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ADVANCED SECONDARY RECOVERY DEMONSTRATION FOR THE SOONER UNIT

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ADVANCED SECONDARY RECOVERY DEMONSTRATION FOR THE SOONER UNIT

Objectives

The objectives of the project are to demonstrate the effectiveness of geologically targeted infill drilling and improved reservoir management to obtain maximum oil recovery from the Sooner Unit field using water injection and gas recycling as secondary methods. The first phase of the project involves an integrated multi-discipline approach to identify optimum well sites and development of a reservoir operations plan.

The second phase will involve drilling of up to three geologically targeted infill wells and establishing production/injection schedules. Reservoir simulation, transient well tests and careful production monitoring will be used to evaluate the results.

The third phase will involve technology transfer through a series of technical papers and presentations of a short course. Emphasis will be on the economics of the project and the implemented technologies.

Summary of Technical Progress

Technology Transfer

A poster presentation was made at the Oklahoma Geological Survey and U.S. DOE workshop "Fluvial-Dominated Deltaic Reservoirs in the Southern Midcontinent" on March 23-24, 1993 in Norman, Oklahoma. The poster session was entitled "Integrated Reservoir Management to Maximize Oil Recovery from a Fluvial-Estuarine Reservoir, A Case Study of the Sooner Unit, Colorado." The presentation summarized the reservoir characterization results to date.

Core Studies

Cores of the "D" sandstone interval were examined from five wells in the township area around the Sooner Unit. The locations of these wells are shown on Figure 1. The cores were examined for identification of sedimentary structures for establishing depositional models of the Sooner "D" reservoir and surrounding area. A macroscopic examination and description of slabbed core were made of grain size, rock types, grading and sedimentary structure. A microscopic examination was made of six thin-sections for mineralogy, cementation, rounding, sorting and diagenesis.

The Sooner 7-21 well was cored over a 34 ft interval through the "D". The core description is summarized as poorly sorted fine to very fine grained sandstone, quartz to subarkosic arenite (refer to Figure 2). The core contains sedimentary structures that suggest estuarine sediment transport and deposition processes. The sedimentary features suggest oscillating sediment transport energy as in a tidally influenced environment. The overall grain size is small which indicates a low energy environment. The lower and more fluvial deposits (interpreted from well-log response) on the western side of the field are not present in the Sooner 7-21 well. The sedimentary structures that suggest estuarine sediment transport and deposition processes are summarized as follows:

inter-bedded sandstones, siltstones and shales;
burrowed shales;
flaser beds;
inclined beds of differing rock types;
trace fossils of plants;
lenticular beds;
clay clasts and clay clast lags;
trough-cross strata;
rhythmite structures;
ripple-drift cross strata and
sharp shale-to sandstone contact.

Three cores are from the Lilli field "D" sandstone reservoir north 1 mile from the Sooner field (refer to Figure CORE for location and Figures 3, 4, and 5 for description). These cores exhibit a similar depositional environment which is marine influenced by wave and tidal energy. The coarsening-upward sequence of sandstone is fine to very fine grained and is bounded below by transgressive surfaces of erosion (TSE). There is an absence of a low-stand surface of erosion (LSE) below the reservoir sandstone. The areal shape of the Lilli field suggests a near-shore bar and is elongated east-west and perpendicular to the north-south axis of the Sooner reservoir trend.

The Wildhorse Nickerson 8-6 core shows clay-filled very fine to fine grained sandstone (see Figure 6). This well is 3 miles southwest from the Sooner field. The clay content, fine-grained rock type, bioturbation and small-scale scour and fill structures are evidence of a low-energy environment of deposition such as a lagoon. The core is not representative of reservoir rock in the Sooner Unit but adds to the regional interpretation of fluvial, estuarine and marine sedimentary styles.

A mineralogy study of six thin-sections was made from three cores from the Sooner and two adjacent fields. Compositional data of primary and secondary minerals were determined on each thin-section with the recognized components summarized in Table 1. The detrital grain population of these samples is dominated by quartz, from 66 to 79%. The abundance of mono-crystalline quartz grains suggests transport of clastic material by fluvial processes over a long distance. The textural grain size is medium to very fine and averages fine sand for most samples. The sampling from the Sooner No. 7-21 core is fine grained. The small preserved grain size and well-rounded shape suggests that the sand particles were winnowed by cyclical, low energy. The size and sorting of the grains support the interpretation of an estuarine environment of deposition. Authigenic cements comprise 20 to 30% of the bulk composition of the samples (Table 1) and include opal, quartz, iron oxide, clay and calcite. Opal cement has not been recognized in lower Cretaceous sandstones from the Denver basin prior to this study. The opal cement is evidence of solution, migration and deposition of hydrated silica, possibly dissolved from bentonite in the overlying Graneros shale. The presence of opal cement is possible evidence of diagenesis resulting from water flowing into the "D" sandstone from above along fault planes.

Reservoir Management

A reservoir management plan was developed which involved evaluation of production and injection volumes by operational reservoir compartments. Operational compartments are portions of the reservoir which contain wells with similar static pressure and are influenced by a common injection well or wells. A total of seven operational compartments were identified and are shown in Figure 7. Injection and reservoir voidage volumes were calculated with the appropriate reservoir volume factors

for oil, gas and water at the average compartment pressure over time between field-wide pressure surveys. Net voidage is the volume of oil, gas and water produced less injected volumes at reservoir conditions. Surface volumes are converted to reservoir volumes using appropriate volume factors based on the current average reservoir pressure in each operational compartment. A positive reservoir voidage calculation indicates that reservoir pressure is decreasing because withdrawal exceeds injection. The average voidage rate exceeded injection by 2,294 reservoir barrels per day during October, 1992 through January, 1993. Operational changes were made in February to increase injection from an average of 1,324 bwpd during the fourth quarter of 1992 to 2,891 bwpd during March, 1993. The production and injection volumes at reservoir conditions are currently nearly in balance after these changes. The results from matching injection volumes to production voidage by operational reservoir compartments appear to have resulted in an increased oil production rate from 250 bopd to 300 bopd.

Problems Encountered

The estuarine tidal-channel depositional setting of the "D" sandstone at Sooner suggests that the continuity of transmissibility should be greatest along the channel or valley axis in the north-south direction. Such anisotropy is supported by several injection-production well pairs in various parts of the field. It is observed that several north-south pairs are highly communicating with similar static pressures, sensitivity to injection rate changes and early water break-through. East-west pairs exhibit minimal to no communication.

Despite the slight improvement of production response to the balancing of injection and production by operational compartments, there are problems of thief zones and strong flow barriers which have become apparent. In some cases, it is evident that increasing water injection rates cause a rapid change (several days) in water production at an offset production well (north-south orientations) without a corresponding increase in measurable oil production. The rapid increase in water production and rise in fluid level above the pump indicate a high permeability thief zone or bedding plane. In other cases, the increased injection rates have not produced a measurable rise in fluid level or production response in offset wells (east-west orientations). The conclusions drawn from these changes are that there is a strong directional permeability and barrier component to the reservoir. The preferential permeability is along the axis of the valley (approximately north-south).

Potential Infill Locations

The operational compartments in conjunction with the geologic and seismic data are under study for potential infill drilling opportunities to increase oil production and recovery. An integrated approach to increase production and recovery from the Sooner Unit focuses development and reservoir management efforts in areas with the greatest oil in place and with minimum potential compartment boundaries. These efforts are directed to the southwest quarter of Section 21 and the north-half of Section 28 (refer to Figure 8). More wells and additional injection volumes will be required to raise the reservoir pressure and improve sweep efficiency in these areas. These areas contain the thickest "D" sediments (from well log and seismic amplitude data) and the wells which have been the most effective to-date for producing secondary reserves. Nearly two-thirds of the Unit oil production was attributed to the S.U. No. 14-21 and 7-28 wells from October 1992 through January 1993.

A comparison of the volumetric OOIP and the material balance OOIP (contacted during primary operations) shows that the wells in the south half of Section 21 and in Section 28 were contacting more oil during primary than is indicated from volumetric estimates using log data. The OOIP by material balance attributable to the wells in these areas is nearly two-thirds of the Unit total. These OOIP estimates are consistent with the fact that the S.U. No. 7-28 and the 14-21 are producing nearly two-thirds of the Unit oil. This area also exhibits seismic attributes which are interpreted as suggesting maximum "D" interval thickness and minimum compartment barriers.

The first location under evaluation is in the SENW of Section 28 (shown as infill No. 1 on Figure 8). This location exhibits a "D" thick and Huntsman thin on the respective seismic amplitude and instantaneous frequency maps. A reservoir pod is indicated by these maps which may not be swept by water injection from the S.U. No. 10-28 well.

The southwest quarter of Section 21 is poorly affected by secondary energy. Water injection at the S.U. No. 10-21A well has not produced a pressure or production response at either the No. 14-21 or 11-21 wells. This portion of the reservoir may require two or three additional wells (shown as infill No. 2, 3 and 4 on Figure 8) to pressurize and sweep the secondary oil. The most promising location for an injection well may be in the NWSW of Section 21 because of structural position and seismic amplitude attributes.

Extension development locations are also identified in the NWSE and NESE of Section 17 (shown as infill wells No. 5 and 6 on Figure 8). These locations are likely to encounter an untapped reservoir compartment. The S.U. No. 16-17 well (SESE Section 17) encountered relatively high reservoir pressure of over 1,300 psi when it was completed in 1988. The nearby wells had pressures of about 700 psi or less at that time. Primary production from the well was disappointing with a rapid decline in rate. The static reservoir pressure rose to nearly 2,500 psi when the well was used for water injection. These facts indicate that the No. 16-17 well is positioned in a small isolated compartment. Lineament boundaries on the seismic maps support this conclusion. The performance of the No. 16-17 well and the seismic lineaments are interpreted to indicate that the "D" sandstone in the NWSE and NESE would be in poor pressure communication with the main Sooner Unit reservoir. The size of the seismic anomaly suggests a "D" interval thick of more than 80 acres which could contain substantial reserves.

Appendix

Table 1

Composition of "D" sandstone samples from Sooner and nearby fields.

Figure 1

Location of cored wells examined for the Sooner Project and named fields in the region.

Table 2

Key to structures, accessories and rock types used in core descriptions.

Figure 2

Core description; Sooner Federal 7-21, SWNE 21-8N-58W

Figure 3

Core description; Lilli 2-7, NWNE 7-8N-58W

Figure 4

Core description; Lilli 2-8, NWNE 8-8N-58W

Figure 5

Core description; Lilli Federal 12-9, NWSW 9-8N-58W

Figure 6

Core description; Nickerson 8-6, SENE 6-7N-58W

Figure 7

Identification of operational compartments in the Sooner Unit.

Figure 8

Simplified seismic amplitude map of "D" interval with lineaments and potential infill well locations.

Table 1. Composition of D Sandstone as determined from samples from the Sooner and nearby fields, D-J basin, CO. Numerical estimates are percentages, determined from 300 point counts on each thin section.

	7-21 6265 ft	7-21 6270 ft	7-21 6283 ft	2-8 6372 ft	2-8 6379 ft	8-6 6374 ft
Mono. Quartz	61	69	58	69	73	65
Poly. Quartz	6	5	8	8	6	10
K. Feld.	1	1	1	1	0	1
Plag.	1	1	0	0	1	0
Mica	0	1	1	1	0	2
Sed. Rx.	1	1	12	1	0	0
Clay Cement	1	6	8	5	7	11
I.O. Cement	4	10	6	8	7	8
Calcite Cement	1	2	1	1	1	0
Opal Cement	15	0	0	2	0	0
Quartz Cement	9	3	4	3	3	2
Por.	0	1	1	1	2	0
TOTALS	100	100	100	100	100	99

* Sedimentary rock fragments (Sed. Rx.) are primarily chert except in sample number 7-21 (6283 ft), where they are primarily calcareous siltstones.

Mono. Quartz = monocrystalline quartz
Poly. Quartz = polycrystalline quartz
K. Feld. = potassium feldspar
Plag = plagioclase
I.O. = iron oxide
Por. = porosity

Figure 1 Location of cored wells examined for the Sooner Project and named fields in the region.

**1 KEY TO STRUCTURES AND
1 ACCESSORIES**

horizontal burrows
vertical burrows
roots
flaser bedding
graded beds
hummocky cross-strata
lenticular bedding
low-angle laminations
small-scale troughs
trough cross-strata
wavy bedding
small-scale slump
small-scale scour & fill
clasts
concretion
fractures
siderite concretion
stylolites

KEY TO ROCK TYPES

shale
siltstone
shaley or silty sandstone
sandstone

KEY TO CONTACTS

erosional
sharp
interlaminated
TSE = transgressive surface of erosion	
LSE = lowstand surface of erosion	

Table 2 Key to structures, accessories and rock types used in core descriptions.

**Diversified Operating Company
7-21 Federal Sooner
SWNE 21-8N-58W
KB: 4703'**

Well No. Fed. Sooner #7-21 Date Dec. 11, 1992
Location Sec 21, T8N, R38W Strat. Unit "D" Sandstone
Weld County, CO Measured by P. G. Ehrbridge

Figure 2 Core description; Sooner Federal 7-21, SWNE 21-8N-58W

Fina Oil and Chemical
2-7 Lilli
NWNE 7-8N-58W
KB: 4807'

Well No. Fina Oil & Chem. 2-7 Lilli Date Jan. 12, 1972
Location NW NE Sec 11, T8N, R53W Strat. Unit "D" sandstone
Well number 20 Measured by E. J. Stenrad

SEDIMENTARY TEXTURES & STRUCTURES	ROCK TYPE, CONTACTS & ACCESSORIES	DESCRIPTORS
64-4 VCCW F. W.	50	6486 ft (core depth) = 6486 ft (log depth)
		DESCRIPTIONS
		Black, fissile, porous chip, marine shale.
		TSE Highly bioturbated, shaley siltstone with very fine, and rare burrows.
		Fine- to very fine-grained sandstone, grading down to a siltstone at 6494 ft; thin siltstone laminae at 6490 and 6491 ft; low-angle laminations; 4 to 1" thick, tight streaks at 6488 ft and 6491 ft; tight streaks bounded by shale laminae; stylolites at various depths; fractures at 6488 ft.
		Black, organic shale with siltstone lenses; low bioturbation in siltstones.
		Sharp-based (possible erosion surface)
		Interlaminated shale to siltstone and shaley to silty sandstone; degree of burrowing decreases and amount of primary sedimentary structures increases down core; lenticular laminations; flaser bedding; small-scale trough cross strata; hummocky cross strata; small-scale density current deposits in lower three feet of core; siderite concretions or laminations scattered in core.

Figure 3 Core description; Lilli 2-7, NWNE 7-8N-58W

Diversified Operating Company
2-8 Lilli
NWNE 8-8N-58W
KB: 4757'

Well No. Lilli 2-8 Date Dec. 11, 1992
Location Sec 3, T3N, R58W Strat. Unit "D" Sandstone
Weld County, CO Measured by F. G. Ethridge

SEDIMENTARY TEXTURES & STRUCTURES		INTERVAL	ROCK TYPE, CONTACTS & ACCESSORIES	SP TEXTURAL MAT. Maturity	DESCRIPTIONS
GRAV	SAND				
64.4	100%	64.4	CLAY		
					6371 ft (core depth) = 6378 ft (log depth)
					Black, poker chip, marine shale.
					Coarse-grained, pebbly sandstone
					TSE
					Coarse-grained, pebbly sandstone
					Fine- to very fine-grained sandstone with low-angle laminations.
					6374-6375 ft: fractured siltstone w/mud cracks grading down into interlaminated very fine-grained sandstone and carbonaceous shale w/horizontal burrows.
					Sharp-based (possible erosion surface)
					Interlaminated siltstone to shale and shaley to silty sandstone; bioturbation decreases and primary sedimentary structures increase downcore; flaser bedding; hummocky cross-strata; possible thin graded beds (density current deposits) in lower portion of core.

Figure 4 Core description; Lilli 2-8, NWNE 8-8N-58W

Diversified Operating Company
12-9 DOC Federal
NWSW 9-8N-58W
KB: 4749'

Well No. DOC, Fed. Sooner #12-9 Date Jan. 1, 1991
 Location Sac 3 T3N R38W Strat. Unit "D" Sandstone
Weld County, CO Measured by P. G. Ethridge

Figure 5 Core description; Lilli Federal 12-9, NWSW 9-8N-58W

Nickerson 8-6
SENE 6-7N-58W
KB: 4789'

"D"

Huntsman

Mowry

"J"

FR 1LD
6500

— 10 —

Well No. Wildhorse Nickerson #8-6
Location Sec 6, T7N, R58W
Weld County, CO

Date Jan. 3, 1993
Strat. Unit "D" Sandstone
Measured by F. G. Ethridge

6370 ft (core depth) =
6372 ft (log depth)

silty to clayey, very fine-grained sandstone alternating with thin zones of clayey siltstone to siltstone; pyrite; large and small burrows; variable degrees of bioturbation from heavily burrowed to no bioturbation; rare vertical burrows; ripple cross-strata, small-scale scour and fill structures.

Core description; Nickerson 8-6, SENE 6-7N-58W

Operational Compartments Seven Well Groups A-G

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