A Discussion of Cities Service Oil Company's Cummins C D&W San Andres Waterflood

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LOCATION

The Cummins-C, D and W Leases are located in the northern portion of the Goldsmith Field and just south of the Goldsmith, North San Andres Consolidated Field approximately seven miles northwest of the City of Goldsmith, Texas (Fig. 1). The subject leases contain approximately 1120 acres. Figure 1 also shows how the Cummins-C, D and W Leases relate to the Atlantic Goldsmith Cummins San Andres Unit.

PRIMARY DEVELOPMENT

Primary development of the Cummins-C, D and W Leases began in October, 1936. Eight wells were completed on the "C", six wells on the "D" and two wells on the "W" Lease. All of the development was completed by 1940 and was confined to the southern half of the leases because of a gas cap extending over a portion of the north half of the leases.

The wells were completed as open-hole producers by setting casing at approximately 3900 ft and then drilling into the San Andres with oil to a depth of approximately 4250 ft. Only four of the 16 wells were shot with nitroglycerin; the remainder were stimulated with 4000 gallons of hydrochloric acid on completion. The primary producing mechanism appeared to have the characteristics of a solution gas drive influenced by a gas cap.

Primary oil production from the 16 wells equaled 986,370 barrels prior to water injection which was approximately 90 per cent of total primary depletion. At the time water injection began, the average well production was two BOPD with an overall GOR of 38,000 SCF/STB. The pilot well, Cummins-C #1, had produced 90,028 barrels of approximately eight per cent of the original oil in place in the 51 acre pilot. The nature of the gas cap is discussed later in the performance of the flood.

RESERVOIR CHARACTERISTICS

The San Andres formation is a massive Dolomite of Permian Age containing several porous and permeable zones. It is found at a depth of approximately 4100 ft in the subject area. (Figure 6 is an example of a typical log of the interval.) The pay section as determined from electric logs and core information lies generally between minus 930 ft and minus 1090 ft subsea datum. The average porosity in this interval is 9.5 per cent. The average horizontal permeability is 16.2 md and ranges from 78 md to less than 0.1 md. Connate water saturation is approximately 27.4 per cent with values averaging 20 per cent in the more porous intervals. The productive interval is highly fractured with a system of microfractures that extends over the entire area.

Because of the extensive microfractures, a detailed study was conducted on a core of the San Andres section in Cummins-D #19W. This study, which was made by Cities Service Research and Development Company was conducted in June, 1963 and was performed to delineate zones of weakness where fracturing or parting was likely to occur.[1] The fractures were divided into three major classes: vertical, horizontal and angular. The fourth major class included styolites, (Figs. 4 and 5).

The results of the investigation of 171 ft of core revealed 35 major vertical fractures, 104 minor fractures, 84 major styolites, 110 minor styolites, 13 major horizontal fractures, 79 minor horizontal fractures, 5 major angular fractures and 21 minor angular fractures. The total for all types was 451 microfractures. The major fractures and styolites were more prevalent in the upper half of the core from 4160 ft to 4250 ft.

Special flow studies and flood-pot tests were conducted on the core after a conventional whole-core analysis was performed.

While conducting flow tests on the core, the 4200 ft sample was fractured when a 500

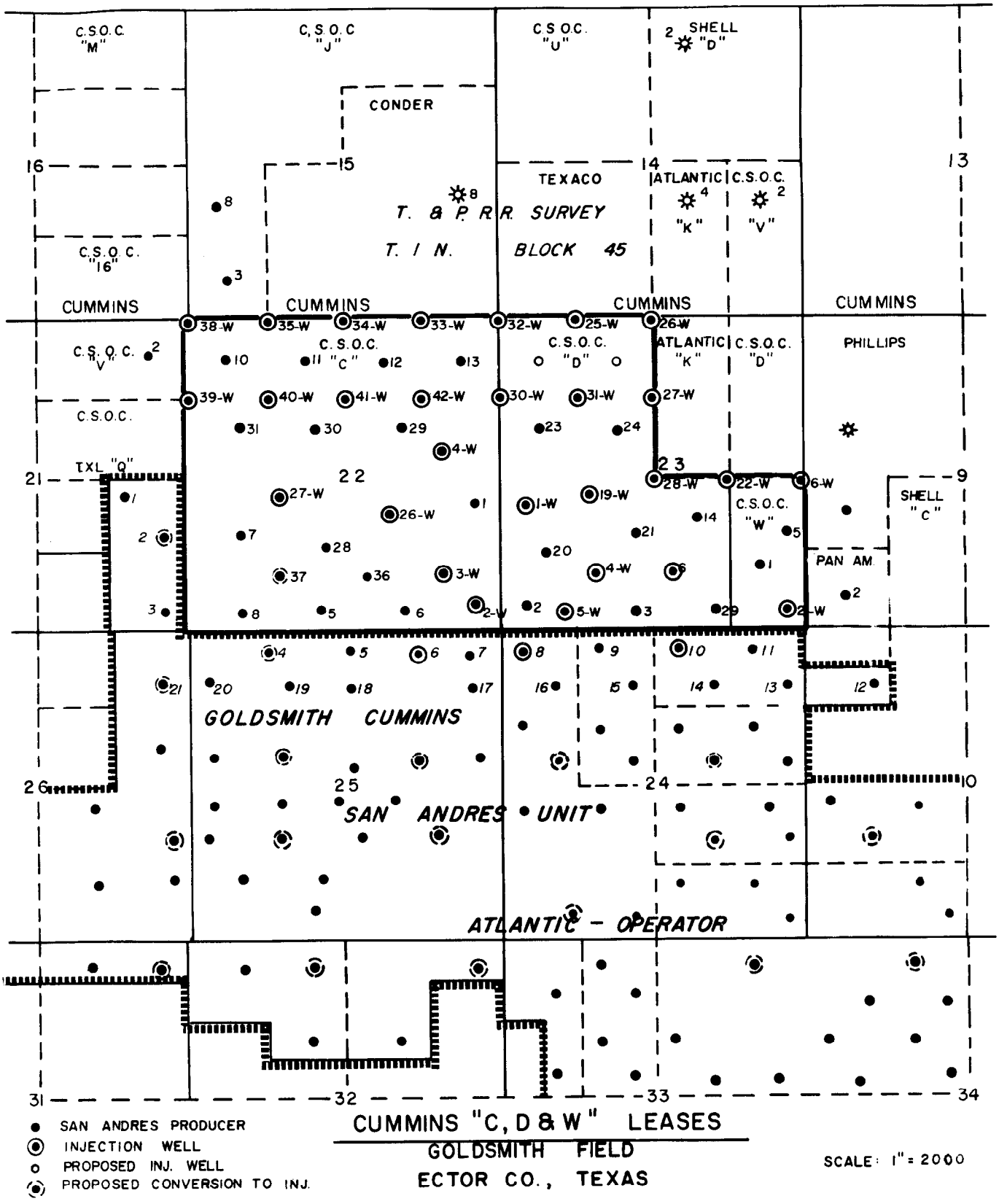

C.S.O.C. "M"
C, S. O. C "J"
C.S.O.C. "U"
2 SHELL "D"
CONDER
16
15
14
13
TEXACO
ATLANTIC
C.S.O.C.
T. & P. R.R. SURVEY
T. 1 N.
BLOCK 45
"K"
"V"
C.S.O.C. "16"
CUMMINS
CUMMINS
CUMMINS
CUMMINS
38-W
35-W
34-W
33-W
32-W
25-W
26-W
C.S.O.C. "V"
C.S.O.C. "C"
C.S.O.C. "D"
ATLANTIC "K"
C.S.O.C. "D"
PHILLIPS
39-W
40-W
41-W
42-W
30-W
31-W
27-W
C.S.O.C.
TXL "Q"
22
23
21
9
4-W
27-W
26-W
1-W
19-W
28-W
22-W
6-W
SHELL "C"
C.S.O.C. "W"
PAN AM
37
36
3-W
4-W
2-W
5-W
GOLDSMITH CUMMINS
25
24
26
10
SAN ANDRES UNIT
ATLANTIC - OPERATOR
31
32
33
34
SAN ANDRES PRODUCER
INJECTION WELL
PROPOSED INJ. WELL
PROPOSED CONVERSION TO INJ.
CUMMINS "C, D & W" LEASES
GOLDSMITH FIELD
ECTOR CO., TEXAS
SCALE: 1" = 2000

FIGURE 1

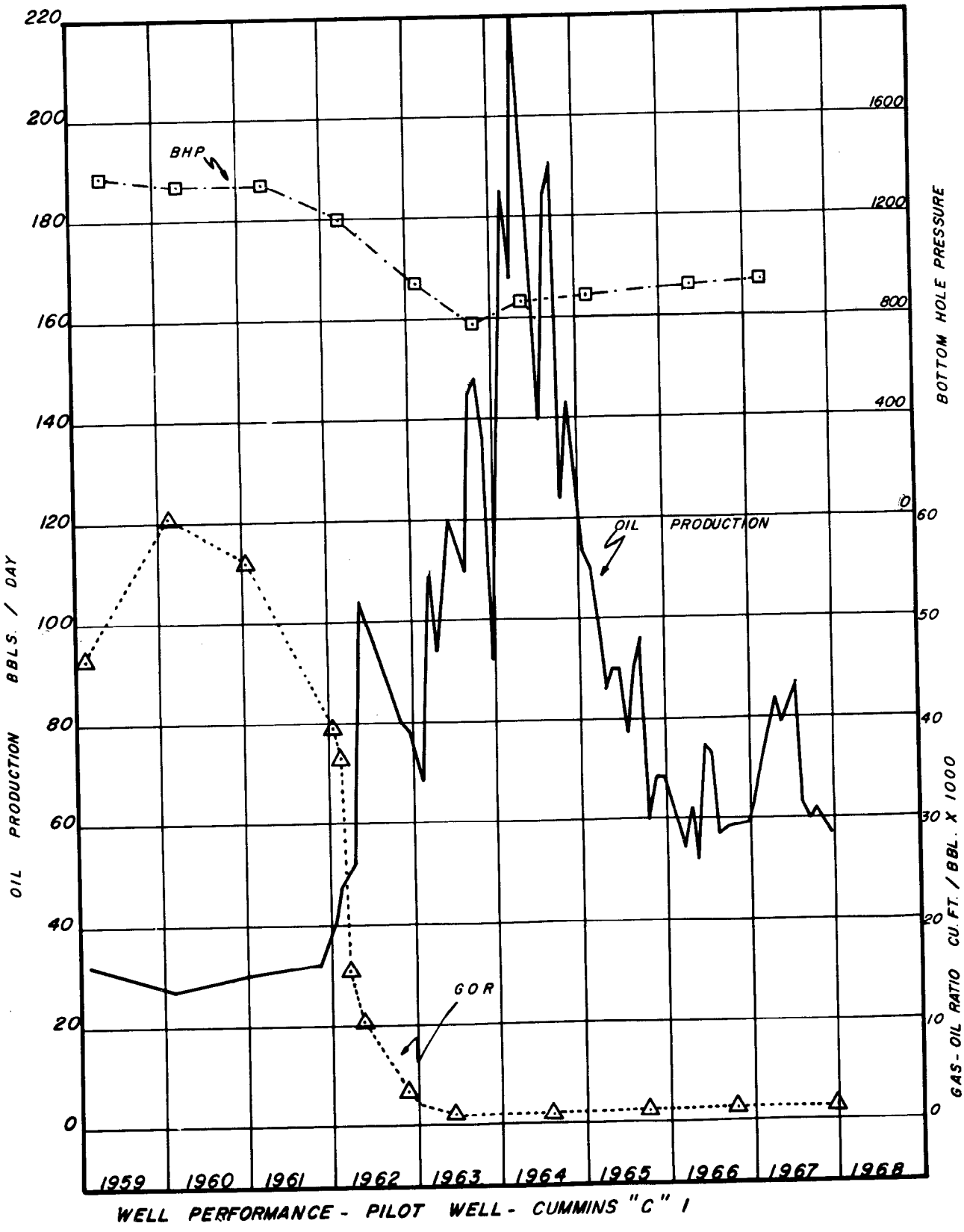

220
200
180
160
140
120
100
80
60
40
20
0
OIL PRODUCTION BBLS. / DAY
1600
1200
800
400
0
BOTTOM HOLE PRESSURE
60
50
40
30
20
10
0
GAS-OIL RATIO CU.FT. / BBL. X 1000
BHP
OIL PRODUCTION
GOR
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
WELL PERFORMANCE - PILOT WELL - CUMMINS "C" 1

FIGURE 2

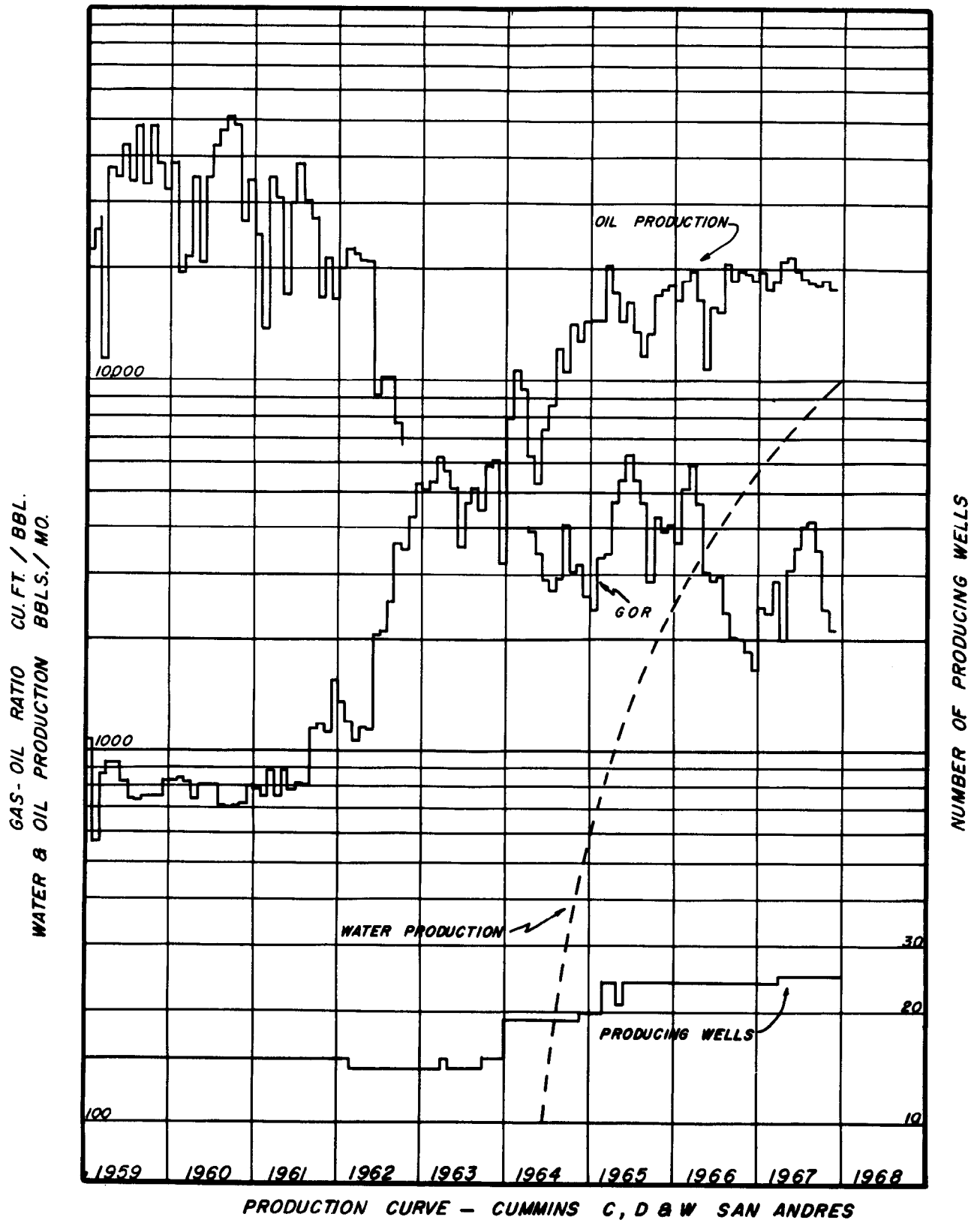

GAS- OIL RATIO CU. FT. / BBL.
WATER & OIL PRODUCTION BBLS./ MO.
NUMBER OF PRODUCING WELLS
OIL PRODUCTION
GOR
WATER PRODUCTION
PRODUCING WELLS
10000
1000
100
30
20
10
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
PRODUCTION CURVE – CUMMINS C, D & W SAN ANDRES

FIGURE 3

psi pressure differential was applied across the core.[2] From this study, it was concluded that high injection pressures and rates could very likely open the microfracture system and result in early water breakthrough.

PILOT OPERATION

The Railroad Commission granted permission to inject fluid under a voidage replacement allowable which provided for a bonus of 88 BPSDPW as long as a positive voidage replacement was maintained.

In August, 1961, water injection began into Cummins-C #4W and Cummins-D #1W (Fig. 1). The pilot oil well, Cummins-C #1, had produced 90,028 bbl of primary oil and was currently producing at the rate of 31 BOPD with a gas-oil ratio of 57,000 SCF/STB. In December, 1961, Cummins-C #26W was drilled for injection and by February, 1962, Cummins-C #3W had been converted to water injection status and the pilot was complete. Water injection rates varied between 200 and 300 BPD per well and injection

Photographs of Microfractures and Stylolites From 19W Cummins "D" Core

4160.8'

Stylolite

4163.0'

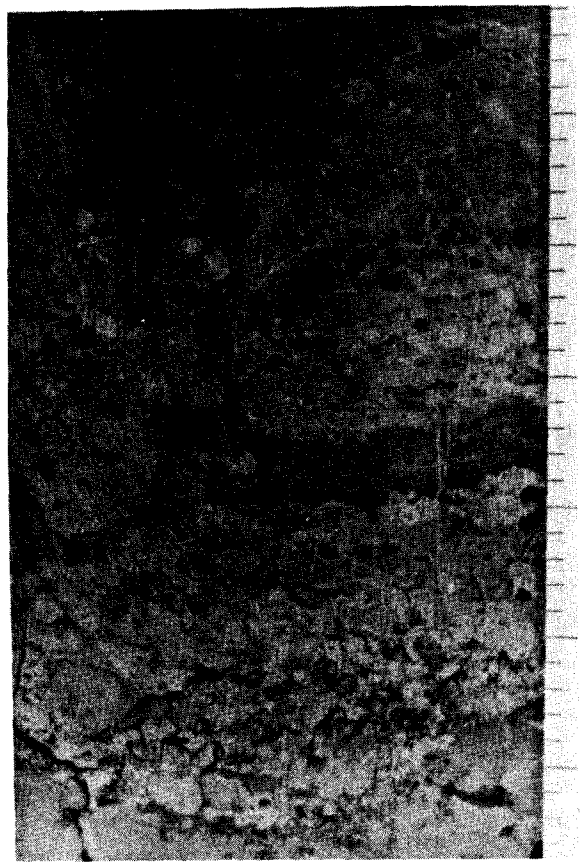
Fracture cut at acute angle.

FIGURE 4

pressures ranged from zero to 300 psi. The injection water was a mixture of produced Ellenburger, Fusselman, Clearfork and San Andres water that was gathered from surrounding leases and transported to the water plant. After a total of 520,000 barrels of water had been injected into the four surrounding input wells, Cummins-C #1 production increased to 125 BOPD and no water and the producing GOR dropped to 1200 SCF/STB (Fig. 2). During this 19 month interval, the pilot oil well had produced over 32,900 bbl of waterflood oil. The pilot well continued to increase in capacity until April, 1964, when oil production peaked at 230 BPD with a gas-oil ratio of 2000 SCF/STB. It is interesting to note that Cummins-C #1 did not produce any water until July, 1964, at which time Cummins-C #1's daily rate was 185 BOPD and one BWPD. Cumulative secondary oil recovery was 62,817 barrels. The bottom-hole pressure of the pilot well was 1264 psi when water injection began. It decreased to 818 psi in 1963 and increased to 1075 psi in 1967.

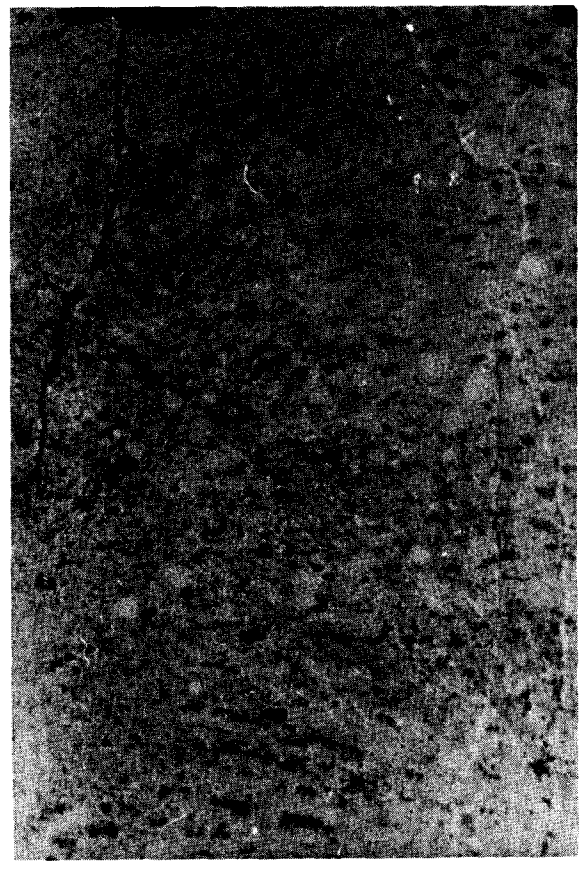
DEVELOPMENT OF PILOT

Based on the successful performance of the pilot project, the injection pattern was expanded on the Cummins-D Lease by drilling "D" #19W and "D" #20 in April, 1963. Cummins "D" #20 potentialed flowing 103 BOPD and 25 BLWPD with a gas-oil ratio of 3060 SCF/STB. Cummins-D #4 was converted to injection status and by



4166.8'

Minor stylolite and open vertical fracture, several minor closed vertical fractures also.



4168.3'

Vertical fractures; one open.

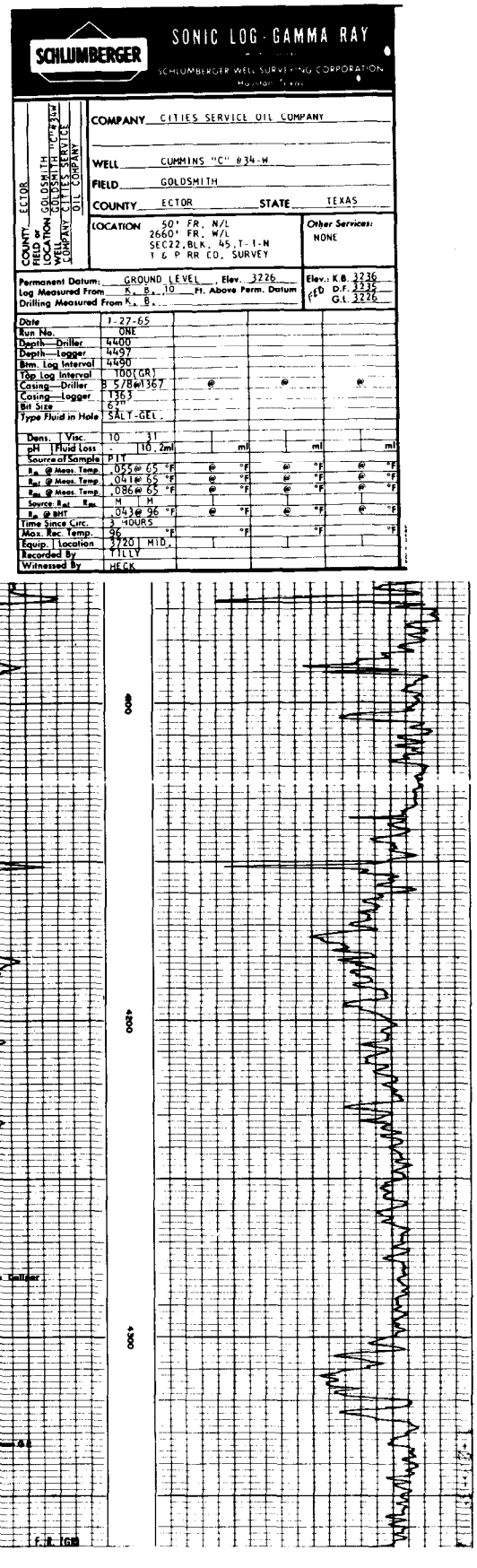
FIGURE 5

December, 1963, "D" #21 was completed for 99 BOPD, no water and a production GOR of 3630 SCF/STB.

By the response of the wells in the immediate area of the pilot it was concluded that the San Andres would respond to water injection and full scale development of the leases was justified. The injection plant was enlarged by installing one additional pump and water supply line to Shell Pipeline Company's El Capitan water system. The expansion of the flood was by 40-acre five-spot pattern or modifications thereof.

In order to prevent migration of oil outward from the pilot area and across the lease lines to the north and south, a cooperative line agreement was signed with Atlantic to the south to provide lease line injection wells.

The San Andres to the north of the Cummins-C, D and W is part of the Goldsmith, North San Andres Consolidated Field and is primarily an area of gas production. Condor, Texaco and Atlantic operate San Andres gas wells in this area. Structurally, the Atlantic and Condor wells are located 25 to 30 ft up structure from the nearest injection well (Fig. 1). By limiting water injection rates to 250 BWPD per well and providing offset producers to monitor early water breakthrough along the lease, Cities was granted permission to drill seven injectors along the northern boundary of the "C" and "D" Leases. These wells were to prevent migration of oil across the lease lines due to the drainage advantage the gas wells had over the heavily penalized Goldsmith wells. The northern line input wells, Cummins "C" #32W, "C" #33W, "C" #34W, "C" #35W and "D" #25W were produced prior to water injection to determine the relative fluid saturations of this particular portion of the reservoir. The average producing gas-oil ratio was 28,400 SCF/STB. From relative permeability data[3] and core information, the fluid saturations were determined to be 75.5 per cent and the gas saturation was determined to be 24.5 per cent. By injecting water into the entire producing horizon along the northern lease line, loss of oil into the gas cap would be minimized. The gas cap in the waterflood area is associated with the oil section and is considered one of a secondary nature in portions of the "C", "D" and "W". As an example of the erratic nature of the gas section, Cities Service Oil Company recom-



pleted its Cummins-J #8 (Fig. 1) in the San Andres with the intent of finding gas and the San Andres was found to be structurally 24 feet higher than Condor's 15-8 gas well. However, on completion, this well flowed 335 barrels of oil with a GOR of 1650 SCF/STB. It was completed as a top allowable oil well in May, 1964, and has continued to be a top allowable oil well. The cumulative recovery from this well to January 1, 1968, was 28,118 barrels.

In March, 1965, Cities began injecting water along the southern boundary of the leases into "C" #2W, "D" #5W and "W" #2W with a cooperative line agreement with Atlantic Richfield Co. Expansion of the entire project continued in 1966 and 1967 and currently comprises 28 injection wells and 25 producing wells. The production of the three leases is depicted in Fig. 3. Oil production has been successfully increased from 800 barrels per month prior to water injection to the current 18,000 to 20,000 BPM. During this time, the producing gas-oil ratio has been lowered from 53,000 SCF/STB to the present 2180 SCF/STB. Cumulative secondary oil production to January 1, 1968, was 826,213 barrels. The final stages of development of the project will be conducted this year when Cummins-C #37 is converted to injection and Atlantic Richfield converts the Goldsmith Cummins San Andres Unit Well #4 to water injection.

The success of this project has been attributed primarily to the relatively close spacing of the water injection wells and the low water injection rates and pressures.

REFERENCES

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3. Engineering Subcommittee Report, Goldsmith-Cummins (San Andres) Unit, Ector Co., Texas (June 1962) unpublished

ACKNOWLEDGEMENT

The author expresses appreciation to the management of Cities Service Oil Co. for permission to prepare and present this paper.