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Evaluation of Enhanced Recovery Operations in Smackover Fields of Southwest Alabama

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by

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EXPLANATION OF MAP SYMBOLS AND ABBREVIATIONS

WELL SYMBOLS

	DRILLING OR LOCATION		GAS WELL
	SHUT-IN OR TEMPORARILY ABANDONED WELL		SHUT-IN OT TEMPORARY ABANDONED GAS WELL
	PLUGGED AND ABANDONED WELL		PLUGGED AND ABANDONED GAS WELL
	SALT WATER DISPOSAL WELL		GAS WELL CONVERTED TO SALT WATER DISPOSAL WELL
	ENHANCED RECOVERY WELL		GAS WELL CONVERTED TO ENHANCED RECOVERY WELL
	OIL WELL		GAS-CONDENSATE WELL
	SHUT-IN OR TEMPORARILY ABANDONED OIL WELL		SHUT-IN OR TEMPORARY ABANDONED GAS-CONDENSATE WELL
	PLUGGED AND ABANDONED OIL WELL		PLUGGED AND ABANDONED GAS-CONDENSATE WELL
	OIL WELL CONVERTED TO SALT WATER DISPOSAL WELL		GAS-CONDENSATE WELL CONVERTED TO SALT WATER DISPOSAL WELL
	OIL WELL CONVERTED TO ENHANCED RECOVERY WELL		GAS-CONDENSATE WELL CONVERTED TO ENHANCED RECOVERY WELL
	CORE DESCRIBED		TYPE LOG

STRUCTURE MAPS

SL	PERMITTED SURFACE LOCATION
BHL	WELL BOTTOM HOLE LOCATION
T4N	TOWNSHIP 4 NORTH
R6E	RANGE 6 EAST
13	SECTION 13 (GENERALLY NUMBERED 1 THROUGH 36; IRREGULAR SECTION NUMBERS MAY EXCEED 36)
1784	STATE PERMIT NUMBER; USED FOR WELL IDENTIFICATION
7354-A	PERMITTED WELL RE-ENTRY AFTER SUSPENSION OF INITIAL OPERATIONS
2763-B	WELL PERMITTED TO BE DIRECTIONALLY DRILLED
---	GWC --- GAS/WATER CONTACT
---	HKW --- HIGHEST KNOWN WATER
---	LKG --- LOWEST KNOWN GAS
---	LKO --- LOWEST KNOWN OIL
---	OWC --- OIL/WATER CONTACT
---	FIELD BOUNDARY
---	COUNTY BOUNDARY
---	STATE BOUNDARY
A ——— A'	LINE OF CROSS SECTION

TOOTH ON DOWNTHROWN SIDE OF FAULT; WIDTH BETWEEN UPTHROWN LINE AND DOWNTHROWN LINE PROPORTIONAL TO AMOUNT OF "MISSING" SECTION AND ASSOCIATED VERTICAL DISPLACEMENT ALONG FAULT PLANE.

KEY TO CORE LOGS

[illegible]

ABBREVIATIONS

Abbreviations

API	American Petroleum Institute
bbls	barrels
bcf	billion cubic feet
bioturb.	bioturbation
c	coarse
cm	centimeters
f	fine
flt.	faulted
ft.	feet
h	interval thickness
intens	intensity
LPG's	Liquified petroleum gases
m	medium
mm	millimeters
mcf	thousand cubic feet
md	millidarcies
na	not available
phi	porosity (%)
sed	sedimentary
soln	solution
STB	Stock tank barrels
STB/D	Stock tank barrels per day
structs.	structures
text.	texture
tr	trace
vc	very coarse
vf	very fine
xc	extra coarse
xf	extra fine
psi	pounds per square inch
psia	pounds per square inch absolute
psig	pounds per square inch gauge

EXECUTIVE SUMMARY

This report contains detailed geologic and engineering information on enhanced-recovery techniques used in unitized Smackover fields in Alabama. The report also makes recommendations on the applicability of these enhanced-recovery techniques to fields that are not now undergoing enhanced recovery.

Eleven Smackover fields in Alabama have been unitized. Three fields were unitized specifically to allow the drilling of a strategically placed well to recover uncontacted oil. Two fields in Alabama are undergoing waterflood projects. Five fields are undergoing gas-injection programs to increase the ultimate recovery of hydrocarbons. Silas and Choctaw Ridge fields were unitized but no enhanced-recovery operations have been implemented.

Appleton, Turkey Creek, and Stave Creek fields were unitized for the purpose of strategic well placement. In each case, an additional well was drilled to increase the recovery of hydrocarbons from the field.

Waterflood operations have been implemented in Womack Hill field in Choctaw and Clarke counties, Alabama; and in Jay-Little Escambia Creek (Jay-LEC) fields which is located in Escambia County, Alabama and in Escambia and Santa Rosa counties, Florida. In the Womack Hill field unit, an additional 13 million barrels have been recovered since unitization. Ultimate recovery from both primary and secondary recovery is predicted to be 17 million barrels of oil.

Jay-LEC fields has experienced infill drilling, waterflood, and gas-injection operations to increase ultimate recovery of hydrocarbons. The waterflood project was implemented initially along with an infill-drilling program in areas of low permeability. Prior to completing the waterflood project it was determined that 355 million barrels of oil would remain in the reservoir after waterflooding and therefore, a water-alternating-gas program or "WAG" using methane and later nitrogen was initiated. Jay-LEC fields has produced approximately 399 million barrels

of oil, 87 percent of which have been recovered since enhanced recovery operations were implemented.

Infill drilling has been utilized in Jay-LEC fields, and it is a successful component of an enhanced recovery project which involved waterflooding and gas injection. Thirty-seven infill wells were drilled in low-permeability parts of the Smackover-Norphlet reservoir to reduce the overall spacing of withdrawal points in the field. Heterogeneity values from the Jay-LEC fields indicates low heterogeneity on the microscopic scale and moderate heterogeneity on the macroscopic scale indicating some compartmentalization of the reservoir may be present. However, the use of multiple enhanced-recovery techniques combined with detailed reservoirs studies seem to explain the excellent results obtained from the field.

Chatom field, which is in Washington County, is the oldest gas-injection project in Alabama. Primary recovery in the field was estimated to be 6.3 million barrels of condensate. Through 1990, 14.3 million barrels of condensate have been recovered using primary and secondary recovery, an incremental increase of 8 million barrels. Ultimate recovery for Chatom field is projected at 15.8 million barrels. Residue gas is the fluid used for injection in the field, and more than 67 billion cubic feet of gas have been injected into the reservoir.

Hatter's Pond field was unitized in 1985 to allow injection of residue gas into the reservoir. A total of 41 million barrels of condensate have been produced from the field, and ultimate recovery under secondary recovery is expected to be 13 million barrels over what would have been produced under primary depletion. Nineteen billion cubic feet of gas have been injected into the reservoir to maintain pressure at favorable levels.

Fanny Church field, in Escambia County, was also unitized in 1985. A nitrogen-injection program was implemented in a portion of the field. Primary recovery was estimated to be 3.9 million barrels. However, using nitrogen injection, 7 million barrels could be recovered. Through 1990, 4.3 million barrels of oil have been recovered from the unit. Approximately 9.3 billion cubic feet of gas have been injected into the Smackover reservoir; although no injection operations are ongoing.

In each of the unitized fields where injection or waterflooding has occurred, additional wells have been drilled. These wells have been drilled as either replacement, infill, or strategically located wells, and in each case appear to be a integral part of the enhanced recovery project.

Unitized fields are present in each of the pore facies defined by Kopaska-Merkel and Mann (1991). Within the Moldic Pore Facies, only strategic well placement has been implemented. Gas injection and infill drilling are the only enhanced-recovery techniques used in the Intercrystalline Pore Facies. Enhanced-recovery methods used in reservoirs with intermediate pore systems include infill drilling, strategic well placement, waterflooding, and gas injection. However, pore facies should not necessarily restrict the type of enhanced recovery methods implemented. Injection operations should be considered for fields in the Moldic Pore Facies and strategic well placement is a viable option in all pore facies where hydrocarbons are updip from existing wells. Also, reservoirs with intercrystalline and moldic pore systems should be evaluated for multiple enhanced recovery techniques as have been implemented in the Jay-LEC fields.

Unitized fields with intermediate pore systems have produced over 435 million barrels of oil (including the Florida portion of Jay-LEC fields). The Intercrystalline Pore Facies has produced approximately 90 million barrels of hydrocarbons from unitized Smackover fields. Approximately 11 million barrels of hydrocarbons liquids have been produced from unitized reservoirs within the Moldic Pore Facies.

Strategic well placement is the most viable enhanced-recovery technique for medium to small reservoirs where injection operations are economically prohibitive. By drilling wells at strategic locations, reservoir that would not be drained by existing wells can be penetrated and hydrocarbon recovery increased.

Potential candidates for enhanced recovery are identified based on similarities in characteristics with fields already unitized. Fields that should be considered for strategic well placement include Movico, Blacksher, Barrytown, and North Choctaw Ridge. Fields which

should be considered candidates for injection include Movico, Big Escambia Creek, and North
Hesslaw Ridge.

ABSTRACT

Eleven Smackover fields in Alabama have been unitized and enhanced-recovery programs have been implemented in 9 of these fields. Enhanced-recovery operations in Smackover reservoirs have involved infill drilling, strategic well placement, and injection of substances into the producing reservoir.

Smackover carbonate reservoirs which are unitized are classified based on a play classification which groups fields relative to basin position, structure, hydrocarbon type, and trap type. Reservoir characteristics are discussed relative to the dominant pore facies in the unitized reservoir. Both classifications facilitate grouping fields with similar characteristics.

Strategic well placement is the only enhanced-recovery method being used in the Moldic Pore Facies. Gas-injection and infill drilling are the only enhanced recovery techniques being used in the Intercrystalline Pore Facies. However, reservoirs with intermediate pore systems have been subjected to not only gas injection and strategic well placement, but infill drilling and waterflooding as well.

Within the Moldic Pore Facies, strategic well placement has been implemented in Turkey Creek, and Stave Creek fields. Additional wells have been drilled at strategic locations within the fields to recover hydrocarbons that could not be recovered by existing wells.

Within the Intercrystalline Pore Facies gas-injection, coupled with infill drilling, is the only enhanced recovery technique presently being implemented. Recovery in the Hatter's Pond field is consistent with the operators original projections. The Chunchula field enhanced recovery project was discussed in subtask 4 of this project.

Reservoirs with intermediate pore systems have had enhanced-recovery operations implemented which include gas injection, waterflooding, strategic well placement, and infill drilling. Appleton field has had a strategic well drilled. A portion of the Womack Hill field is presently undergoing waterflooding. Gas-injection is occurring in Chatom field. Gas injection

has also occurred in Fanny Church field although no enhanced-recovery operations are presently occurring in the field. Multiple techniques involving gas injection and waterflooding have been used in Jay-LEC fields. Additional wells have been drilled in each of the fields undergoing injection to increase recovery from those fields.

With today's economic constraints on hydrocarbon production, a controlling factor in determining the viability of enhanced-recovery methods is the size of the reservoir. Smaller reservoirs may not support implementation of enhanced-recovery methods, with the possible exception of strategic well placement. However, larger fields should be examined as possible candidates for injection programs and infill drilling to increase recovery of hydrocarbons.

INTRODUCTION

Approximately 260 million barrels of oil and condensate have been produced from the Smackover Formation of southwest Alabama; hundreds of millions more are unrecoverable by primary production methods. This report provides geologic and engineering data for evaluating the effectiveness of enhanced-recovery methods in Smackover reservoirs in order to help determine which enhanced-recovery methods would be most effective at increasing Smackover hydrocarbon recovery. These data may also be relevant to evaluations of enhanced-recovery methods in other carbonate reservoirs.

Within this report, unitized Smackover oil fields of southwest Alabama are characterized. The oil play classification of Mancini and others (1991) is used to classify unitized oil fields relative to trap type, basin position, and fluid type. The pore facies classification of Kopaska-Merkel and Mann (1991) is used to define general reservoir characteristics of the different unitized reservoirs. The 11 unitized fields in Alabama are grouped by pore facies and a discussion of their characteristics is provided. The results of the unitization projects and the techniques used are also discussed. Finally, possible candidates for enhanced recovery are identified and recommendations regarding the type of enhanced-recovery method which should be considered are suggested.

This study was undertaken as a part of a research project performed by the Geological Survey of Alabama. The project was sponsored by the United States Department of Energy under DOE Project No. DE-FG22-89BC14425 entitled "Establishment of an oil and gas database for increased recovery and characterization of oil and gas carbonate reservoir heterogeneity." The project consisted of six subtasks, four of which have been completed and submitted to DOE.

The final components of this research project are subtasks 5 and 6, addressed in this volume. Subtask 5 is the evaluation of enhanced recovery projects in Alabama to ascertain

their effectiveness. Subtask 6 requires an economic and volumetric evaluation of hydrocarbon recovery that could be realized by enhanced recovery techniques. Eleven Smackover fields have been unitized in Alabama for the purpose of increasing the recovery of hydrocarbons. Nine of these fields have had some type of program implemented to increase ultimate recovery. Techniques which have been used in Alabama include infill drilling, strategic well placement, waterflood operations, and gas injection. In Jay-LEC fields, several techniques have been implemented concurrently to improve recovery. The purpose of this report is to describe the 11 Smackover fields in Alabama which have been unitized and to discuss the techniques used (if any) to improve the ultimate recovery of hydrocarbons. The geologic, engineering, production, and development characteristics of each field are described in detail. The enhanced-recovery methods used in each field are discussed as well as their effectiveness in producing incremental hydrocarbons. Finally, conclusions about the applicability of enhanced-recovery techniques to other Alabama fields are provided. These conclusions may be applicable to evaluations of the suitability of enhanced-recovery techniques to other carbonate reservoirs.

METHODS

The purpose of this report is to evaluate existing enhanced-recovery technology used in the Smackover Formation of southwest Alabama. In order to accomplish this task, extensive review of geologic and engineering data was undertaken. Reservoir-characterization packets generated as part of subtask 2 of this project (Appendix 1 to Topical Report on subtasks 2 and 3) were evaluated and data generated on unitized fields were incorporated into this report.

Technical exhibits and transcripts of testimony presented during public hearings held at the State Oil and Gas Board of Alabama on these fields were reviewed. Information on file includes type logs, cross sections, structure maps, isopach maps, reservoir-pressure information, and production data on each of the 11 unitized Smackover fields.

Each unitized Smackover field in Alabama is described. The effectiveness of enhanced-recovery methods were analyzed by comparing predicted results to actual performance. Graphical comparisons are made where there are sufficient data to do so.

HISTORICAL OVERVIEW

Alabama's first oil discovery was made in 1944, from the Cretaceous Selma Group in Choctaw County (fig. 1). For over 20 years after the discovery of Gilbertown field, oil discoveries in southwest Alabama were limited to Cretaceous reservoirs. Cretaceous oil fields in Choctaw, Mobile, Escambia, Baldwin, and Clarke counties were discovered between 1944 and 1967. In 1967, 33 years after oil was discovered in Alabama, hydrocarbons were discovered in the Smackover Formation at Toxey field in Choctaw County (fig. 2; table 1) (Bolin and others, 1989). Through 1990, 73 Smackover fields have been established in southwest Alabama. Of this total, 59 are classified as oil reservoirs and 14 are classified as gas-condensate reservoirs (fig. 2).

The largest discoveries in the Smackover of southwest Alabama were made during the early 1970's (fig. 3; table 2) along the regional peripheral fault trend, Wiggins arch complex, and Mobile graben fault system plays which are defined by Mancini and others (1991) and discussed below (fig 4). These fields include Hatter's Pond, Womack Hill, Big Escambia Creek, Chatom, Churchula, and Jay-LEC fields. All of these major fields are still producing and most are undergoing some type of enhanced recovery.

PRODUCTION OVERVIEW

Smackover fields in southwest Alabama have produced nearly 260 million barrels of oil and condensate since the initial discovery of oil in the Smackover in 1967: nearly 114 million barrels of oil and 146 million barrels of condensate. Cumulative production from the Smackover is 54 percent of total oil and condensate produced in Alabama.

Figure 1.--Stratigraphic column of producing horizons in southwest Alabama (Masingill, 1991).

Figure 2.--Index map showing location of Smackover gas-condensate and oil fields in southwest Alabama. (See table 1 for field numbers).

Table 1.--Smackover fields in Alabama as of December 1990

Field No.	Field Name	County	Hydrocarbon Type
1	Appleton	Escambia	Oil
2	Barlow Bend	Clarke and Monroe	Oil
3	Barnett	Conecuh and Escambia	Oil
4	Barrytown	Choctaw	Oil
5	Big Escambia Creek	Escambia	Condensate
6	Blacksher	Baldwin	Oil
7	Broken Leg Creek	Escambia	Oil
8	Bucatumna Creek	Choctaw	Oil
9	Burnt Corn Creek	Escambia	Oil
10	Chappell Hill	Choctaw	Oil
11	Chatom	Washington	Condensate
12	Choctaw Ridge	Choctaw	Oil
13	Churchula	Mobile	Oil/Condensate
14	Cold Creek	Mobile	Oil
15	Copeland Gas	Washington	Condensate
16	Crosbys Creek	Washington	Condensate
17	East Barnett	Conecuh and Escambia	Oil
18	East Huxford	Escambia	Oil
19	Fanny Church	Escambia	Oil
20	Gin Creek	Choctaw	Oil
21	Gulf Crest	Mobile	Oil
22	Hanberry Church	Escambia	Oil
23	Hatter's Pond	Mobile	Condensate
24	Healing Springs	Washington	Condensate
25	Huxford	Escambia	Oil
26	Jay-Little Escambia Creek	Escambia	Oil
27	Little Mill Creek	Choctaw	Oil
28	Little River	Baldwin and Monroe	Oil
29	Little Rock	Escambia	Condensate
30	Lovetts Creek	Monroe	Oil
31	Melvin	Choctaw	Oil
32	Mill Creek	Choctaw	Oil
33	Mineola	Monroe	Oil
34	Movico	Baldwin and Monroe	Oil
35	North Choctaw Ridge	Choctaw	Oil
36	North Smiths Church	Escambia	Oil
37	North Wallers Creek	Monroe	Oil
38	Northeast Barnett	Conecuh	Oil
39	Northwest Range	Conecuh	Oil
40	Pace Creek	Clarke	Oil
41	Palmers Crossroads	Monroe	Oil
42	Perdido	Baldwin and Escambia	Oil
43	Puss Cuss Creek	Choctaw	Oil
44	Red Creek	Washington	Condensate
45	Robinson Creek	Escambia	Oil
40	Pace Creek	Clarke	Oil

Table 1.--Smackover fields in Alabama as of December 1990—Continued

Field No.	Field Name	County	Hydrocarbon Type
41	Palmers Crossroads	Monroe	Oil
42	Perdido	Baldwin and Escambia	Oil
43	Puss Cuss Creek	Choctaw	Oil
44	Red Creek	Washington	Condensate
45	Robinson Creek	Escambia	Oil
46	Silas	Choctaw	Oil
47	Sizemore Creek Gas	Escambia	Condensate
48	Smiths Church	Escambia	Condensate
49	South Burnt Corn Creek	Escambia	Oil
50	South Cold Creek	Mobile	Oil
51	South Vocation	Monroe	Oil
52	South Wild Fork Creek	Escambia	Condensate
53	South Womack Hill	Choctaw and Clarke	Oil
54	Southeast Chatom	Washington	Condensate
55	Southwest Barrytown	Choctaw	Oil
56	Souwilpa Creek	Choctaw	Condensate
57	Stave Creek	Clarke	Oil
58	Sugar Ridge	Choctaw	Oil
59	Toxey	Choctaw	Oil
60	Turkey Creek	Choctaw and Clarke	Oil
61	Turnerville	Mobile	Oil
62	Uriah	Monroe	Oil
63	Vocation	Monroe	Oil
64	Wallace	Escambia	Oil
65	Waller's Creek	Monroe	Oil
66	West Appleton	Escambia	Oil
67	West Barrytown	Choctaw	Oil
68	West Bend	Choctaw and Clarke	Oil
69	West Okatuppa Creek	Choctaw	Oil
70	Wild Fork Creek	Escambia	Oil
71	Wimberly	Choctaw	Oil
72	Womack Hill	Choctaw and Clarke	Oil
73	Zion Chapel	Choctaw	Oil

Table 2.--Ranking of Smackover fields by cumulative hydrocarbon liquids produced

KEY	FIELD	HYDROCARBON TYPE	DISCOVERY DATE (YEAR)	CUMULATIVE LIQUID PRODUCTION (BBLs)	CUMULATIVE GAS PRODUCTION (Mcf)	CUMULATIVE PRODUCTION (Oil Equivalent) (BBLs)	OIL GRAVITY (DEGREES)	ENHANCED RECOVERY METHOD
1	SIZEMORE CREEK	CONDENSATE	1984	0	0	0	NA	NONE
2	LITTLE ROCK	CONDENSATE	1985	648	0	648	54	NONE
3	SMITHS CHURCH	CONDENSATE	1986	1,300	11,265	2,378	57.6	NONE
4	WEST OKATUPPA CREEK	OIL	1986	6,891	0	6,891	26	NONE
5	SOUTHWEST BARRYTOWN	OIL	1986	10,417	10,505	12,287	45.1	NONE
6	NORTH SMITHS CHURCH	OIL	1990	10,783	13,807	13,241	44.7	NONE
7	BURNT CORN CREEK	OIL	1986	10,911	9,036	12,520	49	NONE
8	WALLACE	OIL	1987	11,164	11,286	13,169	44	NONE
9	SOUTH WILD FORK CREEK	CONDENSATE	1988	18,835	61,221	26,940	45.6	NONE
10	NORTH WALLERS CREEK	OIL	1990	22,166	17,293	25,244	38.9	NONE
11	ROBINSONS CREEK	OIL	1990	25,544	46,429	33,808	52.4	NONE
12	MINEOLA	OIL	1990	27,269	22,798	31,327	39.3	NONE
13	BARLOW BEND	OIL	1986	28,089	29,451	33,331	35	NONE
14	SOUTH COLD CREEK	OIL	1975	31,667	38,679	38,572	44	NONE
15	SOUTH VOGATION	OIL	1984	34,220	49,424	43,087	57	NONE
16	SOUWILPA CREEK	CONDENSATE	1979	40,676	241,589	62,253	49	NONE
17	MELVIN	OIL	1977	42,412	0	42,412	18	NONE
18	EAST HUXFORD	OIL	1989	62,194	46,780	70,521	39.5	NONE
19	PUSS CUSS CREEK	OIL	1978	69,883	57,258	79,875	42	NONE
20	HANBERRY CHURCH	OIL	1987	93,819	56,875	109,943	46	NONE
21	WILD FORK CRK	OIL	1988	123,690	74,286	136,913	43.1	NONE
22	TURNERVILLE	OIL	1995	124,203	183,978	156,951	55	NONE
23	WEST APPLETON	OIL	1988	125,053	85,436	140,261	48.4	NONE
24	LITTLE RIVER	OIL	1981	127,400	133,931	151,240	40	NONE
25	GULF CREST	OIL	1987	136,135	109,372	155,603	55.3	NONE
26	PACE CREEK	OIL	1986	139,590	13,419	141,979	38	NONE
27	NORTHWEST RANGE	OIL	1986	166,735	206,763	206,539		NONE
28	SOUTH BURNT CORN CREEK	OIL	1987	186,190	151,789	215,208	49	NONE
29	NORTHEAST BARNETT	OIL	1989	189,447	215,508	227,807	45.2	NONE
30	URIAH	OIL	1970	199,064	120,544	220,539	39	NONE
31	LOVETT'S CREEK	OIL	1982	203,368	224,057	249,250	32	NONE
32	RED CREEK	CONDENSATE	1979	254,056	4,239,672	624,109	46	NONE
33	GIN CREEK	OIL	1985	255,452	259,350	301,616	46	NONE
34	BROKEN LEG CREEK	OIL	1986	256,475	180,916	288,676	41	NONE
35	PALMERS CROSSROADS	OIL	1988	278,292	180,947	304,941	39.2	NONE
36	HEALING SPRINGS	CONDENSATE	1978	318,113	3,513,416	620,106	54	NONE

PLAYS AND SUBPLAYS

- Basement ridge play
 - A. Choctaw ridge complex subplay
 - B. Conecuh and Pensacola-Decatur ridge complexes subplay
- Regional peripheral fault trend play
 - C. Pickens, Gilbertown, and West Bend fault systems subplay
 - D. Pollard and Foshee fault systems subplay
- Mississippi interior salt basin play
- Mobile graben fault system play
 - E. Northern graben subplay
 - F. Southern graben subplay
- Wiggins arch complex play

EXPLANATION

- -Approximate updip limit of potential Smackover reservoirs
- - Basement arch, ridge, or anticline
- -Salt-related fault-block on downthrown side

Figure 4.--Smackover oil plays in Alabama, Mississippi, and Florida panhandle (modified from Mancini and others, 1991).

Mobile County accounts for over 35 percent of all liquid hydrocarbons produced from the Smackover (table 3; fig. 5). Escambia and Choctaw counties have the highest number of pools (22 each) (fig. 6). Mobile County has produced more liquid hydrocarbons per pool than any other county in the Smackover trend. Based on 1990 production, Mobile County averages more than 13 million barrels of liquid hydrocarbons per pool (fig. 7).

Of the 260 million barrels of oil and condensate that have been produced from the Smackover, 169 million barrels (or 65 percent) have been produced from the 11 Smackover fields that have been unitized. Approximately 72 percent (121 million barrels) of the liquid hydrocarbons produced from these fields were produced after unitization (fig. 8). Of the 121 million barrels of liquid hydrocarbons that have been recovered after unitization, 49.4 million barrels are oil.

FLUID COMPOSITION

Determination of reservoir-fluid chemical and physical properties is important in evaluating enhanced-oil-recovery candidates and techniques to be used. Some enhanced-recovery techniques are more applicable to heavy oils whereas others are effective in moderate-to high-gravity hydrocarbons (van Poolen and Associates, Inc., 1980) like those commonly found in the Smackover of Alabama. Characteristics of the reservoir fluid also affect the amount of oil that would be produced by both primary and secondary recovery (National Petroleum Council, 1976).

The Jurassic of the eastern Gulf Coast region has been divided into three producing trends based on type of hydrocarbon produced (fig. 9) (Mink and others, 1985; Mancini and others, 1986). The oil trend lies updip from the regional peripheral fault system in Alabama; produced hydrocarbons are predominantly oil. The oil and gas-condensate trend lies between the oil and deep natural gas trends; fields within this trend produce oil, gas-condensate, and gas. Downdip of the Wiggins arch is the deep natural gas trend which extends into the offshore areas of the Gulf of Mexico (Mink and others, 1985; Mancini and others, 1986). No

Table 3.--Geographical distribution of Smackover production and pools ranked by cumulative production per pool

COUNTY	CUMULATIVE PRODUCTION (BBLs)	NUMBER OF POOLS ¹	CUMULATIVE PRODUCTION PER POOL (BBLs/POOL)
MOBILE	92,864,648	7	13,266,378
CLARKE	22,272,323	6	3,712,054
ESCAMBIA	79,877,828	22	3,630,810
WASHINGTON	17,002,404	6	2,833,734
CHOCTAW	41,095,122	22	1,867,960
BALDWIN	1,977,280	4	494,320
MONROE	3,783,764	9	420,418
CONECUH	735,677	4	183,919
TOTAL	259,609,046		AVERAGE 3,508,230

¹ Pools crossing county boundaries
are assigned to both counties

Figure 5.--Pie diagram indicating cumulative Smackover production for each county in southwest Alabama's Smackover trend. (Values in parentheses indicate cumulative liquid production (in barrels) through December 31, 1990.)

Figure 6.--Pie diagram indicating distribution of Smackover reservoirs in southwest Alabama. (Values in parentheses indicate the number of pools within each county as of December 31, 1990.)

Figure 7.--Average cumulative Smackover production per pool for counties in southwest Alabama.

Figure 8.--Pre-unitization versus post-unitization: production for unitized Smackover fields in southwest Alabama. (Jay-LEC field contains production information from both Alabama and Florida portions of the field.) Vertical scale is logarithmic.

Figure 9.--Upper Jurassic hydrocarbon trends for the onshore tri-state area and eastern Gulf of Mexico (modified from Mancini and others, 1986).

Smackover fields have been established within the deep natural gas trend in Alabama and production is confined to the underlying Norphlet Formation.

Hydrocarbons produced from the Smackover are sourced by organically rich facies within the Smackover (Mancini and Benson, 1980; Oehler, 1984; Sassen and Moore, 1988; Claypool and Mancini, 1989). Variations observed in Smackover hydrocarbons are the result of differences in thermal maturity and organic facies (Sassen and others, 1987; Claypool and Mancini, 1989). With increasing thermal maturity, cracking of oil produced gas condensate (Sassen and Moore, 1988). In some fields, hydrocarbons reacted with evaporitic sulfur thereby generating high percentages of carbon dioxide and hydrogen sulfide (Claypool and Mancini, 1989).

Hydrocarbon liquids produced from the Smackover Formation of southwest Alabama range from 18° gravity oil to 64° gravity condensate (table 4). Wellstreams from Jurassic fields commonly contain non-hydrocarbon gases such as hydrogen sulfide, nitrogen, and carbon dioxide. In some fields, these components are a substantial part of the wellstreams. In Big Escambia Creek field, more than 53 mole percent of the wellstream is non-hydrocarbon components. Non-hydrocarbon gases exceed 15 percent of the wellstream in 20 of the 73 Smackover pools in Alabama (table 4). Condensate production is confined to Escambia, Mobile, Choctaw, and Washington counties.

SMACKOVER PLAYS IN ALABAMA

Before any correlations can be made between unitized fields and nonunitized fields that should be considered candidates for enhanced-recovery operations, fields should be classified based on trap and reservoir characteristics. Mancini and others (1991) defined 5 Smackover oil plays in Alabama, Mississippi, and the Florida panhandle based on location within the basin, trap types, reservoir characteristics, and types of hydrocarbons produced. Smackover hydrocarbon exploration discussed in terms of play areas provides a means to put exploration into a historical perspective and to provide an overview of Smackover production trends.

Table 4.--Variation in wellstreams of Smackover fields in southwest Alabama

FIELD	HYDROCARBON TYPE	API GRAVITY (DEGREES)	H ₂ S (MOLE %)	CO ₂ (MOLE %)	N ₂ (MOLE %)	TOTAL NON-HC'S (MOLE %)
APPLETON	OIL	52	1.75	1.38	5.7	8.83
BARLOW BEND	OIL	35	NULL	0.19	7.74	7.93
BARNETT	OIL	49	NA	1.85	8.86	10.71
BARRYTOWN	OIL	45	0.45	0.92	9.74	11.11
BIG ESCAMBIA CREEK	CONDENSATE	46	25.69	24.88	2.54	53.11
BLACKSHER	OIL	43	0.77	0.35	3.71	4.83
BROKEN LEG CREEK	OIL	41	NULL	0.71	4.27	4.98
BUCATUNNA CREEK	OIL	37	0.84	0.81	5.74	7.39
BURNT CORN CREEK	OIL	49	3.45	0.39	3.51	7.35
CHAPPELL HILL	OIL	38	0.52	1.02	5.05	6.59
CHATOM	CONDENSATE	55	16.7	2.92	1.3	20.92
CHOCTAW RIDGE	OIL	41	2.1	0.63	8.85	11.58
CHUNCHULA	OIL/CONDENSATE	60	0.01	2.26	5.67	7.94
COLD CREEK	OIL	59	0	1.56	4.16	5.72
COPELAND	CONDENSATE	41	22.94	5.52	0.02	28.48
CROSBY CREEK	CONDENSATE	NA	18.4	1.7	1.62	19.72
EAST BARNETT	OIL	45	NA	0.92	8.9	9.82
EAST HUXFORD	OIL	39.5	0	0.57	2.54	3.11
FANNY CHURCH	OIL	51	4.7	1.53	0.87	7.1
GIN CREEK	OIL	48	17.43	5.47	1.76	24.66
GULF CREST	OIL	55.3	NA	1.05	NA	1.05
HANBERRY CHURCH	OIL	46	2.1	4.06	10.91	17.07
HATTER'S POND	CONDENSATE	61	0.62	4.97	6.28	11.87
HEALING SPRINGS	CONDENSATE	54	37.55	4.11	0.84	42.5
HUXFORD	OIL	51	0.07	3.31	11.78	15.16
LITTLE ESCAMBIA CREEK	OIL	51	8.78	2.24	1.28	12.3
LITTLE MILL CREEK	OIL	40	*	0.37	9.64	10.01
LITTLE RIVER	OIL	40	*	0.46	3.22	3.68
LITTLE ROCK	CONDENSATE	54	15.91	2	NA	17.91
LOVETT'S CREEK	OIL	32	*	0.3	10.37	10.67
MELVIN	OIL	18	NA	NA	NA	0
MILL CREEK	OIL	42	1.6	0.38	0.8	2.78
MINEOLA	OIL	39.3	0	0.46	5.82	6.28
MOVICO	OIL	44	0	0.99	5.7	6.69
NORTH CHOCTAW RIDGE	OIL	39	2.1	0.68	5.39	8.17
NORTH SMITHS CHURCH	OIL	44.7	*	1.06	6.3	7.36
NORTH WALLERS CREEK	OIL	36.9	NULL	0	3.73	3.73

Table 4.--Variation in wellstreams of Smackover fields in southwest Alabama-Continued

FIELD	HYDROCARBON TYPE	API GRAVITY (DEGREES)	H ₂ S (MOLE %)	CO ₂ (MOLE %)	N ₂ (MOLE %)	TOTAL NON-HC'S (MOLE %)
NORTHEAST BARNETT	OIL	45.2	NA	NA	NA	0
NORTHWEST RANGE	OIL	NA	NA	NA	NA	0
PACE CREEK	OIL	38	0	0.52	23.69	24.21
PALMERS CROSSROADS	OIL	39.2	NA	NA	NA	0
PERDIDO	OIL	60	NILL	1.04	7.87	8.91
PUSS CUSS CREEK	OIL	42	19.65	2.38	1.05	23.08
RED CREEK	CONDENSATE	48	37.39	9.94	0.54	47.87
ROBINSONS CREEK	OIL	52.4	0	0.85	5.31	6.16
SOUTH BURNT CORN CREEK	OIL	49	0.68	3.29	5.68	9.65
SOUTH COLD CREEK	OIL	44	NA	2.26	1.89	4.15
SOUTH WILD FORK CREEK	CONDENSATE	45.8	3.75	1.36	2.3	7.41
SOUTH WOMACK HILL	OIL	39.2	NA	NA	NA	0
SILAS	OIL	42	11.78	1.88	0.72	14.38
SIZEMORE CREEK	CONDENSATE	NA	6.07	30.37	3.27	39.71
SMITHS CHURCH	CONDENSATE	57.6	8.83	16.5	0.5	25.83
SOUTH VOCATION	OIL	57	NA	NA	NA	0
SOUTHEAST CHATOM	CONDENSATE	63.7	17.29	6.26	2.04	25.59
SOUWILPA CREEK	CONDENSATE	49	25.16	4.33	0.91	30.4
STAVE CREEK	OIL	41	*	2.42	28.81	31.23
SUGAR RIDGE	OIL	38	1.98	1.14	5.23	8.35
SOUTHWEST BARRYTOWN	OIL	45.1	NA	NA	NA	0
TOXEY	OIL	20	NA	NA	NA	0
TURKEY CREEK	OIL	43	*	0.24	29.73	29.97
TURNERVILLE	OIL	55	NA	1.76	2.91	4.67
URIAH	OIL	39	0	0.6	1.31	1.91
VOCATION	OIL	54	0	0.63	7.11	7.74
WALLACE	OIL	44	NILL	1.04	3.61	4.65
WALLERS CREEK	OIL	37	0	NA	NA	0
WEST APPLETON	OIL	46.4	0.69	1.63	3.59	5.91
WEST BARRYTOWN	OIL	46	NA	NA	NA	0
WEST BEND	OIL	42	*	0.64	10.12	10.76
WEST OKATUPPA CREEK	OIL	26	0	0.05	0.45	0.5
WILD FORK CREEK	OIL	43.1	6.36	4.8	8.63	19.79
WIMBERLY	OIL	37	0.01	0.06	4.12	4.21
WOMACK HILL	OIL	37	NILL	NA	NA	0
ZION CHAPEL	OIL	42	22.87	1.68	3.45	28

NA = NOT AVAILABLE

* = LESS THAN 0.001

Further, the play concept of Mancini and others (1991) provides a means to discuss the geologic framework of Smackover fields in Alabama, as well as Mississippi and the Florida panhandle.

The plays defined by Mancini and others (1991) include the basement ridge play, regional peripheral fault trend play, Mississippi interior salt basin play, Mobile graben fault system play, and the Wiggins arch complex play (fig. 4). The basement ridge play is divided into two subplays: the Choctaw ridge complex subplay and the Conecuh and Pensacola-Decatur ridge complexes subplay. The regional peripheral fault trend play is divided into the Pickens, Gilbertown, and West Bend fault system subplay, and the Pollard and Foshee fault systems subplay (Mancini and others, 1991). The Mobile graben fault system subplay can also be divided into northern and southern subplays based on pore types, reservoir depth, reservoir lithology, and hydrocarbon types.

The regional peripheral fault trend play is basinward of the updip limit of the Louann Salt and is typified by salt-related structures. Structural traps are either salt anticlines or faulted salt anticlines. Combination traps are generally the result of permeability terminations on the flanks of structures.

Within the Pollard and Foshee fault systems subplay, major fields include Jay-LEC, Big Escambia Creek, and Fanny Church. Reservoirs within this subplay are typically subtidal to supratidal and partially to completely dolomitized. Reservoir pore systems are dominated by intercrystalline pores but with high percentages of moldic and secondary intraparticle pores (Mancini and others, 1991). Traps within the Pollard and Foshee fault systems subplay are primarily anticlines and faulted anticlines that developed as a result of halokinetic movement of the underlying Louann Salt (Hughes, 1968; Mancini and others, 1985). Stratigraphic components to traps are permeability pinchouts located on the flanks of structures. Discovery of hydrocarbons in this subplay began in 1970 with the discovery of Jay-LEC fields. The latest field discovered within this subplay is Little Rock field, which was discovered in 1985 (table 2). Through 1990, five fields in Alabama had been discovered within the Pollard and Foshee fault

systems subplay. Including production from Jay-LEC fields, which is partially within the state of Florida, 443 million barrels of oil and condensate have been produced from the Smackover Formation within this play area.

Along the Pickens, Gilbertown and West Bend fault systems subplay, medium-size fields have typically produced between one and 5 million barrels each. Most discoveries in this subplay were between 1968 and 1978, although a few fields are younger. Traps along these fault systems are salt-related anticlines and faulted anticlines. Combination traps produced by termination of permeability are also present. Reservoirs within this subplay are peritidal, nondolomitic to completely dolomitized grainstone which produce intermediate gravity oils through predominantly moldic and secondary intraparticle pores (Mancini and others, 1991). Major fields discovered within the Pickens, Gilbertown and West Bend fault systems subplay are Womack Hill, Choctaw Ridge, North Choctaw Ridge, Sugar Ridge, and Turkey Creek fields. Through 1990, more than 56 million barrels of oil and condensate have been produced from this subplay in Alabama.

The first discovery within the Wiggins arch complex play was Churchula field, discovered in 1974. Churchula field is a major hydrocarbon accumulation which has produced 47.5 million barrels of condensate. A total of 6 fields have been discovered within this play in Alabama. Traps within this play are associated with stratigraphic thinning and salt flow and include anticlinal traps and structural noses. Reservoirs are peloidal, oolitic, and oncoidal dolograins and dolopackstone, thrombolitic dolostone, and crystalline dolostone. Intercrystalline pores are the dominant component of the pore systems present (Mancini and others, 1991). Through 1990, six fields have been discovered within the Wiggins arch complex play in Alabama and more than 49 million barrels of oil and condensate have been produced from the Smackover Formation. The Wiggins arch complex play is within the oil and gas-condensate trend of Mink and others (1985).

The Mobile graben fault system play, which is characterized by salt-related structural features, is located along the eastern limit of the Mississippi interior salt basin. Three fields

have been established in the play and cumulative production, through 1990, is approximately 46 million barrels of oil and condensate. The Mobile graben fault system play is within the oil and gas-condensate trend of Mink and others, (1985).

The most productive field within the south Mobile graben subplay is Hatter's Pond field, which was discovered in 1974. Hatter's Pond has produced over 41 million barrels of condensate through 1990. Hydrocarbon traps within the play are primarily salt-related structural and combination traps. Reservoirs are thrombolitic, oolitic, and peloidal dolograine to dolowackestone. Pore systems present are dominated by intercrystalline pores although moldic and secondary intraparticle pores are present. Two fields have been discovered within the south Mobile graben fault system subplay. Production from reservoirs within the subplay includes crude oil and gas-condensate and amounts to more than 43 million barrels of hydrocarbon liquids.

Stave Creek field, discovered in 1979, characterizes the north Mobile graben subplay. The trap at Stave Creek field is a salt related anticline associated with the Mobile graben fault system. The reservoir is primarily an oolitic dolograine. Moldic and secondary intraparticle pores are the dominant pore types present, although intraparticle and intercrystalline pores are also present. Through 1990, Stave Creek field, which is the only field established field within the subplay, produced 2.9 million barrels of oil.

Production within the Mississippi interior salt basin play began with the discovery of Chatom field, which has produced 14.3 million barrels of condensate. Other discoveries were made in this play through the late 1980's but these fields are small. Of these, only Silas field has produced more than one million barrels of oil or condensate.

The Mississippi interior salt basin play is downdip of the Pickens-Gilbertown fault system and is characterized by structural and stratigraphic traps. Anticlines and structural noses produced by the underlying Louann Salt and combination traps produced by porosity and permeability terminations are common. Reservoirs are nondolomitic to completely dolomitized grainstone and packstone. Pore systems are dominated by oomolds and secondary intraooid

pores to the north, and reservoirs in the northernmost part of the play area include intershard pores produced by crushing of moldic pores. In the southern part of the play, predominant pore types are pelmolds and secondary intrapeloid pores (Mancini and others, 1991). Total production from the Mississippi interior salt basin play in Alabama is more than 19 million barrels of oil and condensate from 11 fields.

The basement ridge play is updip of the regional peripheral fault trend. The Louann Salt is thin or absent and structures are associated with pre-Jurassic basement paleotopography. Structural traps include anticlines and faulted anticlines that formed as a result of paleohighs in the underlying basement. Porosity and permeability terminations on some structural features result in combination traps (Mancini and others, 1991).

Discoveries within the Conecuh and Pensacola-Decatur ridge subplay have been made since 1970, beginning with the discovery of Uriah field and continuing sporadically through the mid-1980's. However, between 1985 and 1991 approximately 18 fields were discovered. Improved seismic-processing techniques have facilitated discovery of fields in this area (Schneeflock and others, 1989). Most of these fields are quite small and do not significantly contribute to Alabama's total hydrocarbon-liquid reserves.

Traps within the Conecuh and Pensacola-Decatur ridge subplay are structural and combination traps associated with pre-Jurassic basement paleotopography. Oolitic, oncoidal, intraclastic, and peloidal dolograinstone and dolopackstone, fenestral dolostone, quartz sandstone, and microbial doloboundstone are the dominant reservoirs. Intercrystalline, moldic, and secondary intraparticle pores are common; fractures are locally important because they enhance permeability (Mancini and others, 1991).

Reservoirs within the Choctaw ridge complex subplay are peritidal, partially to completely dolomitized, oolitic, peloidal, and oncoidal grainstone. Pore systems are dominated by moldic and secondary intraparticle pores. Traps are anticlines or faulted anticlines developed over basement highs. Porosity and permeability terminations modify some traps

(Mancini and others, 1991). Total production from the basement ridge play was more than 12 million barrels through 1990.

The largest Smackover discoveries are located in the Pollard and Foshee fault systems subplay; the Wiggins Arch complex play, and the Mobile graben fault system play. Five large reservoirs in these areas have produced more than 20 million barrels of oil or condensate each.

The oil play classification of Mancini and others (1991) defines Smackover fields based on structure, basinal position, trap type, and hydrocarbon type. Therefore, it defines regional trends within the Smackover and facilitates field characterization. However, the pore facies classification of Kopaska-Merkel and Mann (1991) will be used for discussing reservoir characteristics and variations in fluid flow properties within the unitized reservoirs.

SMACKOVER PORE FACIES AND LIQUID-HYDROCARBON PRODUCTION

Classifying fields based on the pore facies as determined by Kopaska-Merkel and Mann (1991) provides a useful method of categorizing Smackover fields in Alabama. The shapes and sizes of pores have profound effects on fluid-flow properties of hydrocarbon reservoirs (e.g., Wardlaw and Taylor 1976; Wardlaw and McKellar, 1981; Kopaska-Merkel and Mann, 1991, and references therein) and may exert more control over hydrocarbon-production-potential of reservoirs than any other feature of the reservoir (Kopaska-Merkel and Mann, 1991). Therefore, a understanding of the pore facies and their characteristics is important in understanding drainage properties of reservoirs and the types of enhanced-recovery methods which could increase ultimate recovery from a reservoir.

Kopaska-Merkel (1992) provided a discussion of the characteristics of the different pore facies in the Smackover of Alabama. Pore systems dominated by moldic pores are characterized by high porosity but low permeability because of small pore throats, high pore-to-throat size ratios, and poor connectivity. Hydrocarbon volumes are greater in moldic pore systems. Reservoirs dominated by moldic pore systems also tend to be heterogeneous at the

microscopic level because coarse and fine pores are found together. However, reservoirs with moldic pore systems tend to be homogeneous at the megascopic level.

Pore systems dominated by intercrystalline pores tend to have variable permeability values, depending on crystal size. Permeability values may be more readily predicted from porosity data. Pore systems consisting of large intercrystalline pores that are well connected tend to have high permeability values. Reservoirs with intercrystalline pore systems have relatively low heterogeneity at the microscopic level, but are relatively heterogeneous at the macroscopic level. Consequently, within the Intercrystalline Pore Facies there is a higher tendency for bypassing potentially productive intervals (Kopaska-Merkel, 1992).

Reservoirs completed in intermediate pore systems petrophysically resemble intercrystalline reservoirs. Intermediate reservoirs have relatively low heterogeneity at the microscopic scale but are relatively heterogeneous on the macroscopic level. Lower porosity values are associated with these pore systems (Kopaska-Merkel, 1992). This discussion is based entirely on data from the Smackover in Alabama; similar reservoirs elsewhere may exhibit different heterogeneity characteristics.

Kopaska-Merkel and Mann (1991) recognized two pore facies in the Smackover of southwest Alabama based on pore types and pore-throat-size distributions (fig. 10): the Moldic Pore Facies and the Intercrystalline Pore Facies. Reservoirs with mixtures of pore types were also identified. The Moldic Pore Facies contains 27 fields, whereas the Intercrystalline Pore Facies contains 18 fields. Twenty-eight fields have a mixture of pore types; the intermediate pore "facies" (table 5).

Review of the distribution of Smackover hydrocarbon production with respect to pore facies indicates that 46 percent of hydrocarbons liquids are produced from intermediate pore systems, making this "facies" the most productive in Alabama (table 6). Major fields which produce from the intermediate pore "facies" include Big Escambia Creek, Little Escambia Creek, Womack Hill, Fanny Church, and Appleton. The Florida portion of Jay-LEC fields is excluded from this analysis, but if it was included the amount of oil produced from the

Figure 10.--Smackover Formation pore facies of southwest Alabama (from Kopaska-Merkel, 1992).

Table 5.--Reservoir characteristics of Smackover fields in southwest Alabama

FIELD	PORE-SYSTEM TYPE	PLAY AREA	POROSITY (%)	PERM (MD)	API GRAVITY	PRODUCTIVE AREA	AVERAGE NET PAY THICKNESS	DRIVE MECHANISM
APPLETON	INTERMEDIATE	BASEMENT RIDGE COMPLEX	NA	NA	52	368	29	SOLN GAS/WATER
BARLOW BEND	INTERMEDIATE*	BASEMENT RIDGE COMPLEX	9.8	0.99	35	45	44	SOLN GAS/WATER
BARNETT	INTERCRYSTALLINE	BASEMENT RIDGE COMPLEX	6	0.14	49	1,237	12	SOLUTION GAS
BARRYTOWN	MOLDC	PERIPHERAL FAULT SYSTEM	15.44	6.81	45	355	43	SOLN GAS/WATER
BIG ESCAMBA CREEK	INTERMEDIATE	PERIPHERAL FAULT SYSTEM	12	0.64	46	15,868	63	DEPLETION
BLACKSHER	INTERMEDIATE	BASEMENT RIDGE COMPLEX	11.6	3.29	43	889	12	SOLN GAS/WATER
BROKEN LEG CREEK	INTERMEDIATE*	BASEMENT RIDGE COMPLEX	9.53	1.32	41	NA	NA	SOLN GAS/WATER
BUCATUNNA CREEK	MOLDC	PERIPHERAL FAULT SYSTEM	17	1.23	36.9	69	45	SOLN GAS/WATER
BURNT CORN CREEK	INTERMEDIATE	BASEMENT RIDGE COMPLEX	NA	NA	49	262	NA	SOLN GAS/WATER
CHAPPELL HILL	MOLDC	PERIPHERAL FAULT SYSTEM	18.2	3.64	38	256	31	SOLN GAS/WATER
CHATOM	MOLDC	MISSISSIPPI INTERIOR SALT BASIN	14.7	1.21	55	2,090	58	DEPLETION
CHOCTAW RIDGE	MOLDC	PERIPHERAL FAULT SYSTEM	14.85	21.44	41	567	22	SOLN GAS/WATER
CHUNGHLA	INTERCRYSTALLINE	WIGGINS ARCH COMPLEX	10.9	0.65	60	22,113	34	DEPLETION
COLD CREEK	INTERCRYSTALLINE*	WIGGINS ARCH COMPLEX	1.25	0.26	59	552	20	SOLUTION GAS
COPELAND	MOLDC*	MISSISSIPPI INTERIOR SALT BASIN	9.48	1.8	41	1,700	14	DEPLETION
CROSBY CREEK	MOLDC	MISSISSIPPI INTERIOR SALT BASIN	21.4	0.59	NA	NA	NA	DEPLETION
EAST BARNETT	INTERCRYSTALLINE	BASEMENT RIDGE COMPLEX	NA	NA	45.1	439	NA	SOLUTION GAS
EAST HUXFORD	INTERMEDIATE*	BASEMENT RIDGE COMPLEX	NA	NA	39.5	160	NA	SOLUTION GAS
FANNY CHURCH	INTERMEDIATE*	PERIPHERAL FAULT SYSTEM	5.6	0.04	51	653	NA	SOLUTION GAS
GIN CREEK	MOLDC	MISSISSIPPI INTERIOR SALT BASIN	10	0.89	49	2,580	12	SOLUTION GAS
GULF CREST	INTERCRYSTALLINE	WIGGINS ARCH COMPLEX	NA	NA	55.3	200	NA	SOLUTION GAS
HANBERRY CHURCH	INTERMEDIATE*	BASEMENT RIDGE COMPLEX	NA	NA	46	46	15	SOLN GAS/WATER
HATTERS ROAD	INTERCRYSTALLINE	MOBILE GRABEN FAULT SYSTEM	9.44	1.44	61	6,418	NA	DEPLETION
HEALING SPRINGS	INTERMEDIATE	MISSISSIPPI INTERIOR SALT BASIN	3.9	0.58	54	718	16	DEPLETION
HUXFORD	INTERMEDIATE	BASEMENT RIDGE COMPLEX	5.51	2.48	51	338	53	SOLN GAS/WATER
LITTLE ESCAMBA CREEK	INTERMEDIATE	PERIPHERAL FAULT SYSTEM	11	0.38	51	1,304	87	SOLUTION GAS
LITTLE MILL CREEK	INTERMEDIATE	PERIPHERAL FAULT SYSTEM	23.08	99.27	40	113	20	SOLUTION GAS
LITTLE RIVER	INTERCRYSTALLINE	PERIPHERAL FAULT SYSTEM	4.89	1.07	40	112	20	SOLUTION GAS
LITTLE ROCK	INTERMEDIATE*	PERIPHERAL FAULT SYSTEM	NA	NA	54	150	3	DEPLETION
LOVETTS CREEK	INTERMEDIATE	BASEMENT RIDGE COMPLEX	9.4	1.01	32	848	28	SOLN GAS/WATER
MELVIN	MOLDC*	PERIPHERAL FAULT SYSTEM	20.09	23.57	46	188	15	SOLN GAS/WATER
MILL CREEK	MOLDC*	PERIPHERAL FAULT SYSTEM	16.2	16.06	42	373	11	NA
MINEOLA	INTERCRYSTALLINE*	BASEMENT RIDGE COMPLEX	NA	NA	29.3	NA	NA	SOLUTION GAS
MOVVO	INTERMEDIATE	MOBILE GRABEN FAULT SYSTEM	5.84	6.73	44	1,949	20	SOLUTION GAS
NORTH CHOCTAW RIDGE	INTERMEDIATE	PERIPHERAL FAULT SYSTEM	20.2	14.18	39	225	49	SOLUTION GAS
NORTH SMITHS CHURCH	INTERCRYSTALLINE*	BASEMENT RIDGE COMPLEX	NA	NA	44.7	160	12	DEPLETION
NORTH WALLERS CREEK	INTERCRYSTALLINE	BASEMENT RIDGE COMPLEX	6.95	0.68	36.9	320	NA	SOLUTION GAS
NORTHEAST BARNETT	INTERCRYSTALLINE*	BASEMENT RIDGE COMPLEX	NA	NA	45.2	220	NA	SOLUTION GAS
NORTHWEST RANGE	INTERCRYSTALLINE*	BASEMENT RIDGE COMPLEX	NA	NA	NA	NA	NA	NA

Table 5.--Reservoir characteristics of Smackover fields in southwest Alabama--Continued

FIELD	POROSITY TYPE	PLAY AREA	POROSITY (%)	PERM (MD)	API GRAVITY	PRODUCTIVE AREA	AVERAGE NET PAY THICKNESS	DRIVE MECHANISM
PAGE CREEK	INTERCRYSTALLINE *	PERIPHERAL FAULT SYSTEM	NA	NA	38	57	18	NA
PALMERS CROSSROADS	INTERCRYSTALLINE *	BASEMENT RIDGE COMPLEX	5.9	1.11	29.2	NA	NA	SOLUTION GAS
PERDUE	INTERCRYSTALLINE	WIGGINS ARCH COMPLEX	7.8	0.71	80	1,042	20	SOLUTION GAS
PUSS CUSS CREEK	MOLDC*	MISSISSIPPI INTERIOR SALT BASIN	11.92	5.97	42	57	11	NA
RED CREEK	MOLDC*	MISSISSIPPI INTERIOR SALT BASIN	3.82	0.56	46	281	8	DEPLETION WATER
ROBINSONS CREEK	INTERCRYSTALLINE *	BASEMENT RIDGE COMPLEX	NA	NA	52.1	NA	13	SOLUTION GAS
SOUTH BURNT CORN CREEK	INTERMEDIATE *	BASEMENT RIDGE COMPLEX	NA	NA	49	268	16	NA
SOUTH WILD FORK CREEK	INTERMEDIATE *	BASEMENT RIDGE COMPLEX	NA	NA	45.8	NA	NA	DEPLETION
SOUTH WIGGINS HILL	INTERMEDIATE *	PERIPHERAL FAULT SYSTEM	NA	NA	39.2	NA	NA	SOLUTION GAS
SULAS	MOLDC	MISSISSIPPI INTERIOR SALT BASIN	12.59	4.07	42	228	18	SOLUTION GAS
SUZEMORE CREEK	MOLDC	PERIPHERAL FAULT SYSTEM	3.97	0.38	NA	83	4	DEPLETION
SMITHS CHURCH	INTERMEDIATE *	BASEMENT RIDGE COMPLEX	NA	NA	57.8	81	11	DEPLETION
SOUTH COLD CREEK	INTERCRYSTALLINE *	WIGGINS ARCH COMPLEX	NA	NA	44	64	14	SOLUTION GAS
SOUTH VIOLET	INTERMEDIATE *	BASEMENT RIDGE COMPLEX	8.8	1.24	57	21	5	SOLUTION GAS
SOUTHEAST CHATAM	MOLDC*	MISSISSIPPI INTERIOR SALT BASIN	15.01	1.25	53.7	228	34	DEPLETION
SCHWILBA CREEK	MOLDC*	MISSISSIPPI INTERIOR SALT BASIN	NA	NA	49	129	12	DEPLETION
STAVE CREEK	MOLDC	MOBILE GRABEN FAULT SYSTEM	15.2	5.87	41	192	85	SOLUTION GAS
SUGAR RIDGE	INTERMEDIATE	PERIPHERAL FAULT SYSTEM	NA	NA	38	249	52	WATER
SOUTHWEST BARRY TOWN	MOLDC*	PERIPHERAL FAULT SYSTEM	NA	NA	45.1	125	9	SOLUTION GAS
TOOLEY	MOLDC	BASEMENT RIDGE COMPLEX	21.7	22.83	20.2	207	31	SOLUTION GAS
TURNER CREEK	MOLDC*	PERIPHERAL FAULT SYSTEM	NA	NA	43	592	19	NA
TURNERVILLE	INTERCRYSTALLINE *	WIGGINS ARCH COMPLEX	10.5	0.71	55	377	31	SOLUTION GAS
URBAN	INTERMEDIATE	BASEMENT RIDGE COMPLEX	10.06	13.87	39	98	19	SOLUTION GAS
VIOLET	INTERMEDIATE	BASEMENT RIDGE COMPLEX	2.85	1.24	54	775	26	SOLUTION GAS
WALLACE	INTERMEDIATE *	BASEMENT RIDGE COMPLEX	NA	NA	44	37	21	SOLUTION GAS
WALERS CREEK	INTERMEDIATE *	BASEMENT RIDGE COMPLEX	9.3	1.49	37	221	16	SOLUTION GAS
WEST APPLETON	INTERMEDIATE *	BASEMENT RIDGE COMPLEX	NA	NA	49.4	290	NA	SOLUTION GAS
WEST BARRY TOWN	MOLDC	PERIPHERAL FAULT SYSTEM	15.25	15.24	46	101	16	SOLUTION GAS
WEST BEND	MOLDC	PERIPHERAL FAULT SYSTEM	10.4	0.38	42	189	24	SOLUTION GAS
WEST CATHLAMET CREEK	MOLDC*	BASEMENT RIDGE COMPLEX	NA	NA	26	NA	NA	SOLUTION GAS
WILD FORK CREEK	INTERMEDIATE *	BASEMENT RIDGE COMPLEX	4.49	1.92	43.1	737	NA	SOLUTION GAS
WIMBERLY	MOLDC*	PERIPHERAL FAULT SYSTEM	17.11	8.23	37	110	34	WATER
WIGGINS HILL	INTERMEDIATE	PERIPHERAL FAULT SYSTEM	14.35	0.39	37	1,637	NA	SOLUTION GAS
ZION CHAPEL	MOLDC	MISSISSIPPI INTERIOR SALT BASIN	7.79	6.95	42	344	9	SOLUTION GAS

* PREDICTED

NA = NOT AVAILABLE

Table 6.--Distribution of Smackover production relative to pore facies

	MOLDIC PORE FACIES	INTERMEDIATE PORE "FACIES"	INTERCRYSTALLINE PORE FACIES
Oil (bbls)	29,599,646 (64%) ¹	80,679,481 (67%) ¹	3,667,134 (4%) ¹
Condensate (bbls)	16,726,969 (36%) ¹	39,257,607 (33%) ¹	89,686,244 (96%) ¹
Total Liquids (bbls)	46,326,615 (18%) ²	119,937,088 ³ (46%) ²	93,353,378 (36%) ²
Oil fields	20	23	16
Condensate fields	7	5	2
Total fields	27	28	18
Cumulative Production Per Field (bbls)	1,715,800	4,283,467	5,186,298

¹ Percentage of facies total production

² Percentage of Smackover total production

³ Includes only Alabama portion
of Jay-LEC fields

intermediate pore "facies" would be an additional 369 million barrels. Large fields completed within the Moldic Pore Facies include Chatom, Choctaw Ridge, Stave Creek, and Turkey Creek fields. Hatter's Pond and Churchula fields are the two major producers of liquid hydrocarbons from the Intercrystalline Pore Facies.

WELL SPACING AND UNITIZATION OF SMACKOVER FIELDS IN ALABAMA

WELL SPACING

In Smackover reservoirs of southwest Alabama, competitive unit sizes range from 40 to 640 acres. Unit shape varies from square to elongate rectangular; some units have been configured to take into consideration the overall development scheme of the reservoir.

Choctaw and Clarke counties exhibit the widest variability in unit spacing of Smackover oil reservoirs. Unit sizes in these counties range from 40 to 160 acres. Unit configuration also varies from square, to elongate rectangular, to variously polygonal. Oil was discovered early in the Smackover in Choctaw and Clarke counties, and most fields were established prior to 1980, before statewide consistency in spacing requirements was implemented (table 7).

Variable spacing within the field is permissible in six Smackover fields in Choctaw and Clark counties. Wimberly Special Field Rules allow wells to be placed on units ranging in size from 55- to 135-acres. Melvin and Womack Hill units can vary in size from 80 to 120 acres and Barrytown, North Choctaw Ridge, and Sugar Ridge unit sizes can vary from 120 to 160 acres. In Sugar Ridge and North Choctaw Ridge fields, 120-acre units have been established.

The largest units for a Smackover oil reservoir are in Movico field, which contains irregular 640-acre units. Movico field is located in the Mobile River Delta of Mobile and Baldwin counties in an ecologically sensitive area. The large size of these development units was the result of environmental concerns over the fate of wetland habitat and the apparent ability of the discovery well to adequately drain the unit.

The most common spacing of Smackover oil pools in Alabama is 160 acres, the maximum allowed by Alabama's spacing statute (table 7). Nearly 70 percent of Smackover oil

Table 7.--Spacing requirements of Smackover fields in southwest Alabama

FIELD	TYPE RESERVOIR	DATE FIELD ESTABLISHED	REQUIRED SPACING (ACRES)	UNIT SHAPE	DISTANCE FROM UNIT LINES (FT)	DISTANCE BETWEEN WELLS (FT)
APPLETON	OIL	8/26/65	180	CONTIGUOUS ACREAGE	660	1320
BARLOW BEND	OIL	9/12/66	180	GOVERNMENTAL 1/4	660	1320
BARNETT	OIL	8/20/75	180	CONTIGUOUS ACREAGE	660	1320
BARRYTOWN	OIL	4/19/72	120-180	CONTIGUOUS ACREAGE	500	1000
BIG ESCAMBIA CREEK	CONDENSATE	2/23/72	640	CONTIGUOUS ACREAGE	1320	NO REQUIREMENT
BLACKSHER	OIL	5/1/81	180	GOVERNMENTAL 1/4	660	1320
BROKEN LEG CREEK	OIL	12/18/66	180	CONTIGUOUS ACREAGE	660	NO REQUIREMENT
BUCATUNNA CREEK	OIL	7/7/78	80	CONTIGUOUS ACREAGE	330	660
BURNT CORN CREEK	OIL	3/7/66	180	CONTIGUOUS ACREAGE	660	1320
CHAPPELL HILL	OIL	5/2/76	120	CONTIGUOUS ACREAGE	330	660
CHATOM	CONDENSATE	11/20/70	640	GOVERNMENTAL SECTION	1320	NO REQUIREMENT
CHOCTAW RIDGE	OIL	10/20/67	80	TWO CONTIGUOUS 40'S	510	1020
CHUNCHULA	OIL/CONDENSATE	11/28/74	640	CONTIGUOUS ACREAGE	1320	NO REQUIREMENT
COLD CREEK	OIL	3/7/80	180	GOVERNMENTAL 1/4	660	NO REQUIREMENT
COPELAND	CONDENSATE	7/17/75	640	CONTIGUOUS ACREAGE	1320	NO REQUIREMENT
CROSBY CREEK	CONDENSATE	1/29/68	640	GOVERNMENTAL SECTION	1320	NO REQUIREMENT
EAST BARNETT	OIL	6/24/68	180	CONTIGUOUS ACREAGE	660	NO REQUIREMENT
EAST HUXFORD	OIL	2/16/90	180	GOVERNMENTAL 1/4	660	NO REQUIREMENT
FANNY CHURCH	OIL	9/26/73	180	GOVERNMENTAL 1/4	660	NO REQUIREMENT
GIN CREEK	OIL	3/25/66	180	GOVERNMENTAL 1/4	660	1320
GULF CREST	OIL	3/11/68	180	CONTIGUOUS ACREAGE	660	NO REQUIREMENT
HANBERRY CHURCH	OIL	9/11/67	180	GOVERNMENTAL 1/4	660	1320
HATTER'S POND	CONDENSATE	12/18/75	640	GOVERNMENTAL OR CONTIGUOUS	1320	NO REQUIREMENT
HEALING SPRINGS	CONDENSATE	11/1/64	640	GOVERNMENTAL	1320	2640
HUXFORD	OIL	2/23/64	180	CONTIGUOUS ACREAGE	660	1320
LITTLE ESCAMBIA CRK	OIL	9/25/70	180	GOVERNMENTAL 1/4	660	NO REQUIREMENT
LITTLE MILL CREEK	OIL	9/29/78	180	CONTIGUOUS ACREAGE	500	1000
LITTLE RIVER	OIL	11/25/61	180	GOVERNMENTAL 1/4	660	1320
LITTLE ROCK	CONDENSATE	5/23/66	320	GOVERNMENTAL 1/2 SECTION	660	NO REQUIREMENT
LOVETTS CREEK	OIL	5/14/62	180	GOVERNMENTAL 1/4	660	1320
MELVIN	OIL	6/26/77	80-120	CONTIGUOUS ACREAGE	330	1000
MILL CREEK	OIL	10/30/75	120	RECTANGULAR	500	1000
MINEOLA	OIL	11/1/90	180	GOVERNMENTAL 1/4	660	NO REQUIREMENT
MOVICO	OIL	10/26/82	640	CONTIGUOUS ACREAGE	1320	2640
NORTH BARNETT	OIL	5/30/91	180	CONTIGUOUS ACREAGE	500	1000
NORTH CHOCTAW RIDGE	OIL	4/19/72	80	CONTIGUOUS 1/4 1/4'S	500	1000
NORTH CHOCTAW RIDGE (CONT)	OIL	1/26/73	120	CONTIGUOUS ACREAGE	500	1000
NORTH CHOCTAW RIDGE (CONT)	OIL	9/14/73	120-180	CONTIGUOUS ACREAGE	500	1000
NORTH SMITHS CHURCH	OIL	3/2/90	180	CONTIGUOUS ACREAGE	660	NO REQUIREMENT

Table 7.--Spacing requirements of Smackover fields in southwest Alabama-Continued

FIELD	TYPE RESERVOIR	DATE FIELD ESTABLISHED	SPACING (ACRES)	UNIT SHAPE	DISTANCE FROM UNIT LINES (FT)	DISTANCE BETWEEN WELLS (FT)
NORTH WALLERS CREEK	OIL	7/27/60	180	GOVERNMENTAL 1/4	660	NO REQUIREMENT
NORTHEAST BARNETT	OIL	3/2/60	180	CONTIGUOUS ACREAGE	660	1320
NORTHWEST RANGE	OIL	12/14/60	180	CONTIGUOUS ACREAGE	660	NO REQUIREMENT
PACE CREEK	OIL	2/28/67	180	GOVERNMENTAL 1/4	660	1320
PALMERS CROSSROADS	OIL	11/14/68	180	GOVERNMENTAL 1/4	660	NO REQUIREMENT
PERDIDO	OIL	8/30/64	180	CONTIGUOUS ACREAGE	660	1320
PUSS CUSS CREEK	OIL	8/3/79	180	CONTIGUOUS ACREAGE	660	1500
RED CREEK	CONDENSATE	6/28/64	640	CONTIGUOUS ACREAGE	1320	NO REQUIREMENT
ROBINSONS CREEK	OIL	10/17/60	180	GOVERNMENTAL 1/4	660	NO REQUIREMENT
SILAS	OIL	12/17/75	180	CONTIGUOUS 80'S	600	1500
SIZEMORE CREEK	CONDENSATE	7/2/66	320	CONTIGUOUS ACREAGE	660	NO REQUIREMENT
SMITHS CHURCH	CONDENSATE	8/5/68	640	GOVERNMENTAL SECTION	1320	NO REQUIREMENT
SOUTH BURNT CORN CREEK	OIL	12/18/67	180	GOVERNMENTAL 1/4	660	1320
SOUTH COLD CREEK	OIL	3/7/60	180	GOVERNMENTAL 1/4	660	NO REQUIREMENT
SOUTH VOCATION	OIL	6/27/66	180	GOVERNMENTAL 1/4	660	NO REQUIREMENT
SOUTH WILD FORK CREEK	CONDENSATE	1/20/69	640	GOVERNMENTAL 1/4	1320	NO REQUIREMENT
SOUTH WOMACK HILL	OIL	11/1/85	40	CONTIGUOUS ACREAGE	330	NO REQUIREMENT
SOUTHEAST CHATOM	CONDENSATE	8/24/68	640	CONTIGUOUS ACREAGE	1320	NO REQUIREMENT
SOUTHWEST BARRYTOWN	OIL	5/23/66	180	GOVERNMENTAL 1/4	660	1320
SOUWILPA CREEK	OIL	8/3/79	180	TWO 80 ACRE TRACTS	600	1500
SOUWILPA CREEK (CONT) (1)	CONDENSATE	12/21/79	180	GOVERNMENTAL 1/4	600	1500
STAVE CREEK	OIL	11/2/79	120 (A)	CONTIGUOUS ACREAGE	500	1500
SUGAR RIDGE	OIL	1/15/74	120-180 (B)	RECTANGULAR	500	1500
TOXEY	OIL	1/19/68	40	GOVERNMENTAL 1/4 1/4	150 OF CENTER	660
TURKEY CREEK	OIL	12/19/69	180	FOUR 40'S	510	1020
TURNERVILLE	OIL	3/7/66	180	GOVERNMENTAL 1/4	660	1320
URIAH	OIL	1/29/71	180	GOVERNMENTAL 1/4 OR CONTIGUOUS	660	1320
VOCATION	OIL	11/17/72	180	CONTIGUOUS ACREAGE	660	1320
WALLACE	OIL	12/18/67	TEMP. 180	FOUR CONTIGUOUS 40'S	660	1320
WALLERS CREEK	OIL	10/10/65	180	CONTIGUOUS ACREAGE	660	1320
WEST APPLETON	OIL	2/16/60	180	GOVERNMENTAL 1/4	660	1320
WEST BARRYTOWN	OIL	9/22/76 (C)	130	CONTIGUOUS ACREAGE	330	1200
WEST BEND	OIL	12/21/79	180	CONTIGUOUS ACREAGE	660	1500
WEST OKATUPPA CREEK	OIL	12/16/68	80	TWO 40 ACRE TRACTS	330	NO REQUIREMENT
WILD FORK CREEK	OIL	4/15/68	180	CONTIGUOUS ACREAGE	660	NO REQUIREMENT
WIMBERLY	OIL	12/16/76	55-135	CONTIGUOUS ACREAGE	330	1320
WOMACK HILL	OIL	4/30/71	80-120	CONTIGUOUS ACREAGE	510	1020
ZION CHAPEL	OIL	3/4/77	180	TWO 80 ACRE TRACTS	660	1500

(1) Changed from oil to gas pool

(A) 120 acres with a 30% tolerance

(B) Unit no longer than 3 times its width

(C) Field discovered earlier. Field rules established by Board Motion

reservoirs in Alabama are developed on 160-acre spacing and the majority of these units are square. Only three oil fields established since 1980, South Womack Hill, West Okatuppa Creek, and Movico, have been spaced on units other than 160 acres. Alabama's regulatory authority, the State Oil and Gas Board of Alabama, prefers that these 160-acre units be governmental quarter sections unless special permission is obtained from the Board (Rogers and Mancini, 1991). This policy was adopted to reduce the risk of island acreage within developing fields. Island acreage is land between producing units that is undrained and too small to be developed as units within the field. The concept of spacing on a governmental quarter section consisting of 160 acres provides a measure of orderly development and also conforms with the previously accepted concept that Smackover reservoirs in Alabama can be effectively drained by 160-acre units.

Offset, or minimum distance, a well can be located to the closest development unit boundary, is commonly 660 feet. These offset distances were established in order to reduce drainage of hydrocarbons from outside the production units and to provide some assurance of efficient recovery of hydrocarbons in the field. Wells may be located closer to the boundary in special instances where reducing the offset distance is required to obtain commercial production from the well.

The majority of Smackover gas-condensate reservoirs in Alabama have been competitively spaced on 640 acres. This is due to the more-effective drainage of gas-condensate reservoirs as opposed to oil reservoirs. Major gas-condensate fields in Alabama such as Big Escambia Creek, Hatter's Pond, Chunchula, and Chatom fields are all spaced on 640 acres. Sizemore Creek, Little Rock, and Souwilpa Creek fields are the only gas-condensate fields that have spacing sizes less than 640 acres. In the case of Sizemore Creek and Little Rock, which are spaced on 320-acre units, size of the reservoir was taken into consideration during spacing determinations because the Smackover reservoirs underlying these fields are considerably less than 640 acres in size and because adjacent fields produce from the same horizon. Souwilpa Creek, on the other hand, which was originally defined as an

oil field, was later redesignated a gas-condensate reservoir and the pre-existing 160 units were allowed to remain unchanged.

UNITIZATION

Unitization is an important facet of production operations in many fields in Alabama. Because the decision to unitize a specific field is made not only by the operator, but by mineral owners and governmental regulatory boards, it is important to understand the various ramifications of this approach to increasing recovery. This section of the report provides a brief overview of the concept of unitization.

Initially, oil and gas fields are normally developed on a competitive basis. This means that the resources produced from a well are only shared by those parties that have an interest in the production unit. Under competitive operations, the amount of acreage that must be pooled to support the drilling of a well and the placement of the well within the unit are governed by various restrictions. These restrictions are sometimes cumbersome and may not allow the placement of wells in strategic locations which would optimally produce the oil and gas resources underlying the tract. As an example, the majority of Smackover oil fields in Alabama allow only one well per 160 acres and have field rules that require that a proposed well can be no closer than 660 feet from the nearest unit boundaries. This requirement in effect reduces the drillable acreage within a unit by 75 percent so that there are only 40 acres in the center of the unit upon which a permit can be approved administratively. Often, there is an additional restriction in the spacing rules requiring that the proposed well be no closer than 1,320 feet to the nearest drilling, completed, or producing well in the field. Consequently, the island of drillable acreage can be further reduced if adjacent wells are closer than 1,320 feet to the proposed location.

Also, competitive operations do not give adequate consideration to conservation or enhancement of reservoir energy. Under competitive operations, there is no mechanism for the maintenance of reservoir energy through either injection or reduction in production allowables.

Consequently, under competitive operations, reservoir energy and therefore hydrocarbons may not be efficiently produced.

Unitization provides an alternative to competitive operations and negates many of the problems associated with it. Upon unitization of a reservoir, or a portion thereof, spacing requirements used in developing the field are no longer applicable. In fact, production-unit boundaries are no longer of any consequence. This allows the operator of the unit to drill the appropriate number of wells necessary to produce the underlying hydrocarbons and to place those wells in the most strategic locations. Further, if pressure maintenance operations are warranted, unitization provides both the legal and technical foundation needed for these operations. Royalties are no longer paid on a per-well basis but instead are paid based on the production from the entire pool in proportion to the tract participation factor assigned to the acreage. Therefore, it is of little economic consequence to interest owners in a well if the well's production rate is reduced or even if the well is shut-in or converted to an injection well, for pressure maintenance, because they will still receive revenues based on the field's total production.

The distribution of revenues in unitized fields is based on tract-participation factors which are values used in unitization programs to insure that interest owners in the unitized area recover their pro rata share of hydrocarbons which can be attributed to their property. Components of tract-participation factors vary and are sometimes based on more than one criterion. Tract-participation factors which have been used in Alabama are hydrocarbon pore volume, daily average production, remaining recoverable reserves, well deliverability, surface acres, total cumulative oil produced, and number of wellbores completed in the reservoir. In many instances the tract participation factor is derived by using more than one criterion. In Jay-LEC fields, the tract-participation factor is a two-phase formula in which the tract-participation factor changes during the history of the field (Masingill, 1990).

The most positive effect of unitization is that it allows field operations that are conducive to maximum recovery of hydrocarbons from the entire field and not from a specific production

unit. Unitization allows infill drilling, strategic well placement, and introduction of some type of gas or liquid into the reservoir to maintain reservoir pressure and facilitate optimum recovery of hydrocarbons.

UNITIZED FIELD CHARACTERIZATIONS

Characterization of reservoirs in which enhanced recovery has been implemented is important because it provides a means to not only evaluate the unitized fields, but also to evaluate fields which may be candidates for enhanced recovery. Eleven Smackover fields have been unitized in southwest Alabama (fig. 11) (table 8). Geologic, engineering, reservoir-fluid, and development data are given below for unitized fields.

FIELDS IN MOLDIC PORE FACIES

Four unitized fields in Alabama are located within the Moldic Pore Facies of Kopaska-Merkel and Mann (1991) (table 9). These fields have proven productive areas of less than 1,000 acres each and cumulative production per field is less than 4 million barrels of oil. These fields are oil fields which have combination drives and are located within either the regional peripheral fault trend play or Mobile graben fault system play.

Choctaw Ridge Field

Choctaw Ridge field was discovered in 1967 by Pruet and Hughes Company with the drilling of the Trice No. 1 well (Permit No. 1413) in Choctaw County, Alabama. The discovery well was perforated in the Smackover Formation in the intervals between 11,940 feet to 11,952 feet and 11,963 feet to 11,964 feet. On the initial test, the Trice No. 1 well flowed at a rate of 840 barrels of 41° gravity oil and 558 Mcf of gas per day on a 1/4 inch choke with a tubing pressure of 1,500 psi (Kopaska-Merkel and others, 1992). The wellstream from Choctaw Ridge field contained approximately 11 percent nonhydrocarbons of which approximately 2 percent was hydrogen sulfide gas.

Figure 11.--Unitized Smackover fields in southwest Alabama.

Table 8.--Characteristics of unitized Smackover fields in Alabama

FIELD	TYPE UNITIZATION	EFFECTIVE DATE	FLUIDS INJECTED	DATE OF INJECTION	PRODUCTION PRIOR TO UNITIZATION (BBLs)	PRODUCTION AFTER UNITIZATION (BBLs)
APPLETON	FIELDWIDE	5/1/88	NONE	NA	937,425	994,987
CHATOM	FIELDWIDE	4/22/76	RESIDUE GAS	8/76	2,217,288	12,149,473
CHOCTAW RIDGE	PARTIAL	5/1/74	NONE	NA	1,952,598	1,670,011
CHUNCHULA	FIELDWIDE	2/1/81	RESIDUE GAS & N ₂	4/82 7/84	10,751,233	36,839,254
FANNY CHURCH	PARTIAL	1/1/85	N ₂	12/85	2,308,798	1,982,333
HATTER'S POND	FIELDWIDE	5/1/85	RESIDUE GAS	7/85	21,292,820	20,387,249
LITTLE ESCAMBIA CREEK	FIELDWIDE	3/1/74	WATER WATER & CH ₄ WATER & N ₂	3/74 1/81 12/81	3,967,377	26,232,835
SILAS	FIELDWIDE	9/1/76	NONE	NA	12,875	1,736,800
STAVE CREEK	FIELDWIDE	3/15/85	NONE	NA	1,278,927	1,669,365
TURKEY CREEK	PARTIAL	1/1/75	NONE	NA	858,062	1,902,811
WOMACK HILL	PARTIAL	1/1/75	WATER	7/75	2,536,279	13,216,488

Table 9.--Distribution of unitized fields relative to pore facies

<u>PORE FACIES</u>	<u>FIELD</u>	<u>EOB METHOD</u>	<u>CUMULATIVE PRODUCTION (BBLs)</u>
MOLDIC	Choctaw Ridge	None	3,622,609
	Silas	None	1,749,675
	Stave Creek	Strategic Well	2,948,292
	Turkey Creek	Strategic Well	2,760,873
		TOTAL	11,081,449
INTERCRYSTALLINE			
	Churchula	Gas Injection	47,590,487
	Hatter's Pond	Gas Injection	41,680,069
		TOTAL	89,270,556
INTERMEDIATE			
	Appleton	Strategic Well	1,932,412
	Chatom	Gas Injection	14,366,761
	Fanny Church	Gas Injection	4,291,131 ¹
	Jay-LEC	Infill drilling	399,324,471 ²
		Waterflood	
		Gas Injection	
	Womack Hill	Waterflood	15,752,867 ³
		TOTAL	435,667,642

¹ Production from Steely pod only ² Includes Alabama and Florida portions of field

³ Production from Womack Hill field unit only

The trap in Choctaw Ridge field is structural, and the Smackover reservoir is located on a faulted salt-cored anticline (fig. 12). The anticline trends approximately east-west and is upthrown to faults on the east and north. The eastern fault is a down to the east normal fault and the northern fault is downthrown to the north (fig. 13). The Choctaw Ridge anticline has over 150 feet of structural closure and the oil water contact for the field is at a subsea depth of 11,846 feet (fig. 13).

The well logs from the Rentz-Trice Unit 35-1 No. 1 well (Permit No. 1427) indicate the most porous portion of the reservoir is in the uppermost part of the Smackover (fig. 14). Porosity in the Smackover of the Choctaw Ridge field ranges from 7.5 to 31.1 percent and averages 19.39 percent with a standard deviation of 4.95 percent. Permeability for the Smackover reservoir ranges from 1.9 to 1,410 md with a geometric mean of 21.44 md (Kopaska-Merkel and others, 1992).

The Smackover reservoir in the Rentz-Trice Unit 35-1 No. 1 well consists of oolitic and pelletal dolomitic grainstone and dolograinstone which was deposited in a high-energy subtidal shoal (fig 15). Moldic pores are dominant in the Rentz-Trice core and comprise 61 percent of the pores identified. Secondary intraparticle pores and interparticle pores represent 36 percent and 3 percent of the pores, respectively (Kopaska-Merkel and others, 1992). Because of the high percentage of molds in the Smackover reservoir of Choctaw Ridge field it is placed in the Moldic Pore Facies (Kopaska-Merkel and Mann, 1991).

Choctaw Ridge field was developed on 80-acre spacing with the requirement that wells could be no closer than 510 feet to the nearest unit line or 1,020 feet from the closest producing well. A total of 7 wells were completed as producers in the field, 6 of which were still producing at the time of unitization. Prior to unitization in 1974, 1.9 million barrels of oil and 1.2 billion cubic feet of gas had been produced.

Figure 12.--Structure contour map on top of Smackover Formation in Choctaw Ridge field, Alabama.

Figure 13.--Structural cross section of Choctaw Ridge field, Alabama. (See figure 12 for line of section.)

Figure 14.-- Well log correlated to lithology, Rentz-Trice Unit 35-1 well, Permit No. 1427, Choctaw Ridge field, Alabama.

Figure 15.--Detailed core log, Rentz-Trice Unit 35-1 well, Permit No. 1427, Choctaw Ridge field, Alabama.

Silas Field

Silas field was discovered in Choctaw County, Alabama, with the drilling of the Chesnut Unit 4-15 No. 1 well (Permit No. 2084) in 1975. The well was completed in the Smackover Formation in the interval between 13,564 to 13,578 feet. On the initial test, the well flowed at a rate of 312 barrels of 42° gravity oil and 250 Mcf of gas through a 1/4 inch choke with a tubing pressure of 650 psi (Kopaska-Merkel and others, 1992). Nonhydrocarbon components account for 14.38 percent of the wellstream; 11.8 percent is hydrogen sulfide.

The Silas field trap is structural, and the reservoir is located on a faulted salt-cored anticline (figs. 16 and 17). The oil/water contact in Silas field is interpreted to be at a subsea depth of 13,290. Average pay thickness in the field is 16 feet and the reservoir-drive mechanism is a combination drive with both water and solution-gas components. Field limits encompass 1,280 acres (Kopaska-Merkel and others, 1992).

The main porous and permeable interval of the Smackover Formation is located in the upper portion of the formation (fig. 18). Porosity in the Smackover ranges from 4.9 to 29.80 percent and averages 15.08 percent. The standard deviation is 6.95 percent. Permeability in the Smackover ranges from 0.05 to 216 md with a geometric mean of 1.17 md (Kopaska-Merkel and others, 1992).

Based on core from the Chesnut Unit 9-1 No. 1 well (Permit No. 2205), the Smackover reservoir in Silas field is dominated by peloidal ooid dolograinstone interpreted to have been deposited in a beach-barrier complex (fig. 19). Moldic and secondary intraparticle pores dominate this lithofacies and therefore, the Smackover reservoir of Silas field is placed in the Moldic Pore Facies of Kopaska-Merkel and Mann (1991). In lithofacies 1, (13,601-13,630 feet) which constitutes about 88 percent of the reservoir, porosity ranges from 13.5 to 26 percent with an average value of 21.5 percent. Standard deviation of porosity values is 2.8 percent. Permeability ranges from 0.90 to 53.7 md with a geometric mean of 3.61 md.

Lithofacies 2 is a mixed nonskeletal dolograinstone and dolomitic grainstone which was probably deposited on a shoreface or flood-tidal delta and tidal-flat complex. Pore types

Figure 16.--Structure contour map on top of Smackover Formation in Silas field, Alabama.

Figure 17.--Structural cross section of Silas field, Alabama. (See figure 16 for line of section.)

Figure 18.--Well log, correlated to porosity and permeability, Chesnut Unit 4-15 No. 1 well, Permit No. 2084, Silas field, Alabama.

Figure 19.--Detailed core log, Chesnut Unit 9-1 No. 1 well, Permit No. 2205, Silas field, Alabama.

observed in this facies include secondary intraparticle pores (47.4 percent), moldic pores (36.8 percent), and intercrystalline pore types (15.8 percent). Only one porosity and one permeability analysis were available from this lithofacies, with values of 25.7 percent and 84.3 md, respectively. Lithofacies 2 is encountered between the depths of 13,630 and 13,634 feet and represents approximately 12 percent of the reservoir (Kopaska-Merkel and others, 1992).

Silas field was developed on 160-acre units with spacing rules that require that wells be no closer than 600 feet to unit boundaries and no closer than 1,500 feet to the nearest wells. A total of 6 wells are located within the field limits, 2 of which are productive.

Total reservoir volume of Silas field is approximately 5,335 acre feet (Pruet and Hughes Co., Exhibit 8, Docket No. 8-13-763, State Oil and Gas Board of Alabama). The field is interpreted to produce by a combination drive consisting of solution-gas expansion and water influx. The original bottomhole pressure of the field was 6,429 psia and has since dropped to 3,448 psia (Kopaska-Merkel and others, 1992).

Stave Creek Field

Stave Creek field was discovered in 1979 with the drilling of the McCorquodale 25-1 No. 1 well, one mile northwest of the city of Jackson in Clarke County. The McCorquodale 25-1 well flowed at a rate of 595 barrels of 41° gravity oil and 216 Mcf of gas on a 9/64 inch choke with a tubing pressure of 2,050 psi. The Smackover was perforated between the depths of 12,454 and 12,473 feet. The Stave Creek structure proved to be difficult to predict and of the 12 wells drilled in the field, 8 were dry holes. The field limits encompass 1,400 acres of which 193 acres are interpreted to be productive (Kopaska-Merkel and others, 1992).

The Stave Creek structure is a salt-cored anticline which trends approximately north-south (fig. 20) and is upthrown to faulting located on the west and southwest. Relief of the structure is in excess of 350 feet. Average pay thickness in the field is 65 feet, and an oil-water contact is at a subsea depth of 12,400 feet (fig. 21). The initial reservoir pressure of the

Figure 20.--Structure contour map on top of Smackover Formation in Stave Creek field, Alabama.

Figure 21.--Structural cross section of Stave Creek field, Alabama. (See figure 20 for line of section.)

field was 6,046 psia and the drive mechanism is interpreted to be primarily water with a solution-gas drive component (Kopaska-Merkel and others, 1992).

Well logs from the McCorquodale 25-1 No. 1 well (Permit No. 2718) indicate that the Buckner Anhydrite provides a seal to the Smackover reservoir, which is extremely porous at the top of the interval (fig. 22). Porosity in the Smackover ranges from 4.9 to 26.7 percent and averages 15.3 percent with a standard deviation of 4.8 percent. Permeability ranges from 0.02 to 733 md with a geometric mean of 5.67 md (Kopaska-Merkel and others, 1992)

The reservoir in the McCorquodale 25-1 well in Stave Creek field is an ooid dolograine (fig. 23) which is believed to have been deposited in a high-energy shoal environment. Porosity in this lithofacies ranges from 12.5 to 26.7 percent with a mean of 19.1 percent and a standard deviation of 3.4 percent. Permeability ranges from 3.92 to 733 md with a geometric mean of 64.47 md. Interparticle, secondary intraparticle, and moldic pores are the most common pore types observed in the field and account for 34, 26, and 21 percent, respectively, of the pores identified. Kopaska-Merkel and Mann (1991) placed the Smackover reservoir of Stave Creek field in the Moldic Pore Facies.

Spacing requirements in Stave Creek field required that wells be drilled on 120-acre rectangular units but did allow a 30-percent tolerance to accommodate fringe areas underlain by hydrocarbons. Wells could be no closer than 500 feet from the unit boundaries and no closer than 1500 feet to the nearest producing wells. Three wells had been completed as producers prior to the unitization hearings which were held in February 1985.

Turkey Creek Field

Turkey Creek field, which is located in Choctaw and Clarke counties, Alabama, was discovered by Chesley Pruet in 1969 with the drilling of the Alco Land and Timber Company, Inc.-Powe Unit 28-5 No. 1 well (Permit No. 1509). The discovery well was perforated in the Smackover Formation between the depths of 12,378 and 12,930 feet and flowed at a rate of

Figure 22.--Well log correlated to lithology, porosity, and permeability, McCorquodale 25-1 No. 1 well, Permit No. 2718, Stave Creek field, Alabama.

Figure 23.--Detailed core log, McCorquodale 25-1 No. 1 well, Permit No. 2718, Stave Creek field, Alabama.

324 barrels of 43° gravity oil and 65 Mcf of gas per day through a 20/64 inch choke with a flowing tubing pressure of 125 psi (Kopaska-Merkel and others, 1992).

The trapping mechanism in Turkey Creek field is a combination trap (fig. 24). The Smackover reservoir is located on a salt-cored anticline which trends northeast-southwest. The Turkey Creek anticline is cut by a down-to-the-north normal fault which has over 100 feet of displacement at the Smackover horizon. The water level in Turkey Creek field occurs at a subsea depth of 12,378 feet and average net pay thickness in the field is 18 feet (fig. 25). The field limits encompass 1,920 acres of which 995 are interpreted to be oil productive (Kopaska-Merkel and others, 1992).

The well log of the Alco Land and Timber Co., Inc. No. 1 well (Permit No. 1400) indicates that porosity in the well is in the upper portion of the Smackover (fig. 26). Porosity in the Smackover reservoir of Turkey Creek field ranges from 12.4 to 33.7 percent with an average of 20.6 percent and a standard deviation of 4.4 percent. Permeability in the Smackover ranges from 1.4 to 385 md with a geometric mean of 47.02 md (Kopaska-Merkel and others, 1992).

Wells in the field were spaced on 160-acre units with spacing rules which required that wells be no closer than 510 feet to the nearest unit line or 1,020 feet from an existing producing well. The field was characterized by low gas/oil ratios and low pressures. Between the years of 1969 and 1975, the water level in the field rose 11 feet from its original subsea depth of 12,378 to a subsea depth of 12,367 feet (Pruet and Hughes Co., Exhibit 3, Docket No. 10-22-747, State Oil and Gas Board of Alabama). The drive mechanism in the field is believed to be the result of solution-gas expansion and water influx.

FIELDS IN INTERCRYSTALLINE PORE FACIES

Two unitized fields in southwest Alabama are located within the Intercrystalline Pore Facies (table 9). Both are gas-condensate fields, and traps include structural and combination traps. Play areas include the Wiggins arch complex play and the Mobile graben fault system

Figure 25.--Structural cross section of Turkey Creek field, Alabama. (See figure 24 for line of section.)

Figure 26.--Well log, Chesley Pruet-Alco Land & Timber Co., Inc. No. 1 well, Permit No. 1400, Turkey Creek field, Alabama. (Density curve is bulk density.)

play. Total production from Churchula and Hatter's Pond fields is over 89 million barrels of condensate.

Churchula Field

Churchula field, in Mobile County, was discovered by Union Oil Company of California in 1974. The discovery well for Churchula field, the International Paper Company 22-13 No. 1 well (Permit No. 1886), was completed in the Smackover Formation and perforated in the interval between 18,421 to 18,438 feet. On its initial test, the well flowed at a rate of 1,158 barrels of 60° gravity condensate and 2,650 Mcf of gas per day on a 16/64 inch choke with a tubing pressure of 2,475 psi. Churchula field is a major hydrocarbon accumulation with field limits encompassing more than 25,000 acres (Kopaska-Merkel and others, 1992).

Churchula field has a combination trap. The field is located on a broad salt-cored anticline which has minimal structural relief (figs. 27 and 28). The gas-water contact in the field varies considerably. Average net pay thickness is 34 feet (Kopaska-Merkel and others, 1992).

The well log from the Annie M. Hill et al. 10-10 No. 1 well (Permit No. 2218) indicates that the Smackover in this well is relatively thin and overlain by the Buckner Anhydrite (fig. 29). Porosity in the Smackover in this well ranges from 1.1 to 26.2 percent and averages 10.9 percent (standard deviation = 4.6 percent). Permeability values range from 0.02 to 392 md and have a geometric mean of 0.65 md (Kopaska-Merkel and others, 1992). Based on the results of the University of Alabama study (subtask 4 of this project), porosity for the entire Churchula reservoir averages 12.9 percent and permeability averages 6.2 md.

The Smackover reservoir in the Annie M. Hill well is a crystalline dolostone which is locally anhydritic. This lithofacies was deposited in a shallow subtidal marine and/or peritidal hypersaline environment. Pores are predominantly intercrystalline (99 percent). Therefore, the Smackover reservoir of Churchula field is placed in the Intercrystalline Pore Facies by Kopaska-Merkel and Mann (1991). Porosity in this lithofacies range from 3.1 to 14.6 percent

Figure 27.--Structure contour map on top of Smackover Formation in Churchula field, Alabama.

Figure 28.--Structural cross section of Chunchula field, Alabama. (See figure 27 for line of section.)

Figure 29.--Well log correlated to lithology, porosity, and permeability, Annie M. Hill et al. 10-10 No. 1 well, Permit No. 2218, Churchula field, Alabama.

and averages 9.9 percent with a standard deviation of 3.1 percent. Permeability in the lithofacies ranges from 0.09 to 5.9 md and has a geometric mean of 1.04 md. The crystalline dolostone lithofacies is present in the interval between 18,444 feet and 18,508 feet in the Annie M. Hill well (fig. 30) (Kopaska-Merkel and others, 1992).

In the University of Alabama's study of Chunchula field (subtask 4 of this project) interparticle, moldic, vuggy, and intercrystalline pores were identified. Interparticle porosity was determined to be one of the dominant pore types in the reservoir but is only present in the dolomitized parts of the Smackover. Molds are also only present in the dolomitized parts of the Smackover and that portion of the reservoir with moldic pores is characterized by moderate to high porosity, but low permeability. Pores classified as vuggy have low permeability but moderate to high porosity. Intercrystalline pores are present in nearly all of the completely dolomitized sections of the reservoir, but do not significantly contribute to the overall volume of the reservoir.

The original bottomhole pressure in Chunchula field was 9,255 psia and has declined to 4,317 psia in 1990 (Kopaska-Merkel and others, 1992). Reservoir fluid composition in the field includes 5.6 mole percent nitrogen, and 2.01 mole percent carbon dioxide. Hydrogen sulfide is present in concentrations of approximately 50 ppm. Based on a reservoir-fluid study on the International Paper Company 22-13 well (Permit No. 1886B) the fluid exists in an undersaturated gas phase. The gas-liquid ratio of the hydrocarbon fluids was 1,670 cubic feet of separator gas per barrel of separator liquid (Union Oil Company of California, Exhibit 13, Docket No. 11-7-8021, State Oil and Gas Board of Alabama).

Additional reservoir fluid data presented to the State of Alabama Oil and Gas Board in 1983 indicated that Chunchula field hydrocarbons existed as both a dense wet gas and a highly volatile oil. Both the wet gas phase and the volatile oil phase have essentially the same chemical composition and differ only in phase present. Very slight changes in chemical composition, pressure, or temperature will cause the reservoir fluids to exhibit a dew point (gas phase), in some instances, or a bubble point (oil phase) in others. The factor controlling which

Figure 30.--Detailed core log, Annie M. Hill et al. 10-10 No. 1 well, Permit No. 2218, Churchula field, Alabama.

phase is present appears to be structural position of the hydrocarbons in the reservoir (Testimony of R. B. Bellamy, December 21, 1983, State Oil and Gas Board). Oil is present around the flanks of the reservoir while gas is dominant on the crest. A transition zone of both oil and gas is present between the two zones (fig. 31).

Chunchula field was developed on 640-acre production units with spacing rules that required wells be no closer than 1,320 feet to the nearest unit lines. Thirty-four producing units were established at the time of unitization in 1981.

Hatter's Pond Field

Hatter's Pond field was discovered in 1974 by Getty Oil Company with the drilling of the Peter Klein 3-14 No. 1 well (Permit No. 1978) in Mobile County, Alabama. The well was drilled to a total depth of 18,358 feet and completed in the Smackover through a perforated interval of 18,042 feet to 18,062 feet (Masingill, 1990). The initial flow rate of the Klein well was 2,166 barrels of 61° gravity condensate and 6,198 Mcf of gas through a 17/64 inch choke with a flowing tubing pressure of 3,270 psi. Reservoir-fluid studies indicated hydrocarbons were in a gas phase in the reservoir, and the reservoir was classified as a gas-condensate reservoir. The underlying Norphlet Formation also produces hydrocarbons (Benson and Mancini, 1982).

The Hatter's Pond reservoir is located on a faulted salt-cored anticline (fig. 32). The structure trends northeast-southwest, adjacent to the Mobile graben and has more than 700 feet of structural relief. Salt piercement occurs on the eastern side of the fault adjacent to the major down to the east normal fault (fig. 33). The field limits encompass more than 9,000 acres of which 6,418 are interpreted to be underlain by hydrocarbons.

The average net pay thickness of the Smackover reservoir is 59 feet (Kopaska-Merkel and others, 1992). Overall, the Smackover reservoir's porosity ranges from 1.20 to 24.4 percent and averages 9.44 percent with a standard deviation of 6.02 percent (fig. 34). Permeability ranges from 0.01 md to 177 md and has a geometric mean of 1.44 md (Kopaska-Merkel and others, 1992).

Figure 31.--Distribution of hydrocarbon phases in Churchula field, Alabama (from Union Oil of California, Exhibit 18, November 11, 1983 State Oil and Gas Board of Alabama).

Figure 32.--Structure contour map on top of Smackover Formation in Hatter's Pond field, Alabama.

Figure 34.-- Well log correlated to lithology, porosity, and permeability, Hatter's Pond Unit 10-3 No. 1 well, Permit No. 6846, Hatter's Pond field, Alabama. (Logs were uninterpretable through upper part of cored interval.)

Reservoir quality rock in the Hatter's Pond Unit 10-3 No. 1 well (Permit No. 6846) is classified into three lithofacies (fig. 35). The uppermost reservoir lithofacies (between 18,054 to 18,084 feet in the Hatter's Pond Unit 10-3 No. 1 well) consists of peloid ooid dolopackstone and grainstone which was deposited on a shoal margin. Major pore types in this lithofacies are intercrystalline and pelmoldic pores with minor amounts of biomoldic and vuggy porosity. Porosity in the dolopackstone-grainstone facies ranges from 5.2 to 24.4 percent and averages 17.3 percent. Permeability ranges from 0.25 to 177 mD with a geometric mean 31.66. The dolopackstone-grainstone facies accounts for 30 percent of the Smackover reservoir in the Hatter's Pond Unit 10-3 No. 1 well (Kopaska-Merkel and others, 1992).

Underlying the dolopackstone-grainstone facies is the ooid peloid dolowackestone facies (18,086 to 18,132 feet). These strata were probably deposited in a restricted lagoon. Intercrystalline porosity is also the major pore type in this lithofacies with minor amounts of moldic and fracture porosity. Porosity ranges from 5.3 to 16.1 percent and averages 10.7 percent. Permeability ranges from 0.01 to 8.5 md with a geometric mean of 0.18 md. The ooid peloid dolowackestone facies accounts for 46.5 percent of the Smackover reservoir in the well (Kopaska-Merkel and others, 1992).

The lowermost lithofacies is thrombolitic, ooid peloid dolostone which was deposited in an ooid shoal to moderate energy thrombolitic reef-lagoon setting. Intercrystalline and moldic pores are dominant with vuggy pores also present. Porosity ranges from 6.6 to 15.8 percent and averages 11.9 percent. Permeability ranges from 0.45 to 30 md with a geometric mean of 9.28 md. This lowermost facies accounts for over 33 percent of the reservoir quality rock (Kopaska-Merkel and others, 1992). The Smackover reservoir of Hatter's Pond field is placed in the Intercrystalline Pore Facies of Kopaska-Merkel and Mann (1991).

Murray (1991), identified 4 pore types in the Hatter's Pond reservoir; interparticulate, intercrystalline, moldic, and vuggy. Interparticulate pore types were determined to be the most common. Average porosity and permeability for the reservoir portions of the Smackover is 13.5 percent and 10.6 md, respectively (Murray, 1991).

Figure 35.--Detailed core log, Hatter's Pond Unit 10-3 No. 1 well, Permit No. 6846, Hatter's Pond field, Alabama.

The original reservoir pressure of Hatter's Pond field was 9,150 psi. Based on fluid studies of the full wellstream, the reservoir fluid was determined to be a gas-condensate with a dewpoint of 3,050 psi at reservoir temperature of 325° F (Four Star Oil and Gas Co., Exhibit 3, Docket No. 11-1-90250, State Oil and Gas Board of Alabama). Analysis of the produced wellstream of the Peter Klein 3-14 No. 1 well (Permit No. 1978), indicates carbon dioxide and nitrogen account for 6.13 mole percent and 2.83 mole percent of the full wellstream, respectively. Hydrogen sulfide content from the analysis was reported as nil (Four Star Oil and Gas Co., Exhibit 16, Docket No. 11-1-90250, State Oil and Gas Board of Alabama).

Hatter's Pond field was developed on 640-acre units consisting of governmental sections or contiguous acreage in the form of a square. Spacing rules required that wells could be no closer than 1,320 feet to the nearest unit boundaries. Thirteen units were developed during competitive operations. Prior to unitization the field produced 21 million barrels of condensate and 82.7 billion cubic feet of gas (Masingill, 1990).

FIELDS IN INTERMEDIATE PORE "FACIES"

Five Smackover fields are located within the intermediate pore "facies" (table 9). Hydrocarbon phases include oil and gas-condensate. Reservoirs range in size from less than 400 acres to over 14,000 acres. Traps include structural and combination traps. Production from unitized fields in the intermediate pore "facies" is more than 435 million barrels of oil and condensate, including the Florida portion of Jay-LEC fields.

Appleton Field

Appleton field was discovered by Texaco, Inc. in 1983, but was not formally established as a field until 1985 (Sexton, 1986). The field is located in north-central Escambia County, Alabama and produces from the Smackover Formation at a depth of approximately 12,900 feet. The discovery well, the D.W. McMillan Trust 2-14 No. 1, tested at a rate of 661 barrels of oil

per day and 1,060 Mcf of gas per day on a 16/64 inch choke through a perforated interval of 12,902 to 12,938 feet (Kopaska-Merkel and others, 1992).

The structure in Appleton field is anticlinal with distinct structural lobes (fig. 36). Two lobes have separate water levels indicating two distinct pools within the field. Water levels within the field range from a subsea depth of 12,685 to 12,710 feet and define the two reservoirs. The Appleton anticline is a consequence of a basement paleohigh below the Smackover Formation (fig. 37).

Based on examination of core from the D.W. McMillan 2-15 No. 5 well (Permit No. 6247), the Smackover reservoir in Appleton field consists of microbial and peloid doloboundstone (fig. 38). The depositional environment is interpreted to have been a backbarrier lagoon in which rapid upward shoaling to restricted peritidal conditions was followed by a period of exposure. Kopaska-Merkel and Mann (1991) placed the Smackover reservoir of Appleton field in the intermediate pore "facies." Pore types in Appleton field include intercrystalline (46 percent), moldic (37 percent), and vuggy (17 percent). Average pay thickness in the field is 39 feet (Kopaska-Merkel and others 1992). Porosity is present throughout the Smackover in the McMillan 2-14 No. 1 well (Permit No. 3854) (fig. 39).

The reservoir fluids in Appleton field exist as a undersaturated oil reservoir with a bubble-point pressure of 3,416 psia. The original bottomhole pressure was 6,264 psia. The interpreted drive mechanism for the field is a combination of solution-gas expansion and water influx.

The wellstream composition at Appleton field contains 1.75 mole percent hydrogen sulfide, 1.38 mole percent carbon dioxide, and 5.7 mole percent nitrogen. The gas/oil ratio was 847 standard cubic feet of gas per stock tank barrel of oil.

As originally established, Appleton field contained 960 acres. The field was spaced on 160-acre units consisting of governmental one-quarter sections. Field rules required that wells could be no closer than 660 feet to the nearest unit boundary and that the distance between wells should be no less than 1,320 feet. Prior to unitization the Appleton field contained 4

Figure 37.--Structural cross section of Appleton field, Alabama. (See figure 36 for line of section.)

Figure 38.--Detailed core log, D.W. McMillan 2-15 No. 5 well, Permit No. 6247, Appleton field, Alabama.

Figure 39.-- Well log, McMillan 2-14 No. 1 well, Permit No. 3854, Appleton field, Alabama.

producing wells. Production from Appleton field prior to unitization was 937,425 barrels of oil and 1.7 billion cubic feet of gas.

Chatom Field

Chatom field was discovered in 1970 with the drilling of the Williams "AA" No. 1 well by Phillips Petroleum Company in Section 20, Township 6 North, Range 4 West, Washington County. The well was perforated between 15,999 and 16,114 feet in the Smackover Formation and had an initial test rate of 988 barrels of condensate per day, 4,029 Mcf of gas per day on a 24/64 inch choke with a tubing pressure of 1,933 psi (Kopaska-Merkel and others, 1992).

Structurally, Chatom field is situated on a salt-cored anticline which has in excess of 800 feet of closure. The trap is interpreted to be structural. The Chatom anticline is slightly elongate and trends northwest-southeast (fig. 40). It is bounded to the south and southeast by a group of small faults which separate Chatom field from the downdip Southeast Chatom field. Southeast Chatom field is also classified as a gas-condensate field and is productive in the Smackover Formation. The lowest known gas is interpreted to be at a subsea depth of 16,004 feet and the highest known water is interpreted to be at a subsea depth of 16,141 feet (fig. 41) (Phillips Petroleum Co., Exhibit 1A, Docket Nos., 5-17-881 through 5-17-883, State Oil and Gas Board of Alabama)

The well log from the Chatom Unit 20-14 No. 1-04 well (Permit No. 7044) (correlated to porosity, permeability, and lithology) indicates that porosity in this well is concentrated in the uppermost portion of the Smackover Formation (fig. 42). Porosity within the Smackover ranges from 0.13 to 37.2 percent and averages 14.7 percent with a standard deviation of 10.2 percent. Permeability ranges from 0.02 to 196 md with a geometric mean of 1.21 md.

The Smackover reservoir in the Chatom Unit 20-14 No. 1-04 well (Permit No. 7044) consists of two lithofacies which are a pelmoldic and crystalline dolostone; and pellet dolograinstone. The pelmoldic and crystalline dolostone was deposited in a shallowing upward

Figure 41.--Structural cross section of Chatom field, Alabama. Highest known water and lowest known gas taken from Phillips Petroleum Co., Exhibit 1A, Docket No. 5-17-881 through 5-17-883, State Oil and Gas Board of Alabama. (See figure 40 for line of section.)

Figure 42.--Well log correlated to lithology, porosity, and permeability, Chatom Unit 20-14 No. 1-04 well, Permit No. 7044, Chatom field, Alabama.

shallow subtidal lagoon and ooid shoal. Intercrystalline pores are dominant within this facies and account for 62 percent of the pores recognized. Moldic and secondary intraparticle pores are also present and account for 22 percent and 16 percent, respectively, of the pores identified. This lithofacies is present in the interval of 16,073 to 16,086 feet and constitutes 62 percent of the reservoir (fig. 43) (Kopaska-Merkel and others, 1992).

Lithofacies 2 is present in the interval of 16,018 to 16,025 feet in the Chatom Unit 20-14 No. 1-04 well (Permit No. 7044) and is a pellet dolograinstone deposited in a microtidal flat. Pelmolds are dominant in the lithofacies and comprise 90 percent of the pores identified. Intercrystalline pores account for only 10 percent of the pores. Porosity in this lithofacies ranges from 8.7 to 37.2 percent and averages 28.4 percent. Permeability ranges from 0.02 to 88 md with a geometric mean of 11.13 md (Kopaska-Merkel and others, 1992). The Smackover reservoir of the Chatom field is in the intermediate pore "facies" of Kopaska-Merkel and Mann (1991).

Permeability within the pelmoldic and crystalline dolomite facies range from 0.55 to 6.58 md and has a geometric mean of 2.83 md. Porosity within this facies ranges from 8.7 to 22.9 percent and averages 18 percent. This lithofacies is present in the Chatom Unit 20-14 No. 1-04 well in the interval between 16,073 to 16,086 feet (Kopaska-Merkel and others, 1992).

Chatom field was developed on 640-acre spacing and wells could be no closer than 1,320 feet from the exterior boundary of the drilling unit. Four productive wells were drilled during competitive operations and cumulative production prior to unitization accounted for 2.2 million barrels of condensate and 9.7 billion cubic feet of gas (Masingill, 1990).

Fanny Church Field

Fanny Church field was discovered in 1973 with the drilling of the Jimmy L. Bush, et ux. No. 25-3 (Permit No. 1833) by Exxon Corporation in Escambia County, Alabama. The well was perforated in the Smackover Formation in the interval of 15,377 to 15,457 feet and initially tested 1,406 barrels of 51° gravity oil and 1,776 Mcf of gas per day on a 14/64 inch choke with

Figure 43.--Detailed core log, Chatom Unit 20-14 No. 1-04 well, Permit No. 7044, Chatom field, Alabama.

a flowing tubing pressure of 3,400 psi (Kopaska-Merkel and others, 1992). Hydrogen sulfide content in the field is approximately 4.7 mole percent. Carbon dioxide and nitrogen account for 1.53 mole percent and 0.87 mole percent, respectively.

The Smackover reservoir of Fanny Church field is located on a northwest-southeast trending monocline which dips gently to the southwest (fig. 44). The hydrocarbon trap at Fanny Church field is a combination trap where both structural dip and facies variations provide the trapping mechanism (fig. 45). Porous and permeable reservoir rocks in the Fanny Church field are located in pods which may be laterally extensive although it is uncertain if they are in pressure communication with one another.

Zones of reservoir quality porosity are present throughout much of the Smackover in Fanny Church field as indicated by the well log from the D. J. Steely 36-2 well (Permit No. 1869) (fig 46). Porosity in the Smackover reservoir ranges from 1 to 23.2 percent with an average of 10.69 percent; the standard deviation is 4.37 percent. Permeability ranges from 0.02 to 120 md; the geometric mean is 0.37 md (Kopaska-Merkel and others, 1992).

Fanny Church field was developed on 160-acre units and encompassed 3,960 acres. Spacing rules for the field required that wells be no closer than 660 feet to nearest unit line. The field had a total of 7 wells that were completed as producers, five of which were still producing as of January 1, 1985. Prior to unitization in 1985, Fanny Church field had produced approximately 2.3 million barrels of oil and 3 billion cubic feet of gas (Masingill, 1990).

Geologic and engineering data suggested that in Fanny Church field there were approximately four separate lenses of reservoir quality rock. Three of these lenses were interpreted to be small, but the fourth encompassed more than 700 acres and contained three productive wells. This lens of productive Smackover reservoir was called the Steely pod and encompassed the Dora J. Steely 36-2 well (Permit No. 1869), the Zelma Pugh 26-15 well (Permit No. 3307B), and the St. Regis Paper Co. 35-1 (Permit No. 3154) (Exxon Corp., Exhibit G-5, Docket No. 12-13-842, State Oil and Gas Board of Alabama).

Figure 45.--Structural cross section of Fanny Church field, Alabama. (See figure 44 for line of section.)

Figure 46.--Well log, D.J. Steely 36-2 well, Permit No. 1869, Fanny Church field, Alabama. (Density curve is bulk density.)

Jay-Little Escambia Creek Fields

Little Escambia Creek field was discovered in 1970 by Humble Oil and Refining Company with the drilling of the T.R. Miller Mill Co. Unit 32-2 No. 2 (Permit No. 1562) in Escambia County, Alabama. The T.R. Miller Mill Co. well was perforated in the Smackover Formation between 15,380 and 15,470 feet. The well initially flowed at a rate of 479 barrels of 51° gravity oil and 1,050 Mcf of gas per day on a 20/64 inch choke with a tubing pressure of 700 psi.

Little Escambia Creek field is part of a large hydrocarbon accumulation which extends into Escambia and Santa Rosa counties, Florida, where it is designated Jay field (fig. 47). The Jay-LEC fields encompass 14,400 productive acres (Shirer and others, 1978). Most of the field is located in Florida. Within the Alabama portion of the field, Little Escambia Creek field limits encompass 3,840 acres, of which 1,304 acres are proven to be productive (Kopaska-Merkel and others, 1992).

The Jay-LEC reservoir is located on a large salt-cored anticline which trends northwest-southeast and is situated just west of the southern extension of the Foshee-Pollard fault system (Ottmann and others, 1973; Sigsby, 1976). The hydrocarbon trap in Little Escambia Creek field is a combination trap. Little Escambia Creek field is located on the north-plunging anticlinal nose of the structure (fig. 48). Also, a facies change to the north provides an impermeable barrier to updip migration of hydrocarbons (fig. 49).

Average pay thickness in the Alabama portion of Jay-LEC fields is 82 feet. Porosity in the field ranges from 2.10 to 23.8 percent and averages 11 percent with a standard deviation of 4.3 percent. Permeability in the field ranges from 0.02 to 91 md with a geometric mean of 0.38 md. Well logs from the Miller Mill 32-3 well indicate that porous and permeable zones of reservoir quality rock are interbedded with nonporous intervals (fig. 50).

Five Smackover lithofacies have been defined in the T.R. Miller Mill Unit 32-3 well in Little Escambia Creek field (figs. 51 and 52). Lithofacies 1, which is the interval between 15,151 to 15,181 feet in the T.R. Miller Mill Unit 32-3 well (Permit No. 1654), consists of peloid

Figure 47.--Structure contour map of top of Smackover Formation in Jay-Little Escambia Creek fields, Santa Rosa and Escambia counties, Florida, and Escambia County, Alabama (modified from Davis and Lambert, 1963).

Figure 48.--Structure contour map on top of Smackover Formation in Little Escambia Creek field, Alabama.

Figure 49.--Structural cross section of Little Escambia Creek field, Alabama. (See figure 48 for line of section.)

Figure 50.--Well log correlated to lithology, porosity, and permeability, T.R. Miller Mill Unit 32-3 well, Permit No. 1654, Little Escambia Creek field, Alabama. (Logs were uninterpretable through upper part of cored interval.)

Figure 51.--Detailed core log (upper part), T.R. Miller Mill Unit 32-3 well, Permit No. 1654, Little Escambia Creek field, Alabama.

Figure 52.--Detailed core log (lower part), T.R. Miller Mill Unit 32-3 well, Permit No. 1654, Little Escambia Creek field, Alabama.

dolograinstone which contains ooids and oncoids, deposited in a shallow subtidal lagoon with moderate to high wave energy. Pore types include secondary intraparticle (44 percent), intercrystalline (33 percent), and moldic (23 percent). Porosity in this facies ranges from 12.4 to 23.2 percent and averages 18.3 percent with a standard deviation of 3 percent. Permeability ranges from 0.36 to 71 md with a geometric mean of 16.2 md. This lithofacies accounts for approximately 16 percent of the reservoir (Kopaska-Merkel and others, 1992).

Lithofacies 2 is a peloid dolograinstone and dolopackstone (15,181 to 15,204.5 feet in the T.R. Miller Mill Unit 32-3 well; Permit No. 1654) deposited in a shallow subtidal lagoon with moderate wave energy. These strata were later subjected to dolomitization and leaching. Secondary intraparticle pores comprise 100 percent of those pores identified. Porosity in this zone ranges from 8.4 to 18.3 percent and averages 12.4 percent. Permeability ranges from 0.16 to 16 md with a geometric mean of 1.67 md. Lithofacies 2 comprises 13 percent of the reservoir (Kopaska-Merkel and others, 1992).

Lithofacies 3 (15,204.5 to 15,265 feet and 15,281 to 15,294 feet) is a peloid wackestone with dolomitized peloids. These strata are interpreted to have been deposited in a shallow subtidal lagoon under low-energy conditions. This facies was also subjected to dolomitization and leaching. Secondary intraparticle pores comprise 100 percent of the pore system. Porosity ranges from 2.1 to 16 percent and averages 9.8 percent. Permeability in this lithofacies ranges from 0.02 to 8 md with a geometric mean of 0.21 md (Kopaska-Merkel and others, 1992).

Lithofacies 4 is comprised of dolomitized microbial reef material and peloidal, oncoidal, and anhydritic mudstone, wackestone, and packstone. The depositional setting for this lithofacies is interpreted to have been a low-energy shallow-marine setting that was subjected to intermittent periods of subaerial exposure. Intercrystalline and secondary intraparticle pores are dominant in the facies and account for 42 and 41 percent of the pores, respectively. Porosity in lithofacies 4 ranges from 4.8 to 12 percent with an average of 9.7 percent.

Permeability ranges from 0.03 to 2.7 md with a geometric mean of 0.32 md. Lithofacies 4 comprises 21 percent of the reservoir (Kopaska-Merkel and others, 1992).

Lithofacies 5 is present in the T.R. Miller Mill 32-3 well in the intervals of 15,401 to 15,414 feet and 15,424 to 15,433 feet. This lithofacies consists of dolomitized microbial reefs and intercalated oncoidal packstone deposited in supratidal to subtidal marine microbial mats with intercalated packstone deposited under moderate energy. Moldic and secondary intraparticle pores are dominant and account for 56 percent and 34 percent, respectively, of the pores identified. Porosity ranges from 3.5 to 17.9 percent and averages 12 percent. Permeability ranges from 0.02 to 2.3 md with a geometric mean of 0.40 md. Lithofacies 5 represents 12 percent of the reservoir (Kopaska-Merkel and others, 1992). Because of the variation in pore types Kopaska-Merkel and Mann (1991), place the Little Escambia Creek Smackover reservoir in the intermediate pore "facies."

Hydrocarbons in Jay-LEC fields are in an undersaturated oil phase. Original bottomhole pressure was 7,850 psia and the bubble point of the hydrocarbons was 2,830 psia. Static reservoir temperature was 285° F. The oil formation volume factor was 1.76 reservoir barrels per stock tank barrel and the original solution gas/oil ratio was 1,806 standard cubic feet per stock tank barrel. API gravity of the oil is 51° (Langston and Shirer, 1985). The full wellstream fluid from the Smackover Formation in Jay-LEC fields contains 8.78 mole percent hydrogen sulfide, 2.24 mole percent carbon dioxide and 1.28 mole percent nitrogen (Exxon Corp., Exhibit E-6, Docket No. 12-7-73, State Oil and Gas Board of Alabama).

Jay-LEC fields were developed on units consisting of 160 acres. Field rules governing spacing required that wells could be no closer than 660 feet to the nearest unit lines. Prior to unitization in 1974, Jay-LEC fields had approximately 85 productive wells within the field limits. Six of these wells were located in Alabama. Cumulative production prior to unitization in the Alabama portion of the field was 3.9 million barrels of oil and 5.4 billion cubic feet of gas (Masingill, 1990).

Jay-LEC fields contains 14,415 productive acres. Average net pay thickness of the Smackover-Norphlet oil pool was determined to be 95 feet. The original oil-in-place was calculated to be 728 million stock tank barrels (Langston and Shirer, 1985).

The drive mechanism for Jay-LEC fields is solution gas expansion coupled with water influx (Applegate and Lloyd, 1985; Lloyd and others, 1986). Pressure surveys performed on wells within the field indicated that reservoir pressure declined to 7,045 psig as of November 1972, and 5,490 psig by October 1973. Based on the rapid decline in reservoir pressure, it was predicted that only 120.7 million barrels of oil, or approximately 17 percent of the oil-in-place, would be recovered without the initiation of an enhanced recovery project (Exxon Corp., Exhibit E-7, Docket No. 12-7-73, State Oil and Gas Board of Alabama).

Womack Hill Field

Womack Hill field was discovered by Pruet & Hughes Company and Pelto Oil Company in 1970 with the drilling of the Carlisle Unit 16-4 No. 1 well (Permit No. 1573). The Carlisle Unit is completed in the Smackover Formation and was perforated in the interval between 11,432 to 11,442 feet. Initially, the well tested at a rate of 600 barrels of oil per day on a 20/64 inch choke with a tubing pressure of 450 psi. API gravity of the oil is 37°. Initial reservoir pressure was 5,418 psia (Kopaska-Merkel and others, 1992).

Since its discovery, Womack Hill field has developed into a major oil field in Alabama and has produced over 25 million barrels of oil. This makes Womack Hill field the third largest oil field in Alabama behind Citronelle field, which is producing from Cretaceous strata, and Little Escambia Creek. Field limits encompass 3,485 acres of which 1,637 are interpreted to be productive (fig. 53) (Kopaska-Merkel and others, 1992). Geologic and engineering studies performed for the operators indicated that total reservoir net pore volume for the Womack Hill field was approximately 20,578 acre feet with a productive area encompassing approximately 1,770 acres based on an 11-percent porosity cut-off. Original oil-in-place in Womack Hill field

Figure 53.--Structure contour map on top of Smackover Formation in Wornack Hill field, Alabama.

was estimated to be over 87 million barrels of stock tank oil (Pruet and Hughes Co., Exhibit 8, Docket No. 11-26-746, State Oil and Gas Board of Alabama).

Womack Hill field is located on a faulted salt-cored anticline which abuts the peripheral fault system that transects much of southwest Alabama. The structure is elongate, being over 4 miles long and less than one mile wide (fig. 53). Structural closure on the Womack Hill anticline is over 300 feet.

The trap in Womack Hill field is interpreted to be structural but a major permeability barrier bisects the field perpendicular to the axis of the structure. This permeability barrier is narrow and transects the entire Smackover interval vertically (fig. 54). The water level which defines the western end of the field is 214 feet lower than the water level to the east.

Well logs from the WHFU Parker-Locke 9-16 No. 1 well (Permit No. 1655) indicate that reservoir-grade porosity is present throughout much of the Smackover reservoir which is overlain by thick Buckner Anhydrite (fig. 55). Porosity in the field ranges from 2.20 to over 33.9 percent and averages 17.61 percent. Standard deviation of porosity values is 5.29 percent. Permeability in the field ranges from 0.02 to over 386 md and has a geometric mean of 6.66 md. Average net pay thickness in the field is 56 feet (Kopaska-Merkel and others, 1992).

The Smackover oil pool in the Turner 13-25 well (Permit No. 2327), which is on the easternmost end of the field, is an oolitic dolostone with minor amounts of dolomitic boundstone (fig. 56). The Smackover reservoir which is overlain by a deepening upward evaporite sequence is interpreted to have been deposited in a shallow subtidal lagoon or tidal flat. Intercrystalline porosity is 71 percent of the pore system whereas moldic porosity accounts for 21 percent. Secondary intraparticle and interparticle pores account for less than 10 percent of the pore system (Kopaska-Merkel and others, 1992). The Smackover reservoir of the Womack Hill field is in the intermediate pore system (Kopaska-Merkel and Mann, 1991).

As of March 1974, 17 wells had been completed in Womack Hill field (Pruet and Hughes Co., Exhibit 8, Docket No. 11-26-746, State Oil and Gas Board of Alabama). The field

Figure 54.--Structural cross section of Womack Hill field, Alabama. (See figure 53 for line of section.)

Figure 55.--Well log, WHFU Parker-Locke 9-16 No. 1 well, Permit No. 1655, Womack Hill field, Alabama. (Density curve is bulk density.)

Figure 56.--Detailed core log, Turner 13-25 well, Permit No. 2327, Womack Hill field, Alabama.

was developed on units which were elongated perpendicular to the axis of the anticline and unit size varied between 80 to 120 acres. Most of these units were the approximate width of 40-acre tracts. Spacing rules required that wells be no closer than 510 feet to the nearest unit lines and 1,020 feet from the nearest producing wells.

DISCUSSION OF RESULTS

ENHANCED RECOVERY TECHNIQUES IN SMACKOVER RESERVOIRS

Within the following discussion, unitized fields are divided into groups based on the most important type of enhanced-recovery techniques used to increase ultimate recovery. In the case of fields undergoing waterflooding or gas injection, additional wells were drilled within the fields after unitization either as replacement, infill, or strategically located wells. Jay-LEC fields, which has had infill drilling, waterflood, and gas injection, is placed in a separate category entitled "Multiple techniques." Fields are evaluated relative to predicted performance and the microscopic and macroscopic heterogeneity values generated by Kopaska-Merkel (1992). At the end of this section are specific recommendations about other fields in Alabama which resemble fields presently undergoing enhanced-recovery and therefore should be considered candidates for analogous enhanced recovery methods.

Eleven fields (or portions thereof) have been unitized for the purpose of increasing the ultimate recovery of hydrocarbons from those fields (table 10). Six of these fields were unitized for the purpose of introducing external energy sources which involves the injection of gas or water for increased recovery. The other five fields were unitized without any specific timetable for fluid injection but instead for the purpose of strategic/infill drilling or manipulation of production rates to obtain maximum recovery.

Unitization Without Enhanced Recovery

Two Smackover fields in Alabama have been unitized in which no infill drilling, strategic well placement, or injection of gas or water has occurred. These fields, Silas and Choctaw

Table 10.--Enhanced recovery techniques used in unitized Smackover fields of Alabama

<u>EOE METHOD</u>	<u>FIELD</u>	<u>CUMULATIVE</u>		<u>PLAY</u>
		<u>PORE FACIES</u>	<u>PRODUCTION</u>	
STRATEGIC WELL PLACEMENT	Stave Creek	Moldic	2,948,292	Mobile graben fault system
	Turkey Creek	Moldic	2,760,873	Regional peripheral fault trend
	Appleton	Intermediate	1,932,412	Basement ridge
		TOTAL	7,641,577	
WATERFLOOD	Womack Hill	Intermediate	15,752,867 ¹	Regional peripheral fault trend
		TOTAL	15,752,867	
GAS INJECTION	Churchula	Intercrystalline	47,590,487	Wiggins arch complex
	Hatter's Pond	Intercrystalline	41,680,069	Mobile graben fault system
	Chatom	Intermediate	14,366,761	
	Fanny Church	Intermediate	4,291,131 ²	Regional peripheral fault trend
MULTIPLE TECHNIQUES		TOTAL	107,928,448	
	Jay-LEC	Intermediate	399,324,471 ³	Regional peripheral fault trend
NONE		TOTAL	399,324,471	
	Choctaw Ridge	Moldic	3,622,609	Regional peripheral fault trend
	Silas	Moldic	1,749,675	Mississippi interior salt basin
		TOTAL	5,372,284	

¹ Production from the Womack Hill field unit only

² Production from the Steely pod only

³ Includes Alabama and Florida portion of the field (Total)

Ridge fields, are located within the Mississippi interior salt basin and regional peripheral fault trend plays, respectively, of Mancini and others (1991). Silas and Choctaw Ridge fields were unitized because the operator presented data indicating that by allowing for the unitization of the fields ultimate recovery of hydrocarbons from the fields would be increased. It was the operators' belief that through unitization of these fields the economic life of the fields would be extended by reducing operating costs.

Choctaw Ridge Field

Pruet and Hughes Company appeared before the State of Alabama Oil and Gas Board in April 1974, requesting the Board approve a plan of unitization for Choctaw Ridge field. The operator contended that the field could be more effectively and economically produced as a reservoir-wide unit rather than as several competitive production units. The operator proposed to shut in 3 of the producing wells in the field (permit numbers 1421, 1427, and 1443) because of large volumes of water being produced from those wells. These wells are located on the northern and eastern flanks of the structure. The Trice No. 1 well (Permit No. 1413) had previously been shut in. It was anticipated that the remaining recoverable oil in the field could be produced through the 3 remaining wells because the drive mechanism was a combination of solution-gas expansion and water influx which would effectively move the recoverable oil. Unitization would also reduce the expense associated with disposal of the volumes of formation water produced. At the time of unitization, the operator anticipated that establishing the reservoir-wide unit, which would permit the manipulation of production rates, would extend the life of the field approximately 6 years and facilitate the recovery of an additional one million barrels of oil.

Since unitization in 1974, Choctaw Ridge field has produced approximately 1.6 million barrels of oil and 490 million cubic feet of gas through 1990. Choctaw Ridge field has a very low macroscopic heterogeneity value (MH) (Kopaska-Merkel, 1992). Cumulative production from Choctaw Ridge field is 3.6 million barrels of oil and 1.85 billion cubic feet of

gas. Production from Choctaw Ridge field has been declining steadily but water-production volumes have increased in recent years (fig. 57).

Silas Field

Silas field was unitized in 1976, and the unitized area included 2 competitive units as well as an additional 146 acres outside the original drilling units that were interpreted to be productive, for a total of approximately 466 acres. The purpose of unitization was to avoid drilling unnecessary wells and to allow the hydrogen-sulfide bearing wellstream to be processed by a single treatment facility. The wellstream from Silas field contains approximately 12 mole percent hydrogen sulfide.

Prior to unitization, Silas field had produced 12,875 barrels of oil and 10 million cubic feet of gas (Masingill, 1990). The operator anticipated that under unitization the field would produce approximately 1.1 million stock tank barrels of oil without any type of pressure maintenance (Pruet and Hughes Co., Exhibit 8, Docket No. 8-13-763, State Oil and Gas Board of Alabama).

Since the field was unitized, Silas field has produced 1.7 million barrels of oil and 1.8 billion cubic feet of gas. Both oil and gas production in Silas field are declining with time; water production has been on the increase in recent years (fig. 58). In 1990, Silas field produced 88,510 barrels of oil and 27,615 Mcf of gas. Silas field is ranked 21 out of 31 (31 being the most heterogeneous) in macroscopic heterogeneity (Kopaska-Merkel, 1992).

Strategic Well Placement

Strategic well placement involves the drilling of additional well(s) at specific locations to increase hydrocarbon recovery. Strategic well placement requires that the operator of the field have a good understanding of reservoir geometry and characteristics. In some instances, wells are strategically located to encounter hydrocarbons updip of existing wells. In other instances, wells may be located in areas where porosity or permeability values are lower than in the

Figure 57.--Graph of production history of Choctaw Ridge field, Alabama.

Figure 58.--Graph of production history of Silas field, Alabama.

surrounding areas prohibiting effective recovery of hydrocarbons. Recovery from such areas will be most cost effective with smaller well spacing.

Three Smackover fields in Alabama have been unitized to allow drilling of additional well(s) at strategic locations. In each case, this was the only enhanced-recovery mechanism employed. The location of the additional wells in these fields were selected so that hydrocarbons could be efficiently recovered. Fields in which strategic well placement have been used are located within the peripheral fault system, Mobile graben fault system, and basement ridge plays of Mancini and others (1991).

Appleton Field

In 1988, Texaco, Inc., petitioned the Alabama Oil and Gas Board to establish a field-wide unit for Appleton field. The proposed tract-participation formula was based on two different criteria: Daily average production rate between the period of May 1, 1985 to December 31, 1987, and acre-feet of hydrocarbon pay. Each component accounted for 50 percent of the tract-participation factor (Masingill, 1990).

Texaco Inc., requested that the field be unitized to allow drilling of an additional well within the field limits. Development of Appleton field necessitated the drilling of an additional well at a strategic location. Units for existing wells encased an advantageous location that could not be drilled without unitization of the field.

Exhibits indicated that by drilling a strategically placed well, an additional 220,000 barrels of oil and 402 million cubic feet of gas could be recovered from the field. Original oil-in-place in Appleton field was estimated to be 5.3 million stock-tank barrels of oil (Texaco Inc., Exhibit 10-A, Docket No. 3-10-8814, State Oil and Gas Board of Alabama).

The field was unitized in 1988 with an effective date of May 1, 1988. In March of 1989, the D.W. McMillan Trust 2-15 No. 5 was drilled as an infill well in an attempt to improve recovery. The well was located in the southern part of Section 2 to encounter the structure of the reservoir at the crest. Based on exhibits presented by Texaco, the D.W. McMillan Trust 2-

15 No. 5 well should have encountered the Smackover reservoir at a subsea depth above 12,650 feet and penetrated over 60 feet of reservoir quality rock (Texaco Inc., Exhibit 3, Docket No. 3-10-8814, State Oil and Gas Board of Alabama). However, the well penetrated the Smackover reservoir significantly lower than had been expected. The Smackover reservoir in the well was encountered at a subsea depth of 12,693 feet and the well penetrated approximately 8 feet of reservoir-quality rock (Texaco Inc., Exhibits 17 and 20, Docket No. 8-9-891, State Oil and Gas Board of Alabama). In January of 1991, the well was sidetracked approximately 700 feet to the southwest where the well encountered permeable and porous Smackover at a subsea depth of 12,663 feet and penetrated 35 feet of Smackover pay. The initial flow rate for the D.W. McMillan Trust 2-15 No. 5 well was 500 barrels of oil per day, 1,410 Mcf of gas per day on a 1 1/4 inch choke with a flowing tubing pressure of 1,320 psig.

A graph of field production excluding the D.W. McMillan Trust 2-15 No. 5 well versus production from all wells shows production in the field as a result of the D.W. McMillan 2-15 No. 5 well (fig. 59). The graph indicates that the D.W. McMillan Trust 2-15 No. 5 well produced at a much higher flow rate than the average of the other wells in the field. Note that although production for both the D.W. McMillan Trust 2-15 No. 5 well and the average of the initial field wells is in a state of decline, the D.W. McMillan Trust 2-15 No. 5 well produces at a significantly higher rate than the average of the other wells in the field and increases the monthly per-well production rates.

Appleton field has a microscopic heterogeneity (μH) value of 1.37 (values ranged from 0.87 to 3.22), but macroscopic heterogeneity (MH) was not determinable (Kopaska-Merkel, 1992). Production from Appleton field is in a state of decline (fig. 60). Prior to unitization, Appleton field had produced approximately 937,000 barrels of oil and 1.7 billion cubic feet of gas (Masingill, 1990). Production after unitization has accounted for 995,000 barrels of oil through December 1990. Cumulative production for the field is 1.9 million barrels of oil and 3.5 billion cubic feet of gas, through December 1990.

Figure 59.--Graph of production for the Appleton field including the D. W. McMillan 2-15 No. 5 well versus field production excluding the D. W. McMillan 2-15 No. 5 well on a per well basis.

Figure 60.--Graph of production history of Appleton field, Alabama.

Stave Creek Field

Pruet Production Company requested the State Oil and Gas Board of Alabama to unitize Stave Creek field in order to provide a mechanism whereby interest owners could receive credit for oil being produced from their respective units and to allow for an additional strategically placed well to be drilled within the field. The drive mechanism in Stave Creek field was interpreted by the operator to be an effective influx of water. The operator proposed that drilling a well on the crest of the structure would allow for the recovery of "attic oil" (oil located above the highest perforations in the field) (Pruet Oil Co., Exhibit 2, Docket No. 1-23-8528, State Oil and Gas Board).

Total reserves within the field were calculated to be over 6 million barrels of oil; of which approximately 3 million barrels were interpreted to be recoverable. The operator concluded that within the crest of the structure, above the highest perforations, there were approximately 26 acres of Smackover reservoir which were not drained by existing wells. This area was interpreted to contain 371,900 stock barrels of oil, of which over 188,000 barrels could be recovered. Including this "attic oil," there would be 1.9 million barrels of remaining recoverable oil (Pruet Oil Co., Exhibits 5 & A-10, Docket No. 1-23-8528, State Oil and Gas Board of Alabama).

The field was unitized in 1985 with an effective date of March 15. The Stave Creek Field Unit No. 1 (Permit No. 4681) was drilled into the apex of the Stave Creek reservoir and tested at a rate of 535 barrels of oil per day on a 14/64 inch choke in October 1985. The Stave Creek Field Unit No. 1 well has cumulatively produced approximately 760,000 barrels of oil, which is 26 percent of the field's total production and approximately 57 percent of the fields' production since unitization.

Prior to unitization, Stave Creek field had produced 1,278,927 barrels of oil and 336,790 Mcf of gas (Masingill, 1990). Since unitization, Stave Creek field has produced 1,669,365 barrels of oil through December 1990. Cumulative production for the field through December 1990, is 2,948,292 barrels. Oil and gas production in the field are decreasing while

water production is on the increase (fig. 61). Stave Creek field has microscopic and macroscopic heterogeneity values of 2.04 and 6.98, respectively (Kopaska-Merkel, 1992).

Turkey Creek Field

Turkey Creek field was unitized in 1975. At the time of unitization, the field contained three producing wells, which had cumulatively produced over 858,062 barrels of oil and 42,903 Mcf of gas (Masingill, 1990). Original oil-in-place for Turkey Creek field is estimated to be approximately 12.2 million barrels of stock tank oil (Pruet and Hughes Co., Exhibit 4, Docket No. 10-22-747, State Oil and Gas Board of Alabama).

The field was unitized by Pruet and Hughes Company to allow the drilling of an additional well within the field. The additional well was warranted because it was estimated that there was approximately 820 acre-feet of reservoir updip to the existing wells which contained an additional 309,000 stock-tank barrels of oil that could be recovered if the additional well was drilled (Pruet and Hughes Co., Exhibit 4, Docket No. 10-22-747, State Oil and Gas Board of Alabama). The entire unitized area encompassed 480 acres.

At the time of unitization, the operator estimated that only 6.8 percent of the original oil-in-place had been recovered, and by unitizing the field and allowing for an additional well, 4.2 million barrels of oil could ultimately be recovered from the reservoir. The additional updip well being proposed by Pruet and Hughes would contribute 309,000 stock tank barrels of this oil (Pruet and Hughes Co., Exhibit 4, Docket No. 10-22-747, State Oil and Gas Board of Alabama).

The Alco Land and Timber Co., Inc.-Powe Unit 28-3 No. 1 well (Permit No. 2030) was completed in the Smackover Formation in 1975 and tested at a rate of 308 barrels of oil and 27 Mcf of gas per day on pump. The well has produced 608,306 barrels of oil. Microscopic heterogeneity in Turkey Creek field is intermediate; macroscopic heterogeneity was not determinable (Kopaska-Merkel, 1992).

Figure 61.--Graph of production history of Stave Creek field, Alabama.

Since Turkey Creek field was discovered, it has produced approximately 2.7 million barrels of oil and 137 million cubic feet of gas through December 31, 1990. Approximately 50 percent of the oil produced was recovered after unitization. The field is currently producing 102 barrels per day. Production from the field in 1990 was 37,457 barrels of oil and 1,871 Mcf of gas. In Turkey Creek field oil production is declining while water production is on the increase (fig. 62).

Waterflood Operations

Waterflooding is an enhanced-recovery technique that involves the injection of water into a reservoir to force crude oil toward producing wells (Schumacker, 1978). This technique provides for increased sweeping of hydrocarbons and increases recovery. Womack Hill and Jay-LEC fields have implemented enhanced recovery projects in which waterflooding is an integral part. Both fields are in the regional peripheral fault trend play of Mancini and others (1991).

Womack Hill Field

In November of 1974, Pruet and Hughes Company went before the State Oil and Gas Board of Alabama requesting that the western portion of Womack Hill field be unitized. During development of the field, it was determined that the Womack Hill reservoir is bisected by an area of reduced permeability near the eastern boundary of the 14-4 unit. Further, it was determined that the eastern portion of the field had a strong water-drive mechanism which maintained reservoir pressure, whereas the western end of the field was experiencing a rapid pressure decline. Original reservoir pressure in Womack Hill field was 5,418 psi. By April 1, 1974, reservoir pressure in the eastern portion of the field was determined to be approximately 5,250 psig with a recovery of 4,763 stock tank barrels of oil per psi drop in reservoir pressure; pressure in the western end of the field had declined to approximately 4,050 psig with an oil recovery of 1,311 stock tank barrels per psi of reservoir pressure drop (Pruet and Hughes Co.,

Figure 62.--Graph of production history of Turkey Creek field, Alabama.

Exhibit 8, Docket No. 11-26-746, State Oil and Gas Board of Alabama). The recovery in the eastern portion of the field was approximately 3.5 times better than that experienced on the western end.

Based on reservoir modelling (Pruet and Hughes Co., Exhibit 8, Docket No. 11-26-746, State Oil and Gas Board of Alabama), it was determined that primary recovery from the entire field should be approximately 25.5 million barrels or 29.2 percent of the oil-in-place. The model did confirm that a barrier to fluid flow exists within the field. Because of the high recovery of oil being observed in the eastern end of the field it was determined that only the western part of the field should be unitized (fig. 53) (Pruet and Hughes Co., Exhibit 8, Docket No. 11-26-746, State Oil and Gas Board of Alabama).

The productive area of the western end of the field contains 796 acres and 10,514 acre-feet of reservoir pore volume. Original oil-in-place under the western end of the field was in excess of 46 million stock tank barrels of oil. As of March 1974, the western end of the field had produced approximately 1.8 million barrels of oil. Ultimate recovery under primary recovery for the western portion of the field was estimated to be approximately 13 million stock tank barrels of oil with an abandonment pressure of 1,500 psig (Pruet and Hughes Co., Exhibit 8, Docket No. 11-26-746, State Oil and Gas Board of Alabama).

The western end of Womack Hill field was unitized in November 1974, with an effective date of January 1, 1975. Based on reservoir modelling performed, it was proposed that a series of injection wells be placed around the flanks of the field in downdip areas and in the small saddle in the northwest quarter of the northeast quarter of Section 15, Township 10 North, Range 2 West, to supplement the natural drive mechanism in the western end of the field. It was also proposed that 4 new producing wells be drilled in the structurally highest portions of the proposed unit so that the maximum recovery of oil could be realized from the waterflood program (fig. 53). Projected ultimate recovery of oil from the western end of Womack Hill field as a result of the waterflood was approximately 17 million barrels of oil, a 30

percent increase over expected primary recovery (Pruet and Hughes Co., Exhibit 8, Docket No. 11-26-746, State Oil and Gas Board of Alabama).

Once the field was unitized, four injector wells were located along the flanks of the reservoir. Permit numbers 1573, 1591, and 1720 were converted to injection wells. Permit number 2168-WI-72 was also drilled as an injection well. Along the crest of the structure, six wells were drilled for production purposes so that the full effect of the waterflood could be realized. One of these wells (Permit No. 2737-B) was plugged and abandoned as noncommercial.

In 1990, Womack Hill field produced 794,599 barrel of oil and has produced 25 million barrels of oil since its discovery in 1970 (fig. 63). Production from the Womack Hill field unit since unitization totals over 13 million barrels. Total water injected into the unit exceeds 20 million barrels. In 1990, the field unit produced 568,650 barrels of oil. The Womack Hill Field Unit 14-5 No. 2 well (Permit No. 4575-B), which was drilled on the eastern end of the unit and was completed in 1985, has produced nearly 780,000 barrels of oil through 1990.

Production from the Womack Hill field unit under waterflood tracked the production that was predicted under primary recovery until 1985, when a significant increase in hydrocarbon recovery began to be realized (fig. 64). In 1990, actual production exceeded for the first time estimated production using enhanced recovery. Womack Hill field has average macroscopic and microscopic heterogeneity (Kopaska-Merkel, 1992).

Gas Injection Operations

Injection of gas is the most common enhanced-recovery method used in Smackover reservoirs of southeast Alabama. It is being implemented in all of the oil plays defined by Mancini and others (1991) except for the basement ridge play. Gas injection is being used in five fields in Alabama. Two of these fields are classified as oil fields and the remaining three are gas-condensate fields. Gases used for injection include residue methane gas and nitrogen.

Figure 63.--Graph of production history of Womack Hill field, Alabama.

Figure 64.--Predicted versus actual cumulative production in Womack Hill field unit.

Chatom Field

The oldest gas-injection program in Alabama is at Chatom field. Chatom field was unitized in 1976 with the purpose of recycling residue gas to increase ultimate recovery (Masingill, 1991). The field area unitized for secondary-recovery operations consisted of 3,300 acres, and the original reservoir volume was determined to be 82,104.7 acre-feet using a 9-percent porosity cutoff (Phillips Petroleum Co., Exhibit 5, Docket No. 4-22-762, State Oil and Gas Board of Alabama). Exhibits presented at the hearing indicated recycling of residue gas would result in 9 million additional barrels of condensate and 5.5 million additional barrels of natural gas liquid. Also, with gas recycling, sulfur recovery would be increased from 196,030 long tons to 530,860 long tons (Phillips Petroleum Co., Exhibit 6, Docket No. 4-22-762, State Oil and Gas Board of Alabama).

An injection well was drilled at the apex of the Chatom field anticline to inject gas into the Chatom reservoir and a producing well was converted to a gas injection well. Injection began in 1976 and over 67 billion cubic feet of gas has been injected through 1990 (Masingill, 1991). Since the field was unitized, five production wells have been drilled into the field. Producing wells were situated off the flanks of the structure to recover the hydrocarbons (fig. 19).

After unitization, the yearly production rate increased for Chatom field (fig. 65). The field has produced over 14 million barrels of condensate through 1990. This includes approximately 8 million barrels of condensate that would not have been produced by primary recovery. Chatom is still producing, and in 1990, Chatom produced 690,000 barrels of condensate. Chatom field has average microscopic heterogeneity and high macroscopic heterogeneity (Kopaska-Merkel, 1992).

Churchula Field

As a part of this project (subtask 4), researchers at the University of Alabama performed a detailed geological, engineering, and statistical study of the Churchula field

Figure 65.--Graph of production history of Chatom field, Alabama.

reservoir and the effectiveness of the enhanced recovery program (Benson and others, 1991).

These data were then used by the University's research team to develop a model of the Churchula field and reservoir simulations were performed using MASTER, a reservoir simulation program developed by the Department of Energy. For a discussion of the results of the University's research and their recommendations, Benson and others (1991) should be consulted.

Fanny Church Field

Fanny Church field was unitized in 1985. The unit operator, Exxon Corporation, intended to institute a miscible-gas injection program in the Steely pod using nitrogen as injection gas, increasing the ultimate recovery of oil in the Steely pod from 30 percent to approximately 54 percent (Exxon Corp., Exhibit E-7, Docket No. 12-13-842, State Oil and Gas Board of Alabama). Exxon estimated that recovery from the Steely pod would only be 3.9 million stock tank barrels of oil under primary recovery, but with miscible-gas injection, the recoverable reserves would be approximately 7 million barrels of oil (an increase of 3.1 million barrels). Implementation of gas injection would also extend the life of the field 4.5 years (Exxon Corp., Exhibits E-8 and E-11, Docket No. 12-13-842, State Oil and Gas Board of Alabama).

Two wells were drilled after approval of unitization. The Dora J. Steely 36-6 No. 1 well (Permit No. 4531) was drilled and then plugged. The A.G. Brantley et al. 36-5 No. 1 well (Permit No. 4922) was drilled and completed as a commercial well. The well had an initial flow rate of 672 barrels of oil and 798 Mcf of gas per day. Both wells were located in the central portion of the Steely pod in the northwest quarter of Section 36.

Two wells within the Steely pod were converted to injection wells to be used in the enhanced-recovery project. The Zelma Pugh 26-15 No. 1 and the Dora J. Steely 36-2 were both used as injection wells. Injection operations began in 1985 and a total of 9.3 billion cubic feet of gas were injected into the reservoir before these two wells were re-converted back to producing wells. At the present time, no wells within the unit are being used for injection.

Production from the Fanny Church field has been declining in recent years (fig. 66).

Through 1990, Fanny Church field has produced 5.69 million barrels of oil. The Steely pod has produced 4.3 million barrels of oil or 75 percent of the total production from the field.

Approximately 46 percent of this total or 1.9 million barrels have been produced since the Steely pod was unitized.

Since its establishment, the unit has produced 1.9 million barrels of oil and 3.5 billion cubic feet of gas through 1990. Total production from the unit area is 4.29 million barrels of oil and 6.6 billion cubic feet of gas. In 1990, the Upper Smackover Reservoir unit produced at a rate of 521 barrels of oil per day (fig. 67).

According to Kopaska-Merkel (1992), Fanny Church has the third lowest microscopic heterogeneity value of all the unitized fields in Alabama. However, of the nine unitized fields in which MH values were generated, Fanny Church is the most heterogeneous (Kopaska-Merkel, 1992).

Hatter's Pond Field

Hatter's Pond field was unitized with an effective date of May 1, 1985. The proposed unit, which contained approximately 9,100 acres, consisted of all previous production units as well as acreage outside those units which was interpreted to be underlain by the Smackover-Norphlet gas pool. The Hatter's Pond Unit contained 96,622.8 porosity acre-feet of productive pore volume (Getty Oil Co., Exhibit 16, Docket No. 4-11-841, State Oil and Gas Board of Alabama). A porosity cutoff of 6 percent and permeability cutoff of 0.1 millidarcy were used in determining net pay which was then used to determine pore volume (Getty Oil Co., Exhibit 2, Docket No. 4-11-841, State Oil and Gas Board of Alabama). The tract-participation factor was based on pore volume and well productivity. Sixty percent of the tract-participation formula was based on pore volume attributed to the tract while 40 percent of the formula was based on the production unit wells' best monthly production rate (Getty Oil Co., Exhibit 18, Docket No. 4-11-841, State Oil and Gas Board of Alabama).

Figure 66.--Graph of production history of Fanny Church field, Alabama.

Figure 67.--Predicted versus actual daily production in Fanny Church field unit (modified from Exxon Corp., Exhibit E-8, Docket No. 12-13-842, State Oil and Gas Board of Alabama).

Engineering studies performed by the operator indicated that the additional recoverable reserves under primary production would be 130 billion cubic feet of full wellstream gas which would contain 69.9 billion cubic feet of sales gas, 33.1 million barrels of condensate, and 6 million barrels of natural gas liquids (Getty Oil Co., Exhibit 21, Docket No. 4-11-841, State Oil and Gas Board of Alabama). However, with implementation of secondary-recovery operations in the form of gas injection, recoverable hydrocarbon reserves could be significantly increased. It was projected that with gas injection, 251 billion cubic feet of full wellstream gas would be recovered which would include 182 billion cubic feet of reservoir gas, 46.5 million barrels of condensate, and 8.7 million barrels of natural gas liquids (Getty Oil Co., Exhibit 22, Docket No. 4-11-841, State Oil and Gas Board of Alabama). By implementing secondary-recovery operations, condensate recovery would be increased by 40 percent and recovery of natural gas liquids would be increased by 45 percent. Therefore, the projected benefit of initiating gas injection would be 13.4 million barrels of condensate, 2.7 million barrels of natural gas liquids, and more than 9 billion cubic feet of sales gas.

The unitization plan presented to the State Oil and Gas Board of Alabama stipulated that injection of residue gas would begin in 1986 and would continue until 1996. Average yearly injection rates during this period would be approximately 8.7 billion cubic feet of gas per year and would total approximately 87 billion cubic feet of gas injected during the life of the project (Getty Oil Co., Exhibit 22, Docket No. 4-11-841, State Oil and Gas Board of Alabama).

Since unitization in 1985, two wells have been converted from producers to injection wells. Both wells are located at median elevation in the reservoir. Four producing wells have also been drilled within the field. One well (Permit No. 4895) was drilled in the southeast portion of Section 16, while three wells were drilled in the south one-half of Section 3 and the north one-half of Section 10, Township 2 South, Range 1 West, in structurally high locations.

Cumulative volume of gas injected is approximately 19 billion cubic feet of gas. However, over 70 percent of that volume was injected during 1989 and 1990. Since the field was unitized, 20.4 million barrels of condensate and 83.6 billion cubic feet of gas have been

produced, through December 1990. Production since the field was established is 41.6 million barrel of condensate (fig. 68) and 171.3 billion cubic feet of gas. Hatter's Pond field has moderate values of microscopic and macroscopic heterogeneity (Kopaska-Merkel, 1992).

Multiple Techniques

Multiple techniques as used herein means the implementation of more than one injection enhanced-recovery technique in the same field either simultaneously or at different times. Jay-LEC fields are the only fields within Alabama in which multiple techniques have been used. Infill drilling, waterflood, and gas injection have all been implemented and have proven to be highly successful. Jay-LEC fields are located in the regional peripheral fault trend play of Mancini and others (1991).

Jay-LEC Fields

Enhanced-recovery operations in the Jay-LEC fields involve many different techniques. Waterflooding, gas-injection, and infill drilling have been used. Jay-LEC fields were unitized in 1974 for the purpose of implementing a water-injection program. Through 1978, injection rates averaged 200,000 barrels of water per day, which resulted in an average of 105,000 stock-tank barrels of oil per day being produced from the Jay-LEC unit (Shirer and others, 1978).

Jay-LEC fields in Escambia County, Alabama, and Escambia and Santa Rosa counties, Florida provides an excellent example of how effective reservoir management can significantly increase recovery. Rapid pressure decline observed in the reservoir necessitated implementation of a waterflood project in the field. Reservoir pressure in the field had declined more than 1,500 psig in one year and based on engineering estimates only 17 percent of the oil would be recovered under primary recovery. A water-injection program was implemented in the field using 25 injection wells situated in a staggered 3:1 line drive pattern (Langston and others, 1981). Waterflood operations began in 1974, and injection volumes averaged 200,000 barrels of water per day by 1978 (Shirer and others, 1978). By implementing a waterflood

Figure 68.--Predicted versus actual cumulative production in Hatter's Pond field.

project, it was estimated that an additional 216 million barrels of oil could be recovered from Jay-LEC fields. By 1978, recovery from the field had totaled approximately 204 million stock tank barrels of oil, which was 84 million barrels more than could have been recovered under primary recovery alone (Shirer and others, 1978). In addition to the waterflood, infill drilling and gas injection have been implemented in Jay-LEC fields.

A gas-injection program was commenced in the Jay-LEC fields in 1981. Estimations of remaining oil after waterflood were 355 million barrels of oil and 13 percent of this oil (47 million barrels) could be recovered by implementing the water-alternating-gas (WAG) program (Langston and Shirer, 1985). WAG operations began in 1981 and methane gas was used initially. A total of 2 billion cubic feet of methane gas was injected into the reservoir until a nitrogen source was developed. Water was injected into the reservoir along with the methane and nitrogen (Langston and Shirer, 1985).

Heterogeneity values generated by Kopaska-Merkel (1992) indicate that the Jay-LEC reservoir has fairly low heterogeneity microscopically and moderate heterogeneity macroscopically. Langston and Shirer (1985), stated that infill drilling in Jay-LEC fields was an important part of the waterflooding project. A total of 37 infill wells were drilled by 1984 in Jay-LEC. These infill wells were located in lower permeability areas to improve drainage patterns and waterflood performance. By drilling the infill wells, spacing in the affected area was reduced from 160 acres to 112 acres per well. Modeling studies of the field indicated that the 160-acre spacing was inadequate to effectively sweep low-permeability areas. As of 1985, infill wells had produced more than 76 million barrels of oil (Langston and Shirer, 1985) which indicates the excellent success of the infill drilling strategy. Total production from the Jay-LEC fields through 1990 is 399 million barrels of oil. An additional 93 million barrels of oil is expected to be recovered from the field (Tootle, 1991).

PORE FACIES AND UNITIZATION

Unitized fields are present in each of the pore facies defined by Kopaska-Merkel and Mann (1991) (table 9) (fig. 69). Within the Moldic Pore Facies are Choctaw Ridge, Silas, Stave Creek, and Turkey Creek fields. Only strategic well placement has been implemented in this pore facies. In Silas and Choctaw Ridge fields, no enhanced recovery techniques have been performed. However, the Moldic Pore Facies has relatively high aspect ratios (pore/throat size) and experimental studies performed by Morrow (1990) suggests that if reservoirs rocks are not "very strongly water-wet" snap-off of oil globules will be inhibited reducing the amount of oil trapped within the reservoir. The reservoir drive in Stave Creek field is interpreted to be primarily due to water influx and recovery from the field could be more than 55 percent of the original oil in place (Pruet Production Co., Exhibit 4, Docket No. 5-3-8417A, State Oil and Gas Board of Alabama). Therefore, if favorable reservoir conditions exists in reservoirs with moldic pore systems, waterflooding may be a viable option to increase recovery.

Traps associated with unitized fields in the Moldic Pore Facies are structural and combination traps. Unitized fields within the Moldic Pore Facies are located in the regional peripheral fault trend, Mobile graben fault system, and Mississippi interior salt basin plays. More than 11 million barrels of oil and condensate have been produced from unitized fields in the Moldic Pore Facies.

Kopaska-Merkel (1992) stated that in the Moldic Pore Facies, pore systems have higher mean porosity values than the Intercrystalline Pore Facies but lower permeability values. Therefore, more oil may be trapped in reservoirs with moldic pores than reservoirs with intercrystalline pores. Consequently, underestimation of reserves may frequently occur in the Moldic Pore Facies. However, a more plausible explanation has to do with the bimodal pore systems associated with the Moldic Pore Facies. That is reservoir zones interpreted to have high water saturations may, in fact, produce water-free because the observed water is bound-water held within microporosity. Keith and Pittman (1983) made a similar conclusion regarding the Rodessa Limestone in Running Duke field of the East Texas basin. Also, megascopic

Figure 69.--Location of unitized fields relative to pore facies.

heterogeneity tends to be low in reservoirs completed in the Moldic Pore Facies implying less oil will be bypassed during production.

Fields unitized within the Intercrystalline Pore Facies are Hatter's Pond and Chunchula fields. Gas injection and infill drilling are the only enhanced-recovery techniques presently employed within this facies. Structural and combination traps are present. Play areas represented include both the Wiggins arch complex and Mobile graben fault system play areas. Total production from these two fields is nearly 90 million barrels of condensate.

Kopaska-Merkel (1992) stated that porosity values within the Intercrystalline Pore Facies are lower than in the Moldic Pore Facies but that permeability values may be high, depending on crystal size. However, reservoirs in the Intercrystalline Pore Facies tend to be more megascopically heterogeneous than reservoirs dominated by moldic pore systems. Therefore, compartmentalization of reservoirs in the Intercrystalline Pore Facies may be common, as was inferred for Chunchula field (Benson and others, 1991).

The intermediate pore "facies" contains the largest variation in enhanced-recovery techniques used. Strategic well placement, infill drilling, waterflood, and gas injection are being implemented in fields located within this pore facies. Strategic well placement was used in Appleton field which is located in the basement ridge play. Waterflood operations were implemented in Jay-LEC and Womack Hill fields which are both located within the regional peripheral fault trend play on anticlinal structures. Gas injection and infill drilling have been implemented in Chatom field which is in the Mississippi interior salt basin play; and in Fanny Church and Jay-LEC fields which are within the regional peripheral fault trend play. Production from unitized fields within the intermediate pore "facies" is more than 435 million barrels of oil (including the Florida portion of Jay-LEC).

Waterflood operations have only been implemented in the intermediate pore "facies" in Jay-LEC and Womack Hill fields along the regional peripheral fault trend play. Traps in which waterflooding has been employed are both structural and combination traps. In addition to waterflooding, Jay-LEC fields have also had infill drilling and gas-injection programs

Size is a controlling factor in determining if a reservoir is suitable for enhanced-recovery operations and what type of techniques should be implemented (fig. 70; table 2). In the smallest fields, no enhanced recovery is usually viable because these fields (those with less than a million barrels of production) do not have the reserves or areal extent to justify drilling of additional wells, and the cost of implementing an injection program would be prohibitive. Fields which have cumulative production in excess of one million barrels but less than 5 million barrels should be evaluated in terms of strategic well placement. Many fields in Alabama have limited areal extent, and spacing requirements (usually one well per 160 acres for oil and 640 acres for gas) may prohibit most efficient well placement unless the fields are unitized. Even certain small fields spaced on 160-acre units may benefit from an additional well. Unitization would permit strategic well placement to recover reserves that would otherwise not be produced.

Strategic well placement is most viable in small- to medium-size reservoirs where initial development made prohibitive the drilling of additional wells without unitization. Also, it appears that those reservoirs having a drive mechanism with a water-influx component seems most applicable. Potential candidates for strategic well placement include Blacksher, Barrytown, and North Choctaw Ridge fields. Each field has reserves-in-place similar to those fields in which strategic well placement has been implemented. Each field is classified as oil with API gravities for Blacksher, Barrytown, and North Choctaw Ridge being 43, 45, and 39°, respectively, which are comparable to fluid characteristic of the fields in which strategic well placement has been used. Barrytown, and North Choctaw Ridge fields are in the regional peripheral fault trend play and therefore, traps of these fields are comparable to traps in which strategic well placement has been used (Kopaska-Merkel, 1992). Blacksher field is within the Wiggins arch complex play and strategic well placement has not yet been implemented in this area.

Figure 70.--Graph of cumulative hydrocarbon production of Smackover fields in southwest Alabama. (See table 2 for field keys).

Barrytown and North Choctaw Ridge fields are also similar to existing fields in which strategic well placement has been employed in that they are in the Moldic Pore Facies (Kopaska-Merkel, 1992; Kopaska-Merkel and others, 1992). Although Blacksher field is in the intermediate pore facies, it has a water-influx component to its drive mechanism and part of the reservoir is moldic (Kopaska-Merkel, 1992); Blacksher field should also be considered for possible strategic well placement. If these fields contain attic oil, then a strategically placed wells should increase ultimate recovery from the field.

Movico field which is in the Mobile graben fault system play should be considered as a potential candidate strategic well placement and possibly a candidate for injection. Movico field is within the Intercrystalline Pore Facies and although strategic well placement has not been used in this pore facies structure maps provided by Kopaska-Merkel and others (1992) indicate uncontacted reservoir updip. However, Movico is interpreted as having a solution-gas-expansion drive mechanism (Kopaska-Merkel and others, 1992) which may not provide for effective recovery during primary operations. Therefore, a program to maintain reservoir pressure or increase sweep efficiency may be necessary. Gas injection programs are presently being implemented in Chunchula and Hatter's Pond fields in the Intercrystalline Pore Facies.

Injection programs have been implemented in large fields such as Chunchula, Chatom, Hatter's Pond, Womack Hill and Jay-LEC. These fields contain the reserves necessary to economically justify the fiscal outlays necessary to implement injection programs. Projects that involve injection of fluids into a reservoir to improve recovery of hydrocarbons seem to be most applicable to fields with considerable reserves and natural drive mechanisms that are ineffective in moving hydrocarbons to the producing wells. Other large fields should also be evaluated for potential injection programs.

Big Escambia Creek field, in Escambia County, is the largest Smackover field in Alabama that has not undergone some type of injection program. It is dominated by intermediate pore systems, as are Jay-LEC and Fanny Church fields. These fields are in the Pollard and Foshee fault system subplay as is Big Escambia Creek; but Jay-LEC and Fanny

Church are oil fields whereas, Big Escambia Creek produces 46° gravity gas condensate. Also, Big Escambia Creek's wellstream is dominated by nonhydrocarbon components (approximately 53 mole percent). Hydrogen sulfide is the largest single component contributing more than 25 mole percent of the wellstream. Detailed reservoir studies should be performed on the Smackover reservoir of Big Escambia Creek to determine if enhanced-recovery operations should be implemented in the field.

North Choctaw Ridge field is within the Moldic Pore Facies, but no gas injection programs have been implemented in this pore facies in Alabama. Also, North Choctaw Ridge's drive mechanism is the result of gas expansion. However the effectiveness of the drive in the field is uncertain. Therefore, North Choctaw Ridge should also be studied in detail for the potential of increasing recovery by injection operations.

Infill drilling appears most applicable in larger fields which are undergoing some type of injection program. Infill drilling has been implemented in fields undergoing waterflood and gas injection and has improved recovery in those fields. Therefore, any field in which injection operations are considered should also be evaluated for infill drilling.

SUMMARY AND CONCLUSIONS

1) Of the 260 million barrels of oil and condensate produced from the 73 Smackover fields of southwest Alabama, 169 million have been produced from 11 unitized fields. Approximately 72 percent of the hydrocarbons produced from these 11 major fields were produced after unitization of the fields.

2) Oil plays defined by Mancini and others (1991) provide a mechanism to classify fields based on basin position, structure, trap type, and hydrocarbon type. This classification facilitates defining fields undergoing enhanced recovery and fields which should be considered potential candidates for certain enhanced-recovery techniques because it helps to group fields with similar characteristics. The largest Smackover discoveries made in Alabama are within the

Wiggins arch complex and Mobile graben fault system plays; and the Pollard and Foshee fault systems subplay.

3) The pore facies classification of Kopaska-Merkel and Mann (1991) provides a means to classify unitized reservoirs within Alabama based on pore types and pore-throat-size distributions. Reservoirs with intermediate pore systems are the most productive in Alabama. Twenty-eight fields with intermediate pore systems account for approximately 46 percent of the hydrocarbons produced from the Smackover Formation of Alabama. There are 27 fields in the Moldic Pore Facies and 18 fields in the Intercrystalline Pore Facies and they account for 18 and 36 percent, respectively, of the hydrocarbon liquids produced.

4) Well spacing in Alabama is quite variable between fields and sometimes does not allow for effective hydrocarbon recovery. Unitization has provided the mechanism for increasing the recovery of hydrocarbons from many Smackover fields in southwest Alabama. Nine of the 11 unitized fields in the Smackover of Alabama have undergone some type of enhanced-recovery technique. Enhanced-recovery procedures used in the Smackover Formation of Alabama include infill drilling, strategic well placement, water injection, residue gas injection, nitrogen injection, or combinations of two or more of these approaches (table 10).

5) Fields undergoing enhanced recovery are located within each of the pore facies defined by Kopaska-Merkel and Mann (1991). Within the Moldic Pore Facies, are Choctaw Ridge, Silas, Stave Creek, and Turkey Creek fields. Hatter's Pond and Chunchula fields are within the Intercrystalline Pore Facies. Appleton, Jay-LEC, Fanny Church, Womack Hill, and Chatom fields have reservoirs with intermediate pore systems.

6) Strategic well placement is the only enhanced-recovery technique that has been implemented within the Moldic Pore facies. Strategic well placement is a viable technique for recovery of additional hydrocarbons from Smackover reservoirs. Not only does the technique provide an additional point of withdrawal for hydrocarbons in reservoirs, but also allows location of wells at the most optimum locations. All three examples show that during the early phases of reservoir development, geologic and engineering interpretation are less than reliable and

sometimes it is late in the development of the reservoir before reservoir geometry is fully understood.

7) Waterflood operations have only been implemented in reservoirs with intermediate pore systems. A portion of Womack Hill field is successfully undergoing waterflood.

8) Gas-injection programs have been implemented in Churchula and Hatter's Pond fields in the Intercrystalline Pore Facies; and in Fanny Church and Chatom fields in the intermediate pore "facies."

9) Additional wells have been drilled in each of the fields undergoing gas injection or waterflood operations. These wells have been drilled as either replacement, infill, or strategically placed wells and facilitate the recovery of hydrocarbons in the injection programs.

10) Jay-LEC fields provides an excellent example of how using multiple enhanced-recovery methods can significantly improve ultimate recovery of oil from the Smackover Formation. Approximately 87 percent of the oil produced from Jay-LEC was under enhanced recovery. The implementation of waterflood, infill drilling, and gas injection vastly improved recovery. Tootle (1991) estimated that an additional 93 million barrels of recoverable oil remain in the reservoir.

11) Even if enhanced-recovery operations are not applicable to a specific field, unitization can provide the economic stimulus for increased recovery of hydrocarbons and equitable distribution of revenues.

12) Size is a major factor in controlling which Smackover fields in Alabama should be considered for enhanced-recovery operations and the type of enhanced-recovery technique that should be contemplated. In most small fields, no enhanced-recovery mechanism is viable because of the limited reserves associated with those fields. Fields of medium size with uncontacted reservoir should be considered for strategic well placement. Fields such as Blacksher, Barrytown, Movico and North Choctaw Ridge should be evaluated in terms of possible strategic well placement. Potential candidates for injection operations include Big Escambia Creek, Movico, and Choctaw Ridge fields.

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LIST OF EXHIBITS

Exxon Corp., Exhibit E-6, Comparison of laboratory analysis Norphlet and Smackover crude: Docket No. 12-7-73, State Oil and Gas Board of Alabama.

Exxon Corp., Exhibit G-5, Area of production, net pay porosity-feet map: Docket No. 12-13-842, State Oil and Gas Board of Alabama.

Exxon Corp., Exhibit E-7, Enhanced recovery schematic: Docket No. 12-7-73, State Oil and Gas Board of Alabama.

Exxon Corp., Exhibit E-8, Upper Smackover Reservoir Unit enhanced recovery project flowstreams: Docket No. 12-13-842, State Oil and Gas Board of Alabama.

Exxon Corp., Exhibit E-11, Upper Smackover Reservoir Unit estimated net revenue and reserves: Docket No. 12-13-842, State Oil and Gas Board of Alabama.

Four Star Oil and Gas Co., Exhibit 3, Producing wells primary production forecast, Hatter's Pond field: Docket No. 11-1-90250, State Oil and Gas Board of Alabama.

Four Star Oil and Gas Co., Exhibit 16, Reservoir fluid study, Peter Klein 3-14 No. 1 well: Docket No. 11-1-90250, State Oil and Gas Board of Alabama.

Getty Oil Co., Exhibit 16, Pore volume above and below 40.98 porosity-feet: Docket No. 4-11-841, State Oil and Gas Board of Alabama.

Getty Oil Co., Exhibit 2, Geologic mapping assumptions: Docket No. 4-11-841, State Oil and Gas Board of Alabama.

Getty Oil Co. Exhibit 18, Unit participation formula: Docket No. 4-11-841, State Oil and Gas Board of Alabama.

Getty Oil Co., Exhibit 21, Production and sales, primary depletion: Docket No. 4-11-841, State Oil and Gas Board of Alabama.

Getty Oil Co., Exhibit 22, Production, injection, and sales, gas cycling: Docket No. 4-11-841, State Oil and Gas Board of Alabama.

Phillips Petroleum Company, Exhibit 5, Structure and isopach maps of the proposed Chatom field unit: Docket No. 4-22-762, State Oil and Gas Board of Alabama.

Phillips Petroleum Company, Exhibit 6, Estimated incremental economics with cycling: Docket No. 4-22-762, State Oil and Gas Board of Alabama.

Phillips Petroleum Company, Exhibit 1A, Chatom Field Area top of Smackover Formation structure map, Docket Nos. 5-17-881 through 5-17-883, State Oil and Gas Board of Alabama.

Pruet and Hughes Co., Exhibit 8, Summary of reservoir data and recoverable reserves: Docket No. 8-13-763, State Oil and Gas Board of Alabama.

Pruet Oil Co., Exhibit 2, Smackover structure map: Docket No. 1-23-8528, State Oil and Gas Board of Alabama.

Pruet Oil Co., Exhibit 5, Stave Creek field tract factor calculation: Docket No. 1-23-8528, State Oil and Gas Board of Alabama.

Pruet Oil Co., Exhibit A-10, Calculation of attic oil recovery: Docket No. 1-23-8528, State Oil and Gas Board of Alabama.

Pruet Production Co., Exhibit 4, Reservoir engineering study, Docket No. 5-3-8417A, State Oil and Gas Board of Alabama.

Pruet and Hughes Co., Exhibit 3, Top of Smackover porosity: Docket No. 10-22-747, State Oil and Gas Board of Alabama.

Pruet and Hughes Co., Exhibit 4, Determination of original oil in place volumetrically: Docket No. 10-22-747, State Oil and Gas Board of Alabama.

Pruet and Hughes Co., Exhibit 8, Suggested program of operation and related future performance, proposed west end unit (prepared by Core Laboratories, Inc.): Docket No. 11-26-746, State Oil and Gas Board of Alabama.

Texaco, Inc., Exhibit No. 10-A, Production plot with and without infill well: Docket No. 3-10-8814, State Oil and Gas Board of Alabama.

- Texaco, Inc., Exhibit No. 3, Subsurface structure map: Docket No. 3-10-8814, State Oil and Gas Board of Alabama.
- Texaco, Inc., Exhibit No. 17, Subsurface structure map: Docket No. 8-9-891A, State Oil and Gas Board of Alabama.
- Texaco, Inc., Exhibit No. 20, Net pay isopach map: Docket No. 8-9-891A, State Oil and Gas Board of Alabama.
- Union Oil Company, Exhibit 13, Reservoir fluid study, International Paper Co. well No. 22-13: Docket No. 11-7-8021, State Oil and Gas Board of Alabama.

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