285	3.8
ROCKER A	Garza	1250	.0042				
ROCKER A	Garza	1200	.0044	19,600	15,544	35,144	4.1
				603,206	537,108	1,140,314	
PERMIAN GUADALUPE - NORTH BASIN							
BRAHANEY	Yoakum	1300	.0045	126,852	95,978	222,830	3.9
BUCKSHOT	Cockran	1250	.0042	80,685	51,026	131,711	4.0
LANDON	Yoakum	1300	.0045	26,348	20,541	46,889	4.2
LEVELLAND	Hockley	1300	.0045	1,023,304	837,653	1,860,957	3.9
OWNBY	Yoakum	1275	.0045	22,470	15,092	37,562	4.1
RUSSELL	Gaines	1500	.0046				
RUSSELL	Gaines	1450	.0047	10,809	9,024	19,833	4.4
SABLE	Yoakum	1300	.0045	10,297	9,202	19,499	5.8
SLAUGHTER	Cockran	1300	.0045	89,255	1,039,096	1,128,351	3.1
WASSON	Yoakum	1250	.0042	1,857,988	2,509,063	4,367,051	6.4
				3,248,008	4,586,675	7,834,683	

TABLE 3 (con't.)

Field	County	Zone	Pore Volume MBbls	Est. Orig. Oil In Place MBbls	Rec. @ 30% Efficiency MBbls	Est. Avg. Oil Sat. (frac)	Sweep Efficiency (frac)	Displace. Factor	CO_2 Flood Oil Recovery MBbls	CO_2 Flood Oil Recovery frac OOIP	Total Oil Recovery MBbls	Total Oil Recovery frac OOIP
PERMIAN GUADALUPE - TATUM BASIN												
CHAVEROO	Chaves/Rsvt.	San Andres	204,811	118,160	35,448	0.525	.46	5.2	34,304	0.290	69,752	0.590
FLYING M	Lea	San Andres	45,035	25,982	7,795	0.525	.50	3.5	7,670	0.295	15,465	0.595
LOVINGTON		San Andres	131,079	80,664	24,199	0.56	.46	2.9	22,596	0.280	46,795	0.580
MILNESAND	Roosevelt	San Andres	109,480	33,686	10,106	0.280	.46	2.9	8,075	0.240	18,181	0.540
				385,985	115,796				72,645		150,193	
PERMIAN GUADALUPE - DELAWARE BASIN												
PRIEST & BEAVERS	Pecos	Quenn SS	64,119	33,809	10,143	0.406	.50	14.1	8,935	0.264	19,078	0.564
				33,809	10,143				8,935		19,078	
PERMIAN GUADALUPE - NORTHWEST SHELF												
ARTESIA	Eddy	San Andres	723,355	445,142	133,543	0.560	.50	15.6	128,728	0.289	262,271	0.589
BENSON, N.	Eddy	Queen	42,600	19,006	5,702	0.405	.50	6.6	5,154	0.271	10,856	0.571
CATO	Chaves	San Andres	159,543	81,885	24,566	0.467	.50	5.0	24,002	0.293	48,568	0.593
E-K	Lea	Yates	36,940	17,276	5,183	0.409*	.41	2.5	3,616	0.209	8,799	0.509
LOCO HILLS	Eddy	Gry/San An.	1,206,213	43,103	12,931	0.592	.41	2.5	195,577	4.537	208,508	4.837
LOVINGTON, W.	Lea	San Andres	62,064	38,193	11,458	0.514*	.41	2.9	10,897	0.285	22,355	0.585
MALJAMAR	Lea & Eddy	Gry/San An.	931,425	597,545	179,264	0.583	.44	2.9	58,316	0.097	237,580	0.397
VACUUM	Lea	San Andres	1,245,252	703,284	210,985	0.494	.36	3.3	149,049	0.212	360,034	0.512
				1,945,434	583,632				673,419		1,158,971	

* $\bar{S}_o$ calculated from 1/1/80 cum. production, greater than 30% ISTOIP

TABLE 3 (con't.)

Field	County	CO_2 Properties MMP psia	CO_2 Properties CO_2 Form. Vol. Fac.	Free CO_2 In Swept Zone MMcf	Solution CO_2 MMcf	Total CO_2 MMcf	CO_2/Oil Ratio Mcf/Bbl
PERMIAN GUADALUPE - TATUM BASIN							
CHAVEROO	Chaves/Roosevelt	1350	.0044	65,886	72,262	138,148	4.0
FLYING M	Lea	1275	.0045	18,262	12,094	30,356	4.0
LOVINGTON		1425	.0043	55,115	40,641	95,756	4.2
MILNESAND	Roosevelt	1425	.0043	19,728	18,605	38,333	4.7
				158,991	143,602	302,593	
PERMIAN GUADALUPE - DELAWARE BASIN							
PRIEST & BEAVERS	Pecos	1100	.0042	20,573	14,730	35,303	4.0
				20,573	14,730	35,303	
PERMIAN GUADALUPE - NORTHWEST SHELF							
ARTESIA	Eddy	1175	.0048	296,161	192,014	488,175	3.8
BENSON, N.	Eddy	1300	.0045	12,746	9,151	21,897	4.2
CATO	Chaves	1275	.0043	68,750	38,307	107,057	4.5
E-K	Lea	1450	.0047	9,227	9,605	18,832	5.2
LOCO Hills	Eddy	1975	.0058	358,448	424,456	782,904	4.0
LOVINGTON, W.	Lea	1450	.0047	22,805	19,806	42,611	3.9
MALJAMAR	Lea & Eddy	1350	.0044	151,846	176,829	328,675	5.6
VACUUM	Lea	1450	.0047	326,694	411,502	738,196	5.0
				1,246,677	1,281,670	2,528,347	

TABLE 3 (con't.)

Field	County	Zone	Pore Volume MBbls	Est. Orig. Oil In Place MBbls	Rec. @ 30% Efficiency MBbls	Est. Avg. Oil Sat. (frac)	Sweep Efficiency (frac)	Displace. Factor	CO_2 Flood Oil Recovery MBbls	CO_2 Flood Oil Recovery frac OOIP	Total Oil Recovery MBbls	Total Oil Recovery frac OOIP
PERMIAN WOLFCAMP - TATUM BASIN												
DENTON	Lea	Wolfcamp	157,378	96,848	29,054	0.512*	.88	2.4	20,128	0.208	49,182	0.508
				96,848	29,054				20,128		49,182	
PERMIAN WOLFCAMP - MIDLAND BASIN												
ADAIR	Terry/Gaines	Wolfcamp	147,184	87,914	26,374	0.363*	.82	1.7	1,943	0.022	28,317	0.322
BAKKE	Andrews	Wolfcamp	110,191	76,606	22,982	0.632	.50	3.0	23,788	0.310	46,770	0.610
NOLLEY	Andrews	Wolfcamp	145,844	95,237	28,571	0.557	.41	3.9	23,338	0.245	51,909	0.545
				259,757	77,927				49,069		126,996	
PERMIAN WOLFCAMP - CENTRAL BASIN PLATFORM												
ANDREWS	Andrews	Wolfcamp	57,347	35,257	10,577	0.416*	.50	1.8	4,494	0.127	15,071	0.427
ANDREWS, S.	Andrews	Wolfcamp	38,479	23,679	7,104	0.391*	.50	1.7	2,213	0.093	9,317	0.393
PECOS VALLEY	Pecos	Wolfcamp	57,980	35,680	10,704	0.56	.47	2.9	9,804	0.275	20,508	0.575
SHAFTER LAKE	Andrews	Wolfcamp	67,301	36,647	10,994	0.536*	.50	2.7	10,728	0.293	21,722	0.593
UNIVERSITY	Andrews	Wolfcamp	93,096	51,276	15,383	0.400*	.50	1.9	7,578	0.148	22,961	0.448
				182,539	54,762				34,817		89,579	
PERMIAN OCHOA - DELAWARE BASIN												
FT. STOCKTON	Pecos	Yates	585,486	390,324	117,097	0.56	.48	2.9	105,549	0.270	222,646	0.570
				390,324	117,097				105,549		222,646	
PERMIAN LEONARD - MATADOR UPLIFT												
ANTON IRISH	Hale	Clear Fork	836,816	514,964	154,408	0.560	.30	2.9	93,783	0.182	248,191	0.482
				514,964	154,408				93,783		248,191	
PERMIAN LEONARD - NORTHWEST SHELF												
CORBIN	Lea	Abo	68,425	36,844	11,053	0.452*	.40	2.4	6,777	0.184	17,830	0.484
				36,844	11,053				6,777		17,830	
PERMIAN LEONARD - TATUM BASIN												
LOVINGTON	Lea	Paddock	52,133	32,082	9,625	0.483*	.50	2.2	6,688	0.208	16,313	0.508
LOVINGTON	Lea	Abo	99,302	61,109	18,333	0.411*	.33	1.8	5,606	0.092	23,939	0.392
				93,191	27,958				12,294		40,252	
PERMIAN LEONARD - EASTERN SHELF												
IATAN, E.	Howard	Clear Fork	997,058	613,574	184,072	0.559	.40	2.9	137,459	0.224	321,531	0.524
PAROCHIAL BADE	Sterling	Clear Fork	27,314	16,808	5,042	0.559	.50	2.9	4,916	0.292	9,958	0.592
				630,382	189,114				142,375		331,489	
PERMIAN LEONARD - MIDLAND BASIN												
KETCHUM MT.	Irion	Clear Fork	33,886	16,027	4,808	0.489	.50	2.8	4,486	0.280	9,294	0.580
REVILO	Scurry	Glorieta	69,837	48,163	14,449	0.559	.50	2.9	14,134	0.293	28,583	0.593
				64,190	19,257				18,620		37,877	

* S_o calculated from 1/1/80 cum. production, greater than 30% ISTOIP

TABLE 3 (con't.)

Field	County	CO_2 Properties MMP psia	CO_2 Properties CO_2 Form. Vol. Fac.	Free CO_2 In Swept Zone MMcf	Solution CO_2 MMcf	Total CO_2 MMcf	CO_2/Oil Ratio Mcf/Bbl
PERMIAN WOLFCAMP - TATUM BASIN							
DENTON	Lea	1950	.0057	47,767	50,224	97,991	4.9
				47,767	50,224	97,991	
PERMIAN WOLFCAMP - MIDLAND BASIN							
ADAIR	Terry/Gaines	1610	.0041	54,544	48,944	103,488	53.3
BAKKE	Andrews	1610	.0041	60,363	35,689	96,052	4.0
NOLLEY	Andrews	1600	.0040	58,757	51,896	110,653	4.7
				173,664	136,529	310,193	
PERMIAN WOLFCAMP - CENTRAL BASIN PLATFORM							
ANDREWS	Andrews	1575	.0049	23,985	16,666	40,651	9.0
ANDREWS, S.	Andrews	1700	.0048	15,754	11,232	26,986	12.2
PECOS VALLEY	Pecos	1200	.0044	24,342	16,688	41,030	4.2
SHAFTER LAKE	Andrews	1550	.0049	26,992	17,556	44,548	4.2
UNIVERSITY	Andrews	1750	.0048	34,304	24,530	58,834	7.8
				125,377	86,672	212,049	
PERMIAN OCHOA - DELAWARE BASIN							
FT. STOCKTON	Pecos	1100	.0042	263,000	167,694	430,694	4.1
				263,000	167,694	430,694	
PERMIAN LEONARD - MATADOR UPLIFT							
ANTON IRISH	Hale	1575	.0049	201,373	262,497	463,870	4.9
				201,373	262,497	463,870	
PERMIAN LEONARD - NORTHWEST SHELF							
CORBIN	Lea	1575	.0049	18,818	20,416	39,234	5.8
				18,818	20,416	39,234	
PERMIAN LEONARD - TATUM BASIN							
LOVINGTON	Lea	1600	.0041	24,988	15,217	40,205	6.0
LOVINGTON	Lea	1875	.0050	25,760	15,550	41,310	7.4
				50,748	30,767	81,515	
PERMIAN LEONARD - EASTERN SHELF							
IATAN, E.	Howard	1150	.0048	373,232	307,837	681,069	5.0
PAROCHIAL BADE	Sterling	1200	.0050	10,735	7,511	18,246	3.7
				383,967	315,348	699,315	
PERMIAN LEONARD - MIDLAND BASIN							
KETCHUM MT.	Irion	1450	.0047	12,144	8,052	20,196	4.5
REVILO	Scurry	1200	.0050	27,449	21,471	48,920	3.5
				39,593	29,523	69,116	

TABLE 3 (con't.)

Field	County	Zone	Pore Volume MBbls	Est. Orig. Oil In Place MBbls	Rec. @ 30% Efficiency MBbls	Est. Avg. Oil Sat. (frac)	Sweep Efficiency (frac)	Displace. Factor	CO_2 Flood Oil Recovery MBbls	CO_2 Flood Oil Recovery frac OOIP	Total Oil Recovery MBbls	Total Oil Recovery frac OOIP
PERMIAN LEONARD - CENTRAL BASIN PLATFORM												
BLINEBRY	Lea	Yeso	458,255	266,493	79,948	0.529	.41	2.9	65,247	0.245	145,195	0.545
BROWN & THORP	Pecos	Clear Fork	109,285	61,237	18,371	0.454	.46	2.8	15,137	0.247	33,508	0.547
DOLLARHIDE	Andrews	Clear Fork	162,918	87,277	26,183	0.494*	.46	2.5	19,999	0.229	46,182	0.529
DOLLARHIDE	Lea	Tubb	64,794	39,873	11,962	0.471*	.50	2.1	7,714	0.193	19,676	0.493
DRINKARD	Lea	Yeso	1,858,351	1,197,921	359,376	0.586	.35	2.9	254,250	0.212	613,626	0.512
FULLERTON	Andrews	Clear Fork	1,715,177	825,826	247,748	0.546	.39	3.4	194,176	0.235	441,924	0.535
GOLDSMITH	Ector	Clear Fork	5,849,532	2,792,679	837,804	0.518	.35	2.9	563,927	0.202	1,401,731	0.502
GOLDSMITH, E.	Ector	Holt	69,974	43,061	12,918	0.560	.44	2.9	11,533	0.268	24,451	0.568
GOLDSMITH, W.	Ector	Clear Fork	1,606,099	1,864,823	559,447	0.490	.48	2.3	202,548	0.108	761,995	0.408
HARRIS	Gaines/Andw.	Glorieta	217,844	157,005	47,101	0.560	.41	2.9	39,172	0.249	86,273	0.549
HOBBS	Lea	Blinebry	83,165	37,104	11,131	0.405	.40	2.7	8,179	0.220	19,310	0.520
MONAHANS	Ward	Clear Fork	191,256	100,732	30,219	0.525	.44	2.9	24,292	0.241	54,511	0.541
RILEY, N.	Gaines	Clear Fork	1,212,652	754,372	226,312	0.559	.40	2.9	177,205	0.235	403,517	0.535
ROBERTSON, N.	Gaines	Clear Fork	185,378	100,749	30,225	0.521*	.48	2.8	28,560	0.283	58,785	0.583
SANDHILLS	Crane	Tubb	707,250	345,280	103,584	0.419	.44	2.8	81,022	0.235	184,606	0.535
TUBB	Lea	Tubb	67,922	41,798	12,539	0.559	.40	2.9	10,114	0.242	22,653	0.542
TXL	Ector	Tubb	873,666	33,480	10,044	0.559	.42	2.9	137,056	4.093	147,100	4.393
				8,749,710	2,601,412				1,840,131		4,465,043	
PERMIAN LEONARD - NORTH BASIN												
RUSSELL	Gaines	Clear Fork	293,485	174,852	52,456	0.452*	.39	2.1	22,670	0.129	75,126	0.429
WASSON 72	Yoakum	Clear Fork	238,822	139,619	41,885	0.532	.39	3.4	27,568	0.197	69,453	0.497
				314,471	94,341				50,238		144,579	
PENNSYLVANIAN-CANYON - BEND ARCH												
BOX	Callahan	Palo Pinto	25,360	15,606	4,682	0.483*	.50	2.2	3,253	0.208	7,935	0.508
				15,606	4,682				3,253		7,935	
PENNSYLVANIAN-STRAWN - NORTHWEST SHELF												
LUSK	Eddy & Lea	Strawn	150,939	80,810	24,243	0.487	.47	2.8	18,115	0.224	42,358	0.524
				80,810	24,243				18,115		42,358	
PENNSYLVANIAN-STRAWN - TATUM BASIN												
ALLISON	Lea/Roosevelt	Penn.	69,423	34,284	10,285	0.243*	.50	1.4	2,373	0.069	12,658	0.369
VADA	Lea/Roosevelt	Penn.	349,544	180,149	54,045	0.468	.50	2.8	53,092	0.295	107,137	0.595
				214,433	64,330				55,465		119,795	
PENNSYLVANIAN-DEVONIAN - TATUM BASIN												
DENTON	Lea	Devonian	849,035	522,483	156,745	0.559	.20	2.9	63,054	0.121	219,799	0.421
LOVINGTON	Lea	Devonian	10,923	6,722	2,017	0.560	.45	2.9	1,841	0.274	3,858	0.574
				529,205	158,762				64,895		223,657	

* $\bar{S}_o$ calculated from 1/1/80 cum. production, greater than 30% ISTOIP

TABLE 3 (con't.)

Field	County	CO_2 Properties MMP psia	CO_2 Properties CO_2 Form. Vol. Fac.	Free CO_2 In Swept Zone MMcf	Solution CO_2 MMcf	Total CO_2 MMcf	CO_2/Oil Ratio Mcf/Bbl
PERMIAN LEONARD - CENTRAL BASIN PLATFORM							
BLINEBRY	Lea	1600	.0041	169,824	104,809	274,633	4.2
BROWN & THORP	Pecos	1100	.0042	36,964	27,634	64,598	4.3
DOLLARHIDE	Andrews	1300	.0045	60,782	43,110	103,892	5.2
DOLLARHIDE	Lea	1750	.0048	26,528	18,884	45,412	5.9
DRINKARD	Lea	1700	.0048	563,035	699,784	1,262,819	5.0
FULLERTON	Andrews	1450	.0047	543,418	460,681	1,004,099	5.2
GOLDSMITH	Ector	1350	.0044	1,672,115	1,599,590	3,271,705	5.8
GOLDSMITH, E.	Ector	1425	.0043	28,142	22,331	50,473	4.4
GOLDSMITH, W.	Ector	1425	.0043	704,681	483,392	1,188,073	5.9
HARRIS	Gaines/Andrews	1510	.0052	67,510	84,876	152,386	3.9
HOBBS	Lea	1275	.0045	19,924	23,166	43,090	5.3
MONAHANS	Ward	1100	.0042	73,127	46,220	119,347	4.9
RILEY, N.	Gaines	1275	.0045	423,673	402,869	826,542	4.7
ROBERTSON, N.	Gaines	1450	.0047	69,097	49,711	118,808	4.2
SANDHILLS	Crane	1150	.0048	182,013	148,522	330,535	4.1
TUBB	Lea	1610	.0041	26,045	22,909	48,954	4.8
TXL	Ector	1550	.0049	294,338	286,751	581,089	4.2
				4,961,216	4,525,239	9,486,455	
PERMIAN LEONARD - NORTH BASIN							
RUSSELL	Gaines	1500	.0046	92,211	97,256	189,467	8.4
WASSON 72	Yoakum	1500	.0046	74,920	77,858	152,778	5.5
				167,131	175,114	342,245	
PENNSYLVANIAN-CANYON - BEND ARCH							
BOX	Callahan	1550	.0049	10,171	6,305	16,476	5.1
				10,171	6,305	16,476	
PENNSYLVANIAN-STRAWN - NORTHWEST SHELF							
LUSK	Eddy & Lea	2275	.0052	45,961	34,888	80,849	4.5
				45,961	34,888	80,849	
PENNSYLVANIAN-STRAWN - TATUM BASIN							
ALLISON	Lea/Roosevelt	1950	.0057	18,464	7,059	25,523	10.8
VADA	Lea/Roosevelt	1800	.0056	117,411	74,655	192,066	3.6
				135,875	81,714	217,589	
PENNSYLVANIAN-DEVONIAN - TATUM BASIN							
DENTON	Lea	2375	.0050	133,485	152,023	285,508	4.5
LOVINGTON	Lea	2325	.0050	3,863	2,917	6,780	3.7
				137,348	154,940	292,288	

TABLE 3 (con't.)

Field	County	Zone	Pore Volume MBbls	Est. Orig. Oil In Place MBbls	Rec. @ 30% Efficiency MBbls	Est. Avg. Oil Sat. (frac)	Sweep Efficiency (frac)	Displace. Factor	CO_2 Flood Oil Recovery MBbls	CO_2 Flood Oil Recovery frac OOIP	Total Oil Recovery MBbls	Total Oil Recovery frac OOIP
PENNSYLVANIAN-BEND - EASTERN SHELF												
BOYD	Stonewall	Congl.	85,015	52,317	15,695	0.464*	.50	2.9	9,664	0.185	25,359	0.485
				52,317	15,695				9,664		25,359	
PENNSYLVANIAN-CISCO - EASTERN SHELF												
I.A.B.	Coke	Menielle	95,854	39,392	11,818	0.414*	.45	1.9	4,812	0.122	16,630	0.422
INBE	Lea	Cisco	50,271	30,933	9,280	0.385*	.50	2.9	2,659	0.086	11,939	0.386
JAMESON	Coke	Penn Reef	274,307	168,804	50,641	0.559	.40	2.9	40,849	0.242	91,490	0.542
SUSAN PEAK	Tom Green	Cisco Canyon	104,615	59,356	17,807	0.559	.45	2.9	16,105	0.271	33,912	0.571
				298,485	89,546				64,425		153,971	
PENNSYLVANIAN-CANYON - EASTERN SHELF												
DIAMOND M	Scurry	Canyon	1,021,225	480,756	144,227	0.396*	.36	1.9	53,974	0.112	198,201	0.412
KELLY SNYDER	Scurry	Canyon Reef	4,508,712	2,149,849	644,955	0.378*	.30	1.8	88,650	0.041	733,605	0.341
OCHO-JUAN	Fisher	Canyon Reef	24,298	10,279	3,084	0.281*	.45	1.7	688	0.067	3,772	0.367
ROUNDTOP	Fisher	Palo Pinto	142,491	76,334	22,900	0.372*	.42	1.7	7,382	0.097	30,282	0.397
SALT CREEK	Kent	Canyon Reef	1,164,924	642,529	192,759	0.514	.26	2.9	98,878	0.154	291,637	0.454
				3,359,747	1,007,925				249,572		1,257,497	
PENNSYLVANIAN-STRAWN - EASTERN SHELF												
CLAIRMONT	Kent	Strawn	73,693	33,799	10,140	0.366*	.50	2.1	6,437	0.190	16,577	0.490
FT. CHADBOURNE	Runnels	Odom Lm.	247,146	152,090	45,627	0.524*	.46	2.5	16,750	0.110	62,377	0.410
H-J	Tom Green	Strawn	57,015	30,411	9,123	0.223	.50	1.3	1,728	0.057	10,851	0.357
JAMESON	Coke	Strawn	540,402	332,555	99,767	0.559	.41	2.9	82,532	0.248	182,299	0.548
NEILL, S.	Fisher	Odom Lm.	66,842	41,134	12,340	0.560	.50	2.9	12,534	0.305	24,874	0.605
NENA LUCIA	Nolan	Strawn	417,681	208,840	62,652	0.454	.43	2.8	52,509	0.251	115,161	0.551
PAGE	Schleicher	Strawn	53,600	32,984	9,895	0.559	.45	2.9	9,010	0.273	18,905	0.573
				831,813	249,544				181,500		431,044	
PENNSYLVANIAN-STRAWN - REAGAN UPLIFT												
TODD DEEP	Crockett	Crinoild	137,532	83,886	25,166	0.525*	.38	2.5	15,061	0.179	40,227	0.479
WORLD, W.	Crockett	Strawn	69,246	21,160	6,348	0.493*	.50	2.3	4,663	0.220	11,011	0.520
				105,046	31,514				19,724		51,238	
PENNSYLVANIAN-STRAWN - MIDLAND BASIN												
FLUVANNA	Borden	Strawn	30,803	17,184	5,155	0.244*	.50	1.3	977	0.057	6,132	0.357
				17,184	5,155				977		6,132	
PENNSYLVANIAN-BEND - MIDLAND BASIN												
AMACKER-TIPPET, S.	Upton	Bend	82,064	22,909	6,873	0.468	.46	3.2	6,188	0.270	13,061	0.570
OCEANIC	Howard	Penn.	96,261	51,930	15,579	0.502*	.42	2.3	8,724	0.168	24,303	0.468
PEGASUS	Upton/Midland	Bend	148,139	49,379	14,814	0.468	.50	2.9	14,480	0.293	29,294	0.593
				124,218	37,266				29,392		66,658	

* $\bar{S}_o$ calculated from 1/1/80 cum. production, greater than 30% ISTOIP

TABLE 3 (con't.)

Field	County	CO_2 Properties MMP psia	CO_2 Properties CO_2 Form. Vol. Fac.	Free CO_2 In Swept Zone MMcf	Solution CO_2 MMcf	Total CO_2 MMcf	CO_2/Oil Ratio Mcf/Bbl
PENNSYLVANIAN-BEND - EASTERN SHELF							
BOYD	Stonewall	1575	.0049	34,097	21,144	55,241	5.7
				34,097	21,144	55,241	
PENNSYLVANIAN-CISCO - EASTERN SHELF							
I.A.B.	Coke	1610	.0041	38,397	17,265	55,662	11.6
INBE	Lea	1775	.0048	20,582	12,503	33,085	12.4
JAMESON	Coke	1810	.0056	77,011	78,303	155,314	3.8
SUSAN PEAK	Tom Green	1950	.0057	32,462	25,840	58,302	3.6
				168,452	133,911	302,363	
PENNSYLVANIAN-CANYON - EASTERN SHELF							
DIAMOND M	Scurry	1575	.0049	261,198	153,047	414,245	7.7
KELLY SNYDER	Scurry	1600	.0041	1,148,500	954,470	2,102,970	23.7
OCHO-JUAN	Fisher	1810	.0056	4,933	4,610	9,543	13.9
ROUNDTOP	Fisher	1600	.0041	53,274	26,035	79,309	10.7
SALT CREEK	Kent	1575	.0049	211,716	284,748	496,464	5.0
				1,679,621	1,422,910	3,102,531	
PENNSYLVANIAN-STRAWN - EASTERN SHELF							
CLAIRMONT	Kent	1800	.0056	18,842	16,610	35,452	5.5
FT. CHADBOURNE	Runnels	1700	.0048	93,093	66,368	159,461	9.5
H-J	Tom Green	1775	.0048	20,675	4,454	25,129	14.5
JAMESON	Coke	1675	.0041	212,405	179,822	392,227	4.8
NEILL, S.	Fisher	1775	.0048	27,366	19,414	46,780	3.7
NENA LUCIA	Nolan	1950	.0057	97,308	112,053	209,361	4.0
PAGE	Schleicher	2010	.0064	14,813	16,865	31,678	3.5
				484,502	415,586	900,088	
PENNSYLVANIAN-STRAWN - REAGAN UPLIFT							
TODD DEEP	Crockett	2010	.0064	32,554	47,171	79,725	5.3
WORLD, W.	Crockett	1975	.0058	23,463	10,051	33,514	7.2
				56,017	57,222	113,239	
PENNSYLVANIAN-STRAWN - MIDLAND BASIN							
FLUVANNA	Borden	1750	.0048	12,611	2,790	15,401	15.8
				12,611	2,790	15,401	
PENNSYLVANIAN-BEND - MIDLAND BASIN							
AMACKER-TIPPET, S.	Upton	2010	.0064	18,878	11,776	30,654	5.0
OCEANIC	Howard	2000	.0064	25,538	27,680	53,218	6.1
PEGASUS	Upton-Midland	2075	.0050	47,412	24,014	71,426	4.9
				91,828	63,470	155,298	

TABLE 3 (con't.)

Field	County	Zone	Pore Volume MBbls	Est. Orig. Oil In Place MBbls	Rec. @ 30% Efficiency MBbls	Est. Avg. Oil Sat. (frac)	Sweep Efficiency (frac)	Displace. Factor	CO_2 Flood Oil Recovery MBbls	CO_2 Flood Oil Recovery frac OOIP	Total Oil Recovery MBbls	Total Oil Recovery frac OOIP
PENNSYLVANIAN-CISCO - MIDLAND BASIN												
VEALMOOR, E.	Howard	Cisco	284,873	87,653	26,296	0.279	.35	1.4	8,345	0.095	34,641	0.395
				87,653	26,296				8,345		34,641	
PENNSYLVANIAN-CANYON - MIDLAND BASIN												
ROPES	Hockley	Canyon Reef	118,895	68,506	20,552	0.512*	.35	2.7	12,518	0.183	33,070	0.483
VON ROEDER	Borden	Canyon Reef	60,396	23,383	7,015	0.206*	.45	1.2	1,249	0.053	8,264	0.353
				91,889	27,567				13,767		41,334	
PENNSYLVANIAN-BEND - CENTRAL BASIN PLATFORM												
UNIVERSITY	Andrews	Penn.	104,267	49,017	14,705	0.489	.46	4.0	13,290	0.271	27,995	0.571
				49,017	14,705				13,290		27,995	
PENNSYLVANIAN-BEND - ANADARKO BASIN												
HITCHLAND	Hansford	Collier	73,229	44,047	13,214	0.547	.50	2.8	13,000	0.295	26,214	0.595
TWIN	Hansford	Morrow	19,685	12,144	3,643	0.561	.50	1.9	3,707	0.305	7,353	0.605
				56,191	16,857				16,707		33,567	
MISSISSIPPIAN - BEND ARCH												
SHACKELFORD, N.E.	Shackelford	Miss.	465,480	286,449	85,935	0.559	.35	2.9	60,521	0.211	146,456	0.511
				286,449	85,935				60,521		146,456	
DEVONIAN - MIDLAND BASIN												
AZALEA	Midland	Devonian	703,805	324,833	97,450	0.419	.41	2.8	76,569	0.236	174,019	0.536
DORA ROBERTS	Midland	Devonian	222,220	136,750	41,025	0.559	.41	2.9	33,933	0.248	74,958	0.548
HUTEX	Midland	Devonian	114,694	58,229	17,469	0.278*	.41	1.9	1,518	0.026	18,987	0.326
MAGUTEX	Midland	Devonian	116,183	65,919	19,776	0.328*	.46	1.5	5,454	0.083	25,230	0.383
				585,731	175,720				117,474		293,194	
DEVONIAN - CENTRAL BASIN PLATFORM												
ANDREWS	Andrews	Devonian	74,933	46,113	13,834	0.560	.50	2.9	14,052	0.305	27,886	0.605
BLOCK 11	Andrews	Devonian	152,637	93,931	28,179	0.560	.45	2.9	28,623	0.305	56,802	0.605
BLOCK 31	Crane	Devonian	1,721,112	529,573	158,872	0.277*	.275	2.4	71,349	0.135	230,221	0.435
CRAWAR	Crane	Devonian	22,343	9,035	2,711	0.291*	.50	1.7	1,232	0.136	3,943	0.436
CROSSETT	Crane	Devonian	114,694	37,652	11,296	0.439*	.41	2.6	8,103	0.215	19,399	0.515
CROSSETT, S.	Crockett	Devonian	173,304	99,983	29,995	0.524	.48	2.9	28,823	0.288	58,818	0.588
DOLLARHIDE	Andrews	Devonian	412,899	157,652	47,296	0.352*	.39	1.7	16,789	0.106	64,085	0.406
DOLLARHIDE	Lea	Devonian	37,703	23,202	6,961	0.710	.38	3.2	8,318	0.358	15,279	0.658
DOLLARHIDE, E.	Andrews	Devonian	27,370	11,636	3,491	0.375*	.50	1.8	2,084	0.179	5,575	0.479
FULLERTON 8500	Andrews	Devonian	567,303	378,202	113,461	0.56	.32	2.9	72,372	0.191	185,833	0.491

* S_o calculated from 1/1/80 cum. production, greater than 30% ISTOIP

TABLE 3 (con't.)

Field	County	CO_2 Properties MMP psia	CO_2 Properties CO_2 Form. Vol. Fac.	Free CO_2 In Swept Zone MMcf	Solution CO_2 MMcf	Total CO_2 MMcf	CO_2/Oil Ratio Mcf/Bbl
PENNSYLVANIAN-CISCO - MIDLAND BASIN							
VEALMOOR, E.	Howard	1975	.0058	67,657	16,297	83,954	10.0
				67,657	16,297	83,954	
PENNSYLVANIAN-CANYON - MIDLAND BASIN							
ROPES	Hockley	1975	.0058	26,588	40,360	66,948	5.3
VON ROEDER	Borden	1610	.0041	20,099	3,197	23,296	18.7
				46,687	43,557	90,244	
PENNSYLVANIAN-BEND - CENTRAL BASIN PLATFORM							
UNIVERSITY	Andrews	1875	.0056	28,854	25,142	53,996	4.1
				28,854	25,142	53,996	
PENNSYLVANIAN-BEND - ANADARKO BASIN							
HITCHLAND	Hansford	1550	.0049	29,371	21,343	50,714	3.9
TWIN	Hansford	1850	.0057	6,787	5,737	12,524	3.4
				36,158	27,080	63,238	
MISSISSIPPIAN - BEND ARCH							
SHACKELFORD, N.E.	Shackelford	1810	.0056	114,348	167,572	281,920	4.7
				114,348	167,572	281,920	
DEVONIAN - MIDLAND BASIN							
AZALEA	Midland	2200	.0050	162,026	180,326	342,352	4.5
DORA ROBERTS	Midland	2275	.0052	68,867	73,957	142,824	4.2
HUTEX	Midland	2010	.0064	23,103	21,017	44,120	29.1
MAGUTEX	Midland	2375	.0053	39,634	15,553	55,187	10.1
				293,630	290,853	584,483	
DEVONIAN - CENTRAL BASIN PLATFORM							
ANDREWS, S.	Andrews	1800	.0056	26,296	21,839	48,135	3.4
BLOCK 11	Andrews	1600	.0041	65,847	48,028	113,875	4.0
BLOCK 31	Crane	1810	.0056	142,372	354,519	496,891	7.0
CRAWAR	Crane	1550	.0049	5,760	3,483	9,243	7.5
CROSSETT	Crane	1450	.0047	30,898	20,791	51,689	6.4
CROSSETT, S.	Crockett	1510	.0052	58,386	49,237	107,623	3.7
DOLLARHIDE	Andrews	1500	.0052	109,545	34,179	143,724	8.6
DOLLARHIDE	Lea	1975	.0058	8,738	6,117	14,855	1.8
DOLLARHIDE, E.	Andrews	1750	.0048	9,766	2,660	12,426	6.0
FULLERTON 8500	Andrews	1810	.0056	145,618	212,171	357,789	4.9

TABLE 3 (con't.)

Field	County	Zone	Pore Volume MBbls	Est. Orig. Oil In Place MBbls	Rec. @ 30% Efficiency MBbls	Est. Avg. Oil Sat. (frac)	Sweep Efficiency (frac)	Displace. Factor	CO_2 Flood Oil Recovery MBbls	CO_2 Flood Oil Recovery frac OOIP	Total Oil Recovery MBbls	Total Oil Recovery frac OOIP
DEVONIAN - CENTRAL BASIN PLATFORM (con't.)												
GOLDSMITH, N.	Ector	Devonian	61,094	37,596	11,279	0.559	.47	2.9	10,731	0.285	22,010	0.585
HARPER	Ector	Devonian	146,713	90,285	27,086	0.560	.39	2.9	21,335	0.236	48,421	0.536
LEA	Lea	Devonian	90,042	51,947	15,584	0.524	.32	2.9	9,913	0.191	25,497	0.491
PECOS VALLEY	Pecos	Devonian	130,334	82,497	24,749	0.575	.41	3.1	21,492	0.261	46,241	0.561
THREE BAR	Andrews	Devonian	183,717	80,376	24,113	0.401*	.40	2.0	10,915	0.136	35,028	0.436
YARBOROUGH/ALLEN	Ector	Devonian	79,441	48,887	14,666	0.560	.375	2.9	11,101	0.227	25,767	0.527
				1,778,567	553,573				373,232		870,805	
SILURIAN - MIDLAND BASIN												
BIG SPRINGS	Howard	Fusselman	23,781	11,098	3,329	0.333*	.50	1.6	1,320	0.119	4,649	0.419
GOOD, S.E.	Borden	Fusselman	48,642	23,078	6,923	0.416*	.50	2.4	5,415	0.235	12,338	0.535
LUTHER, S.E.	Devonian	Silurian	88,673	38,080	11,424	0.362*	.50	1.8	5,056	0.133	16,480	0.433
				72,256	21,676				11,791		33,467	
SILURIAN - CENTRAL BASIN PLATFORM												
ARMER	Crane	Fusselman	15,193	8,681	2,604	0.439*	.48	1.9	1,312	0.151	3,916	0.451
DOLLARHIDE	Andrews	Fusselman	225,827	115,071	34,521	0.555*	.25	2.9	16,875	0.147	51,396	0.447
KEYSTONE	Winkler	Silurian	166,828	72,533	21,760	0.456*	.38	2.5	13,120	0.181	34,880	0.481
				196,285	58,885				30,107		90,192	
ORDOVICIAN - REAGAN UPLIFT												
BARNHART	Reagan	Ellenburger	185,894	114,396	34,319	0.559	.38	2.9	26,280	0.230	60,599	0.530
TODD DEEP	Crockett	Ellenburger	279,567	139,360	41,808	0.460	.28	2.9	22,429	0.161	64,237	0.461
				253,756	76,127				48,709		124,836	
ORDOVICIAN - MIDLAND BASIN												
DORA ROBERTS	Midland	Ellenburger	154,287	94,946	28,484	0.401*	.25	1.8	6,226	0.066	34,710	0.366
				94,946	28,484				6,226		34,710	
ORDOVICIAN - CENTRAL BASIN PLATFORM												
DOLLARHIDE	Andrews	Ellenburger	81,546	50,571	15,171	0.408*	.27	1.8	3,673	0.073	18,844	0.373
DOLLARHIDE	Lea	Ellenburger	22,501	13,846	4,154	0.559	.27	2.9	2,256	0.163	6,410	0.463
GOLDSMITH, W.	Ector	Ellenburger	13,964	8,056	2,417	0.409*	.35	2.3	704	0.087	3,121	0.387
				72,473	21,742				6,633		28,375	

* $\bar{S}_o$ calculated from 1/1/80 cum. production, greater than 30% ISTOIP

TABLE 3 (con't.)

Field	County	CO_2 Properties MMP psia	CO_2 Properties CO_2 Form. Vol. Fac.	Free CO_2 In Swept Zone MMcf	Solution CO_2 MMcf	Total CO_2 MMcf	CO_2/Oil Ratio Mcf/Bbl
DEVONIAN - CENTRAL BASIN PLATFORM (con't.)							
GOLDSMITH, N.	Ector	1775	.0048	26,871	18,633	45,504	4.2
HARPER	Ector	2000	.0064	40,160	50,148	90,308	4.2
LEA	Lea	2700	.0043	24,456	31,654	56,110	5.7
PECOS VALLEY	Pecos	1250	.0042	57,152	40,658	97,810	4.6
THREE BAR	Andrews	1610	.0041	60,384	31,214	91,598	8.4
YARBOROUGH/ALLEN	Ector	1810	.0056	20,909	27,697	48,606	4.4
				833,158	953,028	1,786,186	
SILURIAN - MIDLAND BASIN							
BIG SPRINGS	Howard	2075	.0050	8,012	3,483	11,495	8.7
GOOD, S.E.	Borden	2075	.0059	15,022	11,225	26,247	4.8
LUTHER, S.E.	Devonian	2100	.0050	29,873	15,201	45,074	8.9
				52,907	29,909	82,816	
SILURIAN - CENTRAL BASIN PLATFORM							
ARMER	Crane	1500	.0046	6,231	3,755	9,986	7.6
DOLLARHIDE	Andrews	1600	.0041	54,123	48,243	102,366	6.1
KEYSTONE	Winkler	1550	.0049	43,587	37,089	80,676	6.1
				103,941	89,087	193,028	
ORDOVICIAN - REAGAN UPLIFT							
BARNHART	Reagan	2000	.0064	43,382	64,390	107,772	4.1
TODD DEEP	Crockett	1675	.0041	60,034	76,871	136,905	6.1
				103,416	141,261	244,677	
ORDOVICIAN - MIDLAND BASIN							
DORA ROBERTS	Midland	2375	.0053	28,605	17,513	46,118	7.4
				28,605	17,513	46,118	
ORDOVICIAN - CENTRAL BASIN PLATFORM							
DOLLARHIDE	Andrews	1800	.0056	15,453	10,500	25,953	7.1
DOLLARHIDE	Lea	2110	.0050	4,776	6,360	11,136	4.9
GOLDSMITH, W.	Ector	2075	.0050	3,568	1,957	5,525	7.8
				23,797	18,817	42,614	

TABLE 4

PERMIAN BASIN RESERVOIRS FOR WHICH NO CALCULATIONS WERE PERFORMED

Field	County	Zone	Reason
PERMIAN GUADALUPE - CENTRAL BASIN PLATFORM			
EUNICE	Lea	San Andres	No data
MABEE	Andrews	San Andres	Cumulative production greater than calculated ISTOIP
HUNTLEY	Garza	3400	Cumulative production greater than calculated ISTOIP
HUNTLEY	Garza	Glorieta	Cumulative production greater than calculated ISTOIP
CAPROCK	Charles/Lea	Queen	Average oil saturation less than 0.20 at 1/1/80
PEARL	Lea	San Andres	Calculated ISTOIP only 1.5 million barrels
SQUARE LAKE	Eddy	San Andres	Cumulative production greater than calculated ISTOIP
PERMIAN WOLFCAMP - ANADARKO BASIN			
QUINDUNO	Roberts	Albany	Cumulative production greater than calculated ISTOIP
PERMIAN WOLFCAMP - NORTHWEST SHELF			
KEMITZ	Lea	Wolfcamp	Average oil saturation less than 0.20 at 1/1/80
PERMIAN WOLFCAMP - TATUM BASIN			
TOWNSEND	Lea	Wolfcamp	Average oil saturation less than 0.20 at 1/1/80
PERMIAN WOLFCAMP - MIDLAND BASIN			
FASKEN	Andrews	Wolfcamp	Cumulative production greater than calculated ISTOIP
WELLMAN	Terry	Wolfcamp	Average oil saturation less than 0.20 at 1/1/80
PERMIAN LEONARD - DELAWARE BASIN			
FOWLER	Lea	Upper Yeso	Average oil saturation less than 0.20 at 1/1/80
PERMIAN LEONARD - NORTHWEST SHELF			
EMPIRE	Eddy	Abo	Cumulative production greater than calculated ISTOIP
PENNSYLVANIAN CISCO - TATUM BASIN			
INBE	Lea	Cisco	Cumulative production greater than calculated ISTOIP
PENNSYLVANIAN DEVONIAN - TATUM BASIN			
CAPROCK, E.	Lea	Devonian	Cumulative production greater than calculated ISTOIP
PENNSYLVANIAN CANYON - EASTERN SHELF			
CLAYTONVILLE	Fisher	Canyon Reef	Cumulative production greater than calculated ISTOIP
COGDELL	Kent & Scurry	Canyon Reef	Average oil saturation less than 0.20 at 1/1/80
PENNSYLVANIAN STRAWN - MIDLAND BASIN			
AZALEA	Midland	Strawn	Inconsistent volumetrics
PENNSYLVANIAN CISCO - MIDLAND BASIN			
REINECKE	Borden	Cisco	Average oil saturation less than 0.20 at 1/1/80

TABLE 4 (con't.)

Field	County	Zone	Reason
PENNSYLVANIAN CANYON - MIDLAND BASIN			
VEALMOOR	Howard	Canyon Reef	Cumulative production greater than calculated ISTOIP
VEALMOOR, E.	Borden	Canyon Reef	Average oil saturation less than 0.20 at 1/1/80
PENNSYLVANIAN BEND - ANADARKO BASIN			
TWIN	Hansford	Des Moines	Cumulative production greater than calculated ISTOIP
DEVONIAN - NORTH BASIN			
RUSSELL, N.	Gaines	Devonian	Cumulative production greater than calculated ISTOIP
DEVONIAN - MIDLAND BASIN			
BREEDLOVE	Martin	Devonian	Average oil saturation less than 0.20 at 1/1/80
SILURIAN - MIDLAND BASIN			
TEX-HAMON	Dawson	Fusselman	Average oil saturation less than 0.20 at 1/1-80
ORDOVICIAN - REAGAN UPLIFT			
ELKHORN	Crockett	Ellenburger	Average oil saturation less than 0.20 at 1/1/80
ORDOVICIAN - CENTRAL BASIN PLATFORM			
JUSTIS	Lea	Ellenburger	Average oil saturation less than 0.20 at 1/1/80
LEA	Crane	Ellenburger	Inconsistent volumetrics
TXL	Ector	Ellenburger	Average oil saturation less than 0.20 at 1/1/80
YARBOROUGH & ALLEN	Ector	Ellenburger	Cumulative production greater than calculated ISTOIP

WILLISTON BASIN CALCULATIONS AND ESTIMATES

Geological and reservoir data compiled and reported earlier (3) for selected carbonate reservoirs in the Williston Basin of Montana, North and South Dakota were used to calculate estimates of incremental oil recoverable by carbon dioxide flooding along with related carbon dioxide requirements.

Basic data used for these calculations are summarized for reference on Table C-2 of Appendix C.

DATA AND ASSUMPTIONS USED IN CALCULATIONS

In common with the Permian Basin calculations presented above, it was assumed that pure carbon dioxide would be the injection fluid, allowing volumetric data and miscibility pressures to be estimated knowing reservoir temperature. Carbon dioxide solubility in the reservoir oil was considered in the calculations but solubility in reservoir water was not. One hundred percent recycling of produced carbon dioxide was also assumed.

As may be noted on Table C-2, cumulative production data for the Williston Basin reservoirs were available only through 1978. Test calculations made using average oil saturations based on these cumulative production figures generally resulted in optimistic incremental oil and CO_2/oil ratios. Hence, calculations assuming 30-percent recovery from present methods were considered more realistic. Assumptions regarding sweep postulated 50-percent lateral sweep of the most permeable layer with vertical sweep a function of thickness. The empirical function used, based on very limited data, is shown on Figure 3.

WILLISTON BASIN ESTIMATES OF INCREMENTAL OIL AND CARBON DIOXIDE REQUIREMENTS

The results of calculations for 68 selected carbonate reservoirs in the Williston Basin of Montana, North Dakota, and South Dakota are given on Table 5. Each reservoir entered in this table has information listed on two successive pages. The first page contains data and results of calculations of incremental oil recovery while the second page provides data and results of calculated carbon dioxide requirements. It may be noted that cumulative production from a number of reservoirs exceeded 30 percent of estimated original oil in place. Incremental oil calculations for these reservoirs used average oil saturation values calculated from Equation (3), using the cumulative production figures listed on Table C-2.

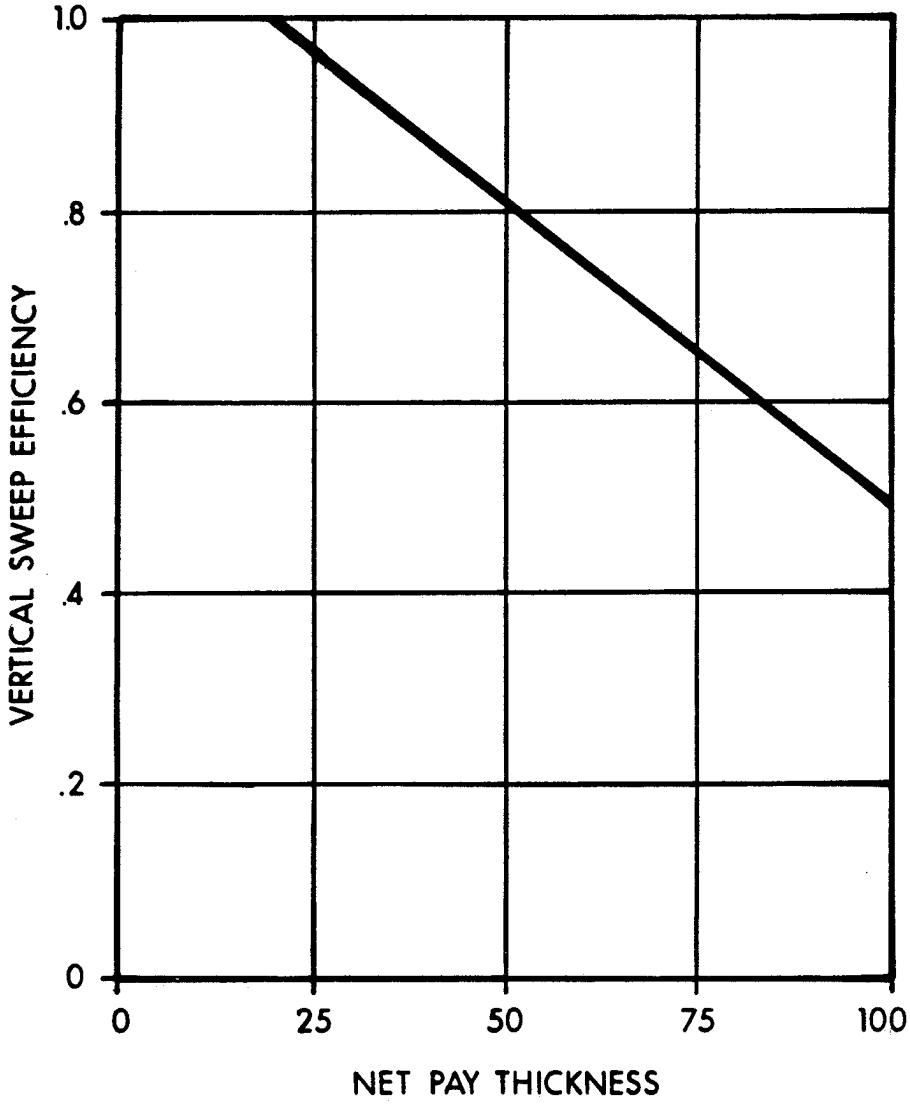

Figure 3 -- Estimated vertical sweep as function of net pay thickness - Williston Basin carbonate reservoirs.

DISCUSSION AND SUMMARY OF RESULTS

The calculations listed in detail on Table 5 may be summarized by states as follows:

State	No. Res.	Inc. Oil MMBbls	CO_2 Required BCF
Montana	36	357	2,107
North Dakota	31	403	2,285
South Dakota	1	6	23
Totals	68	766	4,415

These data show relatively equal potential for Montana and North Dakota reservoirs, with only a minor contribution from the one South Dakota reservoir.

Review of the data listed on Table C-2 of Appendix C showed a number of reservoirs in which the estimated original oil in place was less than 10 million barrels. It was decided that calculations for these reservoirs would not be cost effective in terms of time versus results because the likelihood of carbon dioxide flood projects being done in these small accumulations seemed remote. Hence, no calculations were performed for the 36 reservoirs listed on Table 6. It can be seen from Table 6 that these reservoirs had an aggregate original oil in place of 175 million barrels, or less than 5 percent of the total original oil in place for all reservoirs listed on Table C-2. We would expect the carbon dioxide flooding contribution from these reservoirs would be an even less percentage because of their individual small size.

TABLE 5

ESTIMATED CARBON DIOXIDE FLOODABLE OIL AND CARBON DIOXIDE REQUIREMENTS FOR SELECTED CARBONATE RESERVOIRS IN THE WILLISTON BASIN

MONTANA

Field	County	Zone	Pore Volume MBbls	Est. Orig. Oil In Place MBbls	Rec. @ 30% Efficiency MBbls	Est. Avg. Oil Sat. (frac)	Sweep Efficiency (frac)	Displace. Factor	CO_2 Flood Oil Recovery MBbls	CO_2 Flood Oil Recovery frac OOIP	Total Oil Recovery MBbls	Total Oil Recovery frac OOIP
PENNSYLVANIAN RESERVOIRS												
WOLF SPRINGS	Yellowstone	Amsden	18,023	12,970	3,891	0.50*	0.50	2.9	3,195	0.25	7,747	0.60
				12,970	3,891				3,195		7,747	
MISSISSIPPIAN RESERVOIRS												
BRORSON	Richland	Mis. Cany.	19,860	8,512	2,553	0.42	0.44	2.8	2,125	0.25	4,678	0.55
CABIN CREEK	Fallon	Madison	48,216	25,601	7,680	0.27*	0.48	2.1	2,217	0.09	16,224	0.63
DWYER	Sheridan	Ratcliffe	145,279	48,427	14,528	0.31	0.44	2.6	11,041	0.23	25,569	0.53
FLAT LAKE	Sheridan	Ratcliffe	156,401	68,270	20,481	0.38	0.50	2.7	18,768	0.27	39,249	0.57
GOOSE LAKE	Sheridan	Ratcliffe	341,600	128,100	38,430	0.32	0.44	2.6	29,719	0.23	68,149	0.53
MONDAK WEST	Richland	Madison	297,907	91,664	27,499	0.28	0.25	2.5	11,320	0.12	38,819	0.42
POPLAR, EAST	Roosevelt	Charles	385,514	210,281	63,084	0.42	0.48	2.1	43,949	0.21	107,033	0.51
VAUX	Richland	Mis. Cany.	17,874	8,193	2,457	0.38	0.44	2.7	2,002	0.24	4,459	0.54
				589,048	176,712				119,141		304,180	
SILURIAN-DEVONIAN RESERVOIRS												
OUTLOOK	Sheridan	Sil.-Dev.	19,860	12,413	3,723	0.49	0.50	2.9	3,634	0.29	7,357	0.59
RAYMOND	Sheridan	Nisku	8,738	3,121	936	0.35	0.49	2.7	821	0.26	1,757	0.56
RAYMOND	Sheridan	Winnipeg.	14,895	11,458	3,437	0.63	0.44	3.0	3,038	0.26	6,475	0.57
RICHEY, S.W.	McCone	Interlake	21,868	11,174	3,352	0.49	0.47	2.9	3,062	0.27	6,414	0.57
TULE CREEK	Roosevelt	Nisku	37,238	18,487	5,546	0.46*	0.48	2.9	3,304	0.18	10,567	0.57
				56,653	16,994				13,859		32,570	
ORDOVICIAN RESERVOIRS												
BRORSON	Richland	Red River	14,895	5,695	1,708	0.43*	0.50	2.8	1,420	0.25	3,364	0.59
BRORSON, S.	Richland	Red River	17,874	6,309	1,892	0.42	0.50	2.1	1,430	0.23	3,322	0.53
BRUSH LAKE	Sheridan	Red River	72,987	31,628	9,488	0.46	0.47	2.8	8,539	0.27	18,037	0.57
CABIN CREEK	Fallon	Red River	384,254	224,148	67,244	0.49	0.41	2.9	53,027	0.24	120,271	0.54
CLEAR LAKE	Sheridan	Red River	85,797	33,799	10,139	0.46	0.46	2.8	8,923	0.26	19,062	0.56
CUPTON	Fallon	Red River	65,540	36,702	11,010	0.49	0.44	2.9	9,922	0.27	20,932	0.57
FAIRVIEW	Richland	Red River	57,347	24,288	7,286	0.50	0.45	2.9	6,308	0.26	13,594	0.56
GLENDIVE	Dawson	Red River	116,780	60,725	18,217	0.46	0.18	2.8	5,839	0.10	24,056	0.40
HAY CREEK	Richland	Red River	47,367	18,698	5,609	0.53	0.40	2.9	4,358	0.23	9,967	0.53
LITTLE BEAVER	Fallon	Red River	83,325	38,222	11,466	0.45	0.44	2.7	9,416	0.25	20,882	0.55
LITTLE BEAVER, E.	Fallon	Red River	38,728	16,782	5,034	0.42	0.49	2.4	4,183	0.25	9,217	0.55
LOOKOUT BUTTE	Fallon	Interlake	106,479	69,443	20,832	0.53	0.50	2.9	20,550	0.30	41,382	0.60
MEDICINE LAKE	Sheridan	Red River	67,526	26,176	7,852	0.48	0.46	2.9	6,955	0.27	14,807	0.57
MONDAK WEST	Richland	Red River	67,029	23,297	6,989	0.40	0.42	2.7	5,429	0.23	12,418	0.53
OTIS CREEK	Richland	Red River	27,407	10,122	3,036	0.46	0.48	2.8	2,796	0.28	5,832	0.58

*$\bar{S}_o$ calculated from cum. prod. thru 1978, greater than 30% ISTOIP

TABLE 5 (con't.)

MONTANA

Field	County	CO_2 Properties MMP psia	CO_2 Properties CO_2 Form. Vol. Fac.	Free CO_2 In Swept Zone MMcf	Solution CO_2 MMcf	Total CO_2 MMcf	CO_2/Oil Ratio Mcf/Bbl
PENNSYLVANIAN RESERVOIRS							
WOLF SPRINGS	Yellowstone	2000	.0043	7,882	7,407	15,289	4.8
				7,882	7,407	15,289	
MISSISSIPPIAN RESERVOIRS							
BRORSON	Richland	2950	.0042	5,840	6,095	11,935	5.6
CABIN CREEK	Fallon	2300	.0042	18,561	9,907	28,468	12.8
DWYER	Sheridan	2450	.0044	27,730	40,778	68,508	6.2
FLAT LAKE	Sheridan	2075	.0043	45,943	47,026	92,969	4.9
GOOSE LAKE	Sheridan	2200	.0043	68,681	104,676	173,357	5.8
MONDAK WEST	Richland	2850	.0044	28,507	96,590	125,097	11.1
POPLAR, EAST	Roosevelt	2075	.0043	144,956	150,951	295,907	6.7
VAUX	Richland	2800	.0041	4,845	6,013	10,858	5.4
				345,063	462,036	807,099	
SILURIAN-DEVONIAN RESERVOIRS							
OUTLOOK	Sheridan	2600	.0043	7,778	7,054	14,832	4.1
RAYMOND	Sheridan	2350	.0044	2,731	2,336	5,067	6.2
RAYMOND	Sheridan	2650	.0043	6,845	5,554	12,399	4.1
RICHEY, S.W.	McCone	2650	.0043	8,051	7,093	15,144	4.9
TULE CREEK	Roosevelt	2550	.0042	14,335	11,701	26,036	7.9
				39,740	33,738	73,478	
ORDOVICIAN RESERVOIRS							
BRORSON	Richland	3650	.0042	5,475	3,713	9,188	6.5
BRORSON, S.	Richland	3650	.0042	7,167	4,591	11,758	8.2
BRUSH LAKE	Sheridan	3100	.0041	25,834	21,093	46,927	5.5
CABIN CREEK	Fallon	2550	.0042	126,350	133,116	259,466	4.9
CLEAR LAKE	Sheridan	3050	.0042	29,014	23,103	52,117	5.8
CUPTON	Fallon	2850	.0044	22,076	24,077	46,153	4.7
FAIRVIEW	Richland	3700	.0042	21,386	15,923	37,309	5.9
GLENDIVE	Dawson	2750	.0042	15,453	37,839	53,292	9.1
HAY CREEK	Richland	3050	.0042	16,461	10,944	27,405	6.3
LITTLE BEAVER	Fallon	2450	.0044	25,728	18,781	44,509	4.7
LITTLE BEAVER, EAST	Fallon	2550	.0042	13,951	9,686	23,637	5.7
LOOKOUT BUTTE	Fallon	2700	.0045	43,172	35,060	78,232	3.8
MEDICINE LAKE	Sheridan	3150	.0041	25,093	14,585	39,678	5.7
MONDAK WEST	Richland	3600	.0042	17,686	14,240	31,926	5.9
OTIS CREEK	Richland	3700	.0042	9,671	5,614	15,285	5.5

TABLE 5 (con't.)

Field	County	Zone	Pore Volume MBbls	Est. Orig. Oil In Place MBbls	Rec. @ 30% Efficiency MBbls	Est. Avg. Oil Sat. (frac)	Sweep Efficiency (frac)	Displace. Factor	CO_2 Flood Oil Recovery MBbls	CO_2 Flood Oil Recovery frac OOIP	Total Oil Recovery MBbls	Total Oil Recovery frac OOIP
ORDOVICIAN RESERVOIRS (con't)												
PINE	Fallon	Interlake	396,812	237,409	71,222	0.43*	0.46	2.8	43,246	0.18	133,212	0.56
RAYMOND	Sheridan	Red River	19,662	10,108	3,032	0.51	0.46	2.9	2,716	0.27	5,748	0.57
SIOUX PASS	Richland	Red River	62,561	23,920	7,176	0.45	0.44	2.8	6,006	0.25	13,182	0.55
SIOUX PASS MID.	Richland	Red River	33,763	18,087	5,426	0.52	0.50	2.9	5,301	0.29	10,727	0.59
SIOUX PASS N.	Richland	Sil-Ordo.	117,971	40,553	12,165	0.39	0.43	2.8	9,556	0.24	21,721	0.54
SUNNY HILL	Sheridan	Red River	31,653	11,468	3,440	0.35	0.49	2.7	223	0.02	3,663	0.32
VAUX	Richland	Red River	50,048	17,204	5,161	0.39	0.49	2.7	4,654	0.27	9,815	0.57
				984,783	295,424				220,799		535,211	
NORTH DAKOTA												
MISSISSIPPIAN RESERVOIRS												
ANTELOPE	McKenzie	Madison	101,629	40,414	12,124	0.45*	0.35	2.5	6,743	0.17	20,613	0.51
BEAVER LODGE	Williams	Madison	656,543	177,942	53,382	0.41	0.35	2.8	36,766	0.21	90,248	0.51
BLACK SLOUGH	Burke	Madison	97,527	42,833	12,849	0.46	0.50	2.8	12,679	0.30	25,528	0.60
BLUE BUTTES	McKenzie	Madison	136,199	44,643	13,392	0.28*	0.50	1.6	4,903	0.11	28,504	0.64
CAPA	Williams	Madison	272,942	701047	21,014	0.41	0.40	2.8	16,376	0.23	37,390	0.53
CHARLSON	McKenzie	Madison	410,988	121,700	36,510	0.43	0.32	2.8	23,673	0.19	60,183	0.49
FRYBURG	Billings	Madison	114,794	33,290	9,987	0.41	0.50	2.7	9,757	0.29	19,744	0.59
GLENBURN	Renville	Madison	75,159	46,088	13,826	0.46	0.50	2.8	13,152	0.29	26,978	0.59
HAAS	Bottineau	Madison	34,557	16,500	4,950	0.37	0.50	2.7	4,492	0.27	9,442	0.57
HAWKEYE	McKenzie	Madison	130,483	47,608	14,282	0.51	0.45	2.8	12,917	0.27	27,199	0.57
HOFFLAND	Williams	Madison	53,625	16,113	4,833	0.44	0.45	2.8	4,343	0.27	9,176	0.57
LIGNITE	Burke	Madison	84,904	43,318	12,995	0.53	0.50	2.9	13,160	0.30	26,155	0.60
LITTLE KNIFE	Billings	Madison	465,480	156,903	47,070	0.42	0.48	2.8	44,686	0.28	91,756	0.58
MEDORA	Billings	Madison	139,023	44,488	13,346	0.39	0.50	2.7	11,817	0.27	25,163	0.57
NEWBURG	Bottineau	Spearfish	189,915	71,763	21,528	0.33	0.50	2.6	19,941	0.28	41,469	0.58
NORTH TIOGA	Burke	Madison	185,509	78,279	23,483	0.51	0.50	2.9	22,261	0.28	45,744	0.58
NORTH WESTHOPE	Bottineau	Madison	39,566	21,432	6,429	0.46	0.47	2.8	5,737	0.27	12,166	0.57
RIVAL	Burke	Madison	106,174	47,115	14,134	0.50	0.50	2.9	13,802	0.29	27,936	0.59
ROUGH RIDER	McKenzie	Madison	33,514	12,959	3,887	0.46	0.47	2.9	3,451	0.27	7,338	0.57
SHERWOOD	Renville	Madison	23,832	19,215	5,764	0.32*	0.48	3.0	2,526	0.13	15,375	0.80
TIOGA	Williams	Madison	583,402	194,173	58,251	0.46	0.44	2.8	46,088	0.24	104,339	0.54
WHITE EARTH	Montrail	Madison	69,511	25,819	7,745	0.46	0.50	2.8	7,298	0.28	15,043	0.58
				1,372,642	407,431				336,568		767,389	
DEVONIAN RESERVOIRS												
ANTELOPE	McKenzie	Duperow	49,651	23,052	6,915	0.46	0.40	2.8	5,560	0.24	12,475	0.54
ANTELOPE	McKenzie	Sanish	71,917	33,390	10,017	0.45*	0.50	2.8	8,989	0.27	19,355	0.58
BEAVER LODGE	Williams	Duperow	162,062	75,243	22,572	0.37*	0.50	2.0	11,992	0.16	44,699	0.56
CAMEL BUTTE	McKenzie	Duperow	23,833	12,172	3,651	0.50	0.46	3.7	3,670	0.30	7,321	0.60
				143,857	43,155				30,211		83,850	

*$\bar{S}_o$ = calculated from cum. prod. thru 1978, greater than 30% ISTOIP

TABLE 5 (con't.)

Field	County	CO_2 Properties MMP psia	CO_2 Properties CO_2 Form. Vol. Fac.	Free CO_2 In Swept Zone MMcf	Solution CO_2 MMcf	Total CO_2 MMcf	CO_2/Oil Ratio Mcf/Bbl
ORDOVICIAN RESERVOIRS (con't)							
PINE	Fallon	2400	.0044	139,737	128,584	268,321	6.2
RAYMOND	Sheridan	2800	.0042	7,621	5,463	13,084	4.8
SIOUX PASS	Richland	3700	.0042	20,236	13,833	34,069	5.7
SIOUX PASS MIDDLE	Richland	3650	.0042	14,667	9,183	23,850	4.5
SIOUX PASS, N.	Richland	3550	.0042	30,512	24,773	55,285	5.8
SUNNY HILL	Sheridan	3250	.0042	8,292	6,758	15,050	67.5
VAUX	Richland	3650	.0042	14,750	9,959	24,709	5.3
				640,332	570,918	1,211,250	
NORTH DAKOTA							
MISSISSIPPIAN RESERVOIRS							
ANTELOPE	McKenzie	3100	.0041	28,248	21,186	49,434	7.3
BEAVER LODGE	Williams	2850	.0044	140,732	98,153	238,885	6.5
BLACK SLOUGH	Burke	1850	.0042	35,849	21,163	57,012	4.5
BLUE BUTTES	McKenzie	3100	.0041	45,691	17,067	62,758	12.8
CAPA	Williams	2850	.0044	63,864	44,759	108,623	6.6
CARLSON	McKenzie	3000	.0043	[illegible]	72,457	160,026	6.8
FRYBURG	Billings	3100	.0041	37,724	17,816	55,540	5.7
GLENBURN	Renville	1700	.0041	28,301	24,129	52,430	4.0
HAAS	Bottineau	1500	.0044	9,479	9,233	18,712	4.2
HAWKEYE	McKenzie	3100	.0041	51,455	28,352	79,807	6.2
HOFFLAND	Williams	3000	.0044	16,164	9,440	25,604	5.9
LIGNITE	Burke	2200	.0042	36,883	22,081	58,964	4.5
LITTLE KNIFE	Billings	3100	.0041	152,968	86,695	239,663	5.4
MEDORA	Billings	3100	.0041	43,782	25,529	69,311	5.9
NEWBURG	Bottineau	1350	.0042	46,962	42,794	89,756	4.5
NORTH TIOGA	Burke	2750	.0042	58,435	40,679	99,114	4.5
NORTH WESTHOPE	Bottineau	1350	.0042	10,227	11,715	21,942	3.8
RIVAL	Burke	2200	.0043	32,383	24,575	56,958	4.1
ROUGH RIDER	McKenzie	2850	.0044	11,053	7,251	18,304	5.3
SHERWOOD	Renville	1700	.0041	5,168	5,275	10,443	4.1
TIOGA	Williams	2700	.0042	192,146	113,179	305,325	6.6
WHITE EARTH	Montrail	2650	.0043	19,115	13,984	33,099	4.5
				1,154,198	757,512	1,911,710	
DEVONIAN RESERVOIRS							
ANTELOPE	McKenzie	3400	.0041	14,956	13,703	28,659	5.2
ANTELOPE	McKenzie	3250	.0042	26,435	17,763	44,198	4.9
BEAVER LODGE	Williams	3200	.0041	61,024	38,732	99,756	8.3
CAMEL BUTTE	McKenzie	3400	.0041	8,256	6,172	14,428	3.9
				110,671	76,370	187,041	

TABLE 5 (con't.)

Field	County	Zone	Pore Volume MBbls	Est. Orig. Oil In Place MBbls	Rec. @ 30% Efficiency MBbls	Est. Avg. Oil Sat. (frac)	Sweep Efficiency (frac)	Displace. Factor	CO_2 Flood Oil Recovery MBbls	CO_2 Flood Oil Recovery frac OOIP	Total Oil Recovery MBbls	Total Oil Recovery frac OOIP
SILURIAN RESERVOIRS												
ANTELOPE	McKenzie	Interlake	11,730	5,446	1,633	0.25*	0.50	1.4	410	0.08	3,745	0.69
BEAVER LODGE	Williams	Silurian	125,657	58,341	17,502	0.46	0.44	2.8	14,450	0.25	31,952	0.55
				63,787	19,135				14,860		35,697	
ORDOVICIAN RESERVOIRS												
BEAVER LODGE	Williams	Red River	38,132	22,334	6,700	0.57	0.41	2.9	5,453	0.24	12,153	0.54
CEDAR CREEK	Bowman	Red River	63,321	36,437	10,931	0.48	0.40	2.8	7,852	0.22	18,783	0.52
ELEVEN BAR	Slope	Red River	67,525	31,351	9,405	0.46	0.45	3.2	8,171	0.26	17,576	0.56
				90,122	27,036				21,476		48,512	
SOUTH DAKOTA												
ORDOVICIAN RESERVOIRS												
BUFFALO	Harding	Red River	50,733	21,136	6,340	0.35	0.50	4.4	6,037	0.29	12,377	0.59
				21,136	6,340				6,037		12,377	

* $\bar{S}_o$ calculated from cum. prod. thru 1978, greater than 30% ISTOIP

TABLE 5 (con't.)

Field	County	CO_2 Properties MMP psia	CO_2 Properties CO_2 Form. Vol. Fac.	Free CO_2 In Swept Zone MMcf	Solution CO_2 MMcf	Total CO_2 MMcf	CO_2/Oil Ratio Mcf/Bbl
SILURIAN RESERVOIRS							
ANTELOPE	McKenzie	3500	.0042	4,311	1,454	5,765	14.1
BEAVER LODGE	Williams	3400	.0041	41,638	30,534	72,172	5.0
				45,949	31,988	77,937	
ORDOVICIAN RESERVOIRS							
BEAVER LODGE	Williams	2500	.0043	14,696	12,782	27,478	5.0
CEDAR CREEK	Bowman	2550	.0042	19,249	21,149	40,398	5.1
ELEVEN BAR	Slope	2550	.0042	22,384	17,691	40,075	4.9
				56,329	51,622	107,951	
SOUTH DAKOTA							
ORDOVICIAN RESERVOIRS							
BUFFALO	Harding	2300	.0042	13,562	9,385	22,947	3.8
				13,562	9,385	22,947	

TABLE 6

WILLISTON BASIN FIELDS CONTAINING LESS THAN 10 MILLION BARRELS ORIGINAL OIL IN PLACE

Field	County	Zone	Est. Orig. Oil In Place MBbls
		MONTANA	
RICHEY	McCone et al	Charles	5,494
VOLT	Roosevelt	Nisku	8,689
BAINVILLE, N.	Roosevelt	Winnipegosis	9,123
BIG MUDDY CREEK	Roosevelt	Red River	5,690
BLUE HILL	Richland	Red River	4,708
BURNS CREEK	Dawson	Red River	4,671
CRANE	Richland	Red River	5,055
CULBERTSON	Roosevelt	Red River	5,561
DAGMAR	Sheridan	Red River	6,885
DEER CREEK	Dawson	Interlake	5,778
ENID, N.	Richland	Red River	1,049
FERTILE PRAIRIE	Fallon	Red River	2,220
FOUR MILE CREEK, W.	Richland	Red River	4,469
LONE BUTTE	Richland	Red River	3,149
NOHLY	Richland	Red River	5,208
RESERVE	Sheridan	Red River	5,775
SAND CREEK	Dawson	Red River	7,877
SECOND CREEK	Richland	Red River	8,341
SPRING LAKE	Richland	Red River	1,609
		Sub Total	101,351
		NORTH DAKOTA	
DIMMICK LAKE	McKenzie	Madison	5,243
EAST TIOGA	Montrail	Madison	3,972
ELMORE	Renville	Madison	6,517
KUROKI	Bottineau	Madison	5,499
McGREGOR	Williams	Madison	7,607
NOONAN	Divide	Madison	3,296
N.E. FOOTHILLS	Burke	Madison	6,951
N.E. LANDA	Bottineau	Madison	4,066
NORTH SOURIS	Bottineau	Madison	2,246
N.W. McGREGOR	Williams	Madison	3,754
PERSHING	McKenzie	Madison	3,575
SCOTIA	Bottineau	Madison	1,510
STARBUCK	Bottineau	Spearfish	4,962
S. ANTLER CREEK	Bottineau	Madison	8,866
S. STARBUCK	Bottineau	Madison	938
NORTH FORK	McKenzie	Duperow	2,582
BUFFALO CREEK	Stork	Red River	2,098
		Sub Total	73,682
		Grand Total	175,033

ROCKY MOUNTAIN BASINS CALCULATIONS AND ESTIMATES

Geological and reservoir data compiled and reported earlier (3) for a total of 38 carbonate reservoirs in several intermontane basins of the Rocky Mountains. These data, listed for reference on Table C-3 of Appendix C, were used to calculate estimates of carbon dioxide flood incremental oil and related carbon dioxide requirements for selected reservoirs on this listing.

DATA AND ASSUMPTIONS USED IN CALCULATIONS

Assumptions similar to those employed for the Permian and Williston Basin calculations were used in the Rocky Mountain Basins calculations. In summary, these assumptions are:

Average oil saturation:	after 30-percent recovery
Injectant:	pure CO_2
Pressure:	minimum miscibility
Lateral sweep:	50 percent
Vertical sweep:	Figure 3 (Williston Basin)
Recycling:	100 percent

It may be noted that the empirical curve portraying vertical sweep as a function of thickness developed (from very limited data) for the Williston Basin was also used in these calculations.

DISCUSSION AND SUMMARY OF RESULTS

Results of calculations for 23 reservoirs of the 38 listed on Table C-3 are shown on Table 7. The first page of this table shows data and calculations of incremental oil recovery while the second (following) page provides calculated carbon dioxide requirements. These results can be summarized as follows:

State	No. Res.	Inc. Oil MMBbls	CO_2 Required BCF
Montana	4	115	389
Colorado	2	10	49
Utah	10	290	1,425
Wyoming	7	83	465
Totals	23	498	2,328

It can be seen that the Paradox Basin reservoirs in Utah represent 58 percent of the total calculated incremental oil.

Calculations were not performed for 15 of the reservoirs listed on Table C-3 because of either small size or inconsistencies in available volumetric data. These reservoirs and the reasons why calculations were not performed are shown on Table 8.

TABLE 7

ESTIMATED CARBON DIOXIDE FLOODABLE OIL AND CARBON DIOXIDE REQUIREMENTS FOR SELECTED CARBONATE RESERVOIRS IN THE ROCKY MOUNTAIN BASINS ASSUMING 30 PERCENT RECOVERY BY PRESENT PRACTICES

Field	County	Zone	Pore Volume MBbls	Est. Orig. Oil In Place MBbls	Rec. @ 30% Efficiency MBbls	Est. Avg. Oil Sat. (frac)	Sweep Efficiency (frac)	Displace. Factor	CO_2 Flood Oil Recovery MBbls	CO_2 Flood Oil Recovery frac OOIP	Total Oil Recovery MBbls	Total Oil Recovery frac OOIP
MONTANA - SWEETGRASS ARCH - MISSISSIPPIAN												
CUT BANK		Madison	34,755	22,110	6,633	0.484	0.50	2.8	6,380	0.288	13,013	0.588
KEVIN-SUNBURST		Madison	436,620	262,780	78,834	0.547	0.50	4.3	90,686	0.345	169,520	0.645
PONDERA	Pondera/Teta	Madison	103,522	59,846	17,934	0.445	0.50	2.7	13,456	0.225	31,390	0.525
REAGAN	Glacier	Madison	26,625	16,943	5,083	0.467	0.50	2.6	4,111	0.243	9,194	0.543
				361,679	108,484				114,633		223,117	
COLORADO - PARADOX BASIN - PENNSYLVANIAN												
CACHE	Montezuma	Ismay	47,829	22,206	6,662	0.454	0.375	2.8	4,844	0.218	11,506	0.518
FLODINE PARK	Montezuma	Ismay	50,383	21,233	6,370	0.413	0.425	2.8	5,197	0.245	11,567	0.545
				43,439	13,032				10,041		23,073	
UTAH - PARADOX BASIN - PENNSYLVANIAN												
GREATER ANETH	Desert Creek	Ismay	635,597	363,525	109,057	0.540	0.41	2.9	90,274	0.248	199,331	0.548
ANETH-McELMO	San Juan	Ismay	637,397	331,446	99,434	0.545	0.35	2.9	69,395	0.209	168,829	0.509
ANETH-RATHERFORD	San Juan	Desert Cr.	550,430	305,794	91,738	0.524	0.39	2.9	71,310	0.233	163,048	0.533
ANETH-WHITE MESA	San Juan	Desert Cr.	157,295	83,890	25,167	0.503	0.415	2.9	20,700	0.247	45,867	0.547
ISMAY	San Juan	Ismay	56,956	24,891	7,467	0.373	0.48	2.3	5,019	0.202	12,486	0.502
McELMO MESA	San Juan	Ismay	50,395	22,678	6,803	0.410	0.47	2.4	5,517	0.243	12,320	0.543
TOHONALDA	San Juan	Akah	23,274	11,637	3,491	0.455	0.48	2.4	2,962	0.254	6,453	0.554
TOHONALDA	San Juan	Desert Cr.	6,982	3,840	1,152	0.424	0.50	1.9	588	0.153	1,740	0.453
TOHONALDA	San Juan	Honaker	23,274	12,401	3,720	0.522	0.48	2.9	3,555	0.287	7,275	0.587
				1,160,102	348,029				269,320		617,349	
UTAH - PARADOX BASIN - MISSISSIPPIAN												
LISBON	San Juan	Redwall Lm.	491,546	214,174	64,252	0.396	0.20	2.4	21,175	0.099	85,427	0.399
				214,174	64,252				21,175		85,427	
WYOMING - BIG HORN BASIN - PERMIAN												
COTTONWOOD CREEK	Washakie	Phosphoria	406,803	203,401	61,020	0.490	0.39	2.9	47,119	0.232	108,139	0.532
LAKE CREEK	Hot Springs	Phosphoria	43,693	21,846	6,554	0.425	0.41	2.2	3,519	0.161	10,073	0.461
MANDERSON	Big Horn	Phosphoria	124,038	62,490	18,747	0.490	0.41	2.9	15,115	0.242	33,862	0.542
SLICK CREEK	Washakie	Phosphoria	46,473	23,236	6,971	0.490	0.48	2.9	6,638	0.285	13,609	0.585
TORCHLIGHT	Big Horn	Phosphoria	44,686	22,343	6,703	0.256	0.45	1.4	2,617	0.117	9,320	0.417
				333,316	99,995				75,008		175,003	
WYOMING - WIND RIVER BASIN - PERMIAN												
CIRCLE RIDGE	Fremont	Phosphoria	62,064	31,032	9,309	0.229	0.40	1.3	2,800	0.909	12,109	0.390
				31,032	9,309				2,800		12,109	
WYOMING - GREAT DIVIDE BASIN - MISSISSIPPIAN												
LOST SOLDIER	Sweetwater	Madison	250,279	136,516	40,995	0.420	0.21	1.4	5,583	0.041	46,538	0.341
				136,516	40,995				5,583		46,538	

TABLE 7 (con't.)

Field	County	CO_2 Properties MMP psia	CO_2 Properties CO_2 Form. Vol. Fac.	Free CO_2 In Swept Zone MMcf	Solution CO_2 MMcf	Total CO_2 MMcf	CO_2/Oil Ratio Mcf/Bbl
MONTANA - SWEETGRASS ARCH - MISSISSIPPIAN							
CUT BANK		1500	.0045	13,010	10,693	23,703	3.7
KEVIN-SUNBURST	Toole	1000	.0035	192,627	93,029	285,656	3.1
PONDERA	Pondera/Teta	1100	.0047	36,484	26,180	62,664	4.7
REAGAN	Glacier	1600	.0045	9,966	7,500	17,466	4.2
				252,087	137,402	389,489	
COLORADO - PARADOX BASIN - PENNSYLVANIAN							
CACHE	Montezuma	1700	.0047	11,785	12,798	24,583	5.1
FLODINE PARK	Montezuma	1700	.0047	12,534	11,598	24,132	4.6
				24,319	24,396	48,715	
UTAH - PARADOX BASIN - PENNSYLVANIAN							
GREATER ANETH	Desert Creek	1700	.0047	208,589	196,757	405,346	4.5
ANETH-McELMO	San Juan	1700	.0047	181,233	194,630	375,863	5.4
ANETH-RATHERFORD	San Juan	1700	.0047	166,699	170,805	337,504	4.7
ANETH-WHITE MESA	San Juan	1700	.0047	48,351	45,487	93,838	4.5
ISMAY	San Juan	1700	.0047	16,004	12,185	28,189	5.6
McELMO MESA	San Juan	1700	.0047	14,997	12,451	27,448	5.0
TOHONALDA	San Juan	1700	.0047	8,008	6,219	14,227	2.6
TOHONALDA	San Juan	1675	.0047	2,794	1,734	4,528	7.7
TOHONALDA	San Juan	1675	.0047	8,675	6,147	14,822	4.2
				655,350	646,415	1,301,765	
UTAH - PARADOX BASIN - MISSISSIPPIAN							
LISBON	San Juan	2100	.0045	62,560	60,834	123,394	5.8
				62,560	60,834	123,394	
WYOMING - BIG HORN BASIN - PERMIAN							
COTTONWOOD CREEK	Washakie	2450	.0044	121,478	114,313	235,791	5.0
LAKE CREEK	Hot Springs	1550	.0045	13,412	10,003	23,415	6.7
MANDERSON	Big Horn	2150	.0045	38,074	33,957	72,031	4.8
SLICK CREEK	Washakie	2850	.0044	17,080	11,546	28,626	4.3
TORCHLIGHT	Big Horn	1300	.0045	15,055	4,221	19,276	7.4
				205,099	174,040	379,139	
WYOMING - WIND RIVER BASIN - PERMIAN							
CIRCLE RIDGE	Fremont	1000	.0035	23,896	3,605	27,501	9.8
				23,896	3,605	27,501	
WYOMING - GREAT DIVIDE BASIN - MISSISSIPPIAN							
LOST SOLDIER	Sweetwater	2075	.0043	41,179	17,236	58,415	10.5
				41,179	17,236	58,415	

TABLE 8

ROCKY MOUNTAIN BASIN RESERVOIRS FOR WHICH NO CALCULATIONS WERE MADE

Field	State	County	Zone	Reason
MARBLE WASH	Colorado	Montezuma	Ismay	ISTOIP less than 10 MMBbl
TOWACO	Colorado	Montezuma	Ismay	ISTOIP less than 10 MMBbl
TOCITO DOME	New Mexico	San Juan	Hermosa	Avg. oil saturation less than 0.20
LONG CANYON	Utah	Grand	Cane Creek	ISTOIP less than 10 MMBbl
SALT WASH	Utah	Grand	Leadville	ISTOIP less than 10 MMBbl
PINEVIEW	Utah	Summit	Twin Creek	ISTOIP less than 10 MMBbl
ASHLEY VALLEY	Utah	Uintah	Phosphoria	Cumulative prod. greater than ISTOIP
FRISBY, S.	Wyoming	Washakie	Phosphoria	ISTOIP less than 10 MMBbl
GEBO	Wyoming	Hot Springs	Phosphoria	Avg. oil saturation less than 0.20
BIG SAND DRAW	Wyoming	Fremont	Phosphoria	Cumulative prod. greater than ISTOIP
STEAMBOAT BUTTE	Wyoming	Fremont	Phosphoria	Cumulative prod. greater than ISTOIP
BEAVER CREEK	Wyoming	Fremont	Madison	Cumulative prod. greater than ISTOIP
CIRCLE RIDGE	Wyoming	Fremont	Madison	Cumulative prod. greater than ISTOIP
MULE CREEK	Wyoming	Niobrara	Miss.	ISTOIP less than 10 MMBbl
WERTZ	Wyoming	Carbon et al	Madison	Avg. oil saturation less than 0.20

CONCLUSIONS AND RECOMMENDATIONS

A mathematical model based on simple volumetric concepts has been developed and presented in this report which, in principle, can be used to calculate carbon dioxide flood incremental oil recovery and related carbon dioxide supply requirements.

The model consists of two algebraic equations that can be solved with hand calculators or may easily be programmed for computer solution. In application, it has proved difficult to achieve a high level of confidence in the practicality of calculations made using the equations because many of the important variables, especially average oil saturation and overall sweep efficiency, proved difficult to evaluate from available data.

As part of the work required for this report, calculations were made for a total of 279 reservoirs in the Permian, Williston, and several smaller Rocky Mountain Basins. The results of these calculations are compiled on Table 9. In summary, these results show:

Basin	No. Res.	ISTOIP MMBbls	Inc. Oil From CO_2 MMBbls	CO_2 Req. BCF	Avg. CO_2/ Oil Ratio Mcf/Bbl
Permian	188	56,526	10,557	57,157	5.4
Williston	68	3,336	767	4,415	5.7
Rocky Mountain	23	2,279	498	2,328	4.7
Totals	279	62,141	11,822	63,900	5.4

It is obvious that the carbonate reservoirs of the Permian Basin constitute an order of magnitude larger target for carbon dioxide flooding than do all the carbonate reservoirs of the Williston and Rocky Mountain intermontane basins combined.

Calculations were not performed for 31 reservoirs in the Permian Basin, 36 reservoirs in the Williston Basin, and 15 reservoirs in the Rocky Mountain Basins. A number of these reservoirs, especially in the Williston Basin, were considered too small (less than 10 million barrels original oil in place) to justify performing the calculations. Calculations were not performed on other reservoirs because volumetric data discrepancies (for example: cumulative production greater than calculated oil in place) prevented sensible results from being achieved. We suspect, but cannot identify, that significant discrepancies may be contained in data for some of the other fields for which calculations were performed.

Review of the calculated data indicates that the results reported here are probably optimistic both in terms of incremental oil volumes and of carbon dioxide supply requirements.

TABLE 9

SUMMARY OF POTENTIAL INCREMENTAL OIL AND CARBON DIOXIDE REQUIREMENTS FOR CARBON DIOXIDE FLOODING OF SELECTED CARBONATE RESERVOIRS IN THE PERMIAN, WILLISTON, AND OTHER ROCKY MOUNTAIN BASINS

Basin	No. Res.	OOIP MMBbls	CO_2 Recovery MMBbls	CO_2 Recovery Avg. Frac	Total Recovery MMBbls	Total Recovery Avg. Frac	CO_2 Required BCF	CO_2 Required Average Inc. CO_2/Oil Ratio-Mcf/Bbl
PERMIAN BASIN								
Permian Guadalupe	83	35,941	6,779	0.19	17,269	0.49	36,119	5.3
Permian Wolfcamp	9	539	104	0.19	266	0.49	620	6.0
Permian Ochoa	1	390	105	0.27	223	0.57	431	4.1
Permian Leonard	27	10,404	2,164	0.21	5,285	0.51	11,182	5.2
Sub-total	120	47,274	9,152	0.19	23,043	0.49	48,352	5.3
Pennsylvanian	35	5,913	749	0.13	2,523	0.43	5,543	7.4
Mississippian	1	286	61	0.21	146	0.51	282	4.7
Devonian	20	2,364	491	0.21	1,164	0.49	2,371	4.8
Silurian	6	268	42	0.16	124	0.46	276	6.6
Ordovician	6	421	62	0.15	188	0.45	333	5.4
Total Permian Basin	188	56,526	10,557	0.19	27,188	0.48	57,157	5.4
WILLISTON BASIN								
MONTANA								
Pennsylvanian	1	13	3	0.23	8	0.61	15	5.0
Mississippian	8	589	119	0.20	304	0.52	807	6.8
Silurian and Devonian	5	57	14	0.25	33	0.58	74	5.3
Ordovician	22	985	221	0.22	535	0.54	1,211	5.5
Sub-total Montana	36	1,644	357	0.22	880	0.54	2,107	5.9
NORTH DAKOTA								
Mississippian	22	1,373	337	0.25	767	0.56	1,912	5.7
Devonian	4	144	30	0.21	84	0.58	187	6.2
Silurian	2	64	15	0.23	36	0.56	78	5.2
Ordovician	3	90	22	0.24	49	0.54	108	4.9
Sub-total North Dakota	31	1,671	404	0.24	936	0.56	2,285	5.7
SOUTH DAKOTA								
Ordovician	1	21	6	0.29	12	0.57	23	3.8
Total Williston Basin	68	3,336	767	0.23	1,828	0.55	4,415	5.8
ROCKY MOUNTAIN BASINS								
Sweetgrass Arch	4	362	115	0.32	223	0.62	389	3.4
Paradox Basin	12	1,417	300	0.21	725	0.51	1,474	4.9
Big Horn Basin	5	333	75	0.23	175	0.53	379	5.1
Wind River Basin	1	31	3	0.10	12	0.39	28	9.3
Great Divide Basin	1	136	5	0.04	46	0.34	58	11.6
Total Rocky Mtn. Basins	23	2,279	498	0.22	1,181	0.52	2,328	4.7
Grand Totals	279	62,141	11,822	0.19	30,197	0.49	63,900	5.4

Incremental oil volumes may be optimistic (i.e., too high) because:

1. Recovery from present practices may be larger than 30 percent of initial oil in place--as evidenced by statistics for several fields in this report;

2. Volumetric sweep, especially the vertical component, may be considered poorer than our empirical curves portray; and

3. Total carbon dioxide supply may not be available to support the level of flooding assumed in this report.

Despite these caveats, the incremental oil calculated shows a multi-billion barrel target volume for carbon dioxide flooding exists, principally in the Permian Basin.

Carbon dioxide supply requirements may be optimistically low because the assumptions in the calculations provided for:

1. Injection volumes based on reservoir pressure equal to minimum miscibility pressure; and

2. Complete (100-percent) recycling of produced carbon dioxide.

In many projects, especially if impure carbon dioxide is used, injection must take place at pressures higher than MMP to attain miscibility. This will generally increase the (standard) volume of carbon dioxide source gas required to achieve an equivalent reservoir volume. The assumption of complete recycling probably cannot be realized in most projects because of gathering and processing losses. Hence, in practice, some site-specific produced carbon dioxide/oil ratio (R_{sp} in Equation [2]) will be applicable, which will increase supply requirements.

It should be noted that the carbon dioxide volumes and carbon dioxide/oil ratio figures given in this report are related to source or new supply carbon dioxide only and do not include any reinjected or recycled produced carbon dioxide. As a general rule, recycle volume will approximately equal supply volume so that total <u>injected</u> carbon dioxide volumes will be approximately twice the supply volumes given in this report.

Despite all the possible inaccuracies of detail in the calculations presented here, a larger view of these data indicates that a minimum carbon dioxide supply volume of some 64 trillion cubic feet would be required to recover a target oil volume of some 12 billion barrels now in place in selected carbonate reservoirs of the Permian, Williston, and Rocky Mountain intermontane basins. Of these totals, a minimum supply of 57 trillion cubic feet of carbon dioxide would be required to recover some 10.5 billion barrels of incremental oil in the Permian Basin. This indicates that full-scale carbon dioxide flooding of all the reservoirs that comprise the sums listed on Table 9 is likely to be limited by supply as a first consideration.

Because of the possible optimistic bias to the data presented in this report, use of these figures as the "official DOE and/or Gruy" estimates for individual reservoirs is not recommended. We do recommend that engineering studies of data from field projects be continued and expanded to additional projects as they develop to provide better calibration of the volumetric model presented in this report. This would allow more reliable estimates to be prepared using a simple and, hence, economical procedure.

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APPENDIX A

MATHEMATICAL DEVELOPMENT OF VOLUMETRIC MODEL FOR DISPLACEMENT PROJECTS

Relatively elementary volumetric concepts can be employed to develop an algabraic-equation mathematical model for calculating recovery from displacement projects in which an injected fluid banks and moves oil through a porous underground reservoir.

DERIVATION OF BASIC EQUATIONS

The development that follows assumes:

(1) Oil saturation within the reservoir has been reduced from initial or discovery condition (S_{oi}) to a lower "average" level ($\bar{S}_o$) because of production prior to initiation of the displacement project.

(2) The injected fluid displaces oil as a sharp front from the beginning value ($\bar{S}_o$) to a lower residual or immovable level (S_{or}).

(3) The displaced oil forms a bank of higher oil saturation (S_{ob}) by displacing mobile gas and/or water as the oil bank encroaches into the undisturbed reservoir.

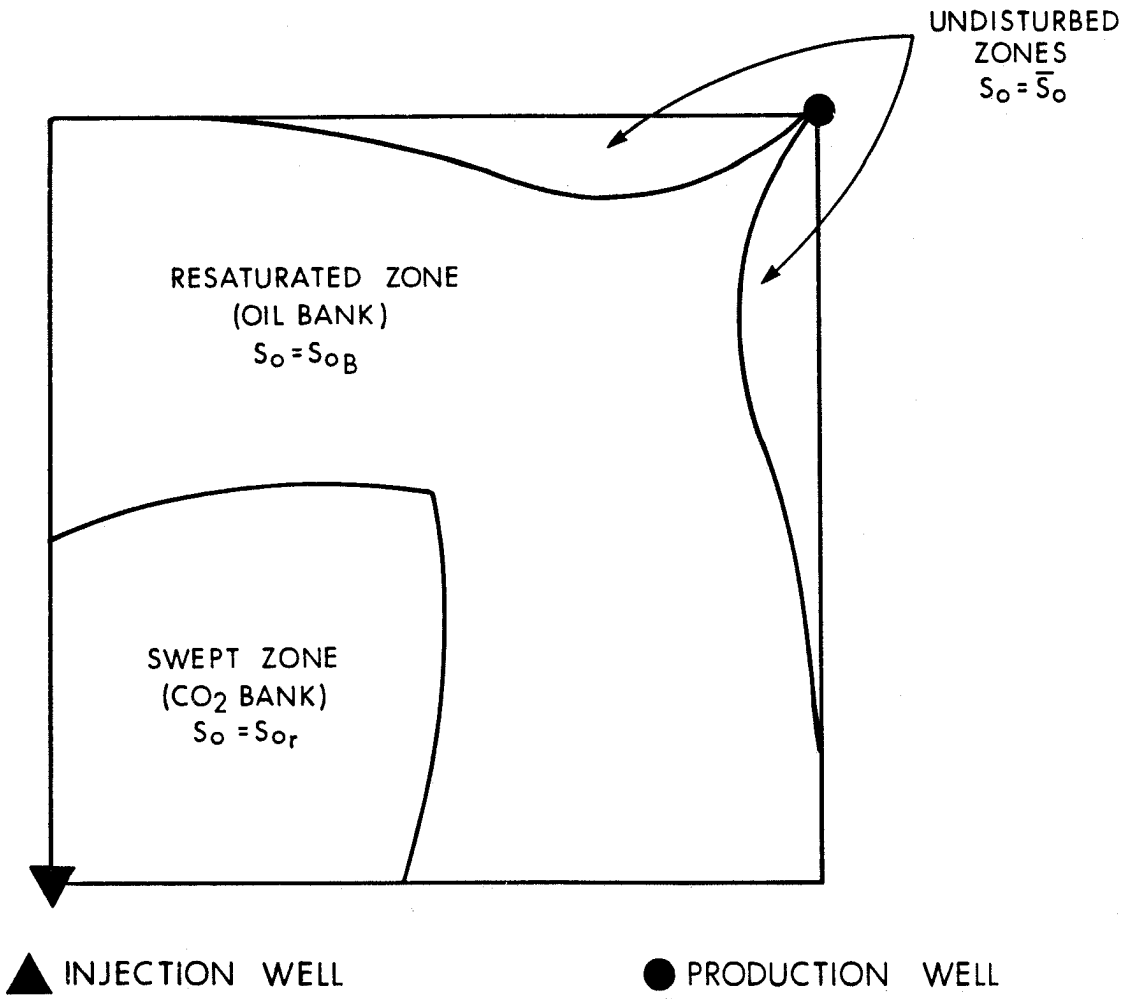
These concepts can be applied to any displacement process in which an injected fluid banks and moves oil. Additional assumptions necessary to particularize these concepts to describe carbon dioxide flooding are as follows:

(4) The injected fluid (carbon dioxide) bank contains the only free carbon dioxide saturation.

(5) Residual oil, oil-bank oil, and residual water are all saturated by carbon dioxide during the displacement process.

These assumptions can be utilized to develop volumetric balances by which to calculate recoverable oil and carbon dioxide requirements.

The volumetric balance employs the geometric concepts illustrated on Figure A-1. As shown, the reservoir element under flood contains a swept zone or volume invaded by the injected fluid (carbon dioxide), a resaturated zone or oil bank volume in which the oil displaced from the swept zone is accumulating, and an undisturbed zone not (as yet) invaded by either oil bank or injected fluid. Saturation distribution within these zones, based on assumptions one through three above, is illustrated on Figure A-2.



$$f_{r_s} = \left\{ \begin{array}{l} \text{FRACTIONAL RESATURATION} \\ \text{OF UNSWEPT ZONE} \end{array} \right\} = \frac{\text{RESATURATED ZONE VOLUME}}{\text{RESATURATED ZONE VOLUME} + \text{UNDISTURBED ZONE VOLUME}}$$

Figure A-1 -- Schematic illustration of sweep and resaturation in five spot symmetry element at monent of oil bank breakthrough.

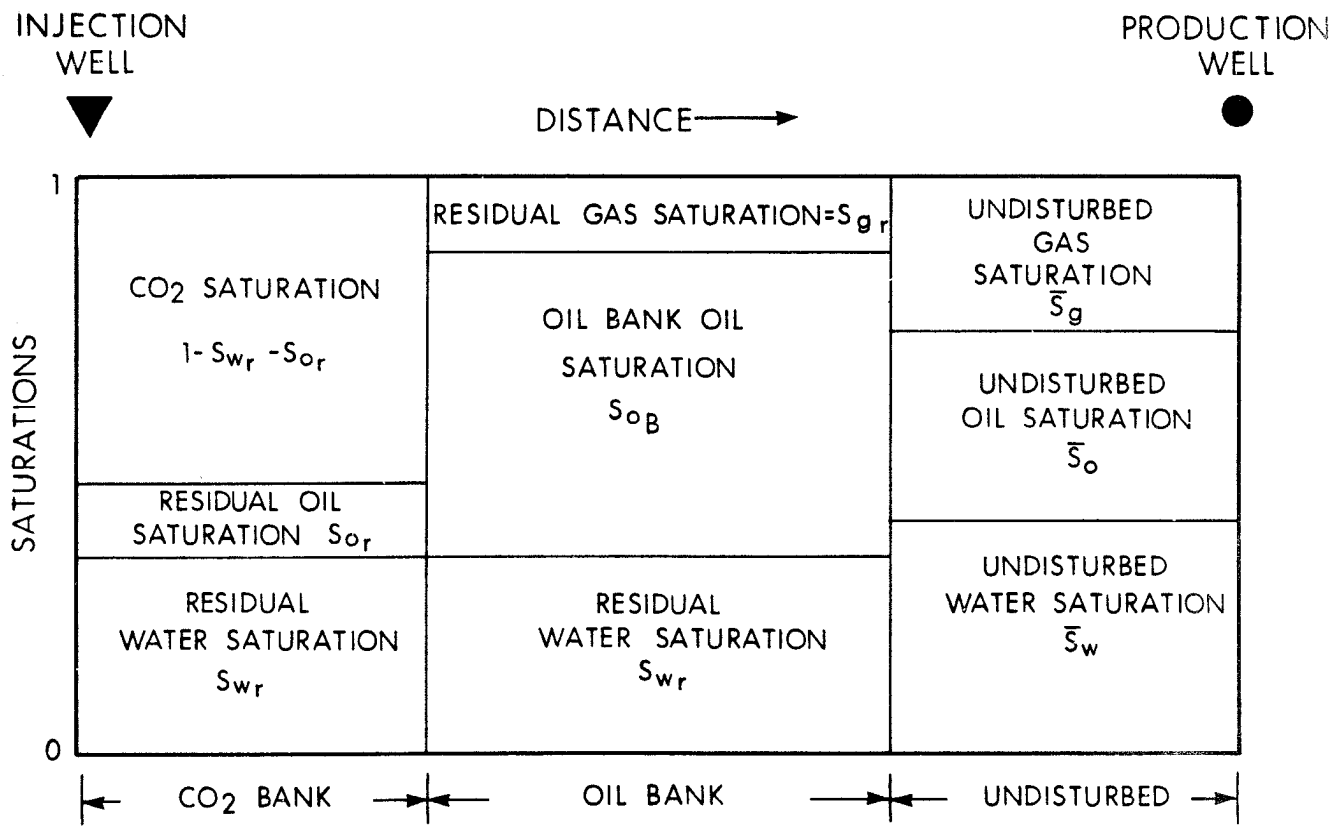


Figure A-2 -- Schematic illustration of saturations within the swept (CO_2 bank), resaturated (oil bank), and undisturbed zones of a CO_2 displacement project.

At any given point in time, volumetric balance requires that:

Stock tank oil recovered =

Stock tank oil in place when injection commenced -

Stock tank oil left in swept zone - Stock tank oil remaining in unswept zone.

Stock tank oil in place at the initiation of the project is simply

$$\bar{N} = (7758Ah\phi\ \bar{S}_o)/\bar{B}_o;$$

and, utilizing the concept of fractional sweep efficiency (Es), stock tank oil left as residual in the swept zone (N_{rs}) is equal to:

$$N_{rs} = Es(7758Ah\phi)S_{or}/B_{or},$$

where E_s = swept volume/total reservoir volume.

The oil left in the unswept volume is the sum of the oil left in the resaturated or oil bank zone plus the oil remaining in the undisturbed zone. The mathematical expressions required to account for this are developed in the next paragraph.

From the definition of fractional sweep efficiency (Es) the total unswept reservoir volume is equal to:

$$V_{us} = (1 - E_s)7758Ah\phi.$$

This total volume contains the oil bank zone plus the undisturbed zone. If the reservoir volume of the oil bank (V_{ob}) is considered to occupy a fraction of the unswept volume as shown on Figure A-1, a quantity defined as the fractional resaturation (f_{rs}) is then:

$$f_{rs} = V_{ob}/V_{us}$$

From this, it can readily be shown that the volume of stock tank oil contained in the oil bank is equal to:

$$(V_{ob}S_{ob})/B_{ob} = (f_{rs})(1 - E_s)7758Ah\phi\ S_{ob}/B_{ob}$$

and the volume of stock tank oil contained in the undisturbed zone is equal to:

$$(V_{us} - V_{ob})\ \bar{S}_o/\bar{B}_o = (1 - f_{rs})(1 - E_s)7758Ah\phi\ \bar{S}_o/\bar{B}_o.$$

These several expressions can now be substituted appropriately in the volumetric balance statements listed above.

Substitution and algebraic manipulation yields the final volumetric balance expression for recoverable oil:

$$N_p = 7758Ah\phi \left[E_s(\bar{S}_o/\bar{B}_o - S_{or}/B_{or}) - (1 - E_s)f_{rs}(S_{ob}/B_{ob} - \bar{S}_o/\bar{B}_o) \right] \quad \text{(A-1)}$$

Equation (A-1) utilizes the geometric and saturation distribution concepts discussed above to provide a means for doing "site-specific" calculations where the physical quantities are known or reasonably can be estimated. It is important to note that negative incremental production can result both mathematically and practically from a combination of low sweep efficiency and large fractional resaturation.

Based on the concepts and nomenclature developed above, a companion equation for estimating carbon dioxide requirements can be developed. This equation considers that:

CO_2 required = free CO_2 in swept zone + solution CO_2 in swept zone + solution CO_2 in resaturated zone + produced CO_2.

In the same symbols and notations as those used above, this relationship can be expressed as:

CO_2 required (Mcf) =

$$I_{CO_2} = 43.560Ah\phi/B_{CO_2} \; E_s(1 - S_{wr} - S_{or})$$

$$+ 7758Ah\phi\left[E_s(R_{so}S_{or}/B_r + R_{sw}\, S_{wr}/B_w) + (1-E_s)f_{rs}R_{so}(S_{ob}/B_{ob})\right] \quad \text{(A-2)}$$

$$+ N_pR_{sp}$$

Equation (A-2) thus allows calculation of the carbon dioxide required to displace the oil calculated by Equation (A-1).

DISPLACEMENT FACTOR

In application of Equations (A-1) and (A-2), the relative growth of the oil bank with respect to the injected fluid bank is an important measure of the performance to be expected from a displacement project. This quantity, termed the displacement factor (4), is evaluated by comparing the volume of reservoir oil displaced to the volume of reservoir that must be occupied by the displaced oil as it forms the oil bank. This concept is developed in the following paragraph.

The reservoir volume of oil displaced from CO_2 zone is equal to:

$$= 7758Ah\phi \; E_s \; (\bar{S}_o - S_{or})$$

$$= V_{CO2} \; (\bar{S}_o - S_{or})$$

This must equal the reservoir pore volume available for oil bank growth considering fractional resaturation of the unswept volume:

$$= 7758Ah\phi \; (1 - E_s)f_{rs}(1 - \bar{S}_o - S_{wr} - S_{gr})$$

$$= V_{ob} \; (S_{ob} - \bar{S}_o)$$

where:

$$1 - S_{wr} - S_{gr} = S_{ob}.$$

The displacement factor (F) is the ratio of the volume of the carbon dioxide bank plus the oil bank volume to the volume of the carbon dioxide bank:

$$F = (V_{CO2} + V_{ob})/V_{CO2} = 1 + (V_{ob}/V_{CO2})$$

where, from volumetric balance, the oil displaced from the carbon dioxide bank builds up to form the oil bank, or, in reservoir barrels:

$$V_{CO2} \; (\bar{S}_o - S_{or}) = V_{ob}(S_{ob} - \bar{S}_o),$$

rearranged:

$$V_{ob}/V_{CO2} = (\bar{S}_o - S_{or})/(S_{ob} - \bar{S}_o)$$

from which:

$$F = 1 + (\bar{S}_o - S_{or})/(S_{ob} - \bar{S}_o)$$

This final relationship provides a means of quantifying the displacement factor on a site-specific basis provided values for the various oil saturations are available or can reasonably be assumed.

The relative sweep or growth of the oil bank, as a function of injected fluid volume (I_{CO_2}), is related to the carbon dioxide front growth sweep by the concept:

Oil bank sweep at a given injected volume =

(CO_2 bank sweep at the given injected volume) x displacement factor.

or, in symbols:

$$Es_{oB} \text{ at } I_{CO_2} = (Es_{CO_2}) \times F.$$

This relationahip is true until oil bank breakthrough. The relationship of oil bank growth before breakthrough to displacement factor magnitude is illustrated in Figure A-3. It can be seen that a large displacement factor provides more rapid oil bank growth. After oil bank breakthrough, the rate of oil bank growth diminishes due to oil production from the system.

DISCUSSION OF CONCEPTS REQUIRED FOR APPLICATION

Some of the physical quantities contained or implied in the basic equations derived above may require additional discussion to provide a useful level of understanding for practical application.

Sweep Efficiency

The concept of overall sweep efficiency (Es) can be subdivided into an areal or lateral view and a vertical view. Overall sweep efficiency is the product of the two "component" sweep efficiencies.

Lateral or areal sweep efficiency can be defined as the ratio of the area invaded by injected fluid to the total project area (Fig. A-1). Analytic mathematical solutions for areal sweep efficiency as a function of cumulative fluid injection are available for simplified physical systems (i.e., isotropic, homogeneous media, unit mobility ratio, incompressible fluids) and a number of regular pattern geometries (5, 6). Non-unit mobility ratio displacements, especially when the displacing fluid is more mobile than the displaced fluid, cause viscous instabilities. These systems are not susceptible to analytic treatment. However, data available from several physical model studies (7, 8, 9) allow estimation of areal sweep efficiencies for a number of pattern geometries. An example drawn from one such study (9) is shown on Figure A-4.

Vertical sweep efficiency is more site specific because it is a function of gravitational instability in single-layer systems and also of injection fluid distribution (profiles) in layered systems. Hence, vertical sweep efficiency cannot readily be estimated from generalized data of the type available for estimating areal or lateral sweep.

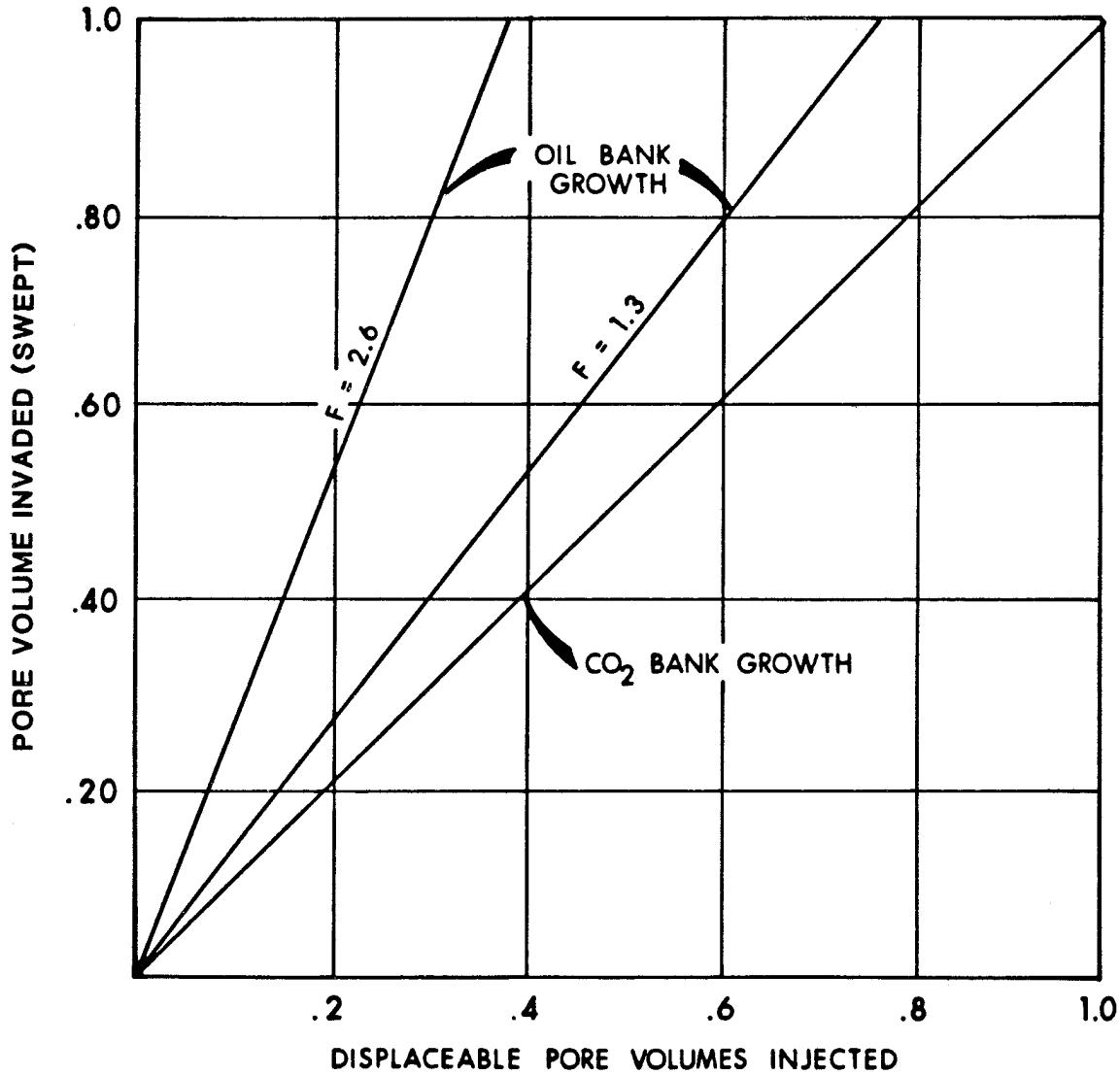


Figure A-3 -- Idealized growth of CO_2 and oil banks before oil bank breakthrough for different displacement factors.

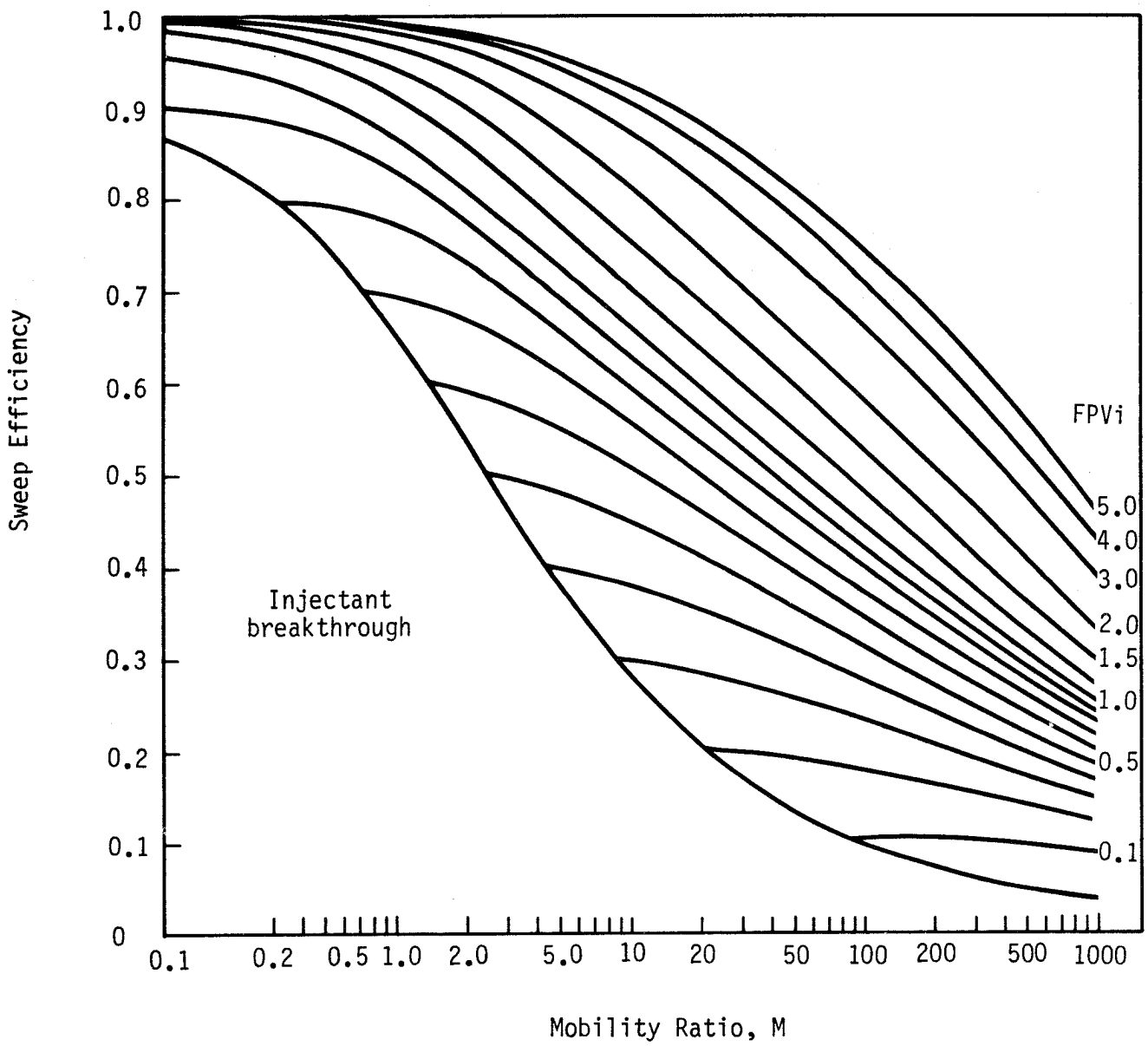


Figure A-4 -- Lateral sweep in miscible flooding for five spot well patterns (from Claridge, SPE Journal, April 1972)

Fractional Resaturation and Displacement Factor

Fractional resaturation is an important factor in displacement projects that use small volumes of injectant. At any given sweep efficiency, the fraction resaturated (fr_s) is related to the relative growth of the oil bank with respect to the growth of the carbon dioxide bank.

The ratio of oil bank growth relative to carbon dioxide bank growth, termed the displacement factor, is obtained by comparing the volume of oil displaced from a given bulk volume invaded by carbon dioxide to the volume of displaceable space into which the oil bank can move and accumulate.

Oil Bank Growth or Sweep

As stated above, oil bank growth or sweep is linearly related to carbon dioxide bank growth or sweep until oil bank breakthrough. Oil bank growth relative to carbon dioxide bank growth is controlled by the displacement factor such that

$$E_{s_{ob}} @ I_{CO_2} = (E_{s_{CO2}} @ I_{CO_2}) \times F.$$

After oil bank breakthrough, when incremental oil production begins, the volume occupied by the oil bank grows at a diminished rate due to oil production from the system.

The rate of oil bank growth then can be calculated from the relationship:

CO_2 volume injected for a given oil bank sweep =

(CO_2 volume injected for comparable CO_2 banksweep)/displacement factor.

or, in symbols:

$$I'_{CO_2} \text{ at } Es_{ob} = (I_{CO_2} \text{ at } Es_{CO_2})/F.$$

An example calculation using published data (9) to estimate Es_{CO_2} is listed in Table A-1. The results of this calculation are shown in Fig. A-5. From inspection of this figure, it can be seen that the fraction resaturated by oil bank is equal to:

$$f_{rs} = (Es_{ob} - Es_{CO_2})/(1 - Es_{CO_2})$$

for any given volume (I_{CO_2}) injected. This function is nonanalytic after oil bank breakthrough and must be evaluated graphically, as shown on Figure A-5 for an I_{CO_2} value of 1.25.

TABLE A-1 EXAMPLE CALCULATION OF OIL BANK GROWTH AFTER BREAKTHROUGH OF OIL BANK AND OF CARBON DIOXIDE BANK

Data from Claridge (1972) - Figure A-4
for M = 4.0 and F = 2.5

CARBON DIOXIDE BANK SWEEP		OIL BANK SWEEP		REMARKS
I_{CO_2} (FPV)	Es_{CO_2} (frac.)	I'_{CO_2} (FPV)	Es_{ob} (frac.)	
0.168	0.168	0.168	0.42	OB BT*
0.42	0.42			CO_2 BT
0.50	0.49	0.50/2.50 = 0.20	0.49	
0.60	0.57	0.60/2.50 = 0.24	0.57	
0.70	0.63	0.70/2.50 = 0.28	0.63	
0.80	0.68	0.80/2.50 = 0.32	0.68	
0.90	0.72	0.90/2.50 = 0.36	0.72	
1.00	0.75	1.0 /2.50 = 0.40	0.75	
1.50	0.85	1.5 /2.50 = 0.60	0.85	
2.00	0.90	2.0 /2.50 = 0.80	0.90	
3.00	0.95	3.0 /2.50 = 1.20	0.95	

*Note: Carbon Dioxide Breakthrough occurs @ $I_{CO_2} = 0.42$

Oil Bank Breakthrough occurs @ $Es_{ob} = 0.42$

when $I'_{CO_2} = 0.42/2.50 = 0.168$ FPV

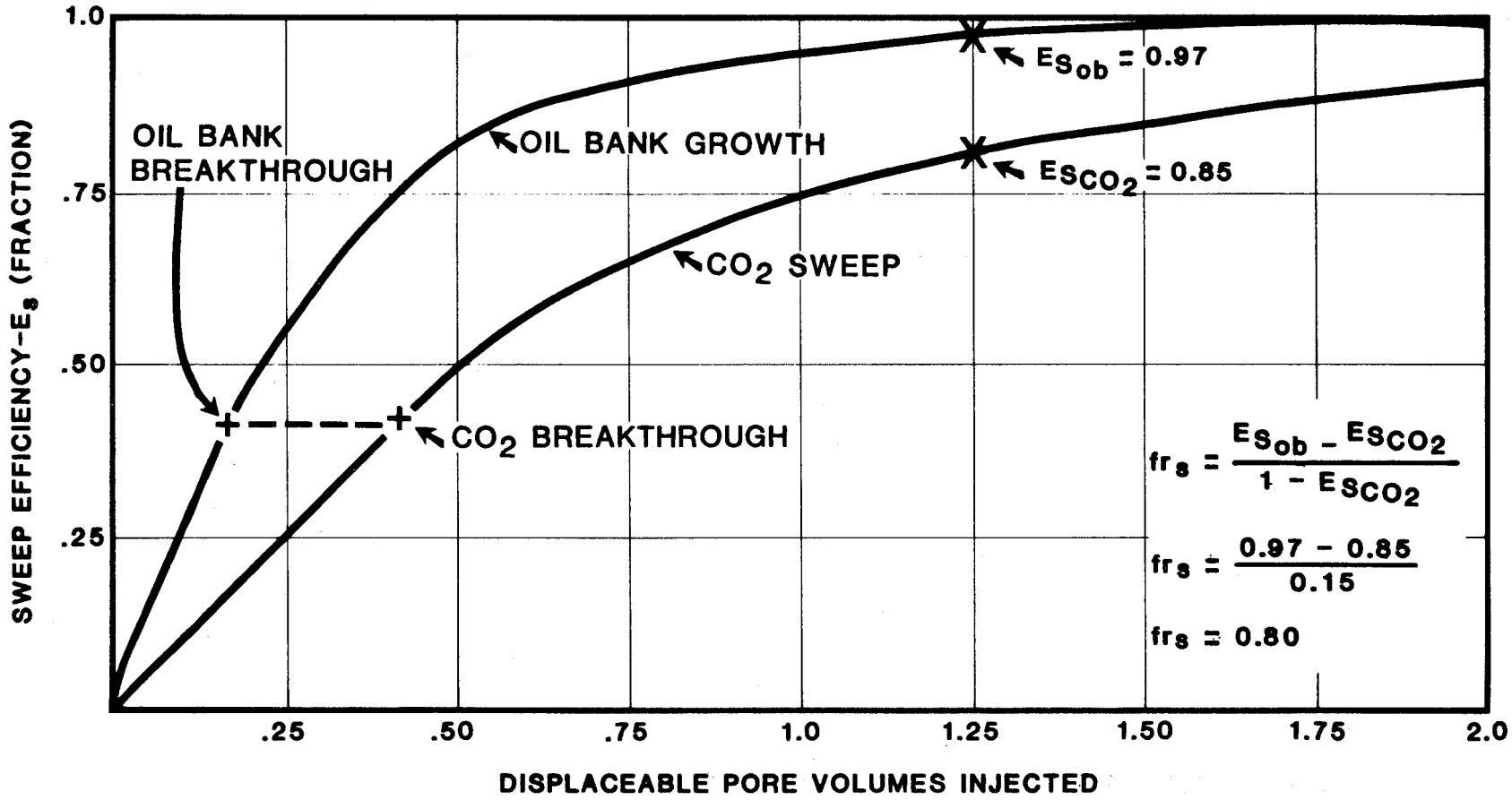


Figure A-5 -- Illustration of growth of CO_2 swept area and oil bank area as function of cumulative injection five-spot pattern, $M_{CO_2, oil} = 4.0, F = 2.5$ (sweep from Claridge).

LIST OF SYMBOLS

Symbol	Meaning	Units
N_{rs}	Residual Stock Tank Oil in Swept Region	S. T. Barrels
$\bar{N}$	Stock Tank Oil in Place at Beginning of Displacement	"
N_p	Cumulative Stock Tank Oil Produced by Displacement Project	"
A	Reservoir Area	Acres
h	Average Thickness	Feet
ϕ	Porosity	Dimensionless, fraction
E_s	Sweep Efficiency	"
V_{us}	Unswept Reservoir Pore Volume	Reservoir Barrels
V_{ob}	Oil Bank Pore Volume	"
f_{rs}	Fractional Resaturation	"
S_{oi}	Initial (Discovery) Oil Saturation	"
S_o	Starting Average Oil Saturation	"
S_{or}	CO_2 Residual Oil Saturation	"
S_{ob}	Oil Bank Oil Saturation	"
S_{wr}	Residual Water Saturation	"
S_{gr}	Residual Gas Saturation	"
$\bar{B}_o$	Starting Formation Volume Factor	Res Vol/S.T. Vol.
B_{ob}	Oil Bank Formation Volume Factor	"
B_{or}	Residual Oil Formation Volume Factor	"
B_{CO_2}	CO_2 Formation Volume Factor	Res Vol/Vol. at S.C.
R_{so}	CO_2 in Oil Solution Ratio	Mcf/Bbl
R_{sw}	CO_2 in Water Solution Ratio	"
R_{sp}	Produced CO_2/Oil Ratio	"
F	Displacement Factor	Dimensionless
I_{CO_2}	Cumulative Injected CO_2	Mcf or FPV
FPV	Floodable Pore Volume	Fraction of Bulk Volume $= \phi(1-S_{or}-S_{wr}-S_{gr})$

* S.T. = stock tank volume
S.C. = standard conditions

APPENDIX B

ILLUSTRATIVE CALCULATIONS USING VOLUMETRIC MODEL EQUATIONS

The volumetric model in developed in Appendix A can be used for calculation of expected incremental oil recovery and carbon dioxide requirements on a reservoir by reservoir basis utilizing reservoir specific data. As discussed in the following paragraphs, illustrative calculations using the model show the impact of site-specific data on carbon dioxide flood performance. This procedure allows the better candidate reservoirs for carbon dioxide flooding to be separated from poorer candidates.

The calculations were designed to illustrate the differences in performance that might be observed between a carbon dioxide flood in a high porosity reservoir at waterflood (drive) residual oil saturation and a low porosity reservoir from which only limited depletion had taken place, leaving relatively high remaining oil saturation. Data used for the calculations are listed on Table B-1. Oil content remaining in each reservoir is 450 barrels per acre foot. Our calculations (arbitrarily) used a reservoir bulk volume of 6,650 net acre feet, so oil in place in each reservoir is approximately 3 million barrels at the initiation of carbon dioxide flooding.

The calculations assumed the reservoir was developed on a uniform five-spot flooding pattern so that published data (9) could be used to estimate lateral sweep. These data, for a carbon dioxide to oil mobility ratio of 4.0, show carbon dioxide sweep as a function of cumulative injection as follows:

I_{CO_2} (floodable pore volumes)	E_{sCO_2} (fraction of total area swept by CO_2)	
0.20	0.20	
0.30	0.30	
0.40	0.40	
0.42	0.42	CO_2 breakthrough
0.50	0.49	
0.60	0.57	
0.70	0.63	
0.80	0.68	
0.90	0.72	
1.00	0.75	
1.50	0.85	
2.00	0.90	
3.00	0.95	

It may be noted that sweep efficiency and cumulative injection are one-to-one related until carbon dioxide breakthrough and that sweep thereafter

progresses at a decreasing rate due to carbon dioxide production from the system. Impractically large injection volumes (approximately five floodable pore volumes) would be needed to attain 100-percent sweep. The calculations used these sweep versus injection figures identically in both reservoir types, so that carbon dioxide sweep is not one of the variables causing differences in performance in these illustrative cases.

Calculated performance data for the high porosity case (termed Case A) are listed on Table B-2. The carbon dioxide sweep data listed at the top of the table are identical to those tabulated above. Oil bank sweep is calculated using the displacement factor (F) as a measure of the relative growth of the oil bank with respect to the carbon dioxide bank. These data are plotted on Figure B-1 as a function of floodable pore volumes of carbon dioxide injected. This illustrates the slow growth of the oil bank caused by low beginning oil saturation, which results in a small displacement factor. It may be noted that oil bank breakthrough does not occur until 0.29 FPV of carbon dioxide are injected, and that the thin oil bank does not entirely fill the unswept area after 2.0 FPV of carbon dioxide are injected.

Data from Figure B-1 are used to evaluate the fractional resaturation of the unswept volume (frs), which is then used in the basic equations to calculate expected oil recovery and carbon dioxide requirements for various sweep efficiencies. These calculations are shown on Table B-2. It is noteworthy that calculated recoveries exceed 60 percent of beginning oil in place with the injection of 1.2 FPV of carbon dioxide. However, CO_2/ oil ratios even with 100-percent recycling of produced carbon dioxide (R_{sp} in Equation A-2 equals zero) are high, leading to relatively poor economics from a flood of this type. CO_2/oil ratios are high because of the large volume of carbon dioxide that must be "stored" in the high porosity of the swept area, which originally contained a low displaceable oil saturation, despite having a relatively high oil content per acre foot.

Equivalent calculations for Case B, the low porosity depletion reservoir case, are presented in Table B-3. Carbon dioxide sweep (identical to Case A) and oil bank sweep are shown on Figure B-2 as a function of floodable pore volumes of carbon dioxide injected. The impact of the high beginning oil saturation and consequent large displacement factor (F=11.0) are evident. Oil bank buildup is very rapid. Breakthrough occurs after injection of only 0.038 floodable pore volumes of carbon dioxide and the oil bank totally fills the unswept volume at 0.45 floodable pore volumes injected.

At any given sweep efficiency (Table B-3 vs Table B-2), oil recovery from Case B is larger at a much lower CO_2/oil ratio. This is illustrated on Figure B-3, where data from Case A and Case B are plotted for comparison.

These comparative calculations, while admittedly idealized, illustrate the differences between better and poorer carbon dioxide flooding candidate reservoirs in terms of oil recovery and CO_2/oil ratios.

TABLE B-1

RESERVOIR PROPERTIES FOR TEST CASE CALCULATIONS, VOLUMETRIC CO_2 FLOODING MODEL

Reservoir Bulk Volume: 6650 Net Acre Feet

Case A. High Porosity Reservoir at Waterflood Residual Oil Saturation

$\phi = 0.31$, $\overline{S}_o = 0.25$, $S_{wr} = 0.30$, $S_{gr} = 0$

$S_{or} = 0.05$, $S_{ob} = 1-S_{wr}-S_{gr} = 0.70$

$$F = 1 + \frac{\overline{S}_o - S_{or}}{S_{ob} - \overline{S}_o} = 1.44$$

$\overline{B}_o = 1.35\ B_{or} = B_{ob} = 2.0$ (swelled by CO_2)

$R_{so} = 1.5$ mcf/bbl, $R_{sw} = 0.1$ mcf/bbl, $B_{CO_2} = 0.0035$

Case B. Low Porosity Reservoir with High Oil Saturation After Primary Depletion

$\phi = 0.12$, $\overline{S}_o = 0.60$, $S_{wr} = 0.25$, $S_{gr} = 0.04$

$S_{or} = 0.05$, $S_{ob} = 1-S_{wr}-S_{gr} = 0.71$

$$F = 1 + \frac{\overline{S}_o - S_{or}}{S_{ob} - \overline{S}_o} = 11$$

$R_{s_o} = 1.5$ mcf/bbl, $R_{s_w} = 0.1$ mcf/bbl, $B_{CO_2} = 0.0035$

Figure B-1 -- CO_2 flood sweep performance case A--high porosity, water driven reservoir.

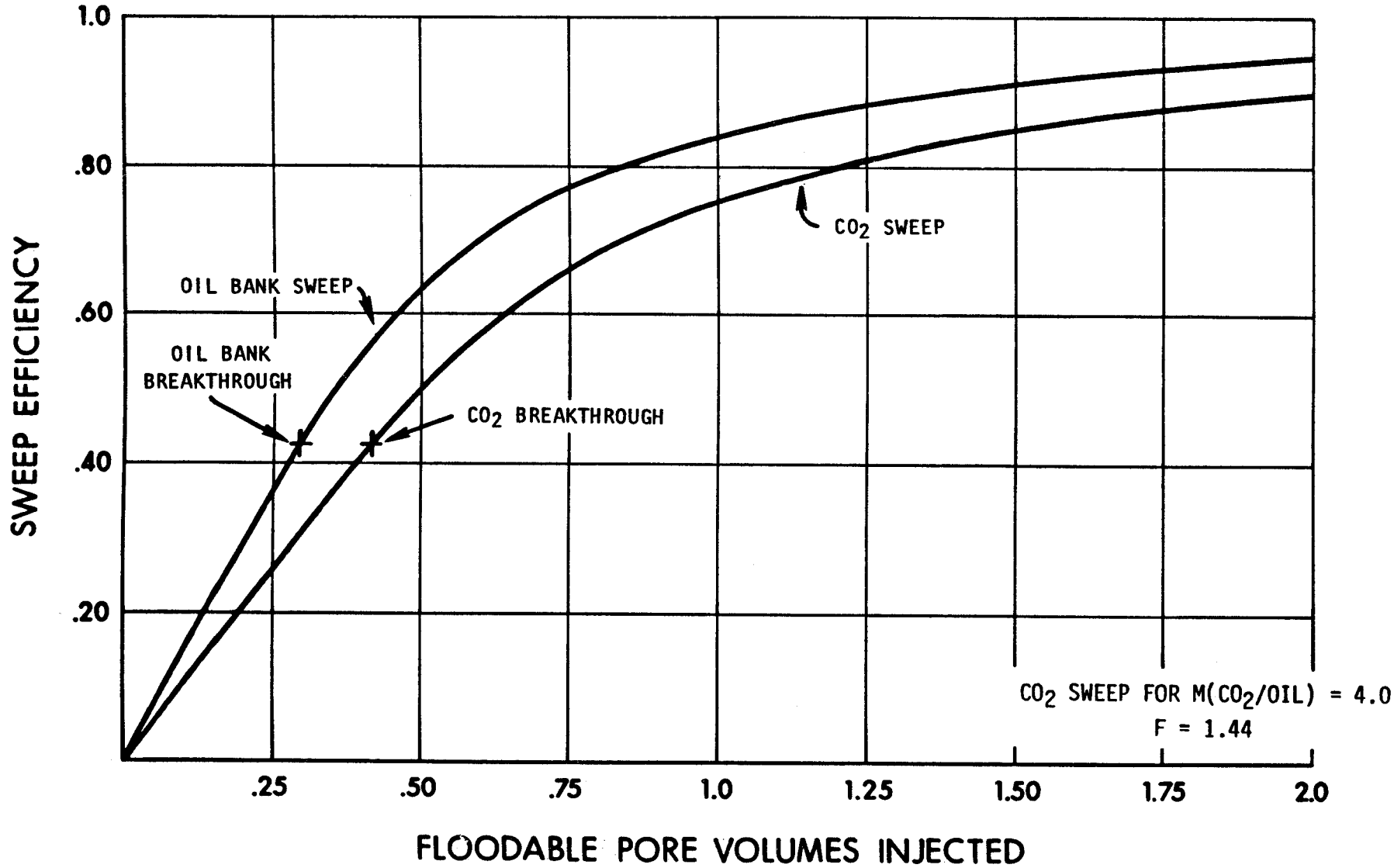


TABLE B-2. CASE A

CO_2 FLOOD PERFORMANCE DATA FOR HIGH POROSITY, WATER DRIVEN RESERVOIR

I_{CO_2} FPV	E_{sCO_2}	$I_{CO_2}/F = I'_{CO_2}$ (see note)	E_{sob}	Remarks
0.29	0.29	0.42/1.44 = 0.29	0.42	Oil bank B.T.
0.42	0.42			CO_2 B.T.
0.50	0.49	0.50/1.44 = 0.35	0.49	
0.60	0.57	0.60/1.44 = 0.42	0.57	
0.70	0.63	0.70/1.44 = 0.49	0.63	
0.80	0.68	0.80/1.44 = 0.56	0.68	
0.90	0.72	0.90/1.44 = 0.63	0.72	
1.00	0.75	1.00/1.44 = 0.69	0.75	
2.00	0.90	2.00/1.44 = 1.39	0.90	

OIL RECOVERY CALCULATION

I_{CO_2} FPV	E_{sCO_2}	E_{sob}	frs	Np M bbls
0.40	0.40	0.54	0.23	659
0.51	0.50	0.63	0.26	937
0.65	0.60	0.73	0.33	1186
0.85	0.70	0.80	0.34	1531
1.20	0.80	0.87	0.35	1863

where:

$$frs = \frac{E_{sob} - E_{sCO_2}}{1 - E_{sCO_2}}$$

CALCULATION OF CO_2 REQUIREMENTS (100% RECYCLING)

E_{sCO_2}	frs	Swept Volume (mmcf)	Solution Volume (mmcf)	Total CO_2 (mmcf)	CO_2/ Oil Ratio (mcf/bbl)
0.40	0.23	6,670	931	7,601	11.50
0.50	0.26	8,338	996	9,334	9.96
0.60	0.33	10,006	1,100	11,106	9.36
0.70	0.34	11,673	1,077	12,750	8.33
0.80	0.35	13,341	1,047	14,388	7.72

1 Floodable Pore Volume = 16,677 mmscf CO_2

Figure B-2 -- CO_2 flood sweep performance case B--low porosity, depletion reservoir.

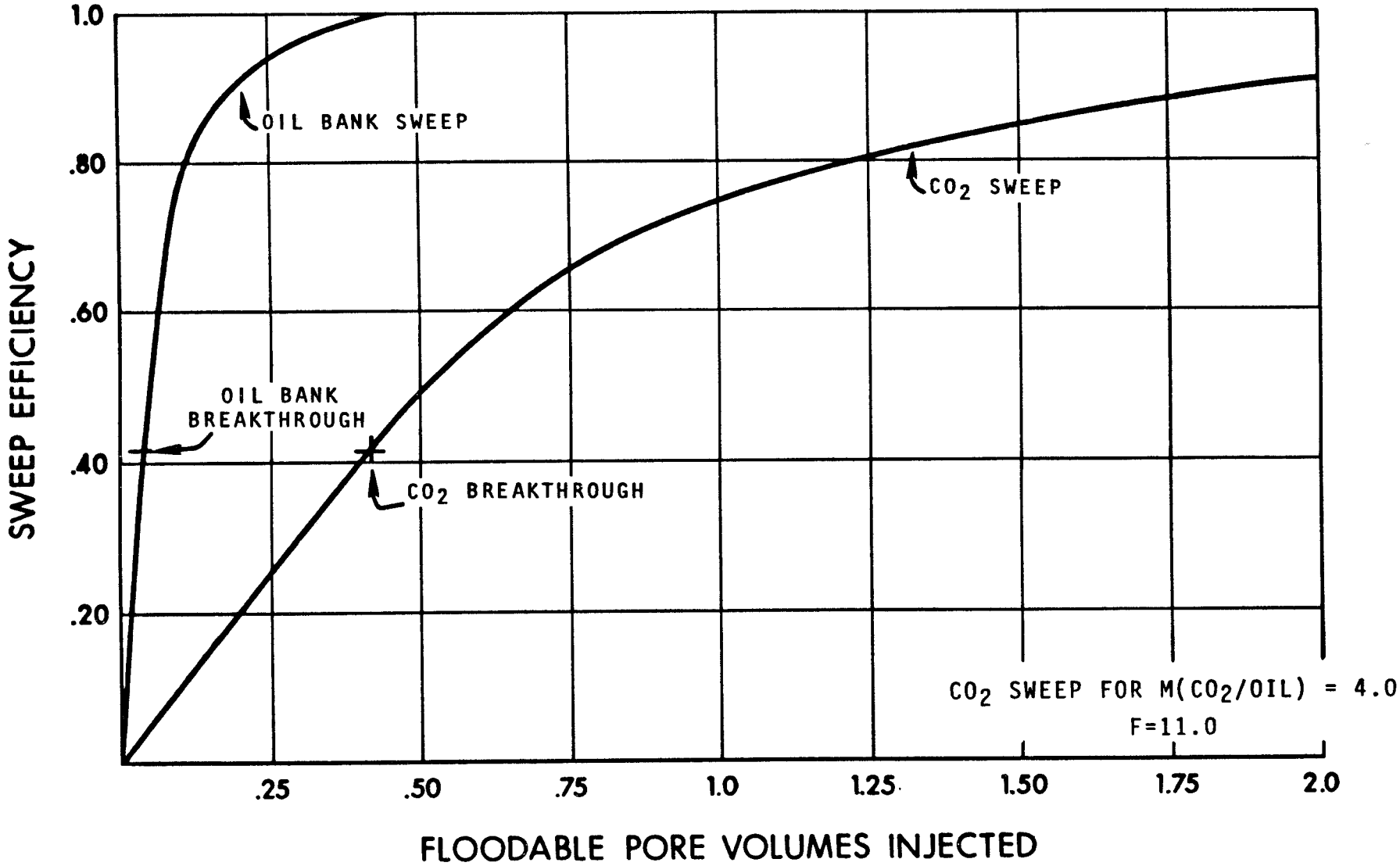


TABLE B-3. CASE B

CO_2 FLOOD PERFORMANCE DATA FOR LOW POROSITY, DEPLETION RESERVOIR

OIL BANK SWEEP CALCULATION

I_{CO_2} FPV	$E_{s_{CO_2}}$	$I_{CO_2}/F = I'_{CO_2}$ (see note)	E_{so_b}	Remarks
0.04	0.04	0.42/11 = 0.038	0.42	Oil bank B.T.
0.125	0.125	1.38/11 = 0.125	0.83	
0.25	0.25	2.75/11 = 0.250	0.94	
0.42	0.42			CO_2 B.T.
0.45	0.44	5.0/11 = 0.450	1.00	Pattern full
0.50	0.49		1.00	

Note: I_{CO_2} is value needed for $E_{s_{CO_2}} = E_{so_b}$ assumed

i.e., 5.00 FPV CO_2 needed for 100% sweep of CO_2, FPV for 100% oil bank sweep = 5.0/11 = 0.450 for I'_{CO_2}

OIL RECOVERY CALCULATION

I_{CO_2} FPV	$E_{s_{CO_2}}$	E_{so_b}	frs	Np M bbls
0.400	0.40	0.99	0.985	1,609
0.455	0.45	1.00	0	1,710
0.650	0.60	1.00	0	2,012
1.200	0.80	1.00	0	2,414

CALCULATION OF CO_2 REQUIREMENTS (100% RECYCLING)

$E_{s_{CO_2}}$	frs	Swept Volume (mmcf)	Solution Volume (mmcf)	Total CO_2 (mmcf)	CO_2/ Oil Ratio (mcf/bbl)
0.40	0.985	2,781	2,127	4,908	3.1
0.45	1.00	3,128	1,980	5,108	3.0
0.60	1.00	4,171	1,542	5,713	2.8
0.80	1.00	5,562	958	6,520	2.7

1 Floodable Pore Volume = 6,952 mmscf CO_2

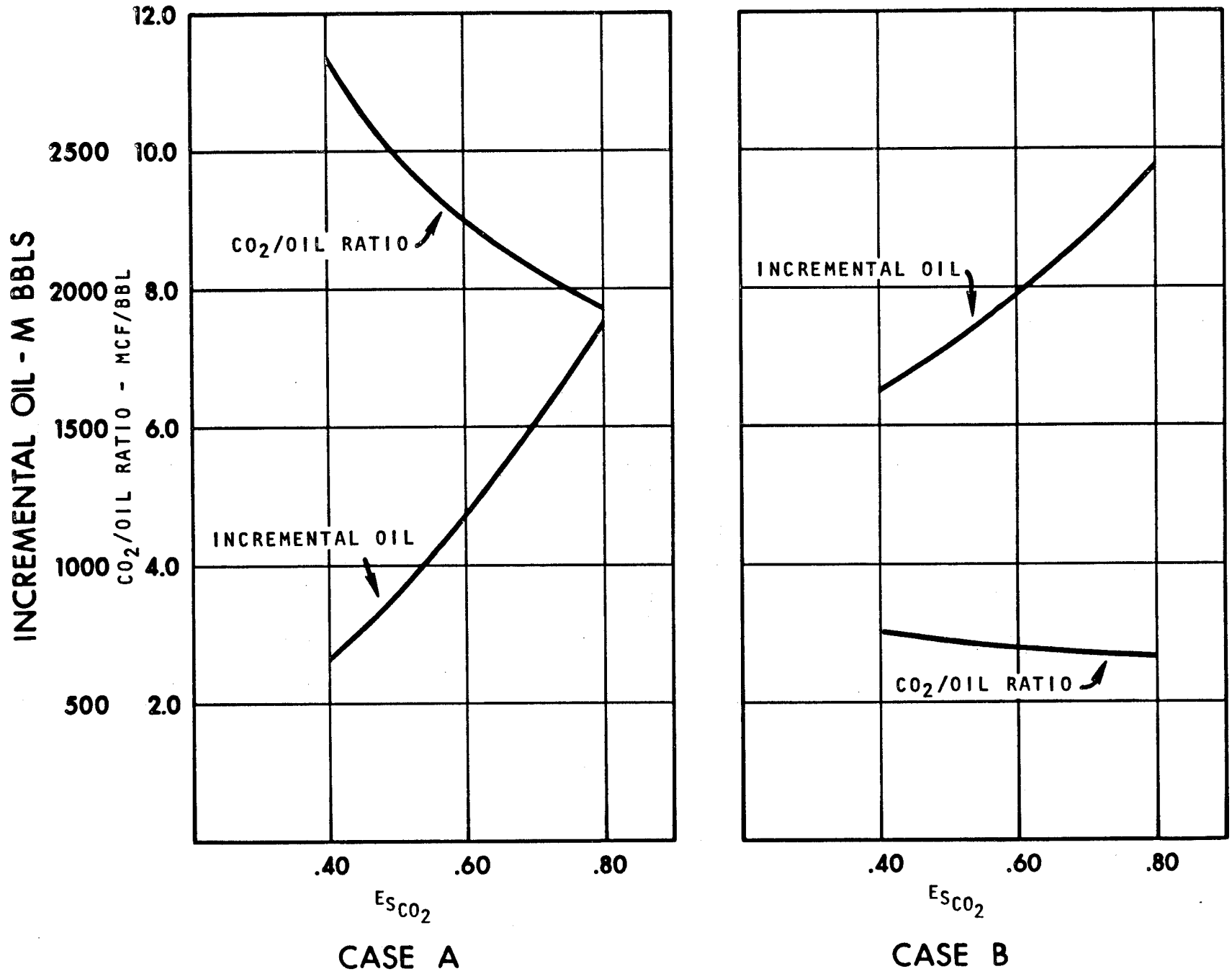


Figure B-3 -- Comparison of case A and case B--oil recovery and CO_2/oil ratios.

APPENDIX C

BASIC VOLUMETRIC DATA FROM PREVIOUS STUDIES

Data published in previous reports (2, 3) were used in the calculations presented in this report. These data, in the form of tables for the Permian (Table C-1), Williston (Table C-2) and Rocky Mountains (Table C-3) Basins, are included for reference in this appendix.

TABLE C-1

BASIC VOLUMETRIC DATA FOR CARBONATE RESERVOIRS IN THE PERMIAN BASIN

TEXAS AND NEW MEXICO

Field	County	Zone	Discovery Date	Depth (ft.)	Proved Acreage	Avg. Net Pay (ft)	Average Porosity (frac)	Initial Water Saturation	Formation Volume Factor	Oil Gravity °API	Res. Temp °F	Est. Orig. Oil In Place (mbbls)	Cum. Prod. Thru 1979 (mbbls)
PERMIAN GUADALUPE - CENTRAL BASIN PLATFORM													
ARROWHEAD	Lea	Grayburg	1938	3,600	8,320	50	0.12	0.20	1.3	34	92	238,325	27,162
BLOCK 31	Crane	Grayburg	1956	3,100	1,710	7	0.16	0.20	1.3	26	90	9,143	3,499
C-BAR	Crane	San Andres	1949	3,500	5,600	35	0.08	0.35	1.19	33	90	55,043	15,455
CORAZON	Scurry	San Andres	1953	2,140	4,540	20	0.08	0.44	1.2	35	93	30,994	3,738
COWDEN, N.	Ector	Gry./San An.	1930	4,150	39,300	120	0.09	0.287	1.26	30	94	1,863,309	314,161
COWDEN, S.	Ector	Gry./San An.	1932	4,600	30,960	120	0.09	0.20	1.1	32	98	1,886,565	121,676
DONNELLY	Ector	San Andres	1950	4,300	2,305	23	0.07	0.312	1.25	35	96	15,846	7,512
DUNE	Crane	San Andres	1938	3,270	29,760	80	0.11	0.31	1.12	36	90	1,251,689	141,820
EDWARDS	Crane	Gry./San An.	1935	3,400	5,160	50	0.058	0.40	1.3	30	90	53,401	7,495
EMMA	Andrews	San Andres	1937	4,240	3,200	40	0.08	0.40	1.15	31	95	11,052	17,601
EMPEROR	Winkler	Deep	1937	2,600	4,000	61	0.16	0.45	1.01	32	92	164,930	22,798
EMPEROR	Winkler	Holt	1946	4,765	2,000	23	0.183	0.33	1.2	36	102	35,004	6,366
EUNICE	Lea	San Andres	1961	4,100	-no data-								
EUNICE-MONUMENT	Lea	Gry./San An.	1929	3,400	39,680	250	0.05	0.20	1.3	32	93	2,367,980	334,553
FOSTER	Ector	Grayburg	1936	4,300	31,000	91	0.10	0.35	1.24	33	93	1,148,140	206,782
FULLERTON	Andrews	San Andres	1945	4,500	6,500	46	0.105	0.385	1.2	33	94	124,825	8,583
GOLDSMITH	Ector	San Andres	1935	4,250	30,000	48	0.098	0.143	1.36	35	110	682,704	313,548
GOLDSMITH, E.	Ector	San Andres	1952	4,180	2,760	90	0.078	0.20	1.3	37	110	92,500	7,322
GOLDSMITH, N.	Ector/Andrews	San Andres	1935	4,300	30,000	49	0.08	0.20	1.3	32	110	561,440	11,431
GOLDSMITH, W.	Ector	San Andres	1956	4,300	4,800	30	0.06	0.20	1.3	34	110	41,248	5,476
HARPER	Ector	San Andres	1933	4,300	12,360	39	0.10	0.20	1.3	35	110	232,133	38,945
HOBBS	Lea	Gry./San An.	1928	3,700	12,160	100	0.15	0.15	1.3	34	107	925,231	242,420
JOHNSON	Ector	Grayburg	1934	4,200	8,000	56	0.068	0.20	1.3	33	112	145,439	21,914
JORDAN	Crane	San Andres	1937	3,700	25,400	53	0.136	0.30	1.2	36	90	828,543	74,007
KEYSTONE	Winkler	Holt	1943	4,700	6,200	53	0.75	0.25	1.49	40	94	953,316	39,542
LAWSON	Ector	San Andres	1950	4,200	4,800	33	0.10	0.35	1.06	36	110	75,355	13,275
LEA	Crane	San Andres	1955	2,925	3,000	29	0.09	0.24	1.12	29	90	41,219	4,378
McCAMEY	Upton	Grayburg	1925	2,200	20,000	75	0.14	0.20	1.3	26	90	1,002,572	127,844
McELROY	Crane	Grayburg	1926	3,000	30,000	129	0.124	0.20	1.15	30	97	1,593,865	373,438
McFARLAND	Andrews	Queen	1955	4,790	15,300	16	0.12	0.25	1.25	30	108	136,739	34,680
MEANS	Andrews	San Andres	1934	4,400	18,500	57	0.077	0.35	1.04	29	100	397,155	129,997
PENWELL	Ector	San Andres	1926	3,800	14,000	60	0.095	0.25	1.22	33	108	378,049	66,142
SCARBOROUGH	Lea	Yates/7 Rvrs.	1926	2,895	2,840	100	0.141	0.468	1.03	37	90	127,132	15,623
SEMINOLE	Gaines	San Andres	1936	5,032	17,345	125	0.132	0.174	1.38	37	108	1,328,951	229,151
SEMINOLE, E.	Gaines	San Andres	1959	5,400	1,218	52	0.08	0.20	1.30	33	110	24,190	3,903
SEMINOLE, W.	Gaines	San Andres	1948	5,042	2,960	100	0.139	0.275	1.382	33	102	167,450	27,947
SHAFTER LAKE	Andrews	San Andres	1929	4,482	15,680	49	0.065	0.30	1.15	30	105	235,833	33,617
SKAGGS	Lea	Grayburg	1937	3,750	3,400	50	0.027	0.182	1.3	36	90	22,406	8,717
WADDELL	Crane	San Andres	1927	3,500	10,000	145	0.10	0.50	1.27	35	90	442,877	89,942
YATES	Pecos	Yates Lime	1926	1,500	26,420	120	0.10	0.20	1.30	30	90	1,513,597	768,661

TABLE C-1(cont.)

Field	County	Zone	Discovery Date	Depth (ft.)	Proved Acreage	Avg. Net Pay (ft)	Average Porosity (frac)	Initial Water Saturation	Formation Volume Factor	Oil Gravity °API	Res. Temp °F	Est. Orig. Oil In Place (mbbls)	Cum. Prod. Thru 1979 (mbbls)
PERMIAN GUADALUPE - MIDLAND BASIN													
ADAIR	Gaines	San Andres	1947	4,870	5,338	50	0.145	0.35	1.12	33	103	174,245	42,671
AZALEA	Midland	Grayburg	1967	4,088	400	18	0.12	0.20*	1.30	30	106	4,124	816
CEDAR LAKE	Gaines	San Andres	1939	4,800	8,600	53	0.12	0.28	1.086	29	103	281,324	63,233
G-M-K	Gaines	San Andres	1957	5,550	1,280	86	0.112	0.427	1.18	32	108	46,446	9,478
MABEE	Andrews	San Andres	1943	4,700	13,500	4	0.11	0.20*	1.30	31	102	28,358	59,604
MIDLAND FARMS	Andrews	Grayburg	1944	4,800	16,300	56	0.15	0.20	1.097	30	102	774,640	113,924
MOORE	Howard	Gry./San An.	1927	3,125	5,200	14	0.09	0.30	1.07	27	104	34,441	8,815
REEVES	Yoakum	San Andres	1957	5,600	6,840	45	0.117	0.30	1.17	31	113	167,153	20,226
SUNILAND	Lynn	San Andres	1956	4,000	160	110	0.14	0.365	1.2	36	139	10,115	2,296
WELCH	Dawson	San Andres	1941	5,000	17,500	44	0.110	0.173	1.11	33	92	491,796	109,507
PERMIAN GUADALUPE - REAGAN UPLIFT													
BIG LAKE	Reagan	Gry./San An.	1923	3,000	6,400	30	0.17	0.20*	1.30	40	104	155,828	125,388
FARMER	Crockett	San Andres	1953	2,240	5,700	40	0.12	0.218	1.2	31	96	138,322	7,789
HALFF	Crockett	Grayburg	1951	2,000	2,900	20	0.158	0.43	0.06	31	98	38,230	3,007
PERMIAN GUADALUPE - EASTERN SHELF													
GARZA	Garza	San Andres	1926	2,900	9,750	54	0.20	0.54	1.3	35	95	289,063	67,099
HOWARD	Howard/Glascock	Gry./San An.	1925	2,066	21,160	76	0.122	0.40	1.30	26	90	702,500	325,221
HUNTLEY	Garza	"3400"	1954	3,400	640	7	0.16	0.20	1.1	37	86	4,044	6,570
HUNTLEY, E.	Garza	San Andres	1956	3,180	850	26	0.16	0.46	1.15	33	104	14,312	4,159
HUNTLEY	Garza	Glorieta	1954	3,966	640	7	0.16	0.20	1.30	37	112	3,422	6,340
P.H.D.	Garza	Glorieta	1944	3,565	2,720	30	0.136	0.331	1.2	35	108	47,998	5,406
ROCKER A	Garza	Glorieta	1955	3,082	1,120	40	0.132	0.615	1.16	34	103	15,226	2,153
ROCKER A	Garza	San Andres	1950	2,485	2,375	15	0.247	0.45	1.14	34	100	32,935	4,118
PERMIAN GUADALUPE - NORTH BASIN													
BRAHANEY	Yoakum	San Andres	1945	5,300	15,000	35	0.08	0.25	1.22	32	111	200,309	30,686
BUCKSHOT	Cochran	San Andres	1956	5,000	12,800	22	0.085	0.248	1.247	21	104	111,983	9,421
LANDON	Yoakum	San Andres	1945	5,100	1,440	50	0.12	0.20*	1.30	30	110	41,248	5,525
LEVELLAND	Hockley	San Andres	1945	4,927	90,000	40	0.110	0.336	1.209	29	108	1,712,587	312,239
OWNBY	Yoakum	San Andres	1941	5,300	2,400	31	0.12	0.38	1.354	30	106	31,715	8,612
RUSSELL	Gaines	Clear Fork	1942	7,350	9,700	75	0.052	0.238	1.279	34	103	174,851	42,272
RUSSELL	Gaines	Glorieta	1942	6,100	1,800	40	0.05	0.184	1.294	34	119	17,612	6,290
SABLE	Yoakum	San Andres	1957	5,258	1,200	39	0.092	0.35	1.2	31	108	18,093	5,644
SLAUGHTER	Cochran	San Andres	1937	5,000	100,000	47	0.098	0.30	1.23	27	108	2,068,219	797,157
WASSON	Yoakum/Gaines	San Andres	1937	4,900	63,500	160	0.095	0.26	1.312	30	120	4,223,426	1,190,937
WASSON 72	Gaines	Clear Fork	1941	7,200	8,320	74	0.05	0.24	1.3	31	121	139,619	35,192
PERMIAN GUADALUPE - TATUM BASIN													
CAPROCK	Chaves/Lea	Queen SS	1940	2,871	29,360	10	0.21	0.35	1.3	36	139	127,492	72,135
CHAVEROO	Chaves/Roosevelt	San Andres	1965	4,184	11,000	40	0.06	0.25	1.3	26	112	118,160	19,519
FLYING M	Lea	San Andres	1964	4,550	3,000	15	0.129	0.25	1.3	26	106	25,981	6,505
LOVINGTON		San Andres	1939	4,600	7,040	40	0.06	0.20*	1.30	33	116	80,664	12,270
MILNESAND	Roosevelt	San Andres	1958	4,554	5,880	40	0.06	0.60	1.3	28	116	33,686	8,782

* Estimated

TABLE C-1(cont.)

Field	County	Zone	Discovery Date	Depth (ft.)	Proved Acreage	Avg. Net Pay (ft)	Average Porosity (frac)	Initial Water Saturation	Formation Volume Factor	Oil Gravity °API	Res. Temp °F	Est. Orig. Oil In Place (mbbls)	Cum. Prod. Thru 1979 (mbbls)
PERMIAN GUADALUPE - DELAWARE BASIN													
PRIEST/BEAVERS	Pecos	Queen SS	1957	2,290	1,900	30	0.145	0.42	1.1	31	87	33,808	1,932
PERMIAN GUADALUPE - NORTHWEST SHELF													
ARTESIA	Eddy	San Andres	1923	1,875	17,760	25	0.21	0.20	1.3	36	97	445,142	24,572
BENSON, N.	Eddy	Queen	1954	2,488	1,760	24	0.13	0.42	1.3	32	108	19,006	2,360
CATO	Chaves	San Andres	1966	3,450	9,140	30	0.075	0.34	1.3	25	105	81,885	14,472
E-K	Lea	Yates/7 Rvrs.	1954	4,375	640	60	0.124	0.392	1.3	37	118	17,276	5,636
LOCO HILLS	Eddy	Gry./San An.	1939	8,900	11,960	65	0.20	0.15	1.3	36	159	784,721	43,103
LOVINGTON, W.	Lea	San Andres	1944	4,700	3,200	50	0.05	0.20*	1.3	36	117	38,193	10,759
MALJAMAR	Lea & Eddy	Gry./San An.	1926	4,050	2,300	450	0.116	0.166	1.3	37	114	597,545	121,282
PEARL	Lea	San Andres	1967	5,320	640	10	0.05	0.20*	1.3	35	123	1,527	62
SQUARE LAKE	Eddy	Gry./San An.	1941	2,700	12,880	15	0.021	0.20*	1.3	38	106	19,369	23,146
VACUUM	Lea	San Andres	1929	4,400	19,200	95	0.088	0.290	1.25	35	118	703,284	180,997
PERMIAN WOLFCAMP - ANADARKO BASIN													
QUINDUNO	Roberts	Albany	1952	4,008	640	25	0.15	0.35	1.5	47	144	4,344	14,797
PERMIAN WOLFCAMP - NORTHWEST SHELF													
KEMITZ	Lea	L. Wolfcamp	1956	10,700	1,320	38	0.093	0.25	1.8	39	158	15,079	14,943
PERMIAN WOLFCAMP - TATUM BASIN													
DENTON	Lea	Wolfcamp	1950	9,150	4,140	50	0.098	0.20	1.3	45	154	96,848	34,852
TOWNSEND	Lea	Wolfcamp	1952	10,400	2,480	29	0.089	0.20*	1.85	40	156	21,473	18,786
PERMIAN WOLFCAMP - MIDLAND BASIN													
ADAIR	Terry/Gaines	Wolfcamp	1950	8,500	2,550	60	0.124	0.245	1.26	43	133	87,914	45,566
BAKKE	Andrews	Wolfcamp	1956	8,500	5,370	23	0.115	0.20*	1.3	40	133	67,810	18,030
FASKEN	Andrews	Wolfcamp	1952	8,571	560	25	0.06	0.20*	1.42	39	144	3,671	5,807
NOLLEY	Andrews	Wolfcamp	1951	9,227	4,476	60	0.07	0.20	1.22	36	130	95,237	20,942
WELLMAN	Terry	Wolfcamp	1950	9,712	1,200	350	0.075	0.20*	1.39	41	150	70,324	44,709
PERMIAN WOLFCAMP - CENTRAL BASIN PLATFORM													
ANDREWS	Andrews	Wolfcamp	1953	8,596	3,360	25	0.088	0.17	1.35	37	127	35,257	17,560
ANDREWS, S.	Andrews	Wolfcamp	1953	9,183	4,960	25	0.04	0.20*	1.3	40	138	23,679	12,089
PECOS VALLEY	Pecos	Wolfcamp	1956	5,200	1,080	40	0.173	0.20*	1.3	36	101	35,680	2,240
SHAFTER LAKE	Andrews	Wolfcamp	1951	8,405	4,980	13	0.134	0.205	1.46	41	125	36,647	11,937
UNIVERSITY	Andrews	Wolfcamp	1953	8,430	4,000	30	0.10	0.268	1.33	38	140	51,276	23,255
PERMIAN OCHOA - DELAWARE BASIN													
FT. STOCKTON	Pecos	Yates	1944	2,892	11,500	37	0.175	0.20*	1.2	33	91	562,067	25,742
PERMIAN LEONARD - MATADOR UPLIFT													
ANTON-IRISH	Hale	Clear Fork	1945	--	9,000	141	0.085	0.20*	1.3	29	127	514,964	123,512

*Estimated

TABLE C-1(cont.)

Field	County	Zone	Discovery Date	Depth (ft.)	Proved Acreage	Avg. Net Pay (ft)	Average Porosity (frac)	Initial Water Saturation	Formation Volume Factor	Oil Gravity °API	Res. Temp °F	Est. Orig. Oil In Place (mbbls)	Cum. Prod. Thru 1979 (mbbls)
PERMIAN LEONARD - DELAWARE BASIN													
FOWLER	Lea	Upper Yeso	1950	6,200	1,200	75	0.015	0.40	1.3	38	132	4,833	3,355
PERMIAN LEONARD - NORTHWEST SHELF													
CORBIN	Lea	Abo	1959	8,400	8,400	70	0.015	0.30	1.3	37	128	36,844	13,052
EMPIRE	Eddy	Abo	1958	6,022	9,600	16	0.015	0.25	1.3	43	130	125,808	185,351
PERMIAN LEONARD - TATUM BASIN													
LOVINGTON	Lea	Paddock	1952	6,150	4,480	25	0.06	0.20*	1.3	33	132	32,082	12,692
LOVINGTON	Lea	Abo	1951	8,117	1,280	125	0.08	0.20*	1.3	39	151	61,109	29,648
PERMIAN LEONARD - EASTERN SHELF													
IATAN, E.	Howard	Clear Fork	1925	2,700	17,000	63	0.12	0.20*	1.30	28	96	613,574	107,268
PAROCHIAL BADE	Sterling	Clear Fork	1954	2,250	1,080	20	0.163	0.20*	1.30	28	98	16,808	2,792
PERMIAN LEONARD - MIDLAND BASIN													
KETCHUM MT.	Irion	Clear Fork	1955	4,548	2,800	12	0.13	0.30	1.48	37	117	16,027	2,381
REVILO	Scurry	Glorietta	1955	2,600	6,430	10	0.140	0.20*	1.16	34	98	48,163	11,220
PERMIAN LEONARD - CENTRAL BASIN PLATFORM													
BLINEBRY	Lea	Yeso	1945	5,600	11,720	60	0.084	0.244	1.3	41	130	266,493	38,811
BROWN & THORP	Pecos	Clear Fork	1951	3,000	3,900	42	0.086	0.35	1.16	38	92	61,237	6,008
DOLLARHIDE	Andrews	Clear Fork	1949	6,500	3,500	40	0.15	0.25	1.4	36	110	87,277	29,743
DOLLARHIDE	Lea	Tubb	1951	6,580	3,480	30	0.08	0.20*	1.3	40	140	39,873	16,386
DOLLARHIDE	Lea	Yeso	1945	6,490	20,650	100	0.116	0.162	1.3	40	138	1,197,921	76,136
FULLERTON	Andrews	Clear Fork	1941	7,000	34,630	75	0.085	0.22	1.62	40	119	825,826	199,544
GOLDSMITH	Ector	Clear Fork	1946	5,600	65,000	100	0.116	0.26	1.55	37	113	893,657	55,610
GOLDSMITH, E.	Ector	Holt	1954	4,950	2,185	48	0.086	0.20*	1.3	38	115	43,061	6,161
GOLDSMITH, W.	Ector	Clear Fork	1956	4,925	65,000	35	0.091	0.20*	1.3	36	115	68,121	6,973
HARRIS	Gaines/Andrews	Glorieta	1949	5,900	5,200	60	0.09	0.20*	1.11	31	122	157,005	30,573
HOBBS	Lea	Blinebry	1968	5,800	1,600	67	0.10	0.42	1.3	37	107	37,104	4,807
MONAHANS	Ward	Clear Fork	1945	4,750	4,800	48	0.107	0.25	1.424	37	90	100,732	8,677
RILEY, N.	Gaines	Clear Fork	1947	6,930	29,000	70	0.077	0.20*	1.285	32	107	754,372	18,232
ROBERTSON, N.	Gaines	Clear Fork	1944	7,220	10,040	35	0.068	0.25	1.38	35	117	100,749	30,719
SANDHILLS	Crane	Tubb	1930	4,360	17,040	50	0.107	0.40	1.23	35	96	345,280	78,746
TUBB	Lea	Tubb	1956	6,105	640	72	0.19	0.20*	1.3	35	135	41,798	5,951
TXL	Ector	Tubb	1950	6,100	17,180	57	0.115	0.20*	1.3	35	125	537,640	33,480
PENNSYLVANIAN-CANYON - BEND ARCH													
BOX	Callahan	Palo Pinto	1952	3,300	1,143	22	0.013	0.20*	1.3	40	126	15,606	6,174
PENNSYLVANIAN-STRAWN - NORTHWEST SHELF													
LUSK	Eddy & Lea	Strawn	1960	11,168	10,240	38	0.05	0.304	1.3	46	181	80,810	18,916

* Estimated

TABLE C-1(cont.)

Field	County	Zone	Discovery Date	Depth (ft.)	Proved Acreage	Avg. Net Pay (ft)	Average Porosity (frac)	Initial Water Saturation	Formation Volume Factor	Oil Gravity °API	Res. Temp °F	Est. Orig. Oil In Place (mbbls)	Cum. Prod. Thru 1979 (mbbls)
PENNSYLVANIAN-STRAWN - TATUM BASIN													
ALLISON	Lea/Roosevelt	Penn.	1954	--	12,175	11	0.07	0.358	1.3	47	154	34,284	21,291
VADA	Lea/Roosevelt	Penn.	1966	9,792	56,320	10	0.08	0.33	1.3	45	145	180,149	40,942
PENNSYLVANIAN-CISCO - TATUM BASIN													
INBE	Lea	Cisco	1962	9,658	4,000	11	0.06	0.20*	1.3	44	143	12,603	16,040
PENNSYLVANIAN-DEVONIAN - TATUM BASIN													
CAPROCK, E.	Lea	Devonian	1951	11,240	1,920	30	0.05	0.20*	1.3	43	182	13,749	22,311
DENTON	Lea	Devonian	1941	11,950	4,560	300	0.08	0.20*	1.3	45	187	522,483	92,722
LOVINGTON	Lea	Devonian	1968	11,476	640	44	0.05	0.20*	1.3	49	184	6,722	1,227
PENNSYLVANIAN-BEND - EASTERN SHELF													
BOYD	Stonewall	Bend Congl.	1951	6,000	2,761	27	0.147	0.20*	1.3	40	128	52,317	21,970
PENNSYLVANIAN-CISCO - EASTERN SHELF													
I.A.B.	Coke	Menielle	1957	5,250	4,903	45	0.056	0.25	1.825	44	134	39,392	17,596
INBE	Lea	Cisco	1962	9,858	4,000	27	0.06	0.20*	1.3	44	143	30,933	16,040
JAMESON	Coke	Penn Reef	1946	6,600	6,000	71	0.083	0.20*	1.3	46	146	168,804	39,778
SUSAN PEAK	Tom Green	Cisco Canyon	1948	4,600	2,240	43	0.14	0.20	1.41	36	154	59,356	1,762
PENNSYLVANIAN-CANYON - EASTERN SHELF													
CLAYTONVILLE	Fisher	Canyon Reef	1952	5,695	3,360	19	0.07	0.20	1.3	40	142	21,334	57,817
COGDELL	Kent & Scurry	Canyon Reef	1949	6,796	15,050	40	0.10	0.35	1.3	41	136	233,515	232,033
DIAMOND M	Scurry	Canyon Lm.	1948	6,569	13,712	96	0.10	0.28	1.53	42	128	480,756	216,080
KELLY-SNYDER	Scurry	Canyon Reef	1948	6,795	52,925	139	0.079	0.28	1.51	41	130	2,149,849	1,020,651
OCHOJUAN	Fisher	Canyon Reef	1955	6,600	1,160	45	0.06	0.45	1.3	40	147	10,279	5,015
ROUNDTOP	Fisher	Palo Pinto	1947	4,758	3,121	55	0.107	0.25	1.4	40	131	76,334	38,390
SALT CREEK	Kent	Canyon Reef	1950	6,200	9,269	180	0.09	0.29	1.29	40	129	642,529	178,420
PENNSYLVANIAN-STRAWN - EASTERN SHELF													
CLAIRMONT	Kent	Strawn	1950	6,700	5,900	23	0.07	0.39	1.33	39	144	33,799	13,152
FT. CHADBOURNE	Runnels	Odom Lm.	1949	5,600	15,170	42	0.05	0.20*	1.3	44	138	152,090	52,299
H-J	Tom Green	Strawn Reef	1954	5,502	3,500	30	0.07	0.28	1.35	41	142	30,411	20,995
JAMESON	Coke	Strawn	1949	5,745	10,535	57	0.116	0.20*	1.3	48	136	332,555	35,798
NEILL, S.	Fisher	Odom Lm.	1955	5,700	8,975	12	0.08	0.20*	1.3	44	142	41,134	6,988
NENA LUCIA	Nolan	Strawn Reef	1955	6,884	14,650	52	0.07	0.35	1.3	45	153	208,840	30,689
PAGE	Schleicher	Strawn	1936	5,725	1,960	47	0.075	0.20*	1.3	37	162	32,984	4,804
PENNSYLVANIAN-STRAWN - REAGAN UPLIFT													
TODD DEEP	Crockett	Crinold	1940	5,778	1,894	80	0.117	0.19	1.328	40	163	83,886	29,437
WORLD, W.	Crockett	Strawn	1954	8,190	2,940	33	0.092	0.20	2.618	41	158	21,160	8,103
PENNSYLVANIAN-STRAWN - MIDLAND BASIN													
AZALEA	Midland	Strawn	1966	10,320	8,000	160	0.08	0.20*	1.3	58	163	30,554	49
FLUVANNA	Borden	Strawn	1949	7,769	3,840	11	0.094	0.20*	1.434	41	140	17,184	11,940

* Estimated

TABLE C-1(cont.)

Field	County	Zone	Discovery Date	Depth (ft.)	Proved Acreage	Avg. Net Pay (ft)	Average Porosity (frac)	Initial Water Saturation	Formation Volume Factor	Oil Gravity °API	Res. Temp °F	Est. Orig. Oil In Place (mbbls)	Cum. Prod. Thru 1979 (mbbls)
PENNSYLVANIAN-BEND - MIDLAND BASIN													
AMACKER TIPPET,S	Upton	Bend	1961	8,596	4,300	41	0.06	0.33	2.4	52	162	22,909	6,116
OCEANIC	Howard	Penn.	1953	8,140	1,880	55	0.12	0.18	1.52	42	160	51,930	20,115
PARKS	Midland	Penn.	1950	10,500	7,130	14	0.067	0.33	2.067	43	174	16,818	13,071
PEGASUS	Upton-Midland	Bend	1951	10,470	10,000	28	0.067	0.33	2.01	44	164	49,379	14,287
PENNSYLVANIAN-CISCO - MIDLAND BASIN													
REINECKE	Borden	Cisco	1950	6,791	2,800	90	0.093	0.20	1.795	44	98	81,032	63,317
VEALMOOR, E.	Howard	Cisco/Wolfcp.	1950	6,960	3,600	100	0.102	0.20*	1.3	40	155	87,653	19
PENNSYLVANIAN-CANYON - MIDLAND BASIN													
ROPES	Hockley	Canyon Reef	1950	9,290	1,803	100	0.085	0.24	1.319	41	159	68,506	22,272
VEALMOOR	Howard	Canyon Reef	1948	7,934	280	75	0.10	0.293	1.695	46	165	18,664	33,749
VEALMOOR, E.	Borden & Howard	Canyon Reef	1950	7,414	3,500	30	0.15	0.163	1.804	47	155	56,691	49,007
VON ROEDER	Borden	Canyon Reef	1959	6,835	1,730	45	0.10	0.36	1.653	38	134	23,383	15,823
PENNSYLVANIAN-BEND - CENTRAL BASIN PLATFORM													
UNIVERSITY	Andrews	Penn.	1954	8,956	2,800	40	0.120	0.30	1.489	40	151	49,017	10,508
PENNSYLVANIAN-BEND - ANADARKO													
HITCHLAND	Hansford	Collier	1954	4,640	13,110	8	0.09	0.20*	1.3	43	125	44,047	3,499
TWIN	Hansford	Des Moines	1956	6,135	640	38	0.06	0.20*	1.3	41	142	6,966	7,791
TWIN	Hansford	Morrow	1954	7,082	700	25	0.145	0.20*	1.3	39	148	12,144	2,660
MISSISSIPPIAN - BEND ARCH													
SHACKELFORD, NE	Shackelford	Miss.	1960	4,592	10,000	100	0.06	0.20*	1.3	42	147	286,449	3,652
DEVONIAN - NORTH BASIN													
RUSSELL, N.	Gaines	Devonian	1948	11,125	1,322	65	0.061	0.131	1.08	38	155	32,720	72,708
DEVONIAN - MIDLAND BASIN													
AZALEA	Midland	Devonian	1957	11,520	36,000	63	0.04	0.40	1.3	47	173	324,833	381
BREEDLOVE	Martin	Devonian	1951	12,078	3,520	46	0.09	0.55	1.09	40	195	46,674	26,092
DORA ROBERTS	Midland	Devonian	1955	12,010	7,000	124	0.066	0.20*	1.3	45	178	136,750	1,928
HUTEX	Andrews	Devonian	1953	12,509	4,480	60	0.055	0.34	1.3	34	162	58,229	33,687
MAGUTEX	Andrews	Devonian	1953	12,504	5,760	40	0.065	0.20	1.41	43	187	65,919	38,833
DEVONIAN - CENTRAL BASIN PLATFORM													
ANDREWS, S.	Andrews	Devonian	1953	10,700	7,840	22	0.056	0.20*	1.3	47	145	46,113	9,920
BLOCK 11	Andrews	Devonian	1951	8,230	1,735	45	0.252	0.20*	1.3	42	132	93,931	7,319
BLOCK 31	Crane	L. Devonian	1945	8,500	8,700	170	0.15	0.20*	1.3	41	147	529,573	162,729
CRAWAR	Crane	Devonian N.	1958	6,450	480	30	0.20	0.45	1.36	35	126	9,035	4,242
CROSSETT	Crane	Devonian	1944	5,400	1,120	60	0.22	0.35	1.98	44	119	37,652	12,183
CROSSETT, S.	Crockett	Devonian	1956	5,200	3,450	37	0.175	0.25	1.3	42	122	99,983	13,572
DOLLARHIDE	Andrews	Devonian	1955	8,051	5,632	70	0.135	0.20	1.65	38	120	157,652	69,418
DOLLARHIDE	Lea	Devonian	1952	8,000	720	75	0.09	0.27	1.65	40	156	23,202	6,608
DOLLARHIDE, E.	Andrews	Devonian	1949	10,186	1,120	15	0.21	0.29	1.67	40	141	11,636	5,478
FULLERTON 8500	Andrews	Devonian	1944	8,500	6,500	125	0.09	0.20	1.2	43	147	378,202	42,937

TABLE C-1(cont.)

Field	County	Zone	Discovery Date	Depth (ft.)	Proved Acreage	Avg. Net Pay (ft)	Average Porosity (frac)	Initial Water Saturation	Formation Volume Factor	Oil Gravity °API	Res. Temp °F	Est. Orig. Oil In Place (mbbls)	Cum. Prod. Thru 1979 (mbbls)
DEVONIAN - CENTRAL BASIN PLATFORM													
GOLDSMITH, N.	Ector	Devonian	1946	8,000	1,050	37	0.20	0.20*	1.3	39	142	37,596	6,785
HARPER	Ector	Devonian	1962	10,100	3,070	70	0.088	0.20*	1.3	42	161	90,285	6,837
LEA	Lea	Devonian	1960	14,350	1,440	124	0.065	0.25	1.3	56	213	51,947	6,120
PECOS VALLEY	Pecos	Devonian	1953	5,500	1,400	60	0.20	0.20*	1.3	34	103	82,497	4,619
THREE BAR	Andrews	Devonian	1945	8,385	1,700	70	0.199	0.30	1.6	41	133	80,376	34,220
YARBOROUGH/ALLEN	Ector	Devonian	1954	8,500	1,600	80	0.08	0.20*	1.3	37	147	48,887	2,536
SILURIAN - MIDLAND BASIN													
BIG SPRINGS	Howard	Fusselman	1955	9,590	1,840	14	0.119	0.30	1.5	49	165	11,098	5,807
GOOD, S.E.	Borden	Fusselman	1958	9,692	3,800	30	0.055	0.35	1.37	43	167	23,078	8,293
LUTHER, S.E.	Devonian	Silurian	1953	9,855	3,600	25	0.127	0.30	1.63	43	168	38,080	18,346
TEX-HAMON	Dawson	Fusselman	1962	11,574	1,200	52	0.070	0.35	1.045	40	143	21,078	14,999
SILURIAN - CENTRAL BASIN PLATFORM													
ARMER	Crane	Fusselman	1955	6,340	960	34	0.06	0.20*	1.4	38	121	8,681	3,915
DOLLARHIDE	Andrews	Montoya	1947	8,500	2,587	194	0.058	0.20*	1.57	42	130	115,071	35,187
KEYSTONE	Winkler	Silurian	1947	8,100	4,480	80	0.06	0.30	1.61	31	125	72,533	25,199
ORDOVICIAN - REAGAN UPLIFT													
BARNHART	Reagan	Ellenburger	1941	9,000	9,600	78	0.032	0.20	1.3	44	160	114,396	15,856
ELKHORN	Crockett	Ellenburger	1951	7,185	2,700	232	0.024	0.355	1.412	37	179	22,964	11,368
TODD DEEP	Crockett	Ellenburger	1940	6,232	2,600	154	0.09	0.342	1.32	40	136	139,360	40,258
ORDOVICIAN - MIDLAND BASIN													
DORA ROBERTS	Midland	Ellenburger	1954	12,835	4,062	204	0.024	0.20*	1.3	52	186	94,946	47,349
ORDOVICIAN - CENTRAL BASIN PLATFORM													
DOLLARHIDE	Andrews	Ellenburger	1944	10,500	2,555	187	0.022	0.20*	1.29	41	144	50,571	24,754
DOLLARHIDE	Lea	Ellenburger	1951	10,000	705	187	0.022	0.20*	1.3	42	170	13,846	3,306
GOLDSMITH, W.	Ector	Ellenburger	1954	9,500	450	100	0.04	0.25	1.3	44	165	8,056	3,657
JUSTIS	Lea	Ellenburger	1957	7,700	1,280	85	0.025	0.45	1.3	39	147	8,927	7,257
LEA	Crane	Ellenburger	1953	8,200	2,066	40	0.018	0.20*	1.3	42	139	30,773	19,323
TXL	Ector	Ellenburger	1949	9,600	5,900	150	0.045	0.15	1.63	44	160	161,115	126,197
YARBOROUGH/ALLEN	Ector	Ellenburger	1947	10,490	3,040	24	0.014	0.33	1.36	41	147	4,486	39,430

* Estimated

TABLE C-2

BASIC VOLUMETRIC DATA FOR CARBONATE RESERVOIRS IN THE WILLISTON BASIN

Field	County	Zone	Discovery Date	Depth (ft.)	Proved Acreage	Avg. Net Pay (ft)	Average Porosity (frac)	Initial Water Saturation	Formation Volume Factor	Oil Gravity °API	Res. Temp °F	Est. Orig. Oil In Place (mbbls)	Cum. Prod. Thru 1978 (mbbls)
					MONTANA - PENNSYLVANIAN RESERVOIRS								
WOLF SPRINGS	Yellowstone	Amsden	1955	6,200	3,520	11	0.06	0.23	1.07	30	159*	12,970	4,552
					MONTANA - MISSISSIPPIAN RESERVOIRS								
BRORSON	Richland	Miss. Can.	1954	9,600	1,280	40	0.05	0.40	1.40	32	230*	8,512	461
CABIN CREEK	Fallon	Madison	1956	7,300	2,260	25	0.11	0.30	1.13	33	180	25,601	14,007
DWYER	Sheridan	Ratcliffe	1960	8,000	4,480	38	0.11	0.56	1.32	37	193	48,427	5,975
FLAT LAKE	Sheridan	Ratcliffe	1964	6,500	9,600	14	0.15	0.45	1.26	33	164*	68,270	11,384
GOOSE LAKE	Sheridan	Ratcliffe	1962	7,000	6,880	40	0.16	0.55	1.20	34	172*	128,100	7,038
MONDAK WEST	Richland	Madison	1976	9,200	9,600	100	0.04	0.60	1.30	30	225*	91,664	1,228
POPLAR, EAST	Roosevelt	Charles	1952	5,500	18,070	25	0.11	0.30	1.10	40	164*	210,281	42,783
RICHEY	McCone et al	Charles	1951	7,000	1,440	25	0.04	0.30	1.22	37	200*	5,494	1,915
VAUX	Richland	Miss. Can.	1977	8,800	1,440	40	0.04	0.45	1.20	34	218*	8,193	82
					MONTANA - SILURIAN-DEVONIAN RESERVOIRS								
OUTLOOK	Sheridan	Sil.-Dev.	1956	9,000	1,600	20	0.08	0.30	1.12	38	204*	12,413	5,501
RAYMOND	Sheridan	Nisku	1972	7,900	640	22	0.08	0.50	1.40	50	186*	3,121	521
RAYMOND	Sheridan	Winnipeg.	1972	9,300	960	40	0.05	0.10	1.17	42	208*	11,458	844
RICHEY, S.W.	McCone	Interlake	1952	9,200	1,160	27	0.09	0.30	1.37	48	207*	11,174	1,848
TULE CREEK	Roosevelt	Nisku	1960	7,500	1,280	25	0.15	0.30	1.41	46	202*	18,487	7,263
VOLT	Roosevelt	Nisku	1964	7,300	800	14	0.20	0.30	1.40	47	198*	8,689	2,236

* Estimated

TABLE C-2 (con't.)

MONTANA - ORDOVICIAN RESERVOIRS

Field	County	Zone	Discovery Date	Depth (ft.)	Proved Acreage	Avg. Net Pay (ft)	Average Porosity (frac)	Initial Water Saturation	Formation Volume Factor	Oil Gravity °API	Res. Temp °F	Est. Orig. Oil In Place (mbbls)	Cum. Prod. Thru 1978 (mbbls)
BAINVILLE, N.	Roosevelt	Winnipegosis	1979	11,600	960	35	0.07	0.20	1.60	45	280*	9,123	47
BIG MUDDY CREEK	Roosevelt	Red River	1975	11,900	1,280	11	0.14	0.36	1.72	48	286*	5,690	818
BLUE HILL	Richland	Red River	1977	12,600	640	32	0.10	0.60	1.35	48	286*	4,708	100
BRORSON	Richland	Red River	1968	12,600	960	20	0.10	0.35	1.70	48	286*	5,695	1,944
BRORSON, S.	Richland	Red River	1968	12,600	960	20	0.12	0.30	1.70	48	286*	6,309	1,178
BRUSH LAKE	Sheridan	Red River	1969	11,400	2,240	30	0.14	0.35	1.50	40	242*	31,628	1,929
BURNS CREEK	Dawson	Red River	1972	11,400	640	14	0.14	0.40	1.25	39	242*	4,671	170
CABIN CREEK	Fallon	Red River	1953	9,000	7,620	50	0.13	0.30	1.20	33	200	224,148	61,961
CLEAR LAKE	Sheridan	Red River	1977	11,200	1,920	32	0.18	0.35	1.65	42	239*	33,799	228
CRANE	Richland	Red River	1979	11,900	640	20	0.12	0.30	1.65	47	274*	5,055	18
CULBERTSON	Roosevelt	Red River	1969	11,900	640	20	0.12	0.16	1.80	48	286*	5,561	69
CUPTON	Fallon	Red River	1955	9,600	1,760	40	0.12	0.30	1.25	38	223*	36,702	1,355
DAGMAR	Sheridan	Red River	1976	11,300	640	22	0.16	0.35	1.65	37	240*	6,885	116
DEER CREEK	Dawson	Interlake	1952	9,400	480	38	0.07	0.30	1.20	43	210*	5,778	1,279
ENID, N.	Richland	Red River	1979	11,800	640	8	0.07	0.34	1.75	47	272*	1,049	20
FAIRVIEW	Richland	Red River	1965	12,700	1,920	35	0.11	0.28	1.70	47	288*	24,288	5,567
FERTILE PRAIRIE	Fallon	Red River	1952	9,300	560	6	0.14	0.27	1.20	29-33	182	2,220	442
FOUR MILE CR. W	Richland	Red River	1976	12,500	640	15	0.13	0.40	1.30	45	285*	4,469	151
GLENDIVE	Dawson	Red River	1952	8,900	1,280	147	0.08	0.35	1.25	38	215	60,725	11,153
HAY CREEK	Richland	Red River	1969	12,600	960	53	0.12	0.25	1.90	46	236*	18,698	922
LITTLE BEAVER	Fallon	Red River	1952	8,300	2,390	37	0.12	0.35	1.40	29	193	38,222	8,838
LITTLE BEAVER E.	Fallon	Red River	1954	8,300	1,600	24	0.13	0.35	1.40	30	200	16,782	4,441
LONE BUTTE	Richland	Red River	1974	12,400	640	14	0.11	0.30	1.70	45	283*	3,149	270
LOOKOUT BUTTE	Fallon	Interlake	1961	8,900	6,100	15	0.15	0.25	1.15	33	211*	69,443	17,274
MEDICINE LAKE	Sheridan	Red River	1979	11,700	1,600	32	0.17	0.31	1.78	44	247*	26,176	233

* Estimated

TABLE C-2 (con't.)

MONTANA - ORDOVICIAN RESERVOIRS

Field	County	Zone	Discovery Date	Depth (ft.)	Proved Acreage	Avg. Net Pay (ft)	Average Porosity (frac)	Initial Water Saturation	Formation Volume Factor	Oil Gravity °API	Res. Temp °F	Est. Orig. Oil In Place (mbbls)	Cum. Prod. Thru 1978 (mbbls)
MON DAK WEST	Richland	Red River	1976	12,300	1,920	45	0.10	0.43	1.64	48	281*	23,297	417
NOHLY	Richland	Red River	1972	12,900	640	25(?)	0.10	0.40	1.43	46	292*	5,208	895
OTIS CREEK	Richland	Red River	1970	12,700	1,280	23	0.12	0.35	1.76	48	288*	10,122	567
PINE	Fallon	Interlake	1951	8,400	13,320	32	0.12	0.30	1.17	34	190	237,409	89,966
RAYMOND	Sheridan	Red River	1972	10,000	640	33	0.12	0.27	1.42	39	220*	10,108	340
RESERVE	Sheridan	Red River	1966	11,100	1,280	18	0.06	0.30	1.30	39	237*	5,775	776
SAND CREEK	Dawson	Red River	1959	9,000	880	25	0.10	0.40	1.30	39	204*	7,877	2,210
SECOND CREEK	Richland	Red River	1972	12,700	1,280	30	0.07	0.40	1.50	46	288*	8,341	757
SIOUX PASS	Richland	Red River	1973	12,700	2,240	40	0.09	0.35	1.70	47	288*	23,920	1,921
SIOUX PASS MID.	Richland	Red River	1976	12,600	1,600	17	0.16	0.25	1.40	45	286*	18,087	466
SIOUX PASS N.	Richland	Sil.-Ordo.	1974	12,000	2,880	44	0.12	0.45	1.60	45	276*	40,553	1,039
SPRING LAKE	Richland	Red River	1963	11,700	480	9	0.12	0.20	2.00	51	270*	1,609	681
SUNNY HILL	Sheridan	Red River	1978	12,000	960	25	0.17	0.50	1.38	45	252*	11,468	50
VAUX	Richland	Red River	1976	12,400	1,920	24	0.14	0.45	1.60	48	283*	17,204	174

* Estimated

TABLE C-2 (con't.)

BASIC VOLUMETRIC DATA FOR CARBONATE RESERVOIRS IN THE WILLISTON BASIN

NORTH DAKOTA - MISSISSIPPIAN RESERVOIRS

Field	County	Zone	Discovery Date	Depth (ft.)	Proved Acreage	Avg. Net Pay (ft)	Average Porosity (frac)	Average Water Saturation	Formation Volume Factor	Oil Gravity °API	Res. Temp °F	Est. Orig. Oil In Place (mbbls)	Cum. Prod. Thru 1978 (mbbls)
ANTELOPE	McKenzie	Madison	1956	9,057	4,160	67	0.047	0.32	1.71	39	240	40,414	13,870
BEAVER LODGE	Williams	Madison	1952	8,555	16,028	66	0.08	0.42	2.14	43	224	177,842	48,443
BLACK SLOUGH	Burke	Madison	1959	6,763	8,730	12	0.12	0.35	1.48	38	147	42,833	3,492
BLUE BUTTES	McKenzie	Madison	1955	9,290	13,200	19	0.07	0.41	1.8	41	241	44,643	23,601
CAPA	Williams	Madison	1953	8,317	7,180	49	0.10	0.42	2.26	43	226	70,047	11,043
CHARLSON	McKenzie	Madison	1952	8,998	8,000	77	0.086	0.39	2.06	41	236	121,700	20,752
DIMMICK LAKE	McKenzie	Madison	1957	9,000	1,280	22	0.08	0.40	2.0*	44	240	5,243	1,679
EAST TIOGA	Montrail	Madison	1953	5,930	800	20	0.08	0.40	1.5*	38	214	3,972	1,178
ELMORE	Renville	Madison	1961	4,000	800	14	0.15	0.35	1.3*	32	120*	6,517	1,422
FRYBURG	Billings	Madison	1953	9,403	5,440	17	0.16	0.42	2.0*	41	244	33,290	8,047
GLENBURN	Renville et al	Madison	1958	4,475	2,800	20	0.173	0.35	1.06	28	134	46,088	13,266
HAAS	Bottineau	Madison	1956	4,004	1,920	16	0.145	0.47	1.11	29	120	16,500	4,062
HAWKEYE	McKenzie	Madison	1955	9,230	5,840	36	0.08	0.26	2.0*	41	240*	47,608	12,477
HOFFLUND	Williams	Madison	1952	8,700	2,140	38	0.085	0.375	2.08	43	234	16,113	2,664
KUROKI	Bottineau	Madison	1956	3,377	900	15	0.09	0.30	1.20	38	118	5,499	492
LIGNITE	Burke	Madison	1957	6,107	3,040	20	0.18	0.25	1.47	39	172	43,318	2,863
LITTLE KNIFE	Billings et al	Madison	1976	9,800	16,000	25	0.15	0.40	1.78	43	240	156,903	5,845
McGREGOR	Williams	Madison	1954	8,148	880	16	0.172	0.34	1.63	41	216	7,607	1,480
MEDORA	Billings	Madison	1964	9,000	6,400	14	0.20	0.44	1.75*	40	238	44,488	4,265
NEWBURG	Bottineau	Spearfish	1955	3,403	8,000	18	0.17	0.53	1.23	36	110	71,763	19,804
NOONAN	Divide	Madison	1956	7,076	1,120	10	0.10	0.45	1.45	37	160	3,296	693
NE FOOTHILLS	Burke	Madison	1959	6,632	1,280	15	0.10	0.30	1.50	40	147	6,951	3,462
NE LANDA	Bottineau	Madison	1953	3,073	480	15	0.14	0.35	1.25*	37	104	4,066	1,095
NORTH SOURIS	Bottineau	Madison	1955	2,980	160	26	0.143	0.45	1.13	37	114	2,246	731
NORTH TIOGA	Burke et al	Madison	1957	8,008	14,000	14	0.122	0.27	1.73	42	216	78,279	14,575

* Estimated

TABLE C-2(con't.)

NORTH DAKOTA - MISSISSIPPIAN RESERVOIRS

Field	County	Zone	Discovery Date	Depth (ft.)	Proved Acreage	Avg. Net Pay (ft)	Average Porosity (frac)	Average Water Saturation	Formation Volume Factor	Oil Gravity °API	Res. Temp °F	Est. Orig. Oil In Place (mbbls)	Cum. Prod. Thru 1978 (mbbls)
NORTH WESTHOPE	Bottineau	Madison	1953	3,216	1,700	30	0.10	0.35	1.20	35	109	21,432	1,954
NW McGREGOR	Williams	Madison	1954	8,200	960	14	0.105	0.40	1.75*	42	220*	3,754	1,234
PERSHING	McKenzie	Madison	1958	6,810	600	28	0.08	0.40	1.75*	43	241	3,575	1,330
RIVAL	Burke	Madison	1957	6,067	8,640	18	0.088	0.29	1.6	40	172	47,115	12,836
ROUGH RIDER	McKenzie	Madison	1959	9,300	960	25	0.18	0.35	1.68	38	226	12,959	3,293
SCOTIA	Bottineau	Madison	1955	3,244	320	9	0.13	0.35	1.25*	37	126	1,510	180
SHERWOOD	Renville	Madison	1958	4,204	1,280	24	0.10	0.57	1.20	29	134	19,215	12,849
STARBUCK	Bottineau	Spearfish	1959	1,840	560	15	0.14	0.38	1.14	38	110	4,962	577
S. ANTLER CREEK	Bottineau	Madison	1964	3,700	800	16	0.18	0.38	1.25*	36	110	8,866	633
S. STARBUCK	Bottineau	Madison	1959	3,248	160	10	0.14	0.385	1.14	38	110	938	146
TIOGA	Williams et al	Madison	1952	8,312	23,500	40	0.08	0.34	1.98	42	212	194,173	53,404
WHITE EARTH	Montrail	Madison	1954	8,420	5,600	20	0.08*	0.35	1.75*	40	208	25,819	2,611

NORTH DAKOTA - DEVONIAN RESERVOIRS

ANTELOPE	McKenzie	Duperow & Nisku	1960	10,728	1,280	50	0.10	0.35	1.40*	40	263	23,052	4,353
ANTELOPE	McKenzie	Sanish	1953	10,525	5,453	20	0.085	0.35	1.40	44	256	33,390	10,366
BEAVER LODGE	Williams	Duperow	1951	10,490	10,240	17	0.12	0.35	1.40*	42	249	75,243	32,707
CAMEL BUTTE	McKenzie	Duperow	1964	11,360	640	32	0.165	0.35*	1.40*	41	265*	12,172	617
NORTH FORK	McKenzie	Duperow	1965	11,630	640	14	0.08*	0.35*	1.40*	49	270*	2,582	565

NORTH DAKOTA - SILURIAN RESERVOIRS

ANTELOPE	McKenzie	Interlake	1960	11,750	960*	21	0.075	0.35*	1.40*	44	274	5,446	3,335
BEAVER LODGE	Williams	Silurian	1951	11,630	5,760	38	0.074	0.35	1.40*	53	265	58,341	6,490

* Estimated

TABLE C-2 (con't.)

NORTH DAKOTA - ORDOVICIAN RESERVOIRS

Field	County	Zone	Discovery Date	Depth (ft.)	Proved Acreage	Avg. Net Pay (ft)	Average Porosity (frac)	Average Water Saturation	Formation Volume Factor	Oil Gravity °API	Res. Temp °F	Est. Orig. Oil In Place (mbbls)	Cum. Prod. Thru 1978 (mbbls)
BEAVER LODGE	Williams	Red River	1957	10,600	1,280*	48	0.08	0.18	1.40*	53	196	22,334	3,022
BUFFALO CREEK	Stork	Red River	1966	10,200	640	7	0.13	0.35	1.40*	49	190*	2,098	393
CEDAR CREEK	Bowman	Red River	1960	8,390	1,100	53	0.14	0.30	1.2	29	?	36,437	10,825
ELEVEN BAR	Slope	Red River	1966	11,300	1,280	34	0.20	0.35*	1.40*	47	200*	31,351(?)	599

* Estimated

TABLE C-2 (con't.)

BASIC VOLUMETRIC DATA FOR CARBONATE RESERVOIRS IN THE WILLISTON BASIN

SOUTH DAKOTA - ORDOVICIAN RESERVOIRS

Field	County	Zone	Discovery Date	Depth (ft.)	Proved Acreage	Avg. Net Pay (ft)	Average Porosity (frac)	Initial Water Saturation	Formation Volume Factor	Oil Gravity °API	Res. Temp °F	Est. Orig. Oil In Place (mbbls)	Cum. Prod. Thru 1978 (mbbls)
BUFFALO	Harding	Red River	1954	8,600	3,840	13	0.131	0.50	1.2	30	180	21,136	3,675

TABLE C-3

BASIC VOLUMETRIC DATA FOR CARBONATE RESERVOIRS IN VARIOUS ROCKY MOUNTAIN BASINS

Field	County	Zone	Discovery Date	Depth (ft.)	Proved Acreage	Avg. Net Pay (ft)	Average Porosity (frac)	Initial Water Saturation	Formation Volume Factor	Oil Gravity °API	Res. Temp °F	Est. Orig. Oil In Place (mbbls)	Cum. Prod. Thru 1979 (mbbls)
MONTANA - SWEETGRASS ARCH - MISSISSIPPIAN													
CUT BANK		Madison	1945	3,000	3,200	10	0.14	0.30	1.10	34	122	22,117	6,787
KEVIN-SUNBURST	Toole	Madison	1922	1,500	40,200	7	0.20	0.35	1.3	32	85	262,780	72,896
PONDERA	Pondera & Teta	Madison	1927	2,100	5,560	15	0.16	0.31	1.20	34	93	59,525	21,435
REAGAN	Glacier	Madison	1947	3,200	2,600	11	0.12	0.30	1.20	38	133	15,531	6,575
COLORADO - PARADOX BASIN - PENNSYLVANIAN													
CACHE	Montezuma	Ismay	1964	5,620	1,040	57	0.104	0.35	1.4	45	143	22,206	3,377
FLODINE PARK	Montezuma	Ismay	1959	5,860	1,440	41	0.11	0.41	1.4	45	146	21,233	2,127
MARBLE WASH	Montezuma	Ismay	1958	5,760	400	15	0.10	0.40	1.4	42	145	1,994	687
TOWACO	Montezuma	Ismay	1959	5,820	160	16	0.10	0.44	1.35	42	146	823	409
NEW MEXICO - PARADOX BASIN - PENNSYLVANIAN													
TOCITO DOME	San Juan	Hermosa	1963	6,940	2,600	17	0.086	0.20	1.3	44	160	14,744	12,012
UTAH - PARADOX BASIN - PENNSYLVANIAN													Thru 1977
GR. ANETH	Desert Creek	Ismay	1956	5,550	16,720	49	0.10	0.23	1.35	42	142	363,525	96,106
ANETH-McELMO	San Juan	Ismay	1957	5,500	12,640	65	0.10	0.22	1.5	42	142	331,446	96,489
ANETH-RATHERFD.	San Juan	Desert Cr.	1956	5,500	12,900	55	0.10	0.25	1.35	41	142	305,794	61,787
ANETH-WHITEMESA	San Juan	Desert Cr.	1957	5,600	5,120	44	0.09	0.28	1.35	41	142	83,890	22,498
ISMAY	San Juan	Ismay	1956	5,660	4,370	24	0.07	0.41	1.4	44	142	24,002	9,711
LONG CANYON	Grand	Cane Creek	1962	7,050	640	25	0.05	0.30	1.3	40	161	3,103	738
McELMO MESA	San Juan	Ismay	1964	5,540	2,240	29	0.10	0.37	1.3	40	142	22,678	2,118
TOHONALDA	San Juan	Akah	1957	5,800	1,200	25	0.10	0.30	1.3	35	145	11,637	1,725
TOHONALDA	San Juan	Desert Cr.	1957	5,200	1,200	15	0.05	0.23	1.4	40	138	3,840	1,725
TOHONALDA	San Juan	Honaker	1957	5,100	1,200	25	0.10	0.254	1.4	35	136	12,401	1,725
UTAH - PARADOX BASIN - MISSISSIPPIAN													Thru 1977
LISBON	San Juan	Redwall Lm.	1960	7,750	5,120	225	0.055	0.39	1.3	54	171	214,174	40,255
SALT WASH	Grand	Leadville	1961	8,693	920	28	0.078	0.25	1.3	50	183	8,350	1,182
UTAH - EASTERN OVERTHRUST - JURASSIC													Thru 1977
PINEVIEW	Summit	Twin Creek	1975	9,850	1,600	100	0.03	0.30	1.5	46	218	7,447	3,535
UTAH - UINTA BASIN - PERMIAN													Thru 1977
ASHLEY VALLEY	Uintah	Phosphoria	1948	4,100	780	14	0.05	0.30	1.4	32	132	2,117	18,831

TABLE C-3 (cont.)

Field	County	Zone	Discovery Date	Depth (ft.)	Proved Acreage	Avg. Net Pay (ft)	Average Porosity (frac)	Initial Water Saturation	Formation Volume Factor	Oil Gravity °API	Res. Temp °F	Est. Orig. Oil In Place (mbbls)	Cum. Prod. Thru 1979 (mbbls)
WYOMING - BIG HORN BASIN - PERMIAN													
COTTONWOOD CR.	Washakie	Phosphoria	1953	7,270	32,979	53	0.03	0.30	1.4	30	190	203,401	42,239
FRISBY, S.	Washakie	Phosphoria	1949	10,575	640	83	0.01	0.30	1.4	32	228	2,060	1,356
GEBO	Hot Springs	Phosphoria	1943	4,700	2,560	30	0.09	0.30	1.4	29	140	26,811	24,645
LAKE CREEK	Hot Springs	Phosphoria	1925	3,690	2,560	44	0.05	0.30	1.4	24	125	21,846	8,576
MANDERSON	Big Horn	Phosphoria	1951	7,200	7,106	45	0.05	0.30	1.4	33	178	62,490	3,547
SLICK CREEK	Washakie	Phosphoria	1950	10,400	2,560	26	0.09	0.30	1.4	33	226	23,236	4,722
TORCHLIGHT	Big Horn	Phosphoria	1913	2,700	3,200	36	0.05	0.30	1.4	31	110	22,343	14,177
WYOMING - WIND RIVER BASIN - PERMIAN													
BIG SAND DRAW	Fremont	Phosphoria	1918	7,000	4,480	50	0.05	0.30	1.4	62	182	43,444	53,147
CIRCLE RIDGE	Fremont	Phosphoria	1923	950	3,200	50	0.05	0.30	1.4	24	72	31,032	20,882
STEAMBOAT BUTTE	Fremont	Phosphoria	1943	6,730	3,840	60	0.05	0.30	1.4	31	178	44,686	78,659
WYOMING - WIND RIVER BASIN - MISSISSIPPIAN													
BEAVER CREEK	Fremont	Madison	1938	11,000	3,200	25	0.05	0.30	1.4	42	246	15,516	48,200
CIRCLE RIDGE	Fremont	Madison	1946	1,700	3,200	25	0.05	0.30	1.4	23	97	15,516	20,888
WYOMING - POWDER RIVER BASIN - MISSISSIPPIAN													
MULE CREEK	Niobrara	Miss.	1919	2,712	2,560	10	0.05	0.30	1.4	32	114	4,965	3,356
WYOMING - GREAT DIVIDE BASIN - MISSISSIPPIAN													
LOST SOLDIER	Sweetwater	Madison	1948	5,700	1,320	188	0.13	0.30	1.1	35	161	159,268	73,412
WYOMING - RED DESERT BASIN - MISSISSIPPIAN													
WERTZ	Carbon & Sweetwater	Madison	1948	6,820	648	260	0.117	0.30	1.1	35	179	97,317	77,262

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