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**Integrated Approach Towards
The Application Of Horizontal Wells
To Improve Waterflooding Performance**

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OBJECTIVES

The overall purpose of the proposed project is to improve secondary recovery performance of a marginal oil field through the use of an appropriate reservoir management plan. The selection of plan will be based on the detailed reservoir description using an integrated approach. We expect that 2 to 5% of the original oil in place will be recovered using this method. This should extend the life of the reservoir by at least 10 years.

The project is divided into two stages. In Stage I of the project, we selected part of the Glenn Pool field - Self Unit. We conducted cross bore hole tomography surveys and formation micro scanner logs through a newly drilled well. By combining the state-of-the-art data with conventional core and log data, we developed a detailed reservoir description based on an integrated approach. After conducting extensive reservoir simulation studies, we evaluated alternate reservoir management strategies to improve the reservoir performance including drilling of a horizontal injection well. We observed that selective completion of many wells followed by an increase in the injection rate was the most feasible option to improve the performance of the Self Unit. This management plan is currently being implemented and the performance is being monitored.

Stage II of the project will involve selection of part of the same reservoir (Berryhill Unit - Tract 7), development of reservoir description using only conventional data, simulation of flow performance using developed reservoir description, selection of an appropriate reservoir management plan, and implementation of the plan followed by monitoring of reservoir performance.

By comparing the results of two budget periods, we will be able to evaluate the utility of collecting additional data using state-of-the-art technology. In addition, we will also be able to evaluate the application of optimum reservoir management plan in improving secondary recovery performance of marginal oil fields.

Successful completion of this project will provide new means of extending the life of marginal oil fields using easily available technology. It will also present a methodology to integrate various qualities and quantities of measured data to develop a detailed reservoir description.

SUMMARY OF TECHNICAL PROGRESS

During the last three months, we have continued to monitor the reservoir management plan in the Self Unit. Over the last three months, the production from the unit has remained steady up to 50 bbls/day (over 200% increase in the production). For Stage II of the project, we have expanded the scope of the project. Instead of concentrating only on Tract 7, we are evaluating all the areas currently operated by Uplands Resources. This way, we will be able to evaluate the best location for either multilateral or a horizontal well. The geological mapping is almost complete, and the geostatistical description and the flow simulation should begin soon. Although not part of this project, we are conducting a 3-D seismic survey on the Glenn Pool Field. This should help us in better evaluating the channel sand structure.

STAGE I PROJECT MONITORING

Last summer, we started implementing the reservoir management plan in the Self Unit. Last quarter, after evaluating each individual well, we decided to install electrical submersible pumps to produce three wells. The other three wells required the use of rod pumps. The production from the field improved significantly once the pumps are installed. Over the last three months, an average daily production has been approximately 50 bbls/day. Compared to a base line production of 13 bbls/day before the implementation, this is more than 200% increase in the production. Based on our current evaluation of the flow simulation results, we expect that the production from the unit should reach between 100 to 120 bbls/day once the implementation is complete.

Part of the reservoir management plan is to increase the water injection rate. We have installed the injection pump and have completed the piping to bring the water from the Arkansas river.

GEOLOGICAL DESCRIPTION

(By Dennis R. Kerr and Liangmiao Ye)

In the second quarter of 1996, geology activities of the Glenn Pool project focused on field scale study, continuation of Tract 7 study, brief evaluation of Chevron polymer flooding acreage, and technology transfer.

Field Scale Study

Field scale study was done with the purpose of broadening our understanding of larger scale variations of the Glenn sandstone, and the relationship between Tract 7 and the other production units. Results of this study will be helpful in evaluating the appropriateness of selecting the Tract 7 area for horizontal drilling.

The area for the field scale study includes the Southern half of the Glenn Pool Field with an area of about 25 square miles (Figure 1), covering all Glenn Pool acreage of several independent oil companies including Uplands Resources, Producers, ELS, Hyperion, Reddy and part of Bazneet.

Three hundred-twenty (320) logs are available within the area for use in public domain; 280 of them cover through the Bartlesville interval. Correlation has been made to the DGI level for all these logs, with reference to the Pink Lime, Inola Lime, and Brown Lime markers. Six cross sections, showing a interval from Pink Lime to Brown Lime, were constructed (see Figure 1 for cross section locations, designated as A-A' to F-F'). Based on correlation results, a sandstone distribution map was constructed for each DGI (Figure 2, as one example). Structure maps were developed for top of Inola Lime, top of Bartlesville sandstone, top of DGI E sandstone, top of DGI F sandstone, and top of Brown Lime (see Figure 3, as one example).

As a result of this field scale study, it is concluded that the Red Fork sandstone interval (between Pink Lime and Inola Lime) was deposited in a generally flat area as indicated

by the fairly constant gross thickness throughout the area. Early interpretation of Bartlesville sandstone as incised valley fill is supported by the evidence that in the east side of Glenn Pool Field the Bartlesville sandstone onlaps Eastward onto the incised valley wall cut into the Savanna shale (Figure 4). Within the valley, the successions of Bartlesville sandstone in different parts of the Glenn Pool Field are quite comparable in terms of profile characteristics, except that the basal part of the Bartlesville sandstone, which fills the unevenness of the incised valley, may not be that persistent throughout the area, dependent on the paleo-topographical relieves. Totally, seven (7) DGIs (A to G in descending order) are recognized. Usually DGI A to F are present everywhere within the valley. However, DGI G may be absent where it was ancient high, resulting in DGI F directly overlying the Savanna shale (Figure 4).

A sandstone distribution map, constructed for each DGI, shows that the reservoir sandstone continuity is getting poorer upwards and back-stepping (compare Figure 2 and Figure 5). This is consistent with what we have discovered in the Self Unit study, the Tract 7 study and outcrop observations, and also support the earlier interpretation that at least the upper part of Bartlesville sandstone was deposited in a retrogradational manner.

Figure 3 is the structure map of the top Inola Lime marker, showing that Tract 7 and the adjacent area is in an obvious structure high. This is also the case for other levels of structure maps.

Continuation of Tract 7 Study

Continuation of Tract 7 study includes shale mapping, petrophysical property evaluation, and re-proposal of cased-hole logging.

Shale Mapping

As has been done for the Self Unit study, several maps showing the shale thickness between DGIs are constructed for investigating the vertical separation of the reservoirs.

As one example, Figure 6 shows the shale thickness between DGI D and E. Generally speaking, Bartlesville sandstone has a pretty good vertical separation between DGIs. Table 1 compiles separation between different DGIs in terms of shale thickness and the number of wells which show no shale break, indicating that the reservoirs of upper part of Bartlesville sandstone (DGI A to C) has a poorer vertical separation than those of lower part (DGI D to G). The explanation for this needs more work, but it is also the case for Self Unit.

Petrophysical Property Evaluation

It is difficult to evaluate the petrophysical property for reservoirs in Tract 7, because all cores (total 20) were cut for DGI F and G only. Fortunately, there are three longer cores cut nearby the Tract 7 (i.e. well 6-F8, 10-49, 4-24) data of which can be used as a reference for Tract 7. Table 2 shows core porosity and permeability data for these three wells, as well as some core data for DGI F and G in Tract 7, in comparison to the data of Self 82 core.

Table 2 indicates that for DGI E to F (or G if present), Tract 7 area and Self Unit have comparable porosity and permeability. However, for DGI B to D, Tract 7 area has a much higher (about one order magnitude) porosity and permeability than that of Self Unit. There is no core sample for DGI A in Tract 7 area, however well logs show good reservoir quality DGI A sandstone in Tract 7 area. This implies that the upper part of Bartlesville sandstone in Tract 7 area could be very good potential for further development of the field. In addition, the engineering studies have shown that the upper part in this area is underdeveloped.

Proposal of Cased-Hole GR Logging

As pointed out before, data coverage in Tract 7 is not good. Thus, additional cased hole GR logging for about 20 wells was proposed in the last quarterly report. After all factors (especially bore hole condition, well type, effect to current production, operation cost etc.) were considered, only 6 wells are proposed for additional cased hole Gamma Ray

logging, as shown in Table 3. There is a suspicion that upper part of Bartlesville sandstone in Tract 7 area may contain a gas cap. Thus, cased-hole pulse neutron logging is also planned for three of these wells except Well 7-79.

Brief Evaluation of Chevron Polymer Flooding Acreage

Chevron's polymer flooding during early 1980's in a 160 acre unit immediate West of Tract 6 has been said to be very successful. An investigation of the real factors leading to this success is performed, in the hope of gaining insight into our Tract 7 management. For this purpose, a brief geological evaluation for this unit is conducted. 14 logs were collected within the unit. Figure 7 shows the location of these wells. Correlation to DGI level and sandstone classification for each DGI is made for each of these wells. Then the results are used for determining the perforation interval in DGI for those wells without logs.

ENGINEERING EVALUATION

(By Sanjay Paranjy and Dr. Mohan Kelkar)

Over the last three months, data have been collected from diverse sources to develop a better reservoir description. These sources are as follows:

- Dwight's data base.
- Well log library (Scout tickets, Completion & Shut in records).
- Files maintained by Uplands Resources, Inc.

From the above sources of information, a database of all the wells that have been drilled has been compiled detailing information pertaining to the location of the well and the perforation depths. A total of 280 wells are included in this database, encompassing both producers and injectors. Every effort has been made to cross-reference the data, and information on shut in and recompletions has also been included. The objective being to trace the field's history from the early part of the century to present time. The following sections detail the work that has been done.

Perforation Maps

The DGI interpretation for Tract 7 and adjacent areas has already been completed. This interpretation was used to observe how the field was completed over its life. The DGI interpretation gives the depth of each DGI (A through G) at each well location where the log data are available.

To estimate DGI depths at other locations where no logs are available a kriging procedure was used. This was done by dividing the area of interest into 10 x 10 ft. gridblocks. The area of interest is approximately 5280 x 5280 ft. The depth of each DGI was then estimated for each of those 10 x 10 ft. gridblocks. By knowing the nearest gridblock location, the DGI depths at all the wells were estimated. Since the depths of the individual DGI's do not vary widely, kriging procedure was deemed adequate for such estimation purposes.

Perforation maps are then generated for each DGI displaying only those wells that have been completed in that DGI with an estimate of the interval that has been completed out of the thickness of the DGI under consideration. Figures 8-10 display the maps for DGIs G, E and B respectively. As can be seen, the density of completed wells decreases dramatically as we move from lower DGI to upper DGI. Part of the reason is the fear that upper DGI's are occupied by a gas cap. We will test this concept by collecting pulse neutron logs on a few sample wells.

Perforation Maps for the Chevron Acreage

Chevron conducted a successful micellar/polymer flood project in early 1980s in William Berryhill Unit which is located Northwest of the study area. To investigate the completion practices in that unit, we plotted the perforated intervals before and after 1980. It should be noted that data used for this comparison is not complete and the records on most of the wells completed before 1942 are unavailable. However, by

comparing the data with other parts of the Berryhill Unit it is reasonable to assume that the wells are completed in the lower DGI's, preferably in DGI's F and G.

Figures 11-13 illustrate the completion practices before and after 1980s for DGI's B, E and G. What is interesting in these figures is that Chevron did not complete any additional wells in DGI G. Instead, it concentrated on the upper DGI's. A lot more wells are completed in the upper intervals. It is not known whether the success of Chevron's project was due to enhanced oil recovery (chemical flooding) or due to improved infill drilling practices. However, it is clear that some of the additional oil recovery must have come from the additional completions. It should also be noted that Tract 7 and its adjacent areas are on a structural high and that the structures are dipping toward the direction of the Chevron acreage. If the gas cap is not present, significant additional potential exists in these tracts.

Well Testing Results

Results for the Self Unit

To compare the effectiveness of reperforations in the Self Unit the wells tests were conducted in newly perforated wells. Table 4 shows the comparison of the old and the new perforations. The letter 's' denotes the results after recompletion. It is observed that the reperforated wells show higher permeability values as compared to the results before the reperforation. This is a clear indication that the reperforation plan has been successful. The skin factor exhibits negative values for the Wells Self 63s and Self 68s, which is another positive indicator. The skin value for the Well Self64s has increased. However, the permeability shows a significant increase.

Technology Transfer

A presentation regarding the progress, working methods, and accomplishments of Glenn Pool project and their significance to other field management was given by Dr. Dennis

Kerr in a Tulsa Geological Society meeting on April 9, 1996. Many geologists and engineers from local independent oil companies and majors attended the meeting and were very interested in and gave very positive comments towards the work done in this project.

In conjunction with the technology transfer, The University of Tulsa will hold four one-day workshops titled, "Cost Effective Strategies to Get New Oil from Mature Oil Fields." The workshops will provide the methodology used in generating a detailed reservoir description of the Self Unit, Glenn Pool Field, the techniques used for improving the performance of the reservoir and the results of the implementation. The workshops will be held in Tulsa on October 3, in Oklahoma City on October 4, in Denver on October 10 and in Houston on October 15.

Table 1
Vertical Separation Condition, Tract 7 and Adjacent Area

Shale Break	Typical Thickness Range (ft)	NWI*	NWWNS*	PWWNS*
A vs. B	1 to 3	89	27	30
B vs. C	2 to 4	89	19	21
C vs. D	2 to 6	89	7	8
D vs. E	2 to 6	89	7	8
E vs. F	2 to 6	89	9	10
F vs. G	3 to 8	116	4	3

*NWI = Number of wells investigated

*NWWNS = Number of wells which shows no shale break

*PWWNS = Percentage of wells which shows no shale break

Table 2

Comparison of Core Porosity and Permeability Between Self Unit and Tract 7 Area

DGI	Well Self 82			Well 6-F8			Well 10-49			Well 4-24		
	Phi (%)	K (md)	Facies	Phi (%)	K (md)	Facies	Phi (%)	K (md)	Facies	Phi (%)	K (md)	Facies
A	NS	NS	CH	NC	NC	FP	NC	NC	FP	NC	NC	FP
B	9.1 (3)	0.018 (1)	CH	11.5 (2)	1.6 (2)	CH	0.1 (1)	13.3 (1)	FP	NS	NS	FP
C	11.8 (16)	0.57 (15)	CH	22.3 (19)	397 (19)	SP	20.6 (17)	148 (17)	CH	5.1 (22)	2.3 (22)	CH
D	16.5 (20)	26.4 (19)	SP	20.7 (17)	237 (17)	SP	17.8 (12)	105 (12)	SP	11.9 (4)	18.2 (4)	SP
E	19.9 (5)	181.8 (5)	SP	19.3 (20)	151 (20)	CH	18.1 (26)	77.6 (26)	CH	15.7 (8)	66.9 (8)	SP
F	21.8 (9)	246 (9)	BS	20.5 (56)	137 (56)	BS	22.2 (24)	217 (24)	BS	18.5 (43)	146 (43)	BS
G	not developed			17.9 (34)	30 (34)	BS	16.2 (49)	18.2 (49)	BS	19.4 (36)	91.4 (36)	BS

DGI	Well 7-100			Well 7-102			Well 7-103		
	Phi (%)	K (md)	Facies	Phi (%)	K (md)	Facies	Phi (%)	K (md)	Facies
A-E	NC	NC		NC	NC		NC	NC	
F	21.2 (22)	162.3 (22)	BS	15.4 (4)	32 (4)	BS	20.2 (20)	141.3 (20)	BS
G	15 (40)	35.5 (40)	BS	17.8 (50)	14.9 (50)	BS	17.2 (36)	29.5 (36)	BS

- Note: 1. The number within parenthesis is the number of samples.
 2. NC=not cored; NS=not sampled; CH=channel-fill sandstone; FP=flood plain mudstone; SP=splay sandstone; BS=braided stream sandstone.

Table 3

Proposed Wells for Cased-Hole GR Logging (Ranked in Priority)

Priority	Well Name	Tract	TD (ft.)	Casing Depth (ft)	Suggested Logging Interval (ft.)*	Well Type
1	7-97	7	1570	1534	1330-1534	producer
2	7-100	7	1547	1515	1330-1515	producer
3	7-103	7	1570	1531	1350-1531	producer
4	7-107	7	1570	1527	1300-1527	producer
5	11-82	11	1580	1528	1340-1528	producer
6	7-99	7	1566	1527	1300-1527	producer

*The suggested logging interval is intended to cover from Inola marker bed to TD. If the Pink Lime is to be included, additional 220 ft or so must be logged above the suggested interval.

Table 4

Well Test Comparisons

	Self 63	Self 63s	Self 64	Self 64s	Self 68s
Ko (md)	0.399	2.919	0.348	1.499	0.298
Kw (md)	11.098	101.397	7.378	49.004	9.726
S	4.82	-0.25	1.55	7.11	-3.99
C (bbl/psi)	0058	0.081	0.05	0.081	0.11
Average Pressure (psia)	549	675		574	549

Figure 1: Index map, Southern Glenn Pool Field and adjacent area.

Figure 2: Distribution of DGI A sandstone, South Glenn Pool Field.

(Top of Inola Lime)

Figure 3: Structure map.

Figure 4: A sketch map showing the stratal pattern of Bartlesville sandstone in the Glenn Pool Field and that the Bartlesville interval onlaps onto the East wall of the incised valley.

Figure 5: Distribution of DGI F sandstone, South Glenn Pool Field.

Figure 6: Shale thickness between DGI D and E.

Figure 7: Chevron polymer flooding acreage, showing wells with logs.

Net Sand Isopach, DGI G (Tract 7 & adjacent area)

20 /30 implies 20 feet of completion in 30 feet of the corresponding dgi.

● logged only ○ cored only ● logged & cored

Figure 8: Perforation map for DGI G.

Net Sand Isopach and Facies Map, DGI E (Tract 7 & adjacent area)

Figure 9: Perforation map for DGI E.

Net Sand Isopach and Facies Map, DGI B (Tract 7 & adjacent area)

0 0.25 mile

CI=10 ft

Channel-fill sandstone
splay sandstone
flood plain mudstone
eroded by overlying interval
20 / 30 implies 20 feet of completion in 30 feet of the corresponding dgt.

● logged only
○ cored only
⊙ logged & cored

Figure 10: Perforation map for DGI B.

Perforation map for Dgi B (Before Berryhill Micellar/Polymer flooding

Perforation map for Dgi B (After Berryhill Micellar/Polymer project)

Figure 11: North Eastern quarter of the Chevron acreage.

Perforation map for Dgi E (Before Berryhill Micellar/Polymer flooding)

Perforation map for Dgi E (After Berryhill Micellar/Polymer flooding)

Figure 12: North Eastern quarter of the Chevron acreage.

Perforation map for Dgi G (Before Berryhill Micellar/Polymer flooding)

Perforation map for Dgi G (After Berryhill Micellar/Polymer flooding)

Figure 13: North Eastern quarter of the Chevron acreage.