WATERFLOOD PATTERN REALIGNMENT AT THE McELROY FIELD - SECTION 205 CASE HISTORY*

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ABSTRACT

A waterflood pattern realignment project in the Grayburg / San Andres McElroy Field is improving the waterflood performance. This paper presents a case history of a 640-acre [259 ha] section of the field that was realigned in 1988. Irregular and widely spaced patterns were developed into smaller and more uniform patterns. The results of the realignment are proving the economic viability of realignment work at McElroy and are improving reservoir characterization.

INTRODUCTION

The McElroy Field has been under waterflood for 26 years. Portions of the field are not performing as a mature waterflood. The Section 205 project area exhibited low bottom hole pressures (BHP's), low water-oil ratios (WOR's), declining oil and water production, and irregular pattern geometry. A pattern realignment was chosen to improve the performance by improving the geometry, decreasing the spacing of the patterns, reducing the producer to injector ratio, and hence improving areal and vertical sweep efficiency and injection support. The historical background of the section area, the support for the realignment, and the results of project implementation are presented below.

BACKGROUND

Overview of the Geology

The McElroy Field is located on the eastern edge of the Central Basin Platform in Crane and Upton Counties, Texas (see **Fig. 1**). Section 205 is located in the southwest portion of the field. It produces from Grayburg and San Andres shelf dolomites. The Grayburg is the main formation under waterflood and is at a depth of approximately 3000 ft [914.4 m].

The field is an example of a classic strato-structural trap. A structure map of the top of the McElroy shows a North-Northwest trending asymmetric anticline with a steeply dipping east flank and a gently dipping west flank (see **Fig. 2**). This structure, along with a permeability barrier located on the gently dipping west limb, provides the trapping mechanism.

The average porosity of the Section 205 main pay, corrected for gypsum, generally increases from west to east and is shown in **Fig. 3**. The zones between the markers "E" and "M" are referred to as the main pay. Average permeability values also increase from west to east (see **Fig.**

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4). However, neither of these maps shows the spatial variability of permeability. Cross-section B-B' (see **Fig. 5**) gives a clearer picture of the heterogeneity of the reservoir. The shaded curves are core permeability. Even though permeability increases from west to east along the cross section, there is a great deal of vertical discontinuity. Many of the individual permeability streaks are very difficult to correlate and disappear before they get to the next well on the cross section.

The permeability, not just porosity, must be considered when evaluating the Grayburg / San Andres reservoir for realignment. The porosity may indicate continuous zones even though the zones are discontinuous due to gypsum plugging. This is clearly seen when permeability data is compared to neutron porosity data (see **Fig. 6**). The permeability is vertically discontinuous even though porosity indicates continuity (track 2 and 4). There are several good porosity zones in J. T. McElroy 900 that do not have good permeability. The separation of the high and low temperature core porosity curves (track 3) denotes gypsum.

The lack of continuity within the Grayburg / San Andres of the McElroy Field is due, in significant part, to the distribution of gypsum. There is a very good correlation between the absence of gypsum and good permeability in the main pay zone. Zones of good permeability also have good porosity. However, neutron logs through gypsum bearing rock give porosity values that are too high because the neutron log records the water in the gypsum crystal lattice as porosity. A gypsum correction has been developed to convert average neutron porosity to "gypsum-free" average porosity using high and low temperature core data throughout the field. The porosity contour map in **Fig. 3** includes the gypsum correction applied to Section 205 wells.

History Of Section 205

The first well was drilled in the southeast corner of Section 205 in 1929. The well was produced under solution gas drive. An additional twenty-four wells were drilled from 1929 to 1949 mainly on the east side of the section. The early producers were drilled in an octagon shape in each quarter-section with one producer in the middle. The octagon patterns were termed "sunflower" patterns and were later altered by infill drilling (see the northeast quarter section in **Fig. 7**). The middle producer was drilled in anticipation of being converted to a gas injector as part of a secondary recovery project to utilize flared gas for pressure support. Gas injection pilots were carried out to the north of Section 205 in 1929, 1931, and 1947. The gas pilots were unsuccessful due to immediate gas breakthrough attributed to the high free-gas saturations present in the reservoir at the start of the pilot program. Also, impurities of the untreated produced gas caused plugging at the formation face limiting injectivity [1].

From 1950 to 1980, producers were drilled to form uniform patterns in the southwest and to further develop the sunflower patterns in the northwest and on the east. During that time, wells were also drilled and converted for use as injection wells. Water injection was initiated in Section 205 in 1963. The production and development history since the start of waterflooding is presented in **Fig. 8**. Injection wells were added by drilling and converting wells from 1963 through 1975 to reach a maximum of 15 injection wells. The injection well count did not increase again until 1988. Infill producers were drilled from 1963 through 1978 to reach a maximum of 51 producers. The producer well count did not increase after 1978.

The history of the project area explains how the irregularity of the pattern geometry developed. **Fig. 7** illustrates the pattern development before the realignment. The southwest quarter section had 40-acre [16 ha] inverted 9-spots. The southeast and northeast quarters had 80-acre [32 ha] sunflower patterns, and the northwest quarter was a transition between the two pattern types. The realignment was designed to create smaller spaced, more uniform patterns to increase the areal and vertical sweep efficiencies through improved injection support.

Realignment Detail

The realignment work was started in May of 1988 and completed in February of 1989. Infill drilling and conversions were completed to create regular 20-acre [8 ha] 5-spot patterns as close to uniform as existing development would allow. Sixteen producers and four injectors were drilled, and seventeen producers were converted to injectors. Three producers and one injector were cored through the main pay. The new producers were drilled on 10-acre [4 ha] spacing and several wells are now on 5-acre [2 ha] spacing due to previous sunflower pattern development. **Fig. 9** illustrates the post realignment pattern development.

The new pattern development takes advantage of apparent directional permeability trends that have been identified in studies on Section 205 and offset sections. A strong tendency for floodwater effects in the West-Northwest (WNW) direction within the McElroy Field have been observed since the 1960's. This long-standing WNW direction coincides with microfracture direction results documented in an in-situ stress study completed on a McElroy well located to the southeast of Section 205[2]. Section 205 production data also qualifies this trend with higher water-cuts and water-oil ratios along the lines N60°W.

The information accumulated above, along with channel maps developed from pulse testing, lend support to a directional permeability trend of approximately N60°W. This trend was used to develop the realigned patterns as shown in **Fig. 9**. The injectors are separately aligned from the producers along this determined trend to avoid channeling and early water breakthrough problems.

REALIGNMENT SUPPORT

Inefficient Existing Patterns

The inefficiency of the prealignment patterns is indicated by the declining production, low WOR's, low BHP's, and a high producer to injector ratio. These indicators are a result of the spacing and irregularity of the patterns. The patterns before the realignment did not connect all productive zones because of discontinuous permeability streaks as discussed in the geology overview. The declining production, low **WOR**, and low **BHP** indicate poor injection support.

The WOR after 25 years of waterflooding is one. It has remained at one for about 11 years without increasing (see **Fig. 10**). This coincides with the last infill drilling program completed in 1978. That program raised the producer to injector ratio in Section 205 from approximately 2.6 in 1970 to 3.4 in 1978 where it remained until the initiation of this project. The 1970's drilling program caused an increase in withdrawals from the reservoir without an increase in injection support which resulted in a flattening of the WOR. This lack of waterflood support is verified by the low BHP's of the project area.

The field reservoir pressure was approximately 1300 psi [9.0 MPa] at the time of the field discovery in 1926. The pressure has been depleted below the initial saturation pressure of 790 psi [5.4 MPa] and tests prior to realignment indicate the pressure around the existing wells was very low. Three build-up tests and three pressure gradient tests showed project area BHP's of 240 psi [1.7 MPa] in 1988 (see well locations and pressures on **Fig. 7**). Build-up tests completed in 1985 on wells to the north and west of the project section indicated similar low BHP's. The low BHP's indicate the prealignment patterns were not building reservoir pressure. The low injector count, irregular pattern geometry, and reservoir discontinuity limited the injection and did not allow reservoir repressurization[3].

Correlation to an Offset Realignment

A realignment pilot project in an area of the field directly north of the west half of Section 205 was used to support the implementation of this realignment. The offset area had 40-acre [16 ha] inverted 9-spots that were realigned to 20-acre [8 ha] 5-spot patterns in 1986-88. The offset area has similiar rock properties and producing characteristics as Section 205. The incremental oil response seen within this offset pilot area was correlated to the Section 205 project area to forecast incremental production expected from the realignment. The forecast was used to economically justify this project and the incremental oil prediction amounted to 951,000 STB [$0.15x10^6$ stock-tank m^3].

POST REALIGNMENT RESULTS

Improved Production And Injection

In May 1988, prior to the realignment of Section 205, the oil production was 575 B/D [91 m^3/d], the water injection was 2300 B/D [366 m^3/d], the WOR was 1.2, the Liquid In Liquid Out Ratio (LI/LO) was 1.8, and the producer to injector ratio was 3.8. By October 1989 the oil production had increased to 1344 B/D [214 m^3/d], the water injection to 8500 B/D [1351 m^3/d], the WOR to 1.5, the LI/LO ratio to 2.5, and the producer to injector ratio had decreased to 1.4. This information is illustrated on **Fig. 10 and 11.**

The incremental oil production response indicates an economically successful project. The dashed lines from 1988 through 1994 represent the incremental oil production forecasted for project economics. The forecast includes approximately 190 B/D [30 m^3/D] of oil that was lost when producers were converted to injectors. The actual production in **Fig. 11** does not include an incremental oil response of 75 B/D [12 m^3/D] identified from wells in the offsetting section to the east.

Injection reached approximately 5200 B/D [827 m^3/d] in January of 1989 and remained at that level until step rate tests indicated the wells were injecting well below parting pressure. With this information, the injection rate was increased to 8500 B/D [1351 m^3/d]. Oil production increased from 1000 B/D [159 m^3/d] in August 1989 to 1344 B/D [214 m^3/d] in October 1989 with this injection increase.

The WOR was close to 2 for a time during 1989 because a previously temporarily abandoned producer (J. T. McElroy 175) was put on production in January 1989. This well was temporarily abandoned again in July 1989 due to high water and low oil production.

The oil and water production from prealignment wells has increased by approximately 565 B/D [90 m^3/d] and 625 B/D [99 m^3/d] respectively (see **Fig. 12**). The amount of oil and water incremental response seen from individual wells within the realignment area is presented in **Table 1.** To date, over 91% of the incremental production is attributed to the east side of the section. The values are based on production during May 1988 and October 1989. The producers that are on 5-acre [2 ha] spacing between injectors on the east side have provided the largest increases in oil production. However, the wells on 10-acre [4 ha] spacing may increase similarly when sufficient time has past for injection to fully take effect.

In October 1989, the total oil and water production from infills drilled in 1988 was 400 B/D [64 m^3/d] and 1085 B/D [173 m^3/d] respectively (see **Fig. 13**). The production from the individual infill wells is presented in **Table 2.** The initial production is the stabilized production after the fracture treatment. The current production is from October 1989 well tests.

Pressure Increases

Fluid levels began rising in producers soon after injection started in offset wells. The first injector was completed in August 1988 and the last in February 1989. The fluid levels have risen mainly in the producers on the east side of the section due to the better permeability. Larger production equipment has been installed on approximately 25 wells within the project area to maintain pumped off conditions. The signs of pressure increases are qualitative, but encouraging. A pressure monitoring program will be implemented to quantify the pressure building condition within the reservoir.

Regional Characterization Of The Reservoir

The new project wells on the west side of the section had higher values of BHP recorded from the Repeat Formation Tester (RFT) log and initial production rates than those on the east of the section, but the production from these wells has dropped off very rapidly. The west side prealignment producing wells have maintained their low BHP's and have exhibited little waterflood response to date (see **Table 1 and 2**). These characteristics reflect a lower permeability area with productive zones that are fairly discontinuous. The west side may require a smaller well density (5-acre [2 ha] spacing) to connect the discontinuous stringers and effectively flood the pay in this area.

Contrarily, the new project wells on the east side of the section had low RFT values and low initial production rates. These wells have experienced improved pressure support and increasing production from the waterflood. These trends have also been observed in the prealignment wells on the east. These characteristics reflect a higher permeability and more continuity than along the western flank.

The regional injection rates and pressures also support the characteristics stated above and will be useful information for offset realignments. The injection rates were higher with lower injection pressures on the east side of Section 205 than on the west side (see **Table 3**).

FUTURE PLANS

The results of this realignment in Section 205 are very favorable and are lending support to continuing realignments throughout the McElroy Field for the next several years. The waterflood response on the west side of Section 205 will be monitored to determine if the realigned patterns are improving the efficiency of the waterflood since 91% of the incremental to date is from the wells on the east side. The performance of the eastside 5-acre [2 ha] wells will be monitored to determine the feasibility of further 5-acre [2 ha] spacing development in this portion of the project area since these wells have provided the best oil response to date.

Reservoir continuity appears to be a very important variable in waterflood performance in the project area. Future studies are planned to evaluate the continuity improvements made from these realigned patterns. This information may help qualify the optimum pattern size for waterflooding the east and west regions of Section 205. Also, the pressures in Section 205 will be monitored to determine if the pressure is building to a carbon dioxide miscible level (1100 psig [7.6 MPa]) within the realigned patterns.

CONCLUSIONS

1. The pattern realignment changed the existing patterns in Section 205 from 40-acre [16 ha] inverted nine-spots and 80-acre [32 ha] sunflower patterns to regular 20-acre [8 ha] 5-spots. This work has improved the efficiency of the waterflood as exhibited by the improvement in the oil production and water injection.

2. The successful results of this realignment are lending support to realignment projects planned for the next several years in the McElroy Field.

3. Permeability must be considered when characterizing the Grayburg / San Andres formation to evaluate potential pattern realignment areas. Log porosity may give false indications of permeability because of gypsum plugging.

4. Reservoir characterization of Section 205 has been improved through formation evaluation on new wells and by the regional production and injection characteristics seen from the realignment. This information will aid in the design of offset realignments and stimulation work.

5. There are qualitative indications of increasing pressures within the realigned patterns. Pressures will be monitored to determine if the realigned patterns are increasing pressure to a miscible level (1100 psig [7.6 MPa]) for future carbon dioxide flooding possibilities.

6. The west side of Section 205 may need to be developed on even smaller spacing to increase the continuity of the pay and effectively flood the reservoir.

7. The producers on 5-acre [2 ha] spacing on the east side of Section 205 have provided the best oil production increases to date. Production will be monitored to determine the feasibility of further 5-acre [2 ha] well spacing on the east side of the section.

ACKNOWLEDGEMENTS

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2. Avashi, J.M., Nolen-Hoeksema, R.C., El Rabaa, A.W., and Wilson, L.E.: "In Situ Stress Evaluation in the McElroy Field, West Texas," SPE Paper 20105.

3. Wash, Renee: "Chevron Tightens McElroy Waterflood," Southwest Oil World, (November 1985).

SI METRIC CONVERSION FACTORS

acres	x 4.046 873	E-01	= ha
bbl	x 1.589 873	E-01	= m^3
ft	x 3.048*	E-01	= m
psi	x 6.894 757	E+00	= kPa

*Conversion factor is exact

Table 1
Section 205 McElroy Field
Comparison of Regional Incremental Response of Prealignment Wells

EAST HALF OF SECTION 205

J.T. McELROY WELL NUMBER	RESPONSE BOPD	BWPD
173	+195	+ 35
317	+135	+ 70
244	+ 65	+ 5
144	+ 55	+ 10
177	+ 55	+ 25
170	+ 45	+ 40
296	+ 15	+ 90
308	+ 10	+115
275	+ 7	+ 0
688	- 5	- 30
429	- 30	+ 55

WEST HALF OF SECTION 205

J.T. McELROY WELL NUMBER	RESPONSE BOPD	BWPD
702	+ 21	+ 3
898	+ 18	- 5
666	+ 10	+ 2
247	- 2	+ 55
899	- 2	+ 35

Table 2
Section 205 McElroy Field
Initial and Current Producing Rates of 1988 Infill Wells

EAST HALF OF SECTION 205

J.T. McELROY WELL NUMBER	INITIAL BOPD/BWPD	CURRENT BOPD/BWPD
1071	4/ 50	48/170
1075	11/ 75	39/100
1076	10/ 40	18/ 60
1077	3/ 40	13/ 57
1079	40/100	33/105
1080	5/ 13	42/ 75
1081	1/100	47/230
1083	35/ 40	68/ 25
1084	10/ 30	21/ 70

WEST HALF OF SECTION 205

J.T. McELROY WELL NUMBER	INITIAL BOPD/BWPD	CURRENT BOPD/BWPD
1072	44/ 0	15/ 15
1073	110/ 80	20/ 14
1074	9/ 20	7/ 5
1078	6/ 8	1/ 19
1082	19/100	27/140

Table 3
Section 205 McElroy Field
Comparison of Regional Injection Rates and Pressures

EAST HALF OF SECTION 205			WEST HALF OF SECTION 205		
J.T. McELROY WELL NUMBER	RATES (BWIPD)	PRESS (PSI)	J.T. McELROY WELL NUMBER	RATES (BWIPD)	PRESS (PSI)
657C	140	1260	264C	126	1100
661C	479	500	389C	257	1000
811C	303	340	419C	73	1220
812C	455	800	440C	36	1320
823C	592	200	441C	51	1350
824C	297	900	626C	41	1220
843C	574	370	627C	99	1100
851C	598	0	1069W	32	1240
865C	588	400	1070W	176	1100
973C	577	300	1086W	0	1360
1068W	339	1060			

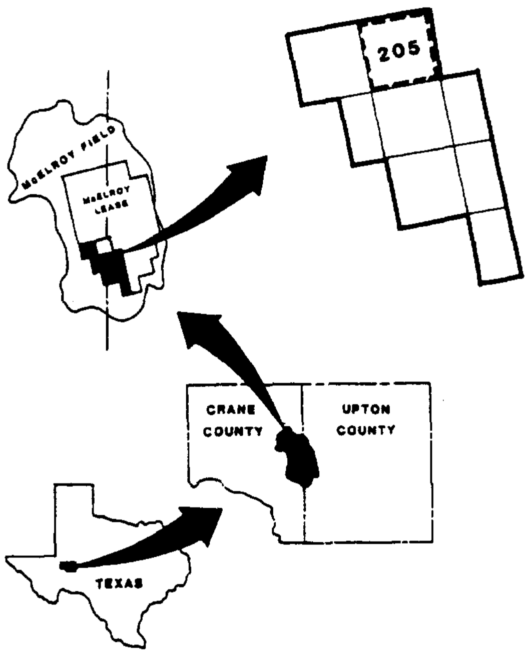

Figure 1 - McElroy Field location map

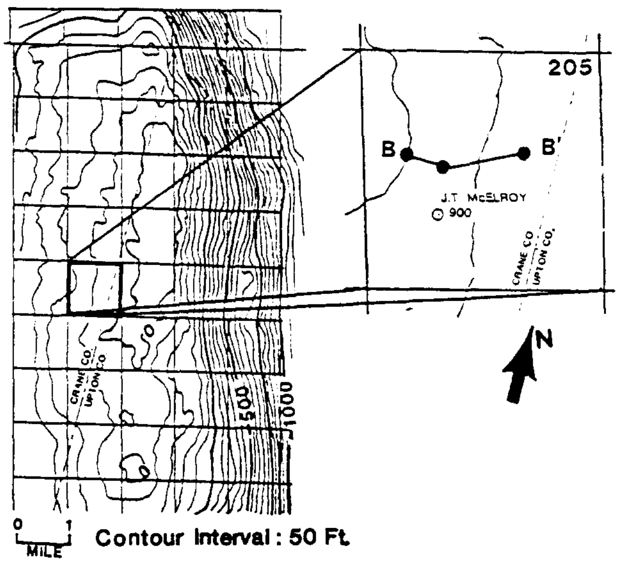

Figure 2 - Top of McElroy Grayburg structure map

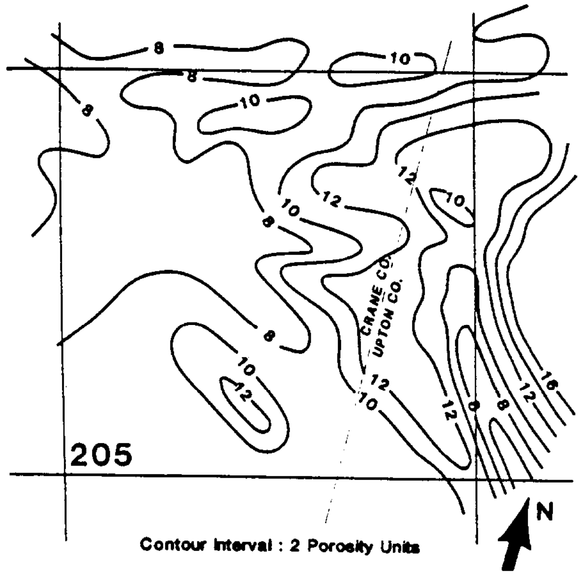

Figure 3 - Section 205 McElroy Field–
average porosity for the main pay

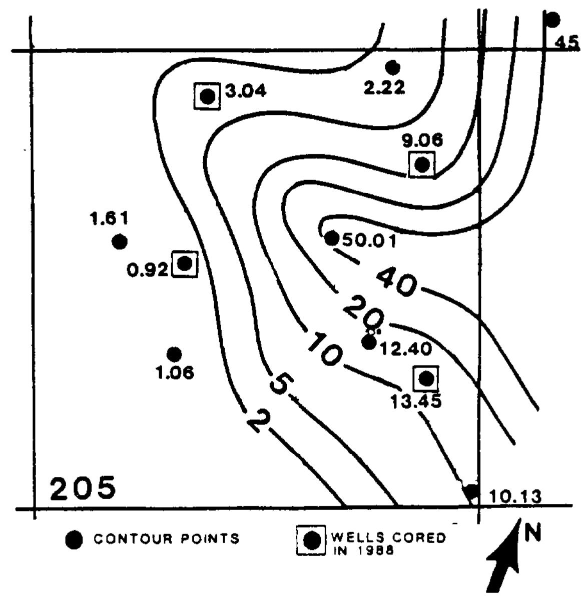

Figure 4 - Section 205 McElroy Field–
average permeability greater than
0.1 md geometrically contoured

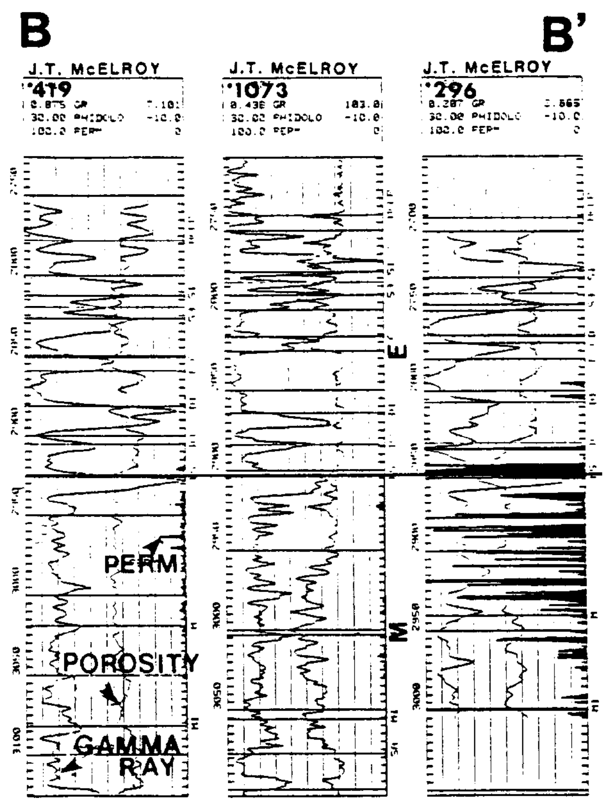

Figure 5 - Section 205 McElroy Field–
cross section B–B showing porosity
and permeability variation

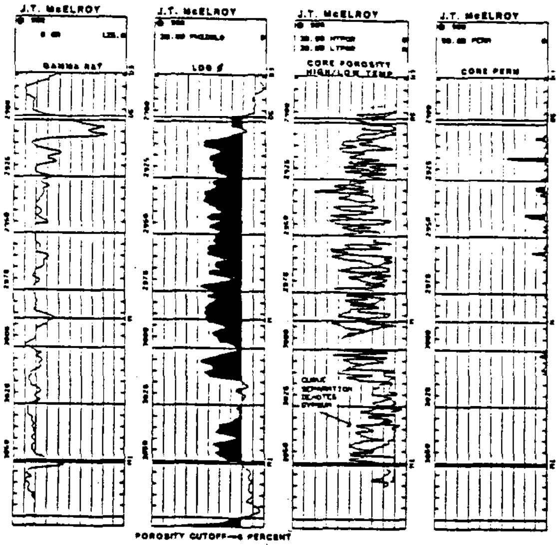

Figure 6 - Section 205 McElroy Field–
J.T. McElroy 900 showing porosity
and permeability do not correlate

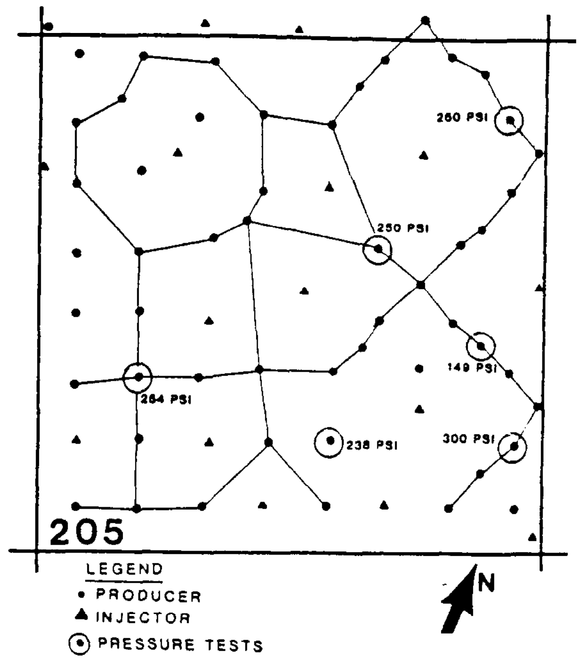

Figure 7 - Section 205 McElroy Field–
prealignment patterns
and pressures

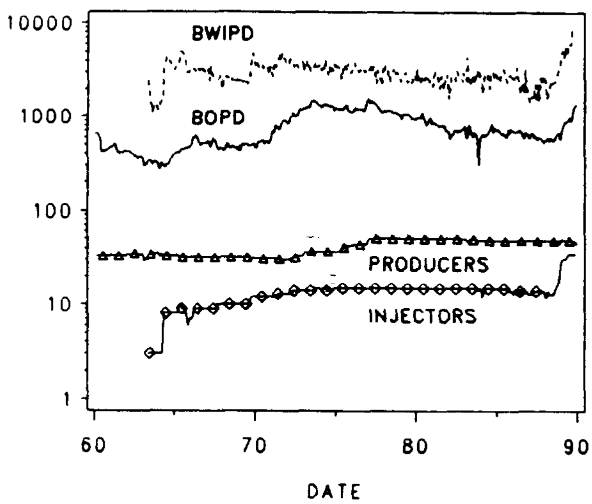

Figure 8 - Section 205 McElroy Field-
production and waterflood
history

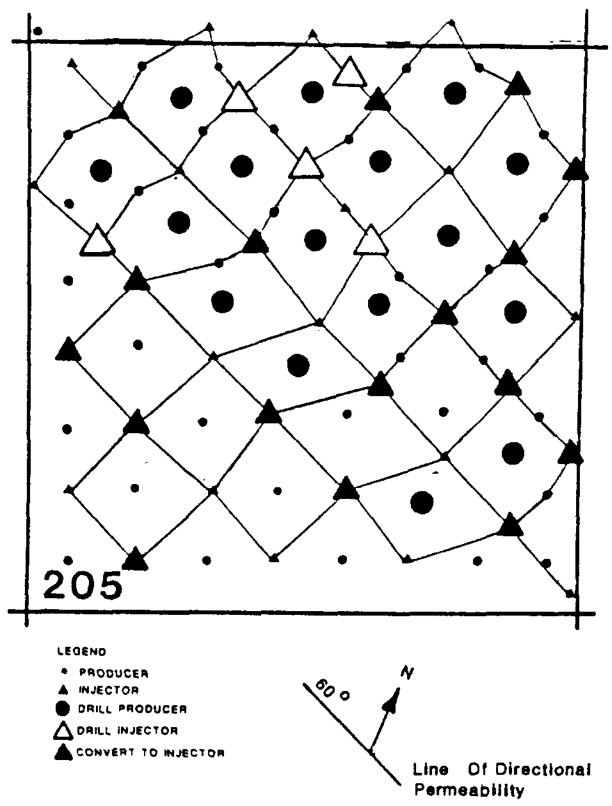

Figure 9 - Section 205 McElroy Field–
post realignment pattern
development

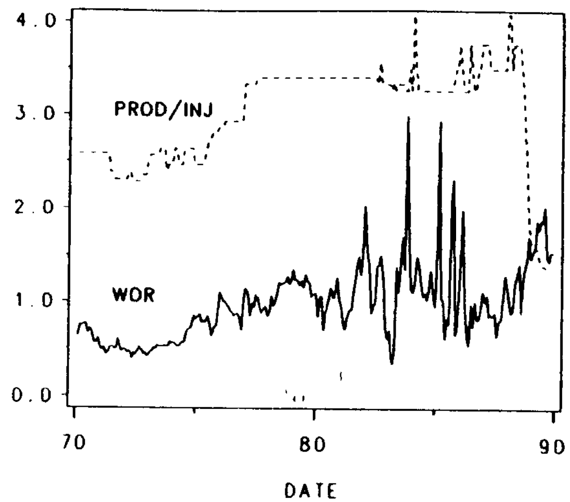

Figure 10 - Section 205 McElroy Field-
producer/injector and
water/oil ratio

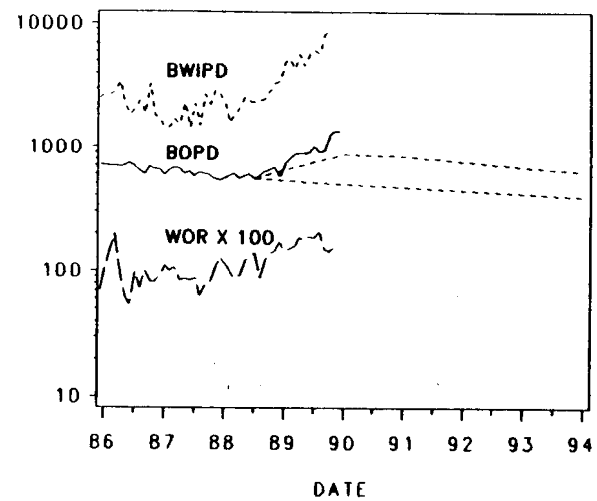

Figure 11 - Section 205 McElroy Field-
actual and projected performance

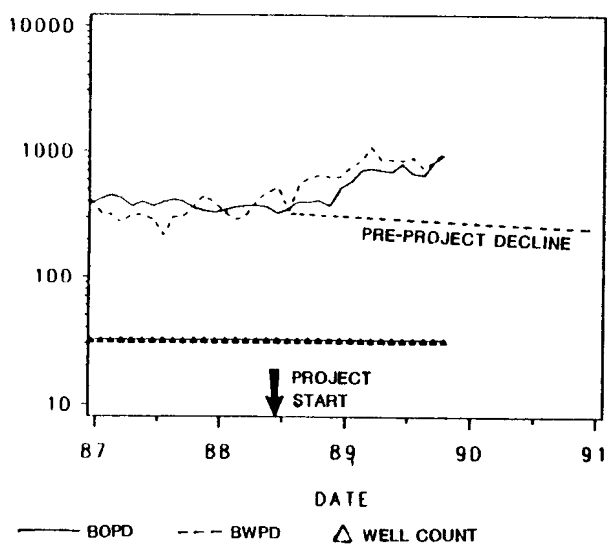

Figure 12 - Section 205 McElroy Field-
production of prealignment wells

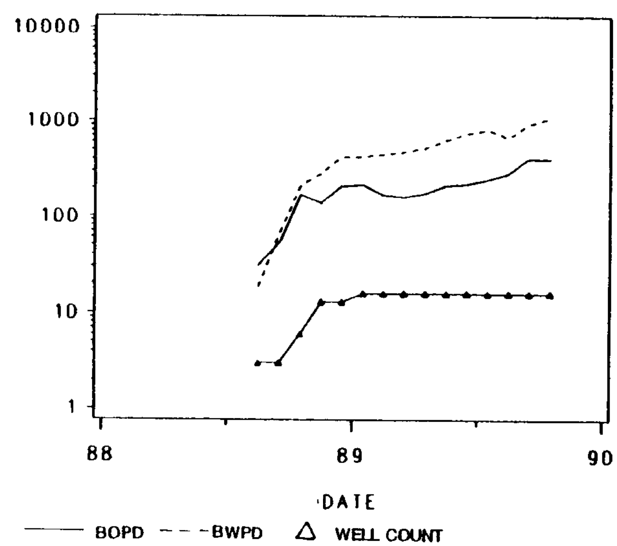

Figure 13 - Section 205 McElroy Field-
production of infill wells