Recoverable Petroleum Beneath the City of Los Angeles*

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Abstract

Southern California oil accumulations, including those in the City of Los Angeles, are extraordinary because: (1) they exhibit what may be the world's highest natural concentration of crude oil, and (2) they underlie a modern mega-city with tens of millions of inhabitants. In spite of L.A.'s early and enthusiastic embrace of both the petroleum industry and the gasoline-powered automobile, oil development and urbanization have been in conflict from the start. Early day town-lot drilling, competing land use practices, and fickle societal acceptance have conspired to severely limit production. As a result, recovery efficiency is low in nearly every accumulation and many fields have been abandoned prematurely, leaving large volumes of recoverable oil behind.

A new evaluation of the oil fields within the L.A. city limits suggests that about 1.6 BB of additional oil (mean estimate) could be recovered with existing technology. The study was done in two steps: First, previous USGS estimates of remaining recoverable oil in Inglewood, Torrance, and Wilmington-Belmont fields were allocated to the field areas falling within L.A. city limits. Second, the volumes of recoverable oil in the seventeen other L.A. basin oil fields within the city were assessed by means of a methodology similar to that used by the USGS. The original oil in place was calculated from a standard petroleum engineering equation using data from the California Department of Conservation, the USGS, and the peer-reviewed literature. Potential recovery efficiencies were estimated from recovery efficiencies modeled in engineering studies, achieved in similar reservoirs in other basins, or indicated by laboratory results reported in technical literature. Resource allocations to the City of Los Angeles were based on maps of historically productive areas within municipal boundaries, modified as necessary by other considerations.

Selected References

Barbat, W.F., 1958, The Los Angeles Basin Area, California, *in* L.G. Weeks, ed., Habitat of Oil: AAPG Special Publication, p. 62-77.

Beyer, L.A., 1995, San Joaquin Basin Province (10), *in* D.L. Gautier, G.L. Dolton, K.I. Takahashi, and K.L. Varnes, eds., 1995 National Assessment of United States Oil and Gas Resources - Results, methodology, and supporting data: US Geological Survey Digital Data Series DDS-30, 28 p.

Biddle, K.T., 1991, The Los Angeles Basin - An Overview, *in* K.T. Biddle, ed., Active Margin Basins: AAPG Geologists Memoir 52, p. 5-24.

California Division of Oil, Gas, and Geothermal Resources, 2010, 2009 Annual Report of the State Oil and Gas Supervisor: California Department of Conservation, Sacramento, Publication PR06, 267 p.

California Council on Science and Technology and Lawrence Berkeley National Laboratory, 2015, An independent scientific assessment of well stimulation in California: Sacramento, CA. Website accessed November 18, 2018.
http://ccst.us/SB4

Cardo ENTRIX, 2012, Hydraulic Fracturing Study - PXP Inglewood Oil Field. Website accessed November 18, 2018.
http://www.scribd.com/doc/109624423/Hydraulic-Fracturing-Study-Inglewood-Field10102012

Eaton, J.E., 1923, Structure of the Los Angeles basin and environs: Oil Age, v. 20/6, p. 8-9, 52.

Eaton, J.E., 1924, Structure of the Los Angeles basin and environs: Oil Age, v. 21/1, p. 16-18, 52, 54.

Gardett, P.H., 1971, Petroleum potential of the Los Angeles basin, *in* I.H. Cram, ed., Future petroleum provinces of the United States - their geology and potential: AAPG Memoir 15, v. 1, p. 298-308.

Gautier, D.L., G.L. Dolton, K.I. Takahashi and K.L. Varnes, 1995, 1995 National Assessment of US Oil and Gas Resources: Results, Methodology, and Supporting Data: US Geological Survey Digital Data Series 30 (available online).

Gautier, D.L., M.E. Tennyson, R.R. Charpentier, T.A. Cook, and T.R. Klett, 2012, Forgone Oil in the Los Angeles Basin: Assessment of Remaining Petroleum in Giant Fields of southern California: AAPG Search and Discovery Article #20164. Website accessed November 18, 2018.

Hoots, H.W., A.L. Blount, and P.H. Jones, 1935, Marine Oil Shale, Source of Oil in Playa Del Rey Field, California: AAPG Bulletin, v.19/2, p. 172-205.

Hornafius, J.S., 1985, Neogene Tectonic Rotation of the Santa Ynez Range, Western Transverse Ranges, California, Suggested by Paleomagnetic Investigation of the Monterey Formation: Journal of Geophysical Research, 90 (B14), p. 12,503-12,522.

Ingersoll, R.V., and P.E. Rummelhart, 1999, Three-stage evolution of the Los Angeles basin, southern California: Geology, v. 27, p. 595-596.

Isaacs, C.M., 1989, Marine Petroleum Source rocks and Reservoir Rocks of the Miocene Monterey Formation, California, USA, *in* H.C. Wagner, L.C. Wagner, F.F.H. Wang, and F.L. Wong, eds., Petroleum resources of China and related subjects: Houston, Texas, Circum-Pacific Council for Energy and Mineral Resources Earth Science Series, v. 10, p. 825-848.

Isaacs, C.M., 2001, Depositional framework of the Monterey Formation, California, *in* C.M. Isaacs, and J. Rullkötter, eds., 2001, The Monterey Formation: From Rocks to Molecules: Columbia University Press, New York, p. 1-30.

Isaacs, C.M., and J. Rullkötter, eds., 2001, The Monterey Formation: From Rocks to Molecules: Columbia University Press, New York, 553 p.

Jeffrey, A.W.A., H.M. Alimi, and P.D. Jenden, 1991, Geochemistry of the Los Angeles Basin Oil and Gas System, *in* K. Biddle, ed., Active Margin Basins: AAPG Memoir 52, p. 197-219.

Kamerling, M.J., and B.P. Luyendyk, 1985, Paleomagnetism and Neogene tectonics of the northern Channel Islands, California: Journal of Geophysical Research, v. 90/814, p. 12,485-12,502.

Kaplan, I.R., M.H. Alimi, C. Hein, A. Jeffrey, M.R. Lafferty, M.P. Mankiewiz, D.E. Meredith, E.B. Edwards, and W.S. Dixon, 1986, Chapter 3, The geometry of hydrocarbons and potential source rocks from the Los Angeles and Ventura basins: Data synthesis and text, v. 1, *in* I.R. Kaplan, ed., Collection of papers about the oil, gas, and source rock investigations carried out in the San Joaquin, Santa Maria, Santa Barbara, Ventura, and Los Angeles Basins, California: AAPG Pacific Section, 238 p.

Klett, T.R., E.D. Attanasi, R.R. Charpentier, and T.A. Cook, P.S. Freeman, D.L. Gautier, P.A. Le, R.T. Ryder, C.J. Schenk, M.E. Tennyson, and M.K. Verma, 2011, New U.S. Geological Survey method for the assessment of reserve growth: U.S. Geological Survey Scientific Investigations Report 2011-5163.

Kruge, M.A., 1986, Biomarker Geochemistry of the Miocene Monterey Formation, West San Joaquin Basin, California: Implications for Petroleum Generation: Organic Geochemistry, v. 10, p. 517-530.

McCulloh, T.H., 1960, Gravity variations and the geology of the Los Angeles basin, California: U.S. Geological Survey Professional Paper 400-B, p. B320-B325.

McCulloh, T.H., and L.A. Beyer, 2004, Mid-Tertiary Isopach and Lithofacies Maps for the Los Angeles Region, California: Templates for Palinspastic Reconstruction to 17.4 Ma: US Geological Survey Professional Paper, 1690, 32 p.

Nardin, T.R., and T.L. Henyey, 1978, Pliocene-Pleistocene diastrophism of Santa Monica and San Pedro shelves, California continental borderland: AAPG Bulletin, v. 62, p. 247-272.

Peters, K.E., L.S. Ramos, and J.E. Zumberge, 2013, Chemometric Recognition of Genetically Distinct Oil Families in the Los Angeles Basin: AAPG, SEG and SEPM Joint Technical Conference, Monterey, California, April 19-25, 2013, Search and Discovery Article #41149 (2013). Website accessed November 18, 2018.

Petersen, N.F, and P.J. Hickey, 1987, California Plio-Miocene Oils: Evidence of Early Generation, *in* R.F. Meyer, ed., Exploration for Heavy Crude Oil and Natural Bitumen, AAPG Studies in Geology no. 25, p. 351-359.

Phillipi, G.T., 1965, On the depth, time, and mechanism of petroleum generation: Geochimica et Cosmochimica Acta, v. 29, p. 1021-1049.

Price, L.C., 1994, Basin richness versus source rock disruption – A fundamental relationship?: Journal of Petroleum Geology, v. 17, p. 5-38.

Piper, K.A., and C.O. Ojukwu, eds., 2014, 2011 National Assessment of Oil and Gas Resources of the Pacific Outer Continental Shelf Region: Bureau of Ocean Energy Management OCS Report 2014-667, 243 p.

Redin, T., 1991, Oil and Gas Production from Submarine Fans of the Los Angeles Basin, *in* K.T. Biddle, ed., Active Margin Basins, AAPG Memoir 52, p. 239-259.

Rintoul, W., 1990, Drilling through Time - 75 Years with California's Division of Oil and Gas: California Department of Conservation, Division of Oil and Gas Publication TR40, 178 p.

Tsutsumi, H., R.S. Yeats, and G.J. Huftile, 2001, Late Cenozoic Tectonics of the Northern Los Angeles Fault System, California: GSA Bull., v. 113/4, p. 454-468.

Wright, T.L., 1987, Geologic summary of the Los Angeles basin, *in* T.L. Wright and R. Heck, eds., Petroleum geology of coastal southern California: Pacific Section, AAPG Guidebook 60, p. 21-31.

Wright, T.L., 1991, Structural Geology and Tectonic Evolution of the Los Angeles Basin, California, *in* K.T. Biddle, ed., Active Margin Basins, AAPG Memoir 52, p. 35-134.

Yerkes, R.F., T.H. McCulloh, J.E. Schoellhamer, and J.G. Vedder, 1965, Geology of the Los Angeles Basin, California – An Introduction: U.S. Geological Survey Professional Paper 420-A, p. A1-A57.

Salt Lake oil field in 1905
USGS Images by Ralph Arnold
Panorama by Valley Design Group

RECOVERABLE OIL BENEATH THE CITY OF LOS ANGELES

BY DONALD L GAUTIER PH.D.

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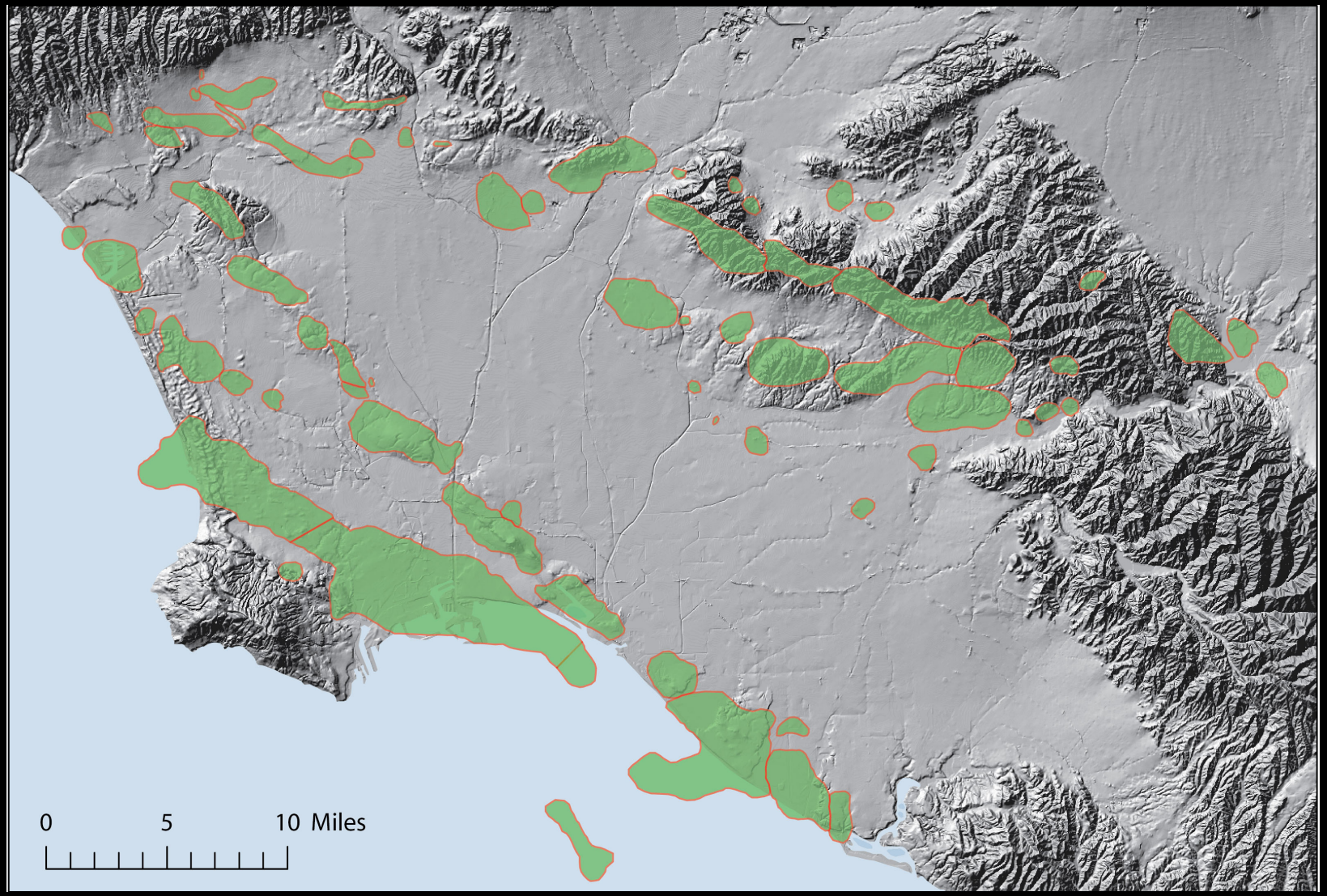
- Scientists and engineers at CDOGGR
- Former colleagues at U.S. Geological Survey
- Students at USC Viterbi School of Engineering

68 named oil fields within ~2200 mi^2



The richest petroleum basin

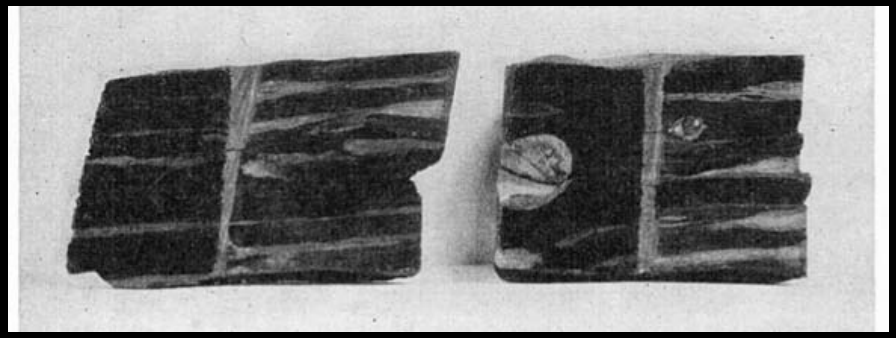
- Probably the world's highest oil density
- Onshore area ~2200 mi^2 *
- Known oil >9 BBO (~4 MMB/mi^2)*
- ~4 $MMBOE/mi^3$ of sediment (Biddle 1991)[1]
- OOIP: 30 to 50 BB (14 to 23 MMB/mi^2)*

*D.L. Gautier estimate

1) K.T. Biddle, 1991, AAPG Memoir 52, pp. 5-24

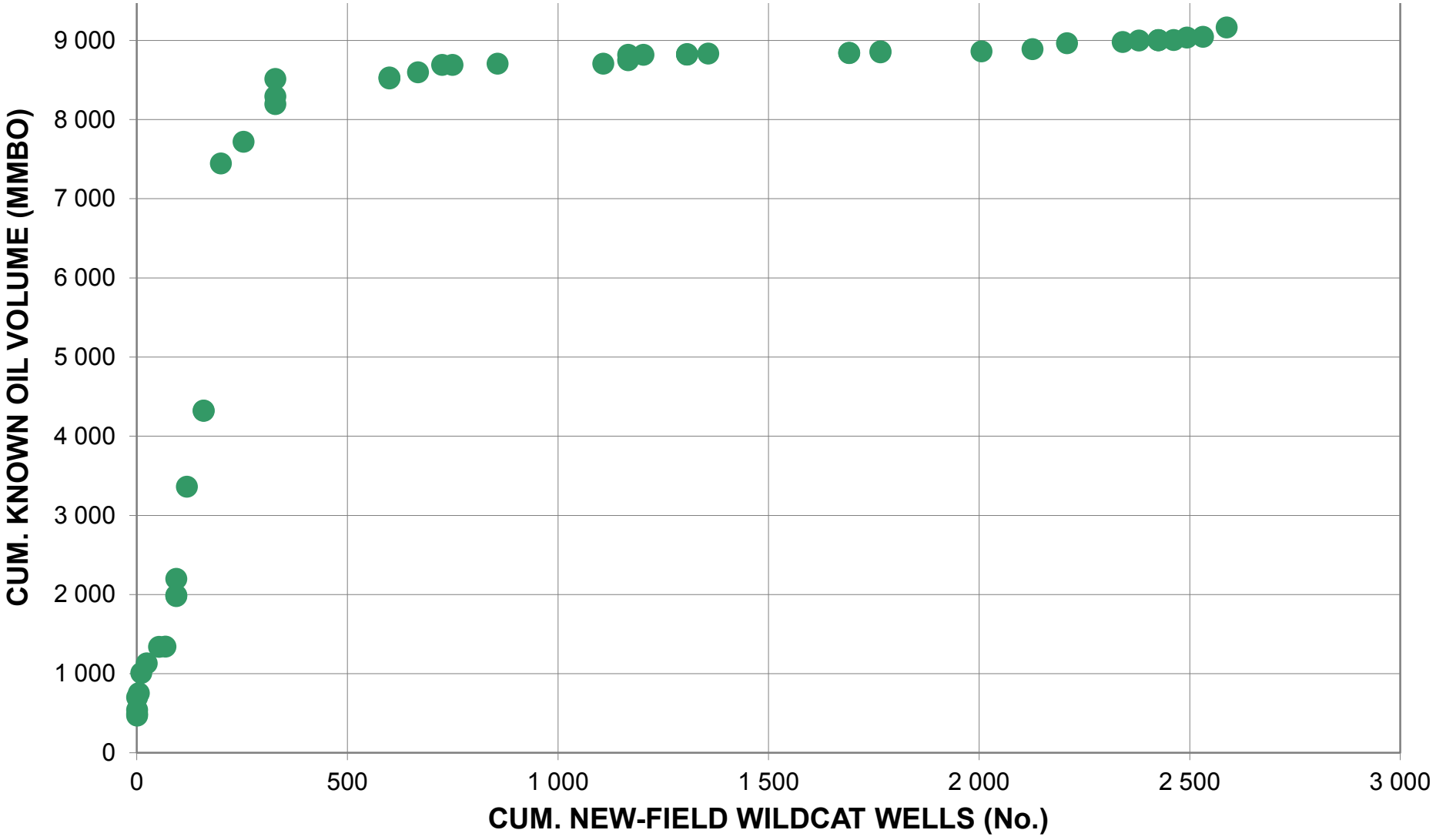
A nearly ideal petroleum system

- Prolific Miocene source rocks
- Extremely high heat flow and active tectonics
- Thick stacks of sandstone reservoirs
- Large structural traps
- Imperfect seals that leak gas but retain oil



Nodular shale with phosphatic laminae:
Playa del Rey oil field; from Hoots et al. 1935
AAPG Bull. V.19, no. 2, pp. 172-205.

First 400 wells found ~90% of the known oil



Data sources: CDOGGR

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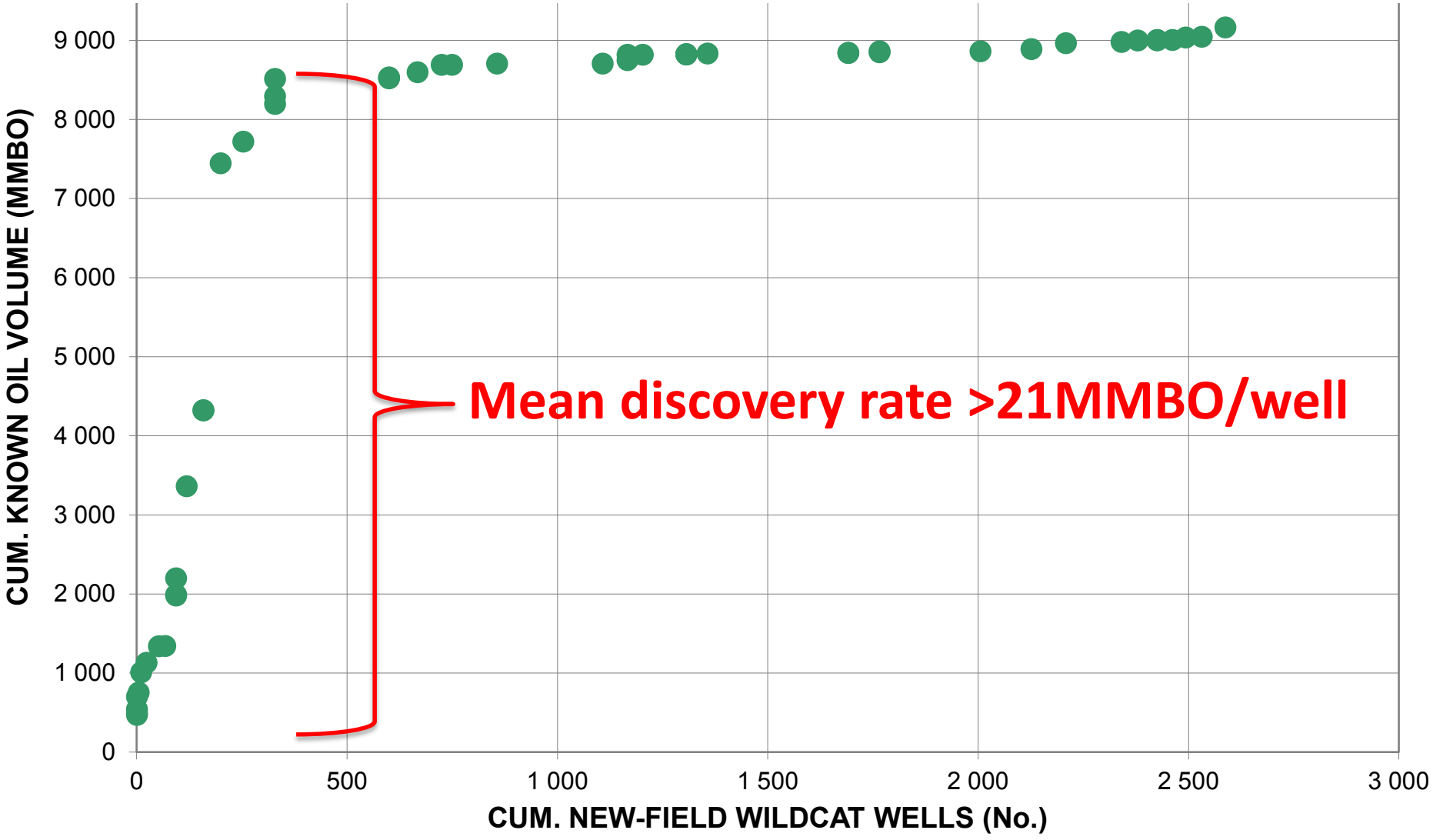


Data sources: CDOGGR

Los Angeles (pop. 50,000) was mostly rural when petroleum development began

Los Angeles City oil field ca. 1905
USGS photo by Ralph Arnold

Now it’s a megacity of >13 million people

Oil and urbanization at odds from day one

First Street, Los Angeles ca. 1895: Seaver Center Photo in the public domain

Consequences

- Damaged reservoirs
- Restricted access
- Low recovery efficiency
- Premature abandonment
- No exploration in more than 40 years

How much recoverable oil remains beneath the City of Los Angeles?

Postcard ca. 1900: Unknown photographer/colorist

20 oil fields are within L.A. city limits

- Beverly Hills
- Boyle Heights
- Cheviot Hills
- El Segundo
- Hyperion
- Inglewood
- Las Cienegas
- Los Angeles City
- Los Angeles Downtown
- Playa del Rey
- Potrero
- Rosecrans
- Salt Lake
- Salt Lake South
- San Vicente
- Sawtelle
- Torrance
- Union Station
- Venice Beach
- Wilmington-Belmont

Methodology

1. Evaluate OOIP in each field
2. Determine current recovery efficiency
3. Estimate potential recovery efficiency
4. Calculate remaining recoverable oil
5. Allocate results to areas within L.A. city limits

$$OOIP = 7758AhØ(1-S_w)/B_o$$

A = productive area

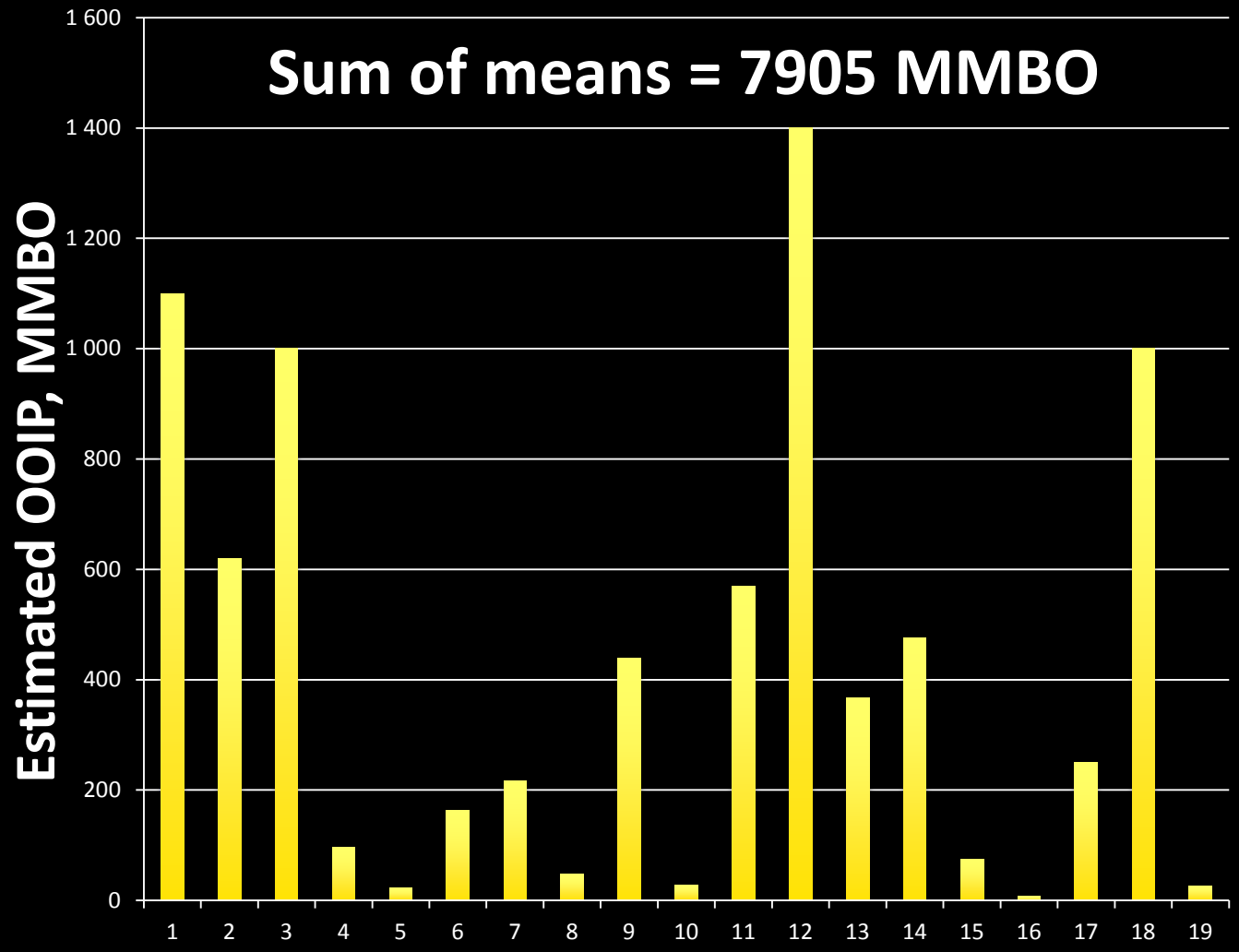
h = net reservoir thickness

$Ø$ = decimal porosity

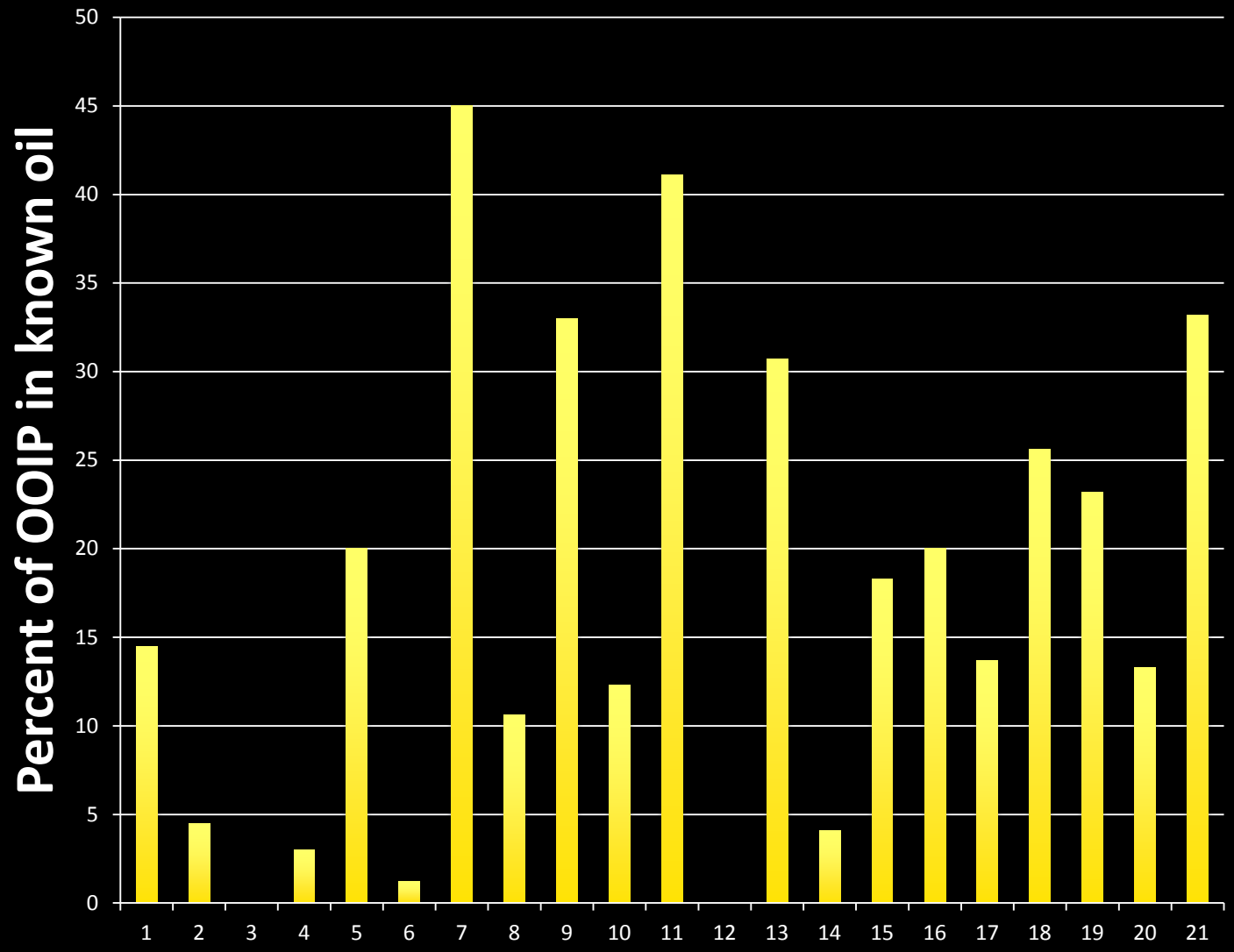
S_w = decimal water saturation

B_o = formation volume factor

Mean OOIP per field (except Wilmington)



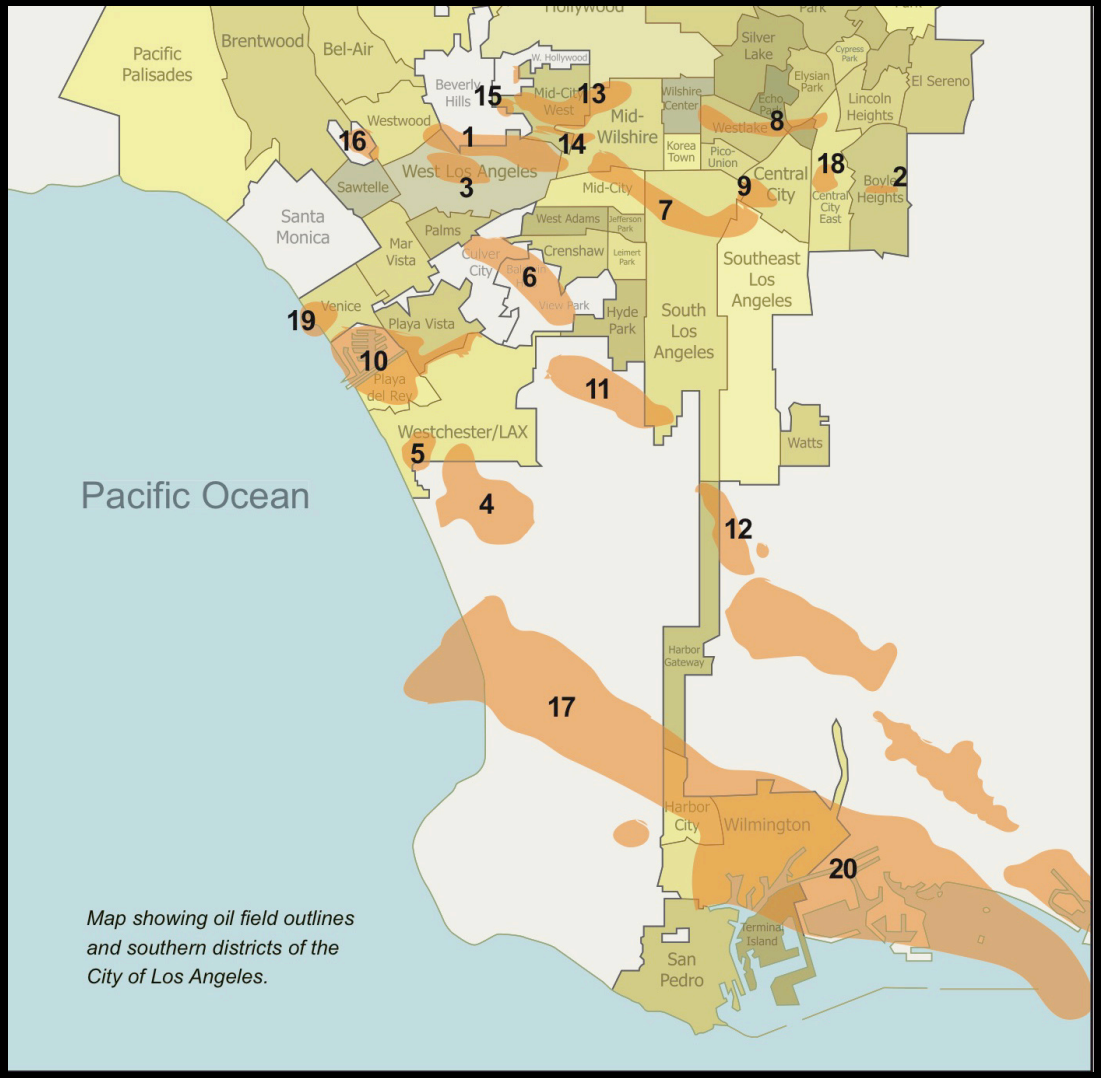
Mean recovery efficiency ~17.5%



Potential recovery efficiency varies by field

- Reported recovery from similar reservoirs
- Laboratory studies
- Reservoir modeling simulations
- Data from CDOGGR, USGS, AAPG, SPE, etc.
- Optimal recovery ranges from 30 to 60%

Allocation to areas within L.A. city limits



Map: Courtesy of the City of Los Angeles

Field Name	Location on map	Known Recoverable Oil	OOIP	Current %RE	Max %RE	Additional oil	Oil in L.A.
BEVERLY HILLS	1	159	1100	14.5	40	287	230
BOYLE HEIGHTS (abd 1973)	2	0.27	22	1.2	35	8	8
CHEVIOT HILLS	3	28.1	620	4.5	35	189	189
EL SEGUNDO	4	15	75	20	35	11	1
HYPERION	5	0.96	7	13.7	30	1	1
INGLEWOOD	6	430	1400	30.7	45	250	13
LAS CIENEGAS	7	73.4	163	45	45	1	1
LOS ANGELES CITY	8	23.2	217	10.6	60	107	107
LOS ANGELES DOWNTOWN	9	15.8	48	33	35	1	1
PLAYA DEL REY (abd 1942)	10	63.5	250	25.6	30	11	10
POTRERO (abd 1996)	11	15.2	367	4.1	35	113	11
ROSECRANS	12	87	475	18.3	35	79	24
SALT LAKE	13	54	439	12.3	60	209	209
SALT LAKE, SOUTH	14	11.5	28	41.1	45	1	1
SAN VICENTE	15	28.5	1000	3	30	272	136
SAWTELLE	16	19.4	97	20	35	15	5
TORRANCE	17	232	1000	23.2	40	227	23
UNION STATION	18	2	570	<1%	30	170	170
VENICE BEACH (abd 1991)	19	3.6	27	13.3	30	5	2
WILMINGTON-BELMONT	20	2984	9000	33.2	40	973	486
Totals		**4246.43**	**16905**			**2930**	**1628**

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Initial mean estimate of recoverable oil beneath City of Los Angeles: 1628 MMB

Summary of results

- OOIP in 20 fields ~ 17 BBO
- 13/20 fields have OOIP >100 MMBO
- Average recovery efficiency is now ~17.5%
- 6% increase in recovery efficiency adds >1BBO
- Mean recoverable oil in existing fields ~ 1.6 BB
- Estimates do not include yet-to-find oil
- Estimates do not include source-rock plays

The End

Public domain image