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AN OVERVIEW OF DEVONIAN DUPEROW FORMATION PRODUCTION, BILLINGS ANTICLINE, NORTH DAKOTA

by Randolph B. Burke

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CONTENTS

	Page
INTRODUCTION	1
STRUCTURE	1
LITHOLOGY	2
DUPEROW PRODUCTION	2
DISCUSSION	3
SOME ECONOMIC SCENARIOS	3
CONCLUSIONS	4
REFERENCES	5

ILLUSTRATIONS

Figure

1. Oil, gas, and water production curves for all wells that have produced from the Duperow Fm. as of March 7, 1987 . . . . (in pocket)

2. Combined total Duperow Fm. isopach and present Duperow Fm. structure map . . . . (in pocket)

3. Duperow Fm. cycles, perforated horizons, average daily oil and water production, and multiple-pay zones are indicated by well and field . . . . (in pocket)

4. Initial oil production (IP) and cumulative oil and water production (CP) for the Duperow Fm. by well and by field, and well status as of January 1, 1988 . . . . (in pocket)

INTRODUCTION

Oil exploration on the Billings Anticline began in earnest in 1978, 12 years after Anderson's (1966a, 1966b) discussions of the oil potential of southwestern North Dakota. The Billings Anticline is a north-plunging structure in the north-central part of southwestern North Dakota (figs. 1 and 2). Forty-two fields are included in the Billings Anticline area, defined here as townships 140 through 144N and ranges 98 through 102W, and part of 103W.

Most of the early discoveries on the anticline produced oil from Mississippian carbonates of the Fryburg zone in the Mission Canyon Formation. Major Devonian Duperow Formation production began in 1978 with Tenneco's discovery well in Four Eyes Field. Mississippian Madison reservoirs are the most prolific hydrocarbon producers on the Billings Anticline; Duperow Formation reservoirs are second. Additional recent production, however, from horizontal drilling in the fractured shales of the Mississippian Bakken Formation may soon cause the Bakken Formation to surpass the Duperow as the second largest producing horizon on the anticline.

Most Duperow reservoirs in the Billings Anticline area were discovered by chance rather than design. Standard exploration strategy has been to drill Madison targets, or Red River structural "bumps" defined from seismic data. Duperow reservoirs are typically found by drill-stem testing of porous dolomites during extension of Madison tests, or by log analysis during drilling toward deeper objectives (e.g., the Ordovician Red River Formation). The data base is thus biased because it results from Red River and Mission Canyon exploration models rather than a Duperow model. Therefore, one must avoid interpreting the following observations as indicating a formal Duperow exploration strategy, and accordingly, must use appropriate caution in applying these observations to future Duperow exploration models.

STRUCTURE

The first published maps of the Billings Anticline structure were made by Sidney B. Anderson and included in North Dakota Geological Survey Report of Investigation 42 (1966a). Subsequent drilling allowed more detailed maps to be made (fig. 2). The anticlinal structure is about 6 miles wide, over 30 miles long, and is comprised of several minor noses superimposed on the broader feature. Close spacing of Duperow structure contour lines define a lineament on the east side of the structure. A corresponding thickening in isopach contours parallels the lineament (fig. 2). One can interpret from this lineament that the east side of the structure is faulted, and for the same reasons, that the minor noses also may be fault defined (Burke and Heck, 1989). However, log cross sections indicate little present displacement, so these lineaments could represent just fractures. Although the log sections don't show displacement, minor thinning is seen along the axis of the structure. A Duperow Formation isopach map emphasizes this thinning and suggests that the Billings Anticline had subtle structural relief at the time of Duperow deposition (fig. 2).

LITHOLOGY

Duperow Formation lithologies consist of interbedded limestones, dolomites, and anhydrites punctuated by siliciclastic and argillaceous units commonly used to define the top of a cycle. Numerous complete and incomplete sedimentary cycles have been recognized by various workers, the number of cycles varying according to each one's definition of a cycle. The most complete cycles are developed in the lower Duperow, where six cycles are generally recognized (fig. 3). Following Wilson (1967) and Wilson and Pilatzke (1987), the cycles of the lower Duperow were numerically ordered from 1 at the bottom to 6 at the top by Pilatzke et al. (1987). Depositional facies comprising a complete cycle begins with a suite of normal marine facies, including stromatoporoid banks, and continues upward through restricted marine strand-line facies that may include channels. The cycle is capped by various subaerial facies including anhydrites.

DUPEROW PRODUCTION

The following observations result from the compilation of Duperow production data as part of a larger study of the diagenesis and depositional environments of the Duperow Formation in the area. Hydrocarbons are produced from 6 cycles in the lower Duperow as well as from the upper Duperow. However, the most prolific zone is cycle 3 of the lower Duperow. The least prolific wells are the 9 that produce from the upper Duperow (figs. 3 and 4). Daily oil production per well ranges from 9 to 615 barrels with an average daily oil production per well of 139 barrels (47 wells, 6292 BOPD), and 68 barrels of water (BW - based on 47 wells and 3176 BWPD) (fig. 3). The average cumulative oil production per well is 150,623 barrels (fig. 4). The field with the greatest oil production is T.R. Field with 1.7 millon barrels of oil, with an average field production per well of 425,287 barrels of oil. Cumulative oil production of fields ranges from 3755 BO in Buckhorn Field to 1.7 millon in T.R. Field (fig. 4).

Seventeen, or 41%, of the 42 oil fields in the area produce from the Duperow Formation; 6 of the fields are along the crest of the Billings Anticline. Duperow Formation pools are small; the largest, T.R., Whiskey Joe, and Tree Top, have 6 wells each and the average size is 3 wells. Total Duperow production in the Billings Anticline area is 7.4 million barrels of oil as of January 1988 with about half, or 3.4 million barrels of oil, produced from the anticline proper.

One thousand and fifty-five wells have been drilled in the 936-square-mile study area as of June 1988. Two hundred and seventy of these wells, or 26%, penetrated the Duperow Formation. Fifty-one Duperow penetrations, or 19%, produce from the Duperow. Only 48 Duperow wells are reported in figures 3 and 4 because the production history is too short for the other 3 wells. Of the 48 wells, 44% (21 wells) produce from more than the Devonian Duperow Formation, 18 from shallower horizons, and 6 wells from deeper horizons (fig. 3). Three wells produce from 2 or more additional horizons (i.e., Ordovician, Silurian, and Mississippian). This number of wells will increase if additional production behind pipe is completed. Most Duperow wells with multiple-pay zones produce from the lower Duperow cycle 3, whereas only 2 of the wells completed in the upper Duperow have also been completed in additional horizons (fig. 3).

Production curves show that the wells are high volume but short-lived and that fields are generally small (fig. 1). Of the 51 wells producing from the Duperow since the anticline discovery in Four Eyes Field in 1978, 25 wells (49%) are plugged and abandoned. Twenty-six wells (51%) are still in production as of January 1988 (fig. 4). Production curves indicate reservoirs produce by a combination of solution-gas and water-drive mechanisms (fig. 1).

DISCUSSION

A map showing the location of Duperow production plotted on a combined Duperow structure and isopach map is shown in figure 2. When this map is evaluated in light of figures 3 and 4, it shows that the best production is on the flanks, but near the apex, of isopach thins and the highest points of present structure (fig. 2). Although oil production is from the flanks of isopach thins, it is not from the thinnest locations, but from the proximal, slightly thicker areas surrounding or parallel to thins. The slightly thicker (approximately 10 feet thicker) areas between thins form digitate patterns (paleochannels?) between thin areas. Oil production most commonly occurs on the eastern flank of a structural nose, but rarely in the structurally highest point. The trend of production on the eastern flanks of structures may reflect a hydrodynamic component to trapping as was noted in the overlying Mississippian Madison Formation (Breig, 1988). Average daily water production also shows a slight propensity to increase in slightly thicker beds and decrease in slightly thinner beds. In a few cases the converse is true. Wells off structure in thicker beds show an increase in water production earlier than those higher on the structure and in thinner beds (fig. 1).

No wells with significant Duperow production are located on the thins or on the highest structural positions. This suggests that production can be expected on the flanks of Duperow highs and thins. If one accepts that faults or fractures define structural elements on the anticline, it can be postulated that fluids migrating along fracture and/or fault systems proximal to these areas may have contributed to reservoir formation through late-stage diagenesis. This also may help explain the coincidence of the greater production of Duperow cycle 3 with multiple-pay zones. Late-stage diagenetic changes observed in Duperow cores and thin sections include dolomitization, calcitization, dissolution, and cementation (Burke and Heck, 1989).

SOME CONSERVATIVE ECONOMIC SCENARIOS

The cost of a Duperow test in the early 1980s when most of these wells were drilled and completed was about $1.5 million. Using this cost assumption and $10/BO (after royalties and operating costs), one sees that 37.5%, or 18, of the Duperow producing wells paid out (fig. 4). Although this is only 7% of all Duperow penetrations, this serendipitous production (Gerhard et al., 1987) pays more than the cost of the well, and production from other horizons is profit. Of those 18 wells, 56%, or 10, are proven multiple producers and additional production exists behind pipe in other wells. Because drilling costs are substantially lower now than they were in the early 1980s, the number of wells that would pay out would be greater.

Since most Duperow production is discovered as a secondary target, it is useful to consider incremental costs. Using NDGS well #7097 as an example, the Mississippian Fryburg producing zone is approximately 1600 feet shallower than the Duperow Formation cycle 3 production.

Assuming an additional 8 days to drill, log, and test the Duperow, rig costs of $10,000 per day, and $10,000 for extra logs and a drill stem test (DST), an additional $90,000 cost is incurred to test the Duperow Formation. Completion costs could raise this figure to $160,000. Using the $160,000 cost for a Duperow well drilled as a secondary target (rather than the $1.5 million cost for drilling from scratch), the number of wells making a profit is increased to 41 (83%). This is 15% of all Duperow penetrations (270).

Recompleting in the Duperow from deeper tests should not cost more than the figures estimated above, but some additional risks are involved. Besides inherent technical difficulties in recompleting a well, existing casing is subject to corrosion and salt flowage. Despite these potential problems, the Duperow Formation is an attractive target because of the high percentage of wells discovering economic production by the extension of shallower tests or wells. Additionally, a reasonable rate of return on the drilling costs can be expected from the large volumes and high production rates over the life of the well. Perhaps an exploration strategy designed specifically for Duperow targets would provide even better results.

CONCLUSIONS

Production from the Duperow Formation in the Billings Anticline area is on the flanks of present and paleo (isopach thins) structural highs, generally on the east side. The most prolific hydrocarbon zone in the Duperow Formation is cycle 3. Reservoirs are small and pod-like. This pattern to the distribution of production may be partially a function of data (lack of well control), but equally possible, it may be due to the need for three-way structural closure coincident with depositional thins and fractures and/or faults. The fractures would not only provide conduits for fluids to diagenetically enhance reservoir quality, but also for hydrocarbon migration. This potential control on fluid migration along fracture/fault systems may also explain the high coincidence of additional production in the same well from different formations. The data presented here suggest that Duperow tests can be profitable and that a very high possibility exists for profitable recompletion in the Duperow Formation.

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Figure 1. Oil, gas, and water production curves for all wells that have produced from the Duperow Fm. as of March 7, 1987. Production from cycle 3 is highlighted with a stippled pattern. Scale on the right side of a graph is for gas and is indicated only when it is different from the scale on the left side of the graph. Those wells without curves and no special symbol designated in the explanation are too recent to have an informative production history. Three wells producing from the Duperow Fm. in Little Knife Field are not shown because they are on a separate structure and not from the prolific Duperow Fm. cycle 3 producing zone.

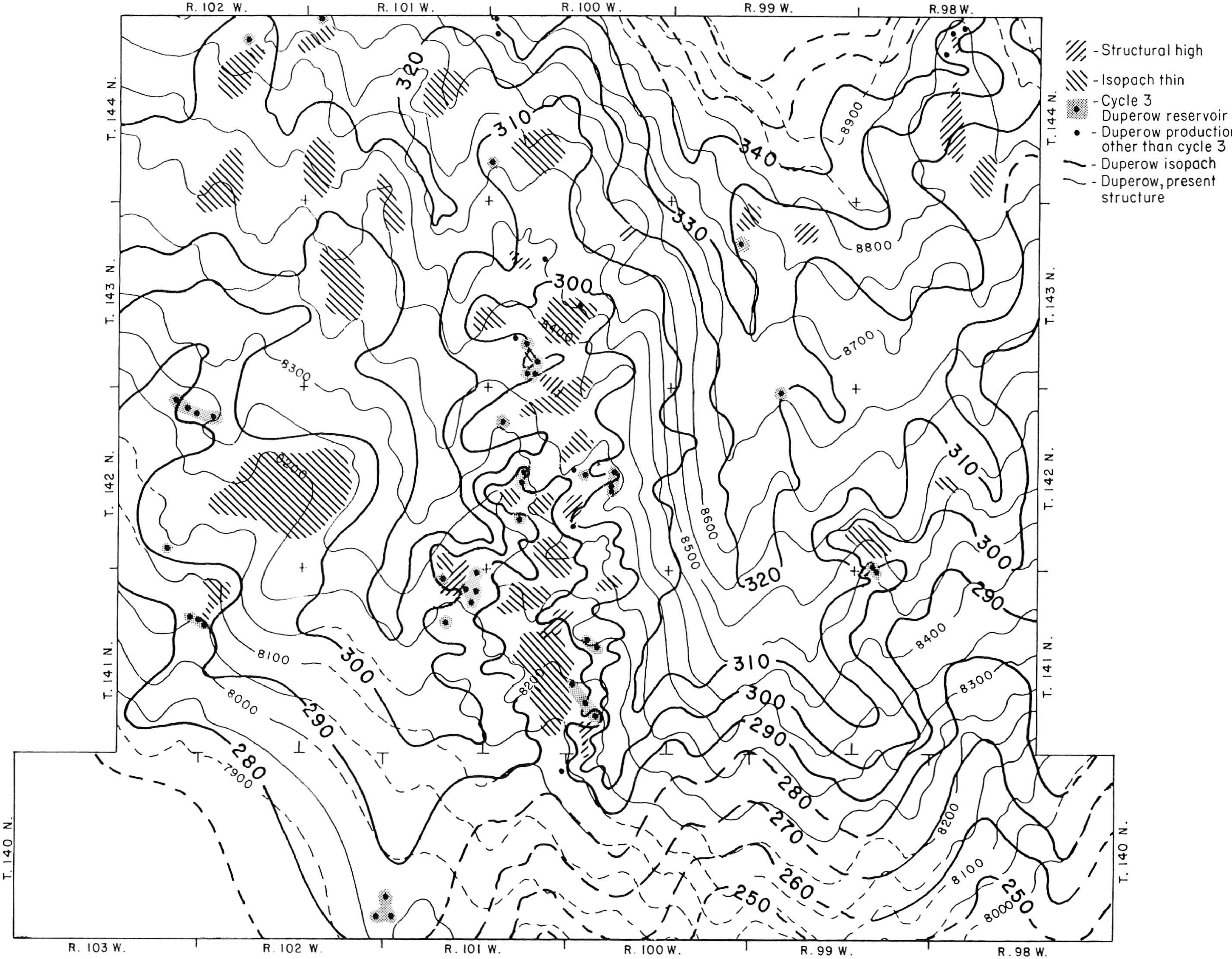

Figure 2. Combined total Duperow Fm. isopach and present Duperow Fm. structure map. Duperow production is indicated with cycle 3 production highlighted by a stippled pattern. Isopach thins and present structural highs are indicated by opposing cross-hatch patterns. All wells producing from the Duperow Fm. in the Billings Anticline area are shown on this map. Note that production is on the flanks of present and paleo (isopach thins) structural highs, and generally on the east side of structures.

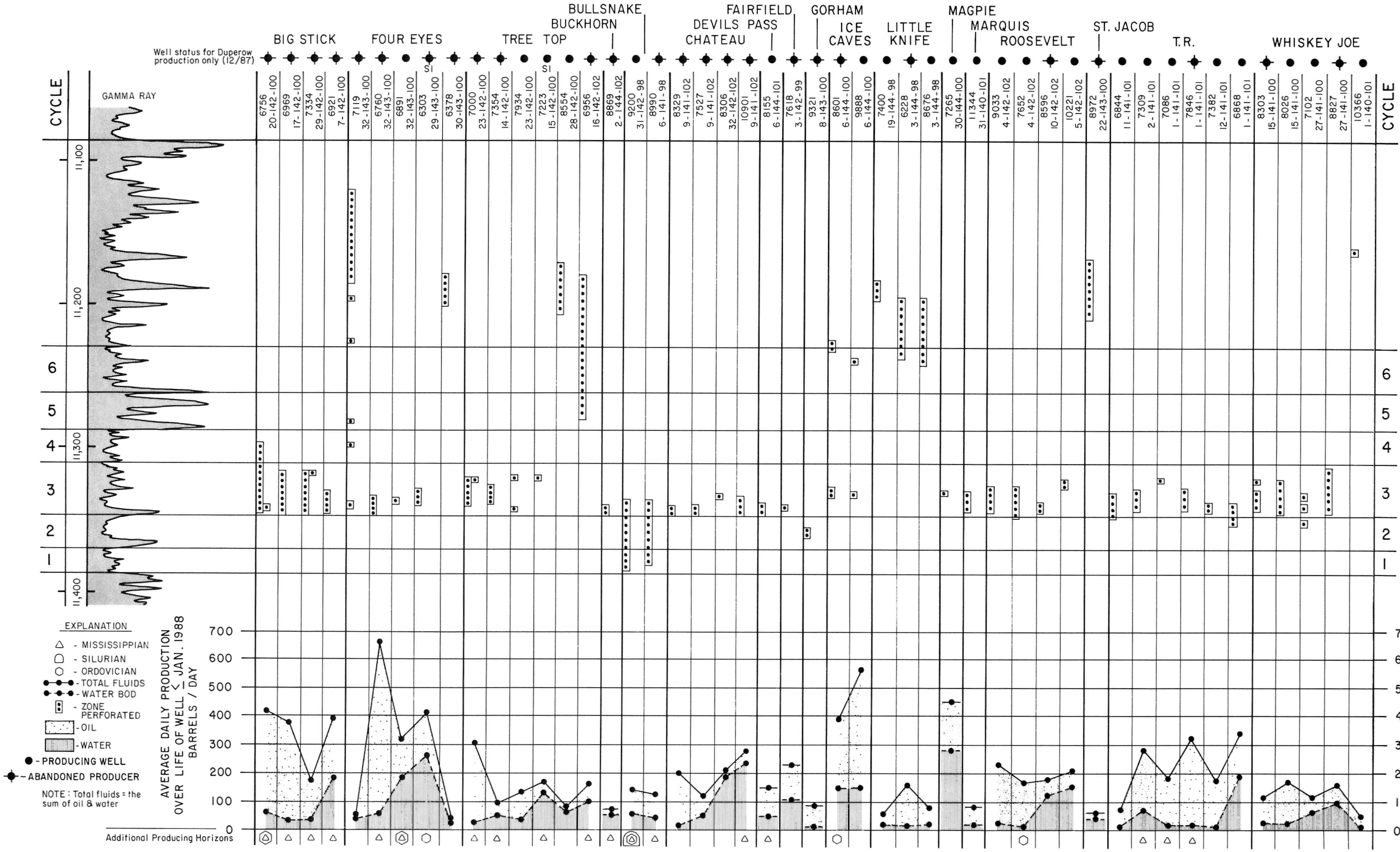

Figure 3. Duperow Fm. cycles, perforated horizons, average daily oil and water production, and multiple-pay zones are indicated by well and field. Cycle 3 is the most frequently perforated horizon and the most prolific producing zone. Two of every five wells have more than one pay zone. Data current to January 1, 1988. Three wells, two in Marquis Field and one in T143N, R99W are not included because they are too recent to have informative production histories.

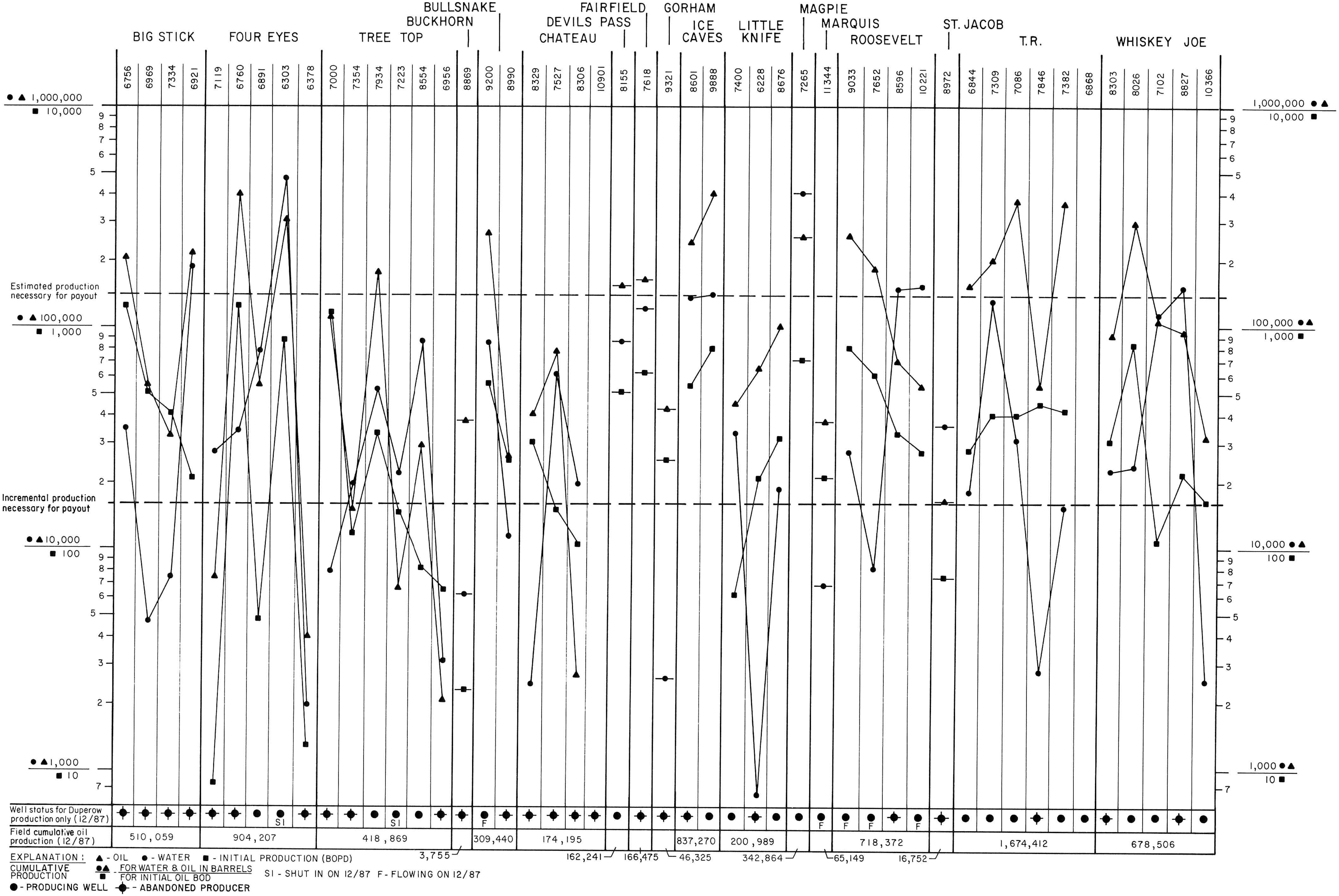

Figure 4. Initial oil production (IP) and cumulative oil and water production (CP) for the Duperow Fm. by well and by field, and well status as of January 1, 1988. Plotted on log scale with different scales for IP (lower) and CP (upper). Note two dashed lines indicate selected economic scenarios. Upper dashed line indicates production necessary to pay for Duperow Fm. test, whereas lower dashed line indicates incremental production necessary if Duperow Fm. is secondary pay zone. Three wells, two in Marquis Field and one in T143N, R99W are not included because they are too recent to have informative production histories.