HISTORY OF THE WILMINGTON FIELD - 1986-1996

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Introduction

The Wilmington Field is the third largest oil field in the United States, based on cumulative production. Original oil in place was approximately 8.8 billion barrels. Cumulative oil production to date is approximately 2.4 billion barrels leaving a target of 6.4 billion barrels for improved recovery methods. This history will update the work of Mayuga (1970) and Ames (1987).

Onshore Wilmington Field

Brief History

The Wilmington Oil Field is located in the Los Angeles Basin of Southern California (Figure 1). It was discovered in 1932 when Ranger Petroleum Corporation's Watson No. 2 was drilled and completed in the Ranger Zone. At the time, the discovery was thought to be an extension of the adjacent Torrance Oil Field. It was not until 1936, with the drilling and completion of General Petroleum Company's Terminal No. 1, that Wilmington was discovered to be a separate field. By 1946, the Ranger, Upper Terminal, Lower Terminal, Union-Pacific, Ford, and 237 Zones had been discovered and were under production. The limits of the Wilmington Field were subsequently extended from the Torrance field on the northwest to the Harbor District of the City of Long Beach on the southeast. It was not known at that time how far the Wilmington field extended offshore to the southeast.

Due to the very small size of individual holdings and resultant small well spacing (less than three acres per well) peak production was reached very quickly and individual well rates declined sharply. Beginning in the ear

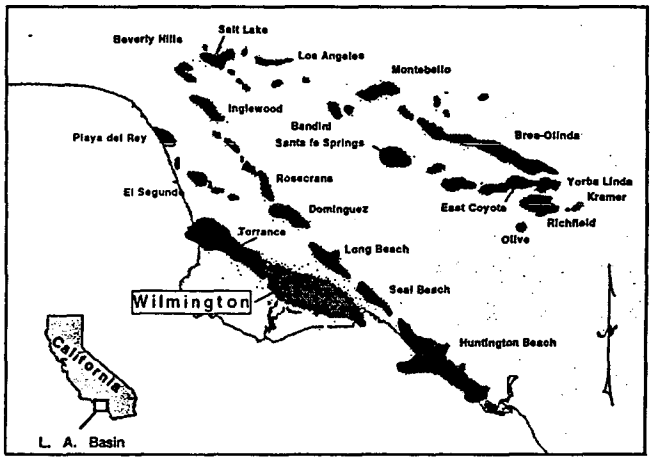

Figure 1. Location map, showing the Wilmington Oil Field in the Los Angeles Basin (after Mayuga, 1970).

early 1940's, land subsidence was observed in the Wilmington Oil Field (Strehle 1987 and 1996). The main area of subsidence was shaped like a bowl with the center of subsidence located on the east end of Terminal Island. At its maximum, about 30 feet of subsidence occurred at the surface. The City of Long Beach therefore delayed further development of the field under the harbor until a solution to the problem of subsidence was found. In 1953, the city and its contractor, Long Beach Oil Development Co., started a pilot water injection operation in the Upper Terminal Zone to determine the feasibility of water injection for repressurization to control subsidence and to increase oil recovery. By 1956, experience gained in the pilot operation and several other water injection projects proved that water injection controlled subsidence and improved oil recovery. To expand the water injection program for fieldwide application, it was necessary for the individual holdings in the field to be pooled under unit or cooperative agreements.

By 1964, four unit agreements were completed in the previously developed area of the field. Fault Block IV was unitized in April 1964, with the City of Long Beach as operator in Segment I and Long Beach Oil Development Company (predecessor to Tidelands Oil Production Company) as its field contractor. Segment II was initially operated by Mobil Oil Corporation with Long Beach Oil Development Company as its field contractor. In January 1991, operatorship of Segment II passed from Mobil Oil Corporation to the City of Long Beach. As of April 1994, the largest working interest owners are the Long Beach Department of Oil Properties (52%) and the City of Long Beach (17%) with the remaining 31% ownership distributed among several hundred entities.

A part of the Ranger Zone of Fault Block V was unitized in April 1964. The non-Unit portions of Ranger V are referred to as Parcels "A" and "L."

The Tidelands Units and Old Wilmington

Tidelands Oil Production Company was formed by Chanse Long Beach Production Company and Neste Oil Services, Inc, a subsidiary of Neste Oy on January 1, 1989. On March 1, 1989 Tidelands Oil Production Company took over as operator of the tidelands leases for the City of Long Beach replacing Long Beach Oil Development Company which had operated the leases for the previous 50 years. During 1989 and 1990 Tidelands became operator for Mobil Oil Corporation and Chanse Energy Corporation in the Wilmington field. In 1993 Tidelands became the field contractor for Union Pacific Resources Company and in 1994 Tidelands became the field contractor for the City of Long Beach Harbor Department.

Production is from the middle Miocene and Pliocene turbidite sands. Like the eastern portion of the field the section is divided into six productive zones. Currently there are 675 active wells and about 300 idle wells. Tidelands produces 11,000 barrels per day oil, 270.000 barrels per day water and 12 million cubic feet of gas per day. Water injection is about 400,000 barrels per day water and 30,000 barrels per day of water equivalent steam.

Offshore Wilmington Field -- Long Beach Unit

Brief History.

In 1954, seismic exploration showed that the Wilmington anticline extended at least four miles to the southeast and under Long Beach Harbor. After water injection proved feasible for solving the subsidence problems, the City prepared a comprehensive plan for the development of the eastern part of the Wilmington Oil Field by pressure-maintenance operation. In 1962, a voter referendum approved offshore drilling under the harbor and the plan was implemented. In accordance with the restrictions imposed under the plan, the number of drill site islands was limited to four, each not to exceed 10 acres nor to be built closer than 1,500 feet from the city's shoreline. It was further required that the development be under a single pressure-maintenance operation.

By 1964, the City of Long Beach, the private landowners, and the townlot operators concluded a unit agreement under which the eastern extension of the Wilmington Oil Field could be developed. In addition, the City also prepared a field contractor's agreement for drilling and production operations for the City and the new unit. Both agreements were approved by the California State Lands Commission and bids were called in early 1965 to select the field contractor for the City of Long Beach. THUMS Long Beach Company, a joint venture of Texaco, Inc., Humble Oil and Refining Company (now Exxon), Union Oil Company (now UNOCAL), Mobil Oil Corporation, and Shell Oil company, was the successful bidder.

The new unit was officially named the Long Beach Unit. The City of Long Beach was named the Unit Operator and THUMS Long Beach Company the field contractor. The first well of the new unit was completed by THUMS in August 1965 from a drill site on Pier J in the Harbor District. During 1965 and 1966, while drilling continued from the Pier J site, four 10-acre islands were constructed in Long Beach Harbor. As soon as each island was completed, drilling was commenced from it. The THUMS islands and Pier J are shown in Figure 2.

Total stock tank oil originally in place (STOOIP) for the Long Beach Unit has been estimated at 3.13 billion barrels of oil. The Ranger Zone, which is the largest reservoir, has 2.24 billion STOOIP, followed by the Terminal Zone with 473 million barrels of oil, the Union Pacific and Ford Zones with 370 million barrels of oil, the Tar Zone with 27 million barrels of oil, and the 237 Zone

with 16 million barrels of oil. Berman and Clarke (1987) describe the oil operations and facilities.

The Long Beach Unit has been under waterflood operations since development started in 1965 due to the requirement for pressure maintenance under the Unit Agreement. The Ranger Zone waterflood was developed as a staggered line drive pattern with three rows of producing wells between injection well rows. Wells are located along structural strike with spacing approximately 10 acres per well. In addition, Ranger Zone injection is augmented by peripheral injection. In the Terminal and UP-Ford Zones, peripheral injection is the main method of pressure maintenance and oil recovery.

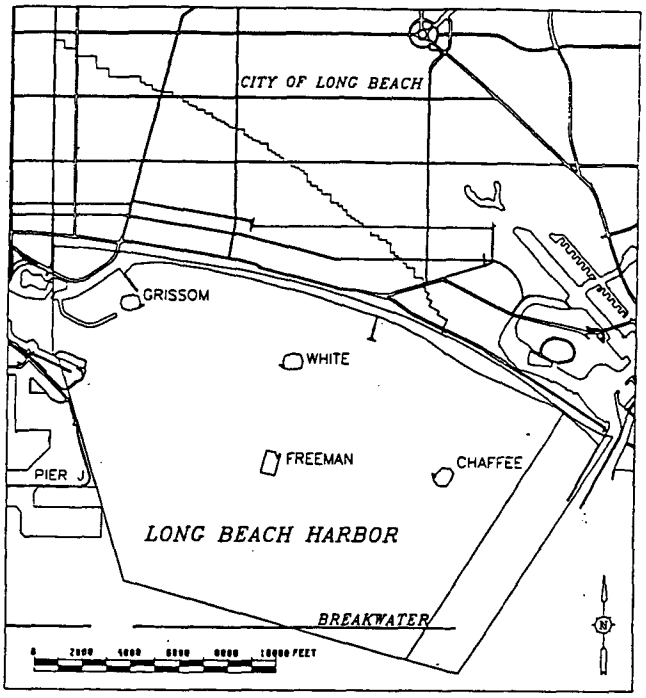

Figure 2. Map of the Long Beach Unit portion of the Wilmington Oil Field showing the oil islands.

Original reservoir development utilized long, gravel-packed, slotted liners for sand control. Completion intervals tended to cover entire zones, such as Ranger, Upper Terminal, Lower Terminal, and UP-Ford (Figure 3). Rarely was subzone isolation within zones provided in individual completions. The Unit, having typical characteristics of slope-basin clastic sediments, is very heterogeneous vertically, which made efficient waterflood management a challenge. Waterflood breakthrough occurred early in the offset producers. The presence of higher-permeability sand layers in the upper portion of most zones resulted in preferential water injection into, and oil production out of, the upper sands, leaving unrecovered oil in the lower subzones. This was heightened by a reluctance to set the large diameter, electric submersible pumps into the liners, resulting in high fluid heads over the lower sands. Fill accumulation in the lower portion of the long liners was another common problem.

In 1982, the City of Long Beach (Unit Operator) and THUMS Long Beach Company (Field Contractor) initiated a major program of infill subzone redevelopment to improve vertical waterflood conformance. In this case, "subzone" refers to completion intervals smaller than the zone but larger than individual sand packages or "markers". For example, whereas previous full-zone Ranger completions were commonly open to the FO through G6 sand packages, subzone redevelopment completions were shortened to include only the FO to X or X through G6 sand packages. Pore-volume throughput calculations were used to determine reserves by subzone, years remaining to the economic limit, and additional throughput required to obtain established reservoir goals. These were then used to design a reservoir subzone redevelopment plan to increase production and add incremental reserves that would not have been recovered otherwise.

During the program, which lasted from 1982 through 1986, some 480 wells were drilled or redrilled using shorter completion intervals in individual subzones or layers. Daily production was increased from 60,000 BOPD to 73,000 BOPD by 1985. The program resulted in 160 million barrels of incremental recovery and improved future reservoir management opportunities by improving subzone/layer monitoring and control.

Between 1989 and 1992, ARCO Oil and Gas Company purchased THUMS shares from the original five parent companies.

The Long Beach Unit participants, including ARCO, recognized that significant reserves could be recovered by further redevelopment of the waterflood. Carrying out the development, however, was made difficult by the lack of common incentives among the participants, an inability to risk public funds, and a lack of available investment capital. To address these issues, on January 1, 1992 the State of California, the City of Long Beach (City), and ARCO entered into an Optimized Waterflood Plan Agreement (OWPA), which received authorization by California Assembly Bill 227 (AB 227). AB 227 allowed ARCO to ensure that at least $100 million dollars would be invested in development drilling

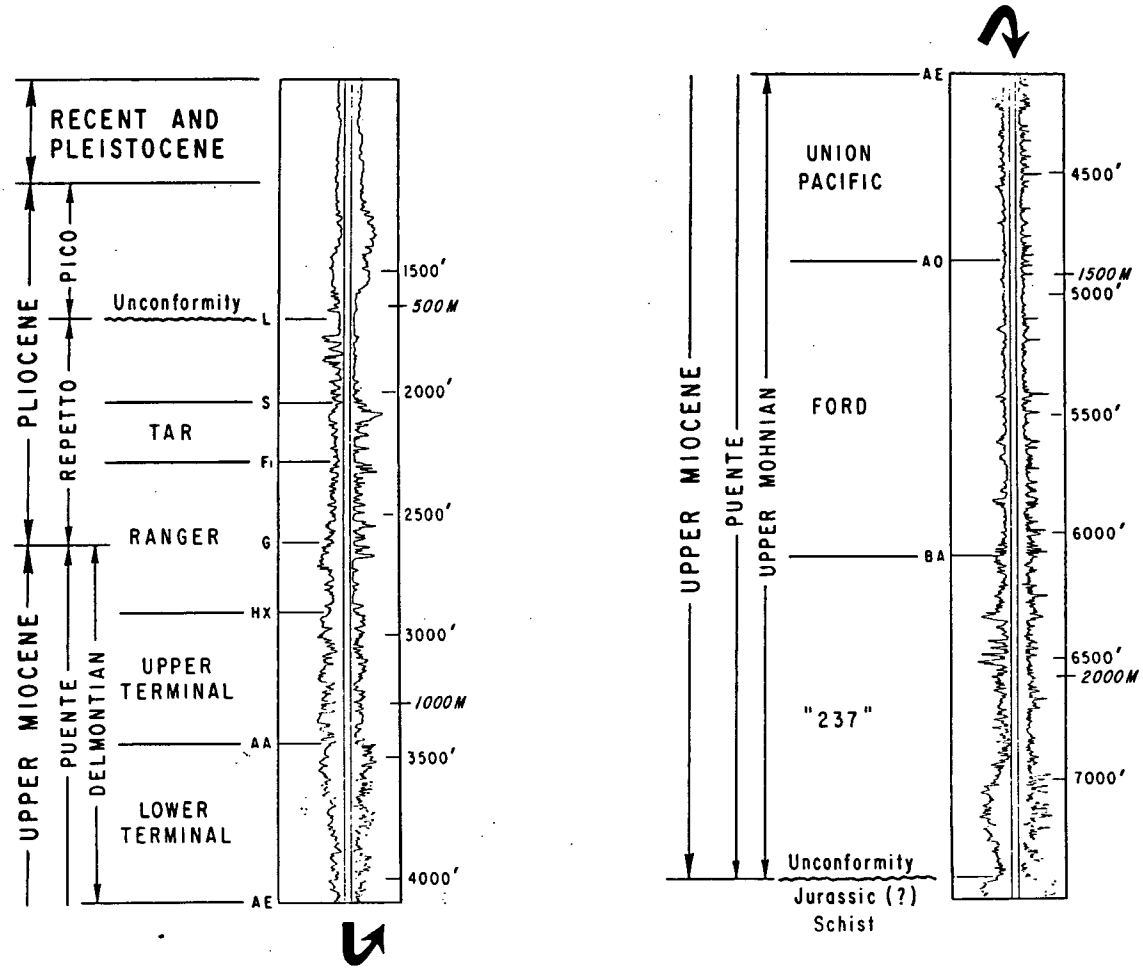

Figure 3. Composite type electric log of the Wilmington Oil Field from Mayuga, 1970.

and other waterflood optimization projects in return for significant input to the City of Long Beach during the design and implementation of the redevelopment. ARCO formed ARCO Long Beach, Inc. (ALBI) to assist the City of Long Beach Department of Oil Properties in the management of the OWPA. ALBI, the City, and the State of California would also share incremental profits which resulted from the redevelopment. As part of the OWPA, disputed offshore leases at Coal Oil Point, California were returned to the State, redevelopment could be implemented without State investment, and the State was guaranteed revenues during the period of high initial investment. In addition, the City received a profitability stake in the field. Initial plans for the redevelopment were to drill or redrill 600 wells over seven years and add reserves of 137 MMBO.

Coinciding with the implementation of the Optimized Waterflood Plan Agreement was the delineation of the reservoir into Unitized Formations (UF) and the establishment of multi-disciplinary, inter-agency Unitized Formation Teams to manage them. Teams were formed to manage the Ranger West, Ranger East, and Terminal/UP-Ford Zones. Each Unitized Formation Team is self-directed and self-motivated and is made up of reservoir engineers from the City, a waterflood surveillance engineer from ALBI, and a geologist and an operations/analytical engineer from THUMS (Figure 4). The teams are responsible for reservoir management and optimization of the waterflood within their unitized

formations, for selection of drilling locations and completion intervals, for selection and implementation of advanced secondary recovery technologies, and for review and analysis of the results of their work.

The success of the Unitized Formation Teams in the Long Beach Unit contributed to the idea of expanding the team concept to the business and operations side of THUMS' responsibilities. In July 1993, THUMS reorganized to create Profit Center Teams which manage the business and operations of each of the production sites (the four islands and Pier J). Each team consists of: the island superintendent; production, electrical, and maintenance supervisors; a production engineer; production engineering assistant; technical field maintenance engineer; business analyst, and unitized formation team liaison, who is a THUMS geologist or operations/analytical engineer. The role of the liaison is to ensure that the business and operations goals of the Profit Center Teams are consistent with the reservoir management goals of the Unitized Formation Teams. Profit Center Teams meet regularly to discuss and plan island operational issues, production and injection well work, business/budget plans, training and safety, and other relevant issues.

Long Beach Unit Reservoirs.

The producing zones of the Long Beach Unit reservoirs consist of, from top to bottom, the Tar Zone, Ranger Zone, Terminal Zone, Union Pacific Zone, Ford Zone, and the 237 Zone. Early on in the development of the Unit, the Union Pacific and Ford Zones were considered as one reservoir, named the UP-Ford Zone, because of their similar characteristics and lithologies. Table 1 lists the VSS of the LBU zone.

Table 1. Depth to the Producing Zones

Zone	VSS-Depth Range*
Ranger West	2300' - 3450'
Ranger East	2250' - 2800'
Terminal	2825' - 4250'
UP-Ford	4200' - 4800'
237	4800' - 9400'

* The depth range is from the average depth at the crest of the anticline to the average oil-water contact depth for each Unitized Formation.

The Unitized Formations are further subdivided into 19 Fault Blocks (Tar, 1; Ranger West, 2; Ranger East, 4; Terminal, 6; UP-Ford, 4; 237, 2).

Number of Wells in the Long Beach Unit.

To date, over 1400 Long Beach Unit wells have been drilled from the four islands and Pier J, of which over 330 have been redrilled one or more times. There are currently 638 active producing wells and 355 active water injection wells in the Long Beach Unit. The total active producers and injectors are summarized by Zone below. Table 2 shows the primary zone in which the wells are completed.

Table 2. Well Completion by Zone

Zone	Active Producers	Active Injectors
Tar 6	2	0
Range	453	274
Terminal	127	56
UP-Ford	52	23
237	0	0
Total	638	355

Long Beach Unit Cumulative and Current Production. Cumulative production and cumulative water injection from the Long Beach Unit through December 1995 was:

Oil production	**809 MMBO**
Gross Fluid production	**4,552 MMB**
Gas production	**215 MMCF**
Water Injection	**5,323 MMBW**

Daily production and water injection from the Long Beach Unit for December 1995 was:

Oil production	**43,570 BOPD**
Gross Fluid production	**609,100 BFPD**
Gas production	**8,025 MCFPD**
Water Injection	**565,500 BWPD**

Long Beach Unit Reservoir Properties.

Table 3 gives a summary of the Long Beach Unit reservoir properties.

References

Mayuga, M. N., 1970, Geology and Development of California's Giant - Wilmington Oil Field: *in* Geology of Giant Petroleum Fields, American Association of Petroleum Geologists, Memoir 14, p.158-184.

Table 3. Long Beach Unit Reservoir Data

Zone	Subzones	Datum Depth VSS	API Oil Gravity	Reservoir Temperature °F	FVF Blb/Blb	Oil Viscosity cp	Water Viscosity cp
Tar	S - Fo	2500	14.0	104 - 120	1.05 - 1.06	117 - 223	.59 - .65
Ranger West	Fo - Hx1	3000	12.3 - 20.5	114 - 164	1.06 - 1.09	15 - 86	.43 - .62
Ranger East	Fo - Y	3000	13.0 - 21.1	116 - 152	1.07 - 1.10	14 - 123	.46 - .61
Upper Terminal West	Hx1 - AA	3300	14.0 - 19.5	132 - 175	1.07 - 1.10	19 - 81	.49 - .53
Lower Terminal West	AA - AE	3800	17.2	145 - 168	1.10 - 1.12	14 - 24	.41 - .48
Terminal East	Y4 - AE	3800	17.0 - 20.3	143 - 171	1.09 - 1.13	9 - 24	.40 - .49
UP-Ford	AE - BA	5600	23.1 - 29.7	183 - 211	1.22 - 1.30	1.07 - 2.01	.31 - .36
237	BA - BS	na	31.3	264 - 280	1.49 - 1.53	.34 - .39	.22 - .24