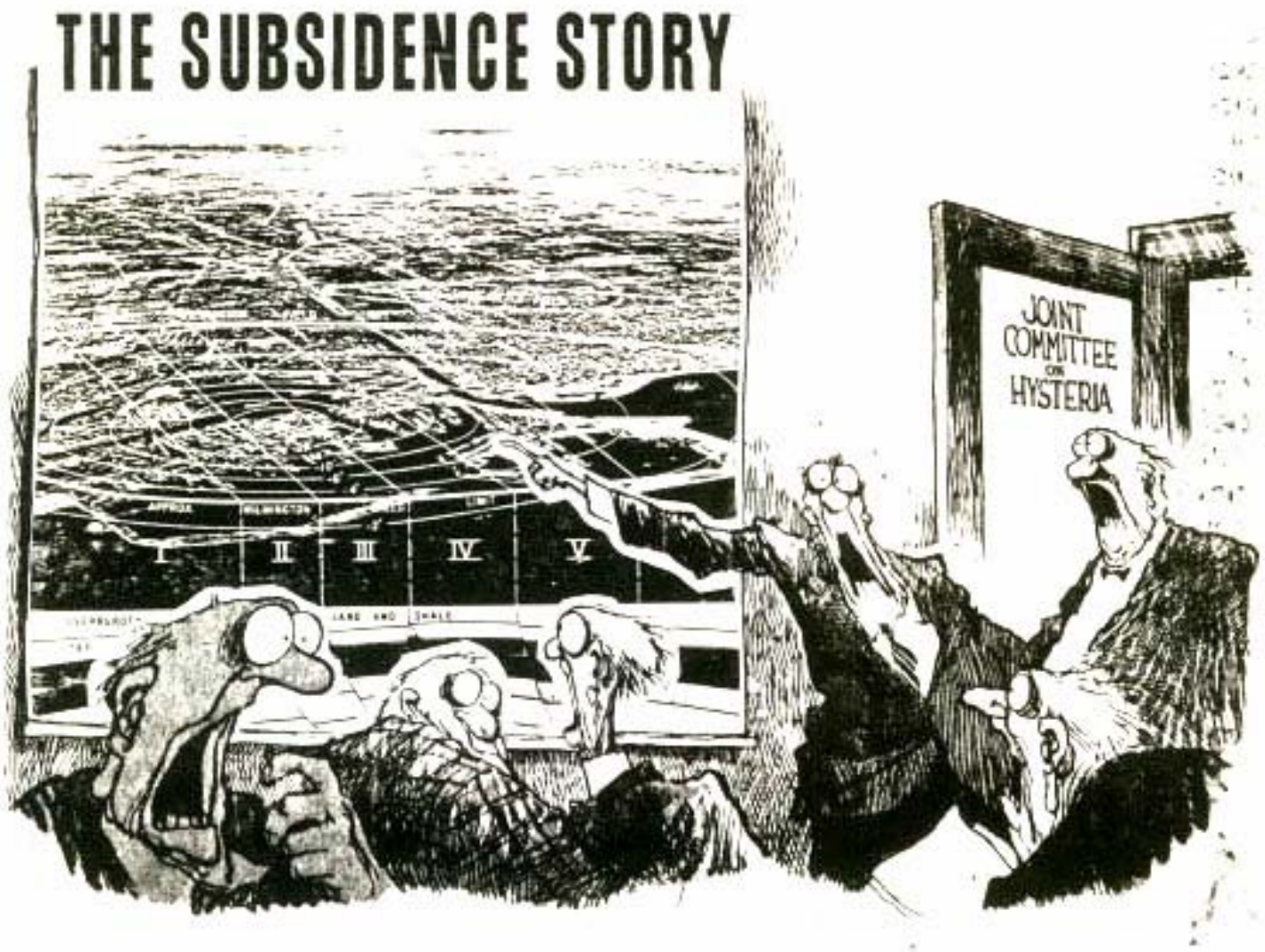
O I L

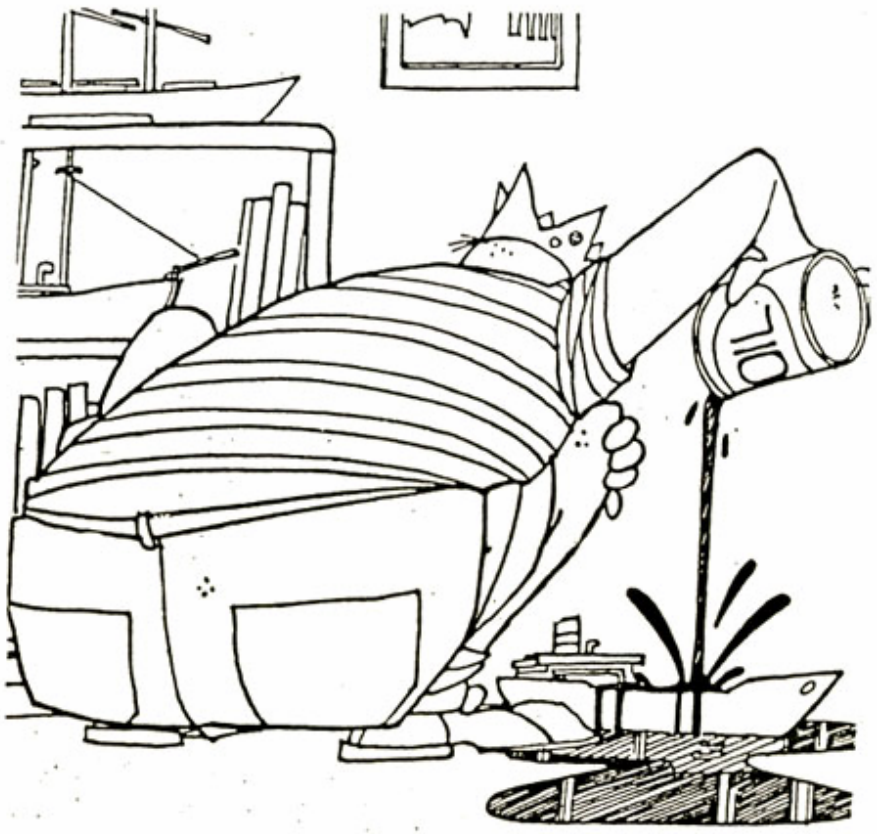
Curtis P. Henderson
Manager of Oil Operations

CITY OF LONG BEACH
Gas & Oil
DEPARTMENT


THE SUBSIDENCE STORY
I
II
III
IV
V
JOINT COMMITTEE ON HYSTERIA

CPH

THE NEIGHBORHOOD By Jerry Van Amerongen



© 1989 Cowles Syndicate, Inc

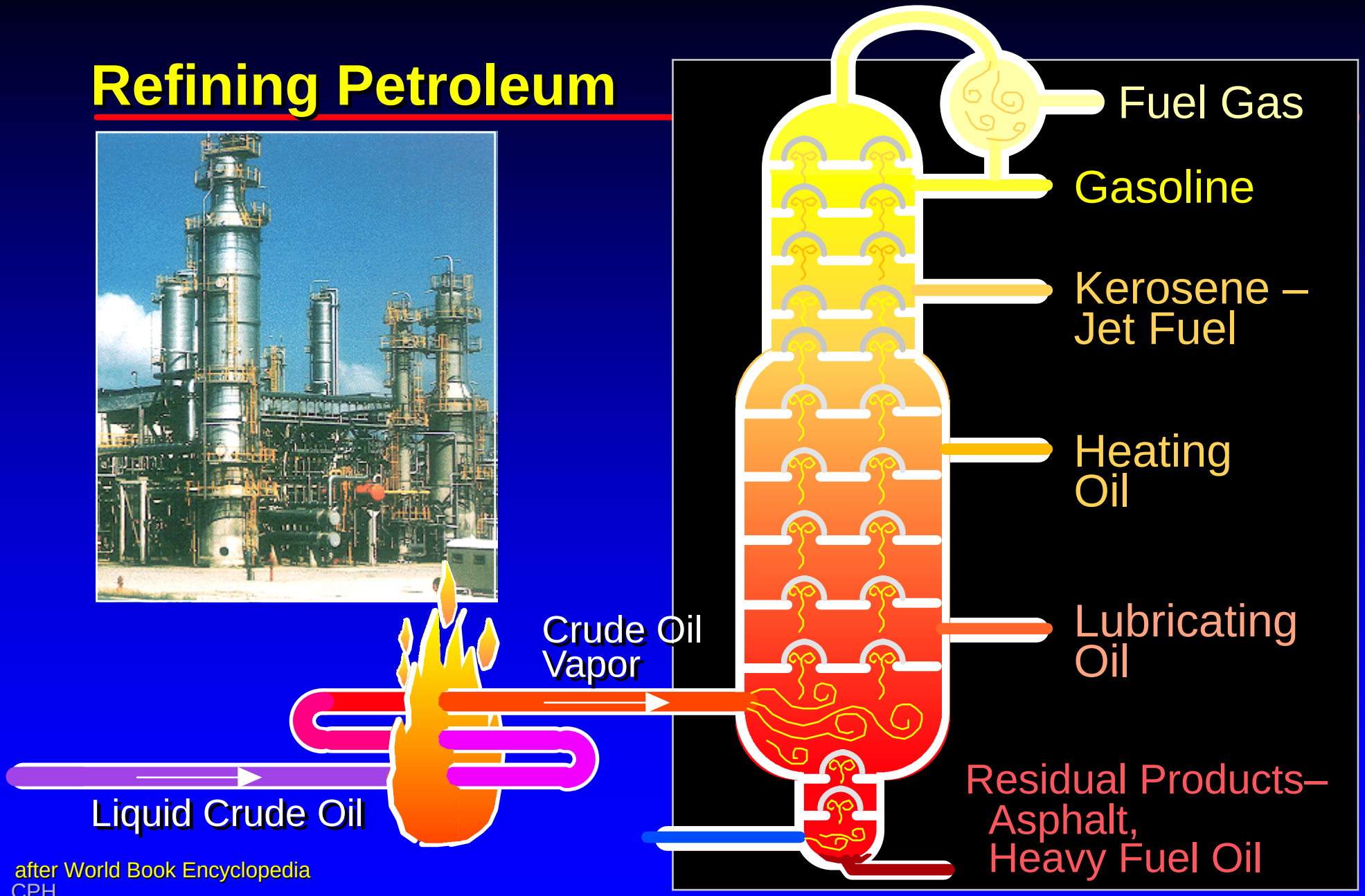
Curtis is a stickler for realism.

What is Petroleum?

- **Petroleum:** a natural yellow-to-black flammable liquid hydrocarbon found beneath the earth's surface

- **Hydrocarbon:** an organic compound made up of carbon and hydrogen atoms

Refining Petroleum



after World Book Encyclopedia

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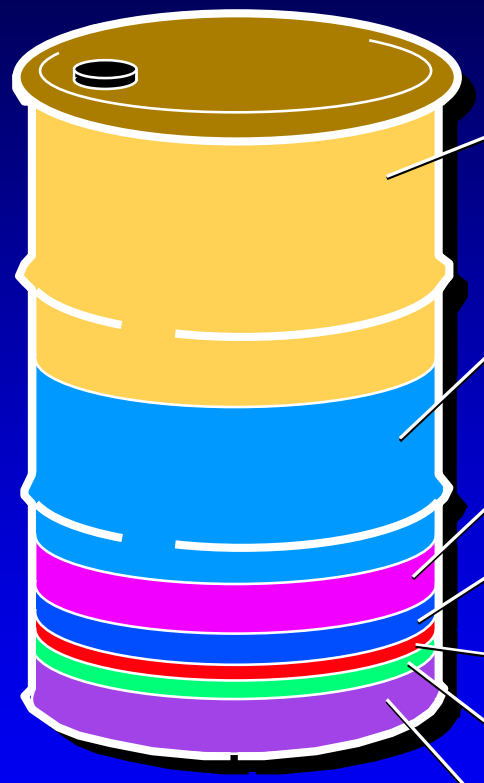
Petroleum Products

A Barrel of Crude Oil Provides:

One Barrel =
42 gallons



Gasoline - 19.5 gallons

Fuel Oil - 9.2 gallons

Jet Fuel - 4.1 gallons

Asphalt - 2.3 gallons

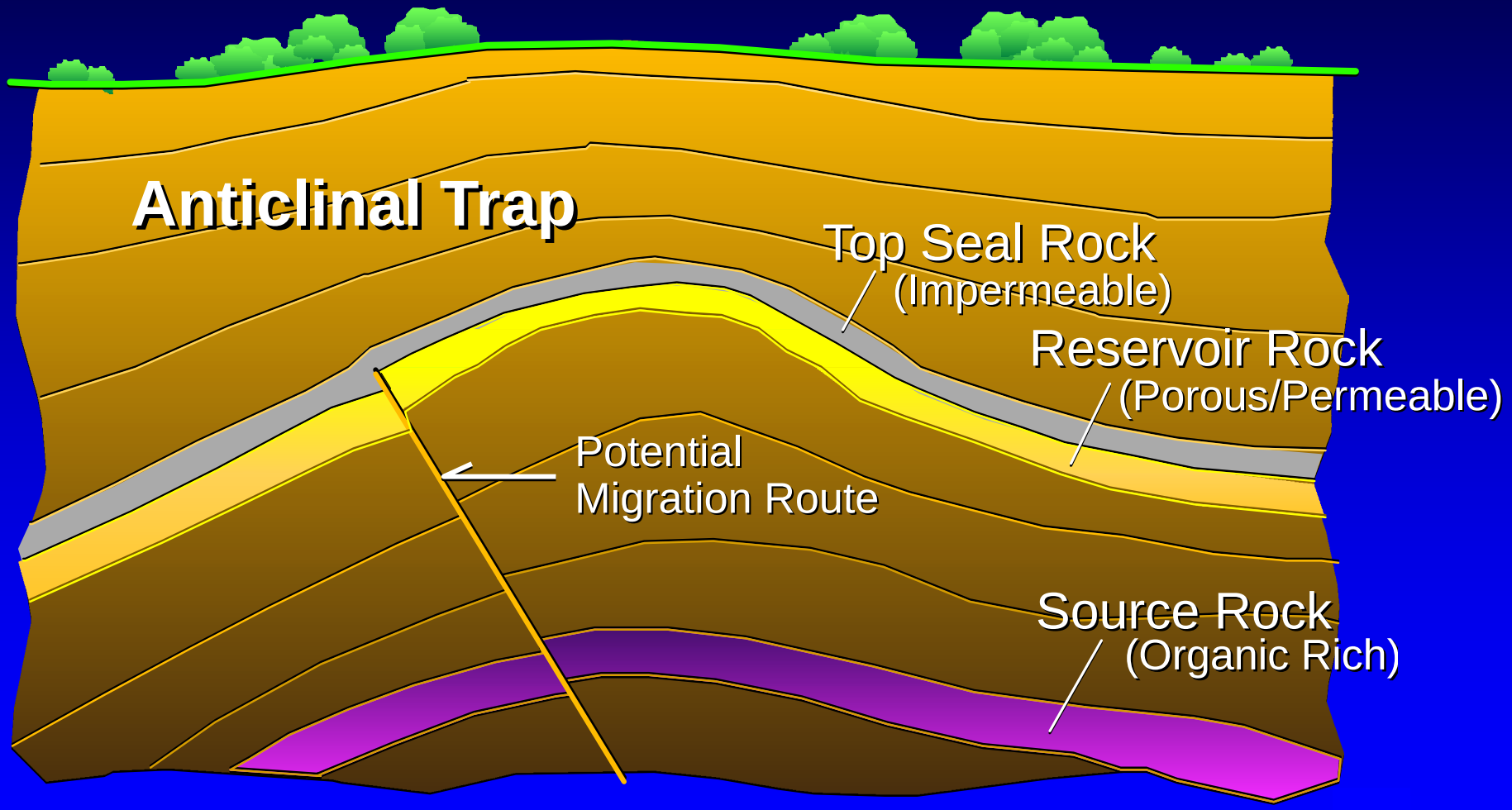
Kerosene - 0.2 gallons

Lubricants - 0.5 gallons

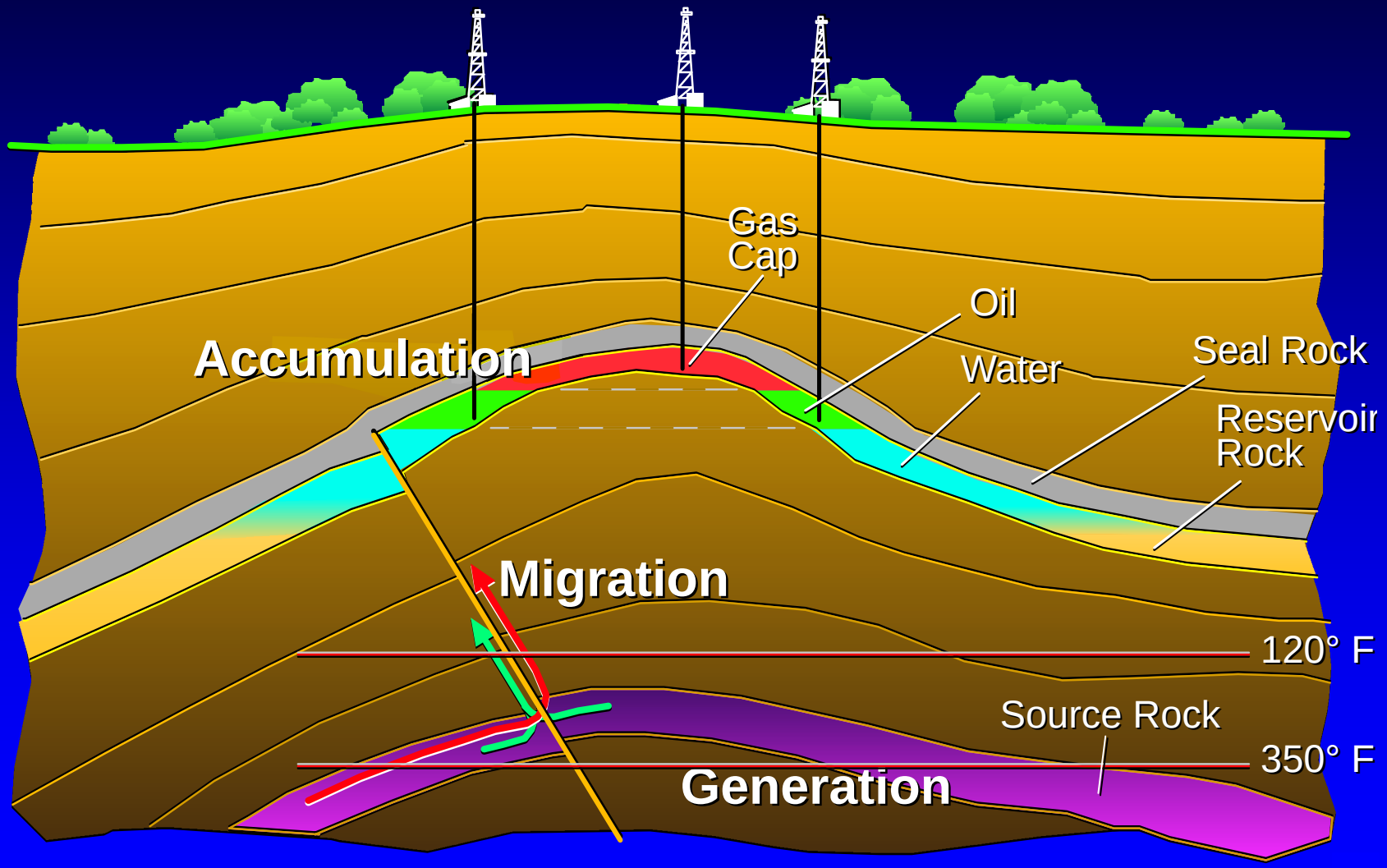
Petrochemicals,
other products - 6.2 gallons

American Petroleum Institute, 1999

Petroleum System Elements



Petroleum System Processes



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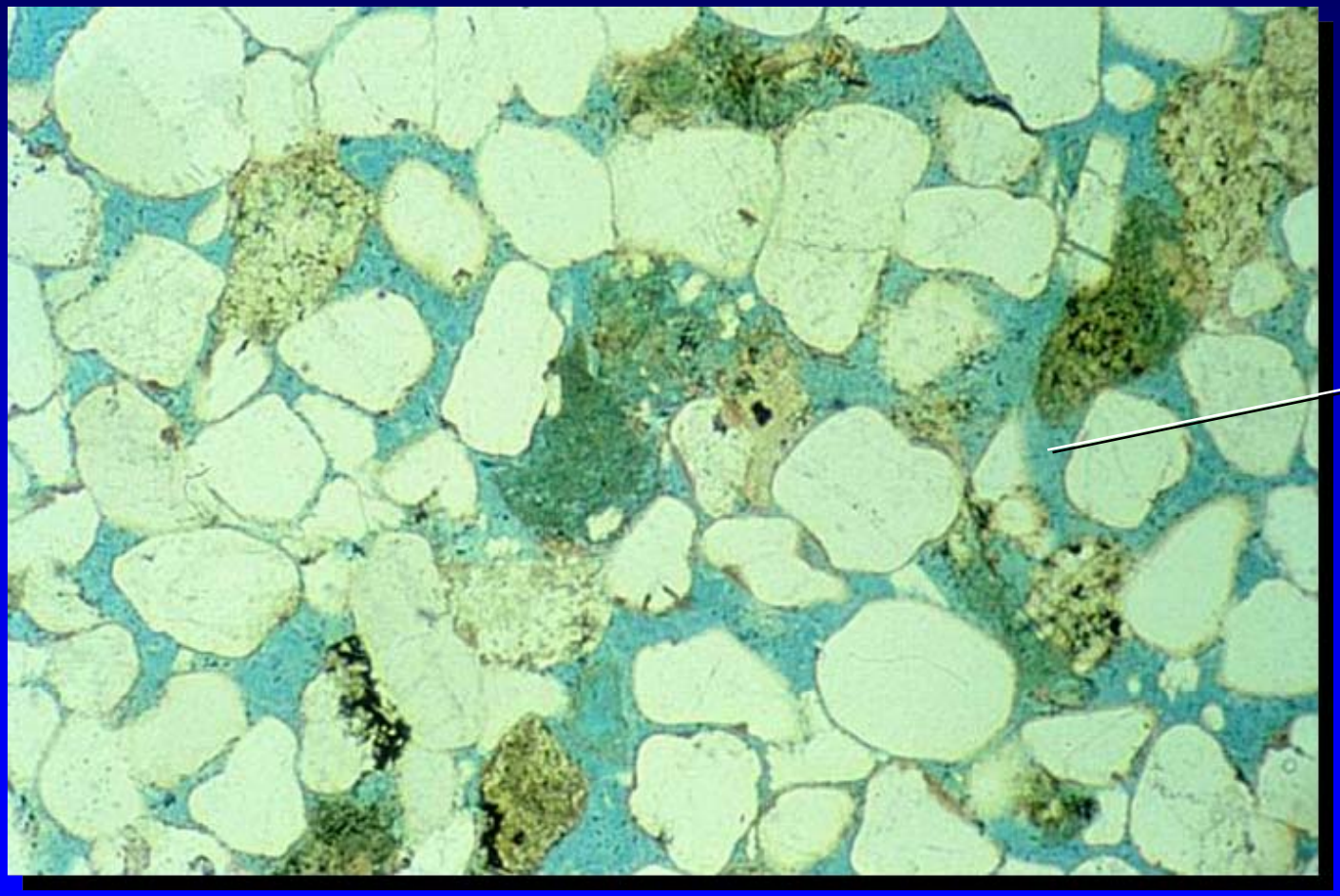
Reservoir Sandstone

Good Porosity = Lots of Space for Petroleum

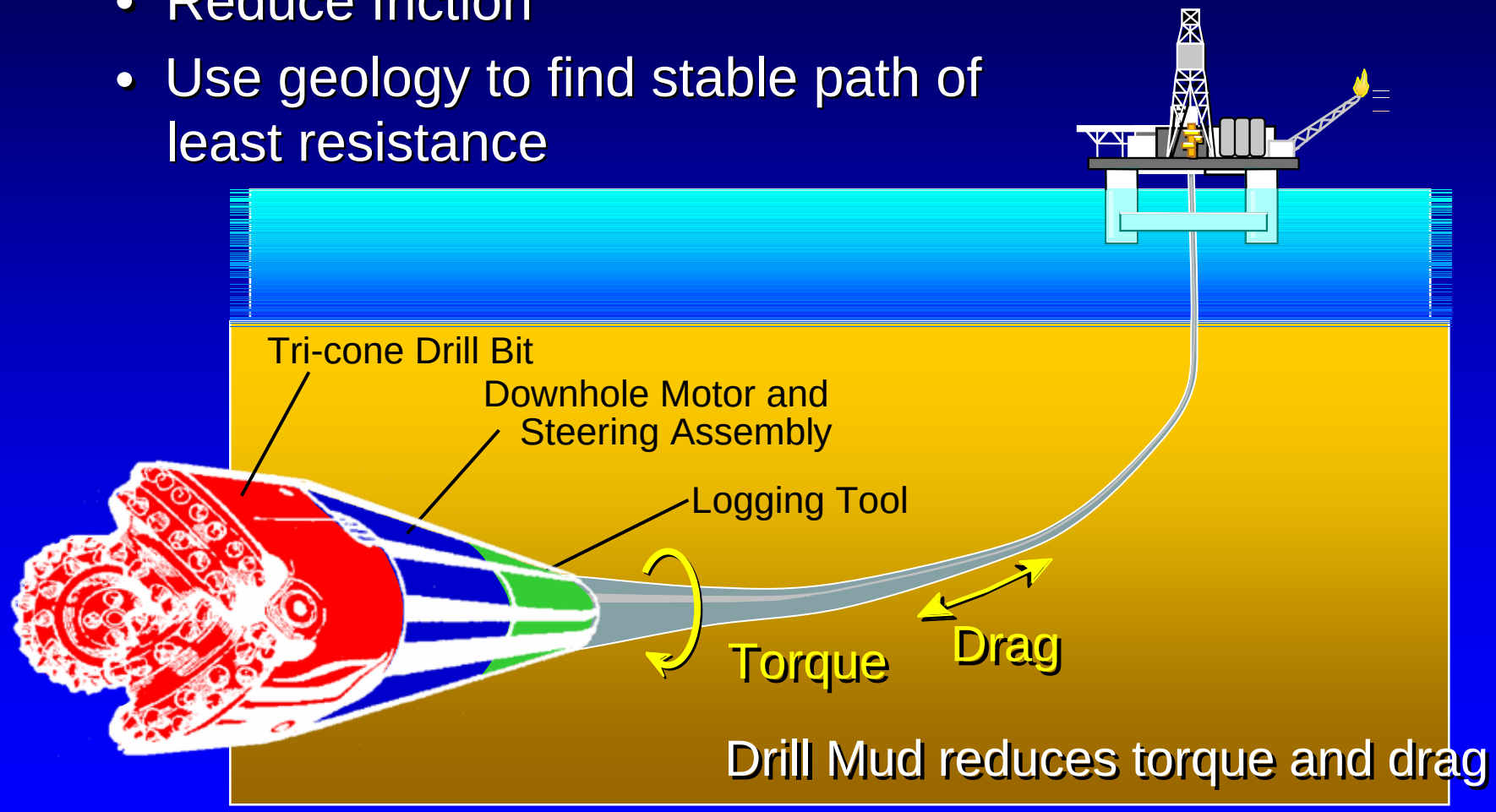


Pores
(blue)

Extended Reach Drilling

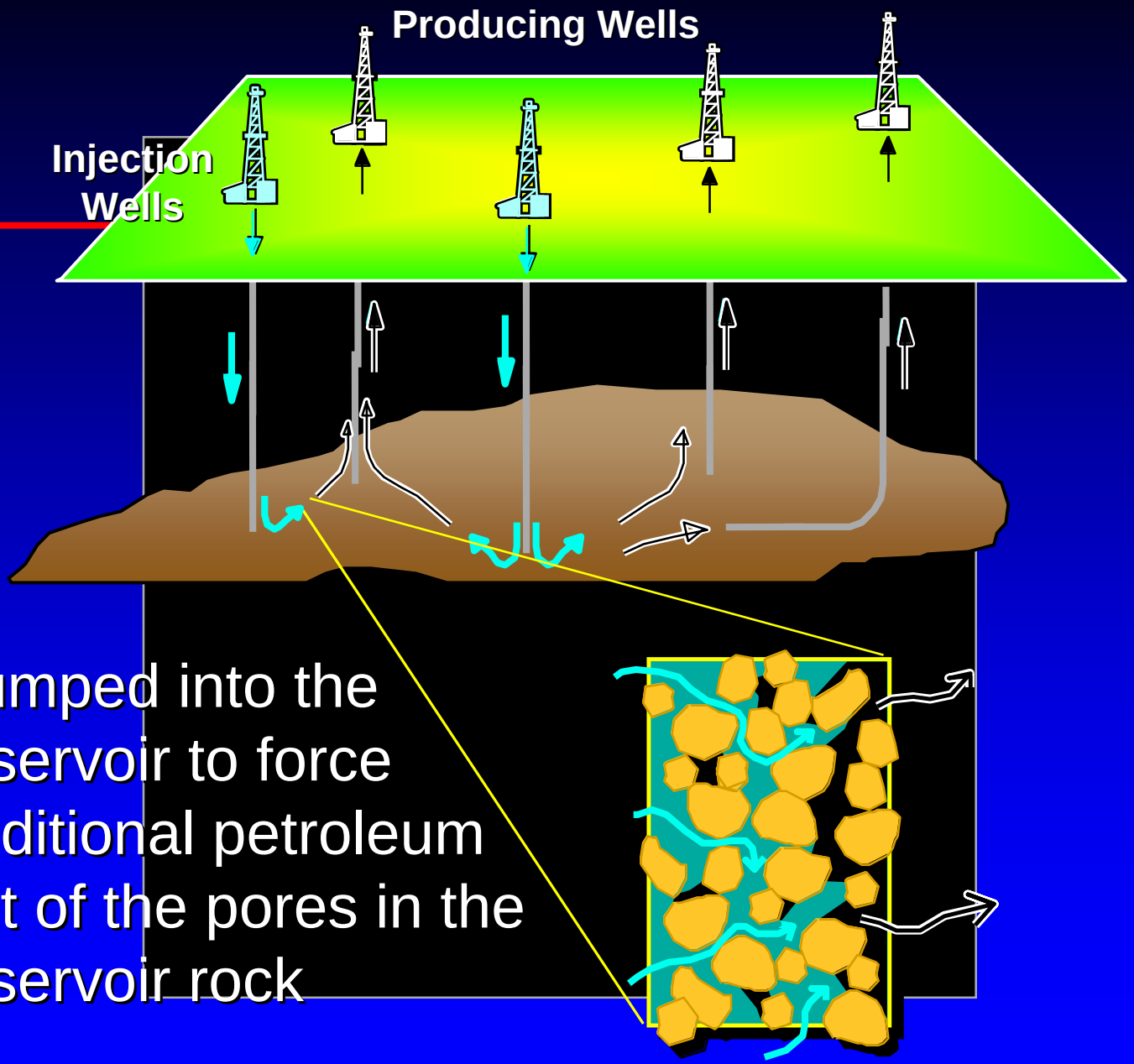
Technology Advances Result in More Cost-Effective Wells

- Reduce friction
- Use geology to find stable path of least resistance



Secondary Recovery

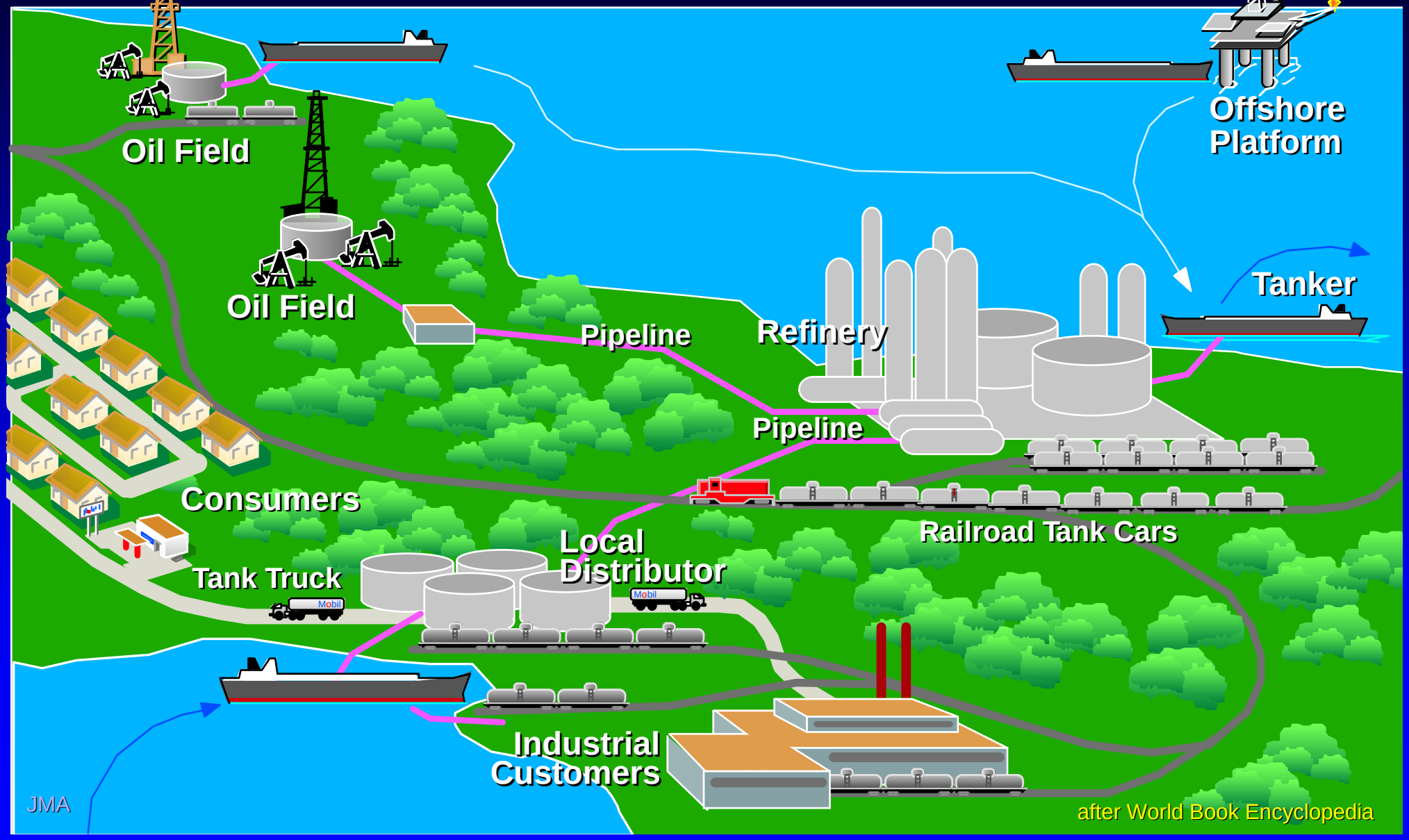
Of 60% Remaining in Reservoir



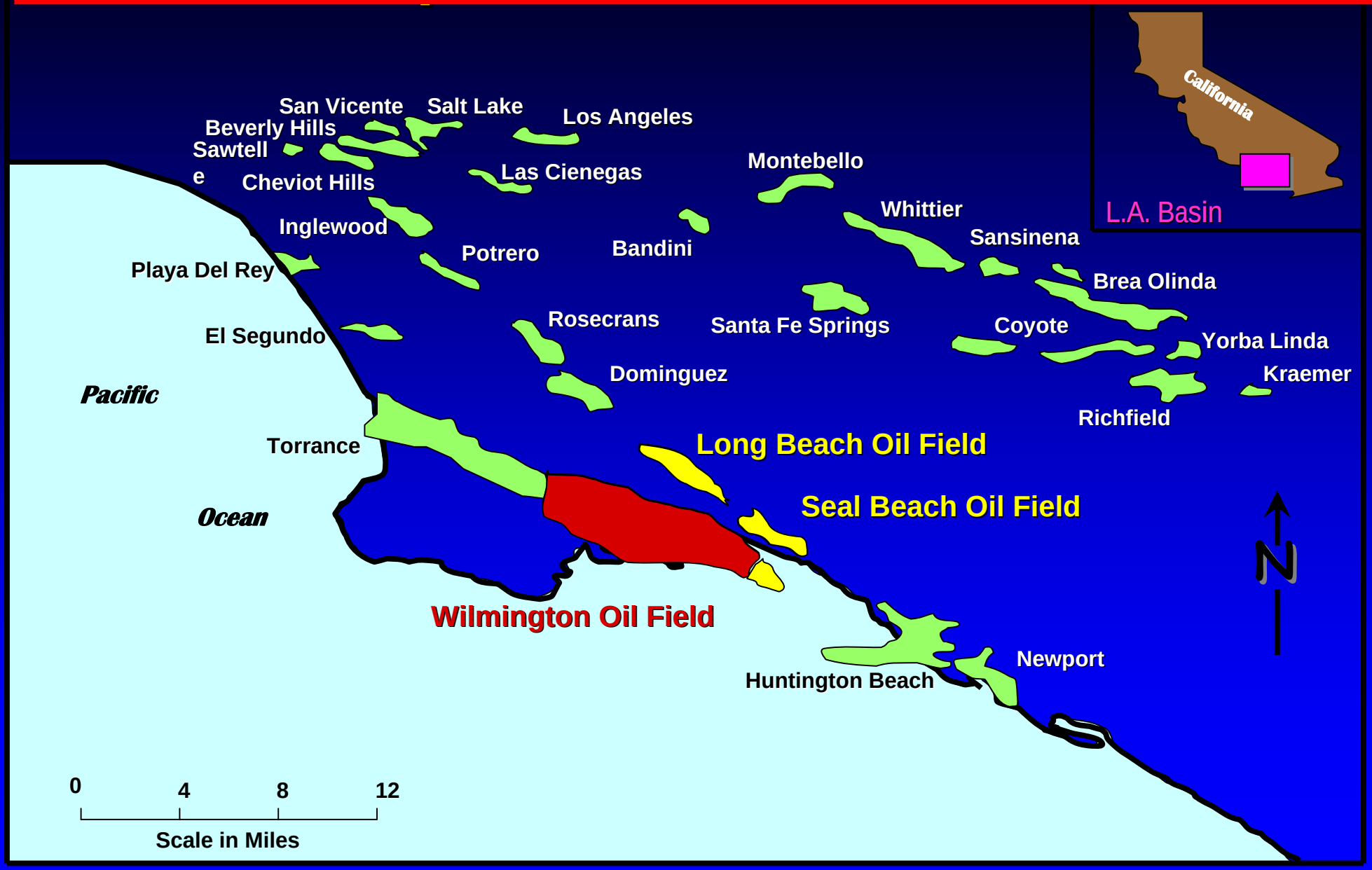
- Water
- Gas
- Steam
- Chemical
- Fire

Pumped into the reservoir to force additional petroleum out of the pores in the reservoir rock

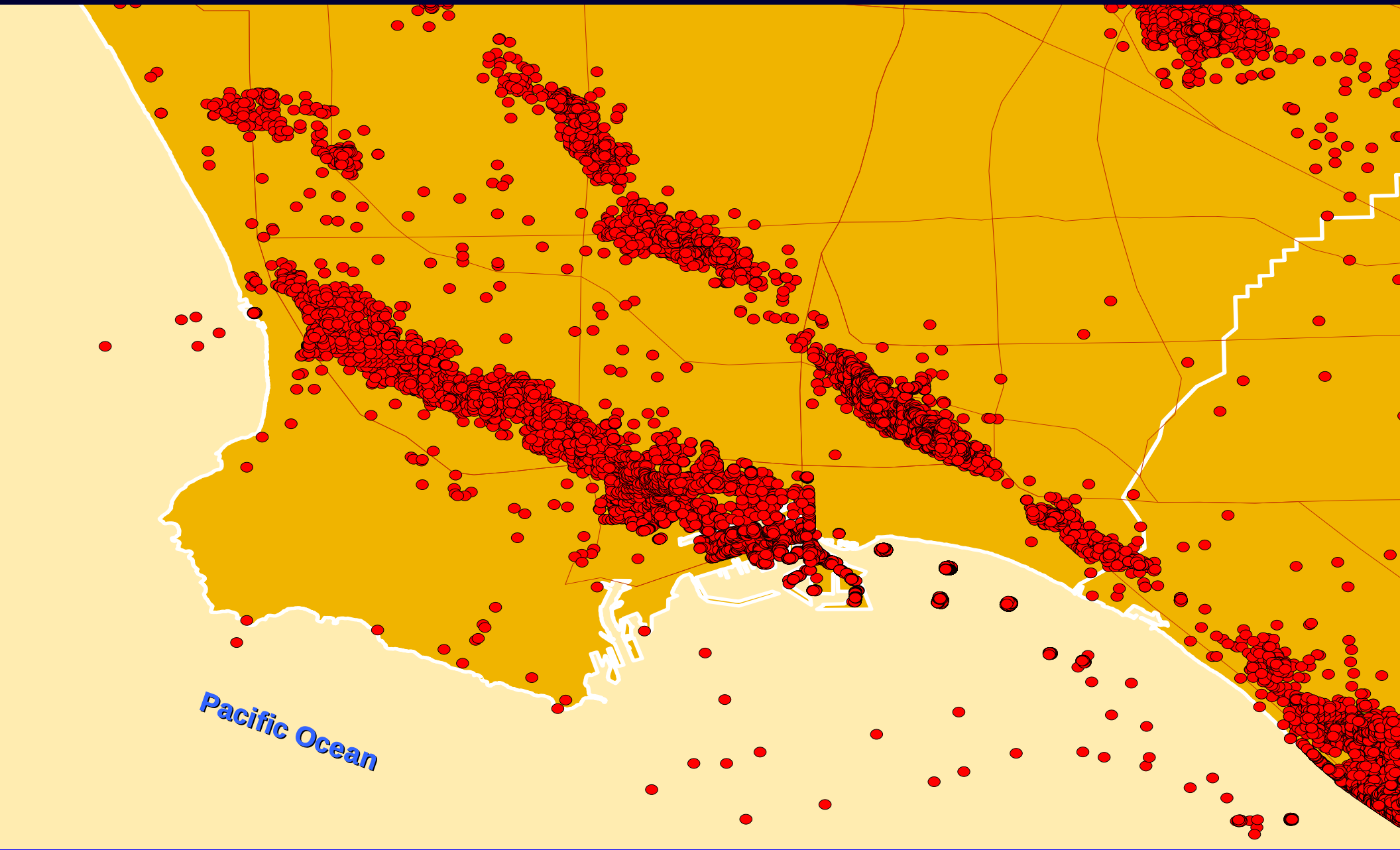
Transporting Petroleum



Location Map



LA Basin Oil Wells



Wilmington Oil Field

- More than 6000 wells drilled total
- Currently
  - Production from 1,200 wells:
    - Oil - 40,370 bbl oil per day
    - Water - 1,005,870 bbl water per day
- Water Injection from 600 wells:
    - 1,121,412 bbl water per day

Wilmington Oil Field

- **Expenditures**
  - ~$600 million per year
- **Net Revenues**
  - ~$300 million per year
- **Cumulative Revenue**
  - State of California
    - $4.5 billion
  - City of Long Beach
    - $500 million

S U B S I D E N C E

What is Subsidence

- **Gradual lowering of the surface above**
  - Oil fields
  - Fresh Water Aquifers
  - Mining
  - Other

1925
1955
SAN JOAQUIN VALLEY
CALIFORNIA
BM 5861
SUBSIDENCE BM
1925-1977
1977

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Governing Equations in Coupled Analysis

Reservoir model

$$\nabla \cdot [\lambda_w(\nabla p_w - \gamma_w \nabla z)] = \frac{\partial}{\partial t}[\frac{\phi S_w}{B_w}] + q_w$$

$$\nabla \cdot [\lambda_o(\nabla p_o - \gamma_o \nabla z)] = \frac{\partial}{\partial t}[\frac{\phi S_o}{B_o}] + q_o$$

$$\nabla \cdot [R_s \lambda_o(\nabla p_o - \gamma_o \nabla z) + \lambda_g(\nabla p_g - \gamma_g \nabla z)] =$$

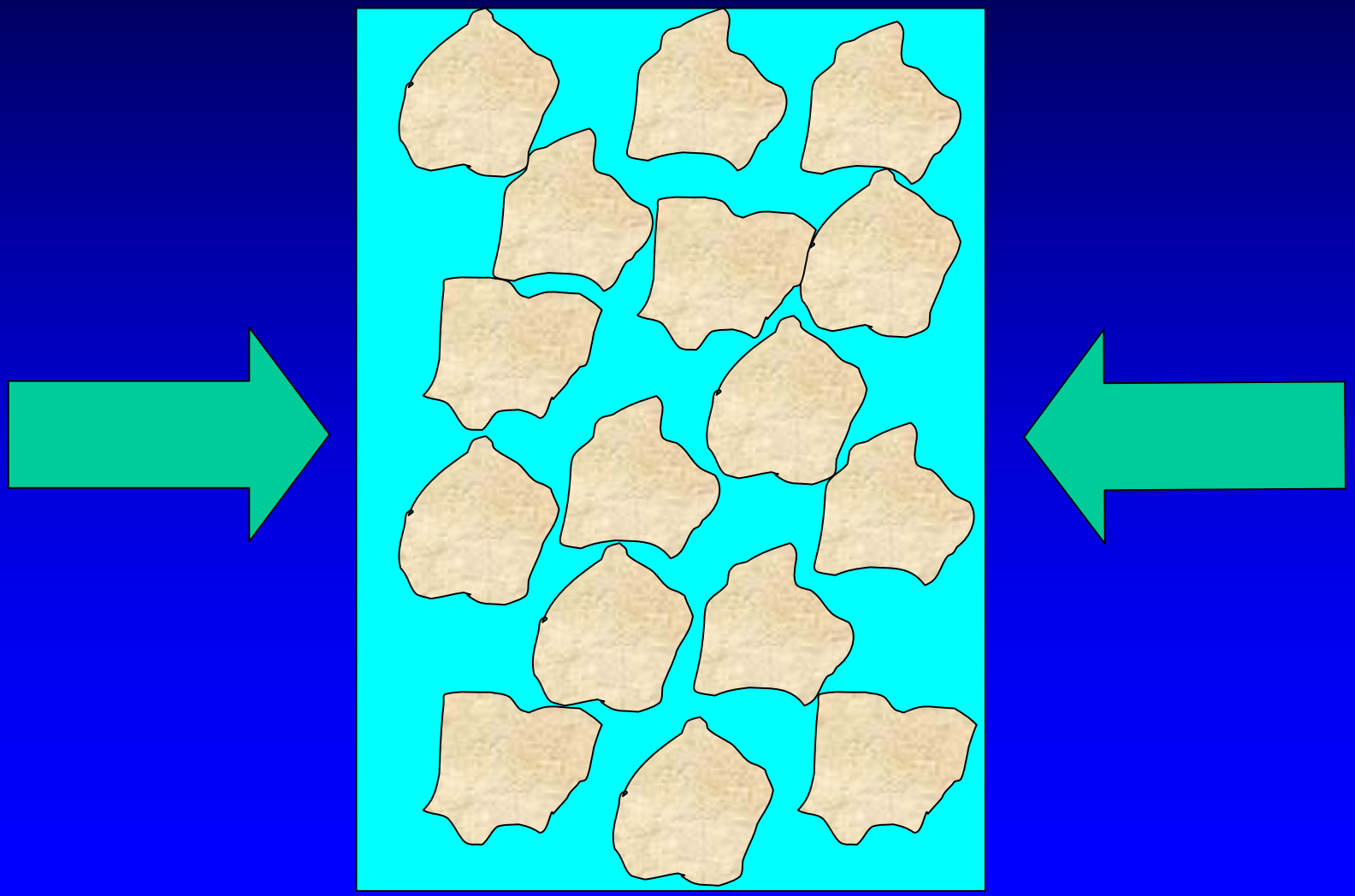
$$\frac{\partial}{\partial t}[\phi(\frac{R_s}{B_o} S_o + \frac{S_g}{B_g})] + R_s q_o + q_g$$

Geomechanics model

$$\nabla \cdot (\sigma' - p\delta) + \rho \mathbf{b} = \mathbf{0}$$

$$\sigma' = \mathbf{f}(\varepsilon, \mathrm{K})$$

$$\phi = \phi_0 + (e^{\varepsilon_v} - 1)$$



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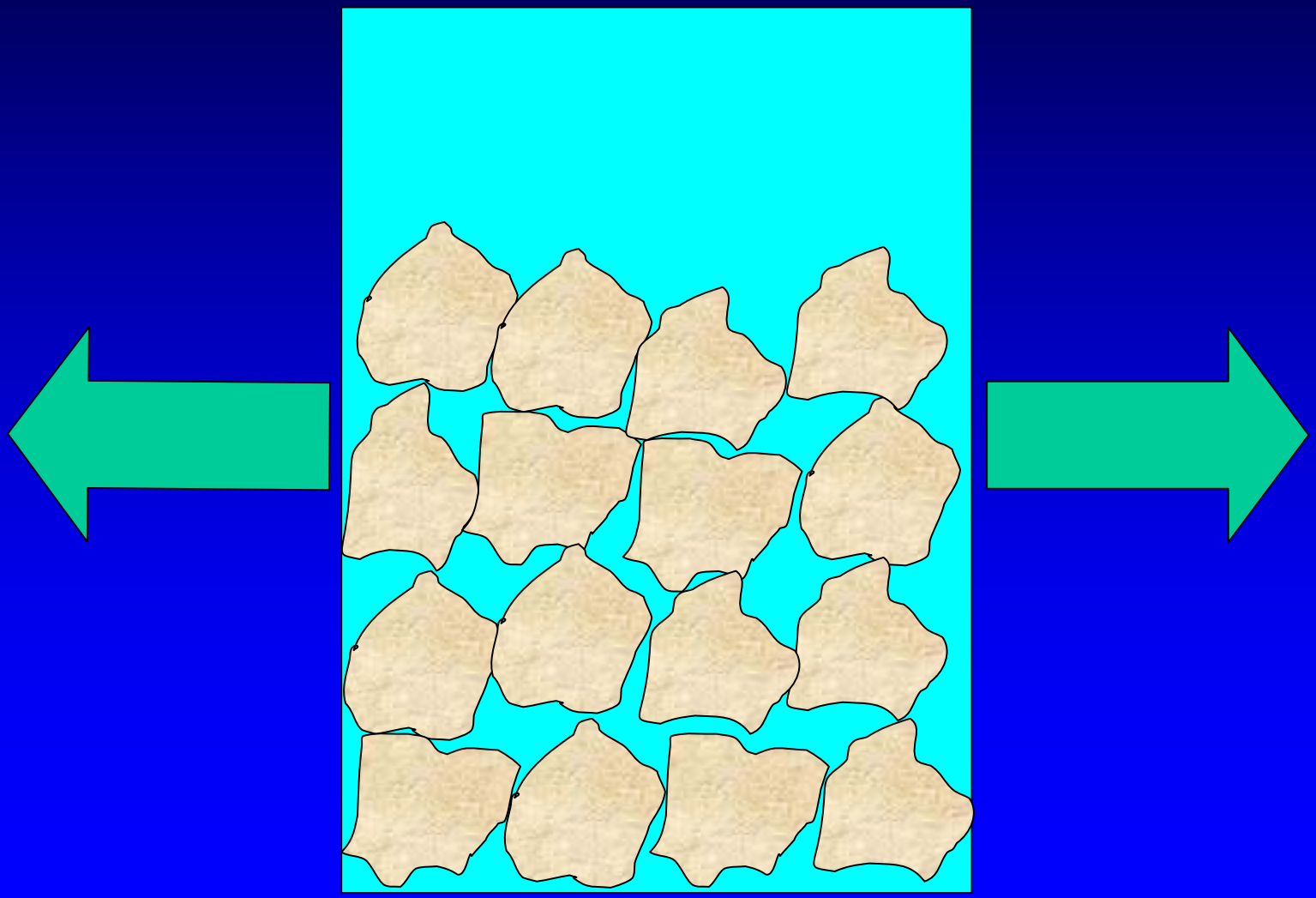

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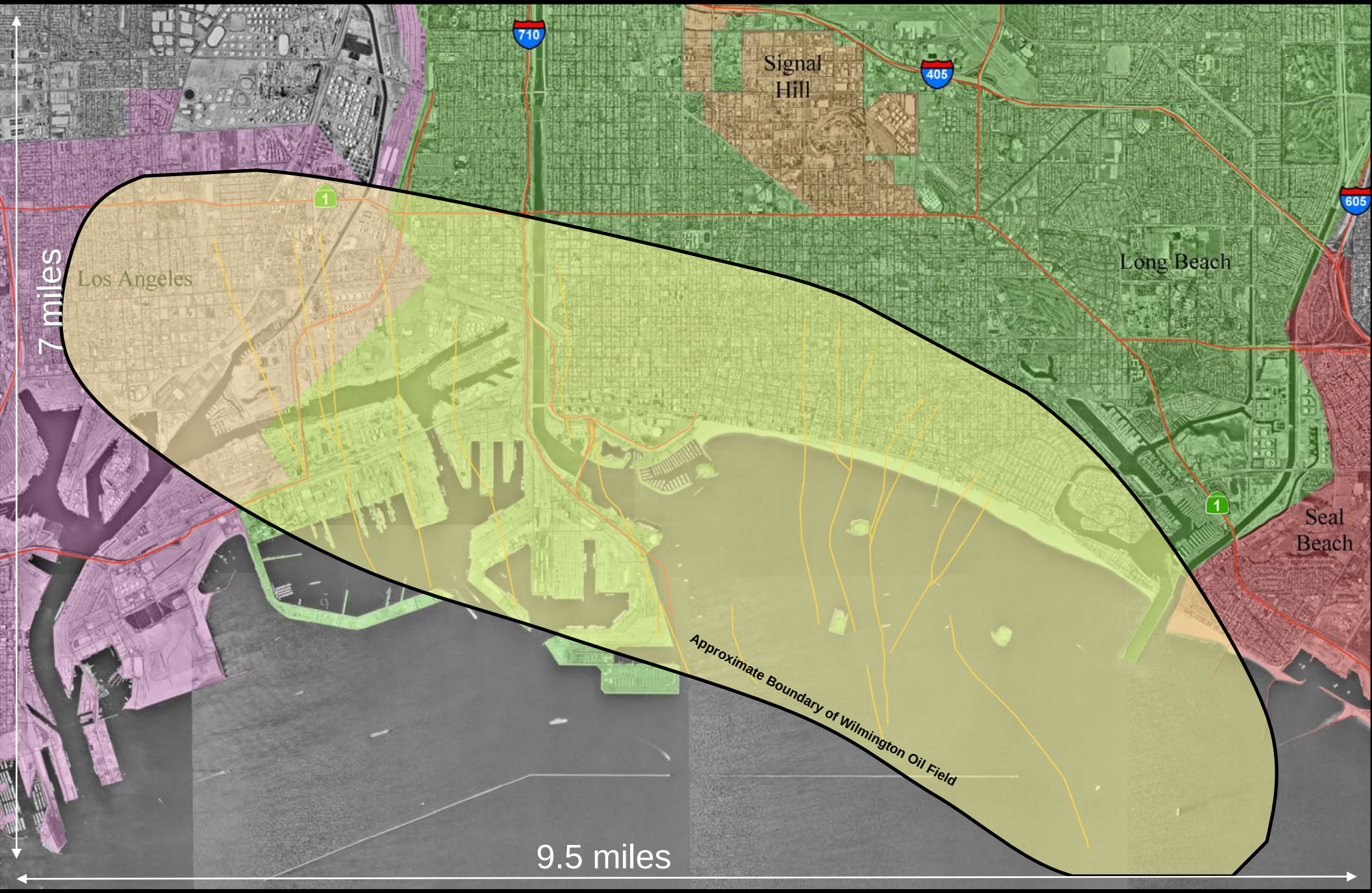
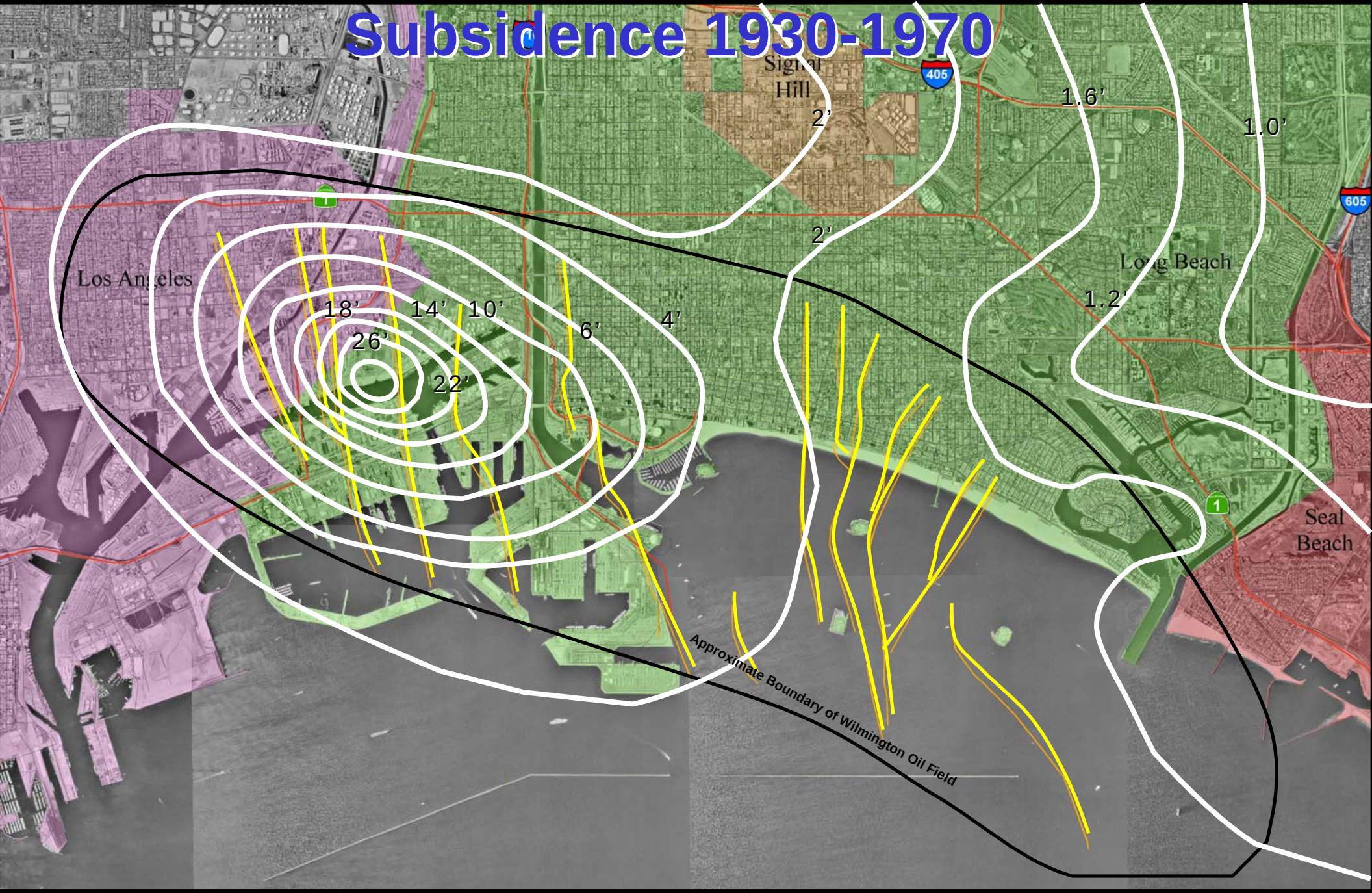
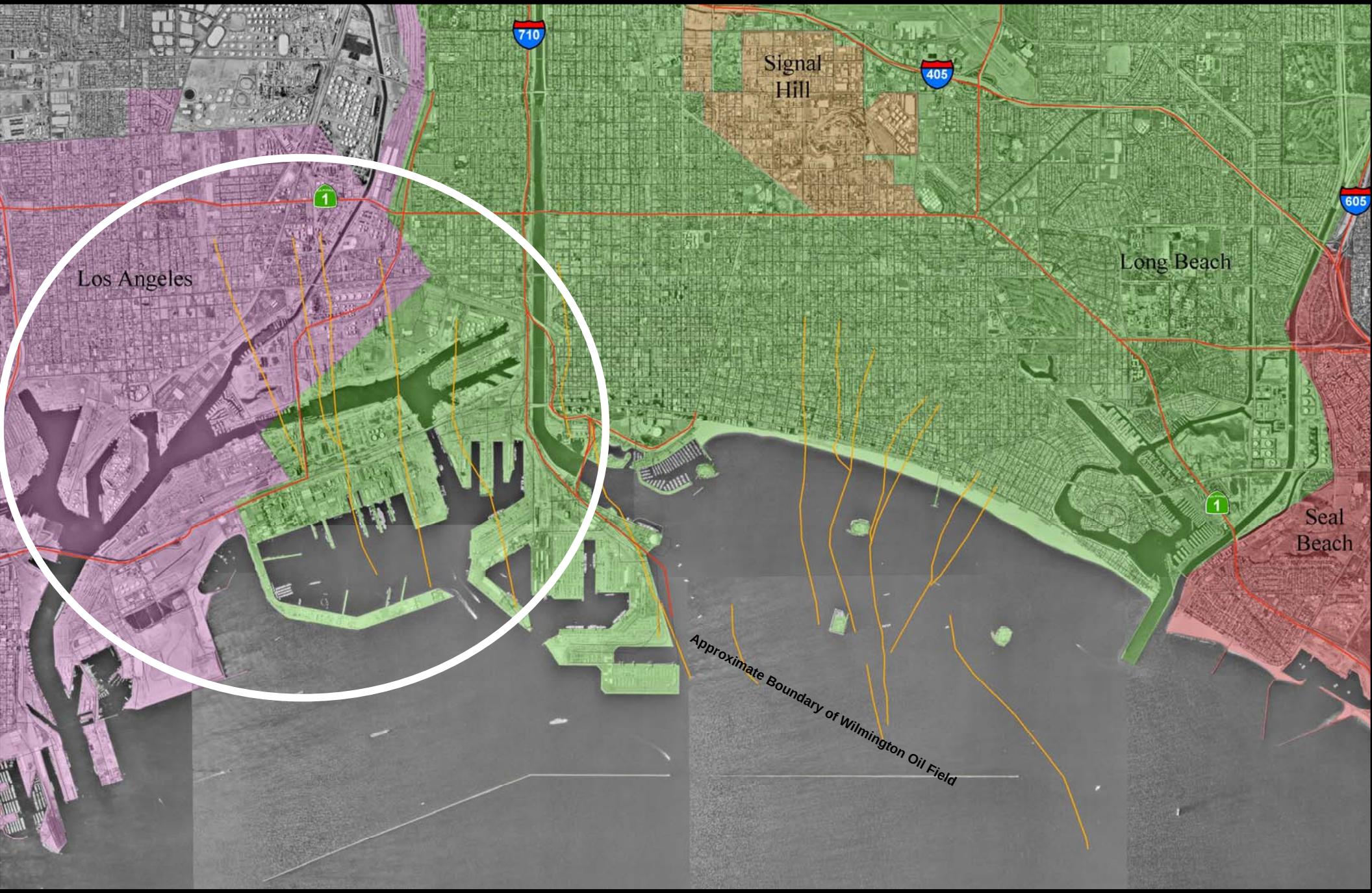

710
405
605
1
Signal Hill
Long Beach
Los Angeles
Seal Beach
Approximate Boundary of Wilmington Oil Field
7 miles
9.5 miles

Subsidence 1930-1970




710
Signal Hill
405
605
Long Beach
Los Angeles
1
1
Seal Beach
Approximate Boundary of Wilmington Oil Field

3.5 miles
5 miles

Terminal Island, prior to Wilmington Oil Field, 1923

Hancock Oil Co. Wells, 1940's

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Initial Subsidence Causes

- **Fresh water aquifer depressurization**
  - Farming
  - Influx of housing
- **Navy dry dock**
  - United States Geological Survey – elevation survey
- **Adjoining oil fields**
  - Long Beach field – discovered 1921
  - Seal Beach field – discovered 1923

Initial Subsidence Causes

- **Wilmington Oil Field discovery**
  - Discovered 1936
- **Early development**
  - Started on western edge of field and moved eastward
- **Geologic factors**
  - Shallow reservoir
  - Lost of pressure / compactable sands
  - Large area involved

Subsidence History

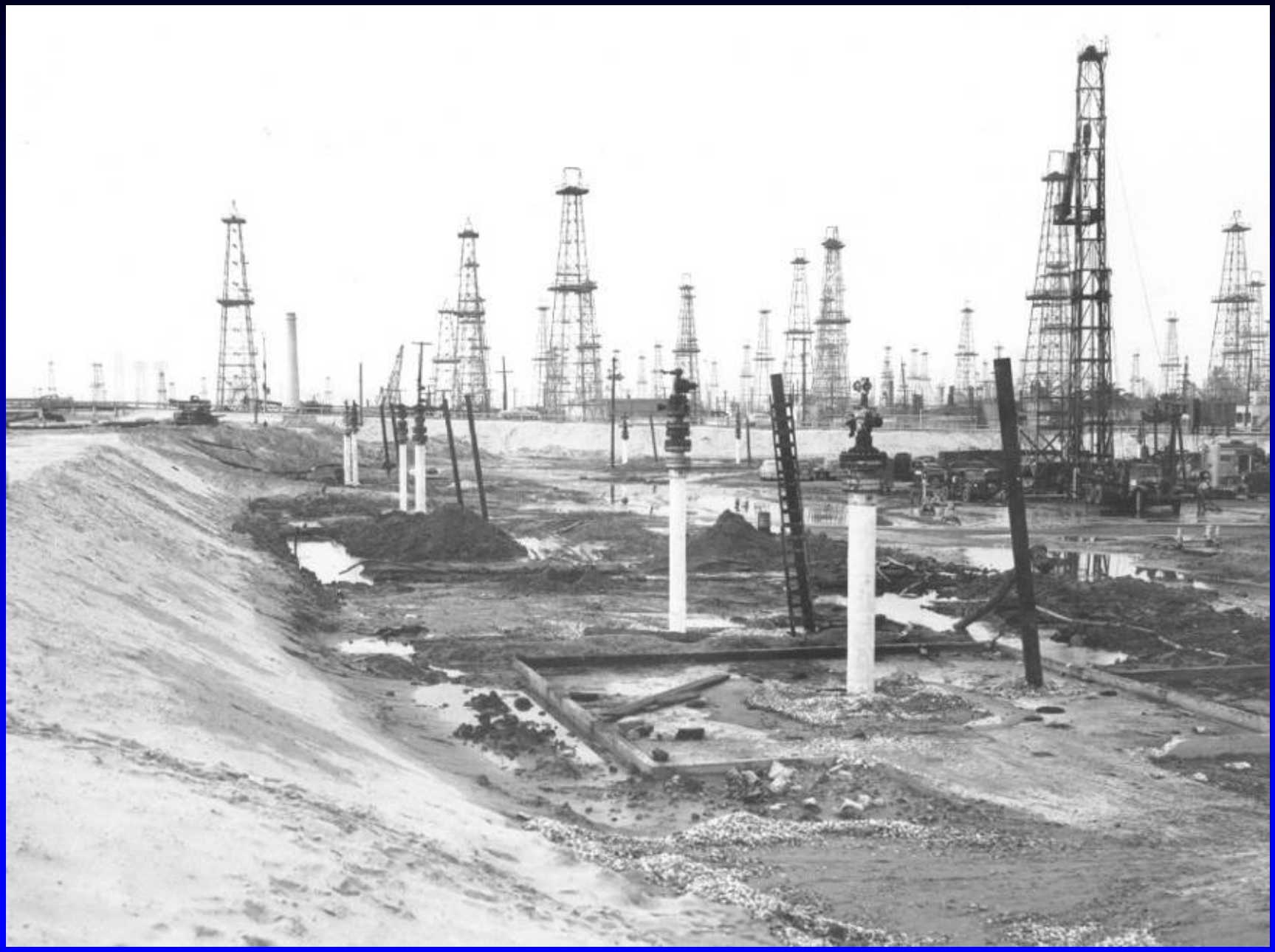
- 1941 – Initial drop in elevation at east end of Terminal Island – regarded as temporary
- 1945 – Craig shipyard experienced higher tides
- 1945 – United States Geodetic Survey
  - confirmed a 4.2 drop in elevation between 1931-1945 at Terminal Island
- 1949 – Lateral displacement of 1 ft (30cm) sheared off 155 oil wells at 1700’ (565 meters) below the surface

Subsidence

- 1952 rate of subsidence was 2.4 ft/yr.
- Maximum subsidence was 29 feet (8.8 meters)
- Re-pressurization from waterflood stabilized surface elevations
- Continued gross production and water injection monitoring are required to maintain minimum changes in elevations
- Leveling survey is best method of measuring subsidence currently

Subsidence History

- 1952 – 32 miles (51 km) of dikes in place
- 1952 – 300 tons of earth being added per day on the dikes and surface areas to keep up with the subsidence.
- 1958 – first injection pilot project started
- 1961 – unitization of Fault Blocks I – VI
  - Allowed for City to control injection and production



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WARNING
TO USERS OF WATER

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Subsidence History

- 1965 - Department of Oil Properties formed in to meet mandate of City Charter.
- 1965 - THUMS awarded field contract
- 1967 - Surface elevation stabilized
- 1970 - Maximum oil production achieved

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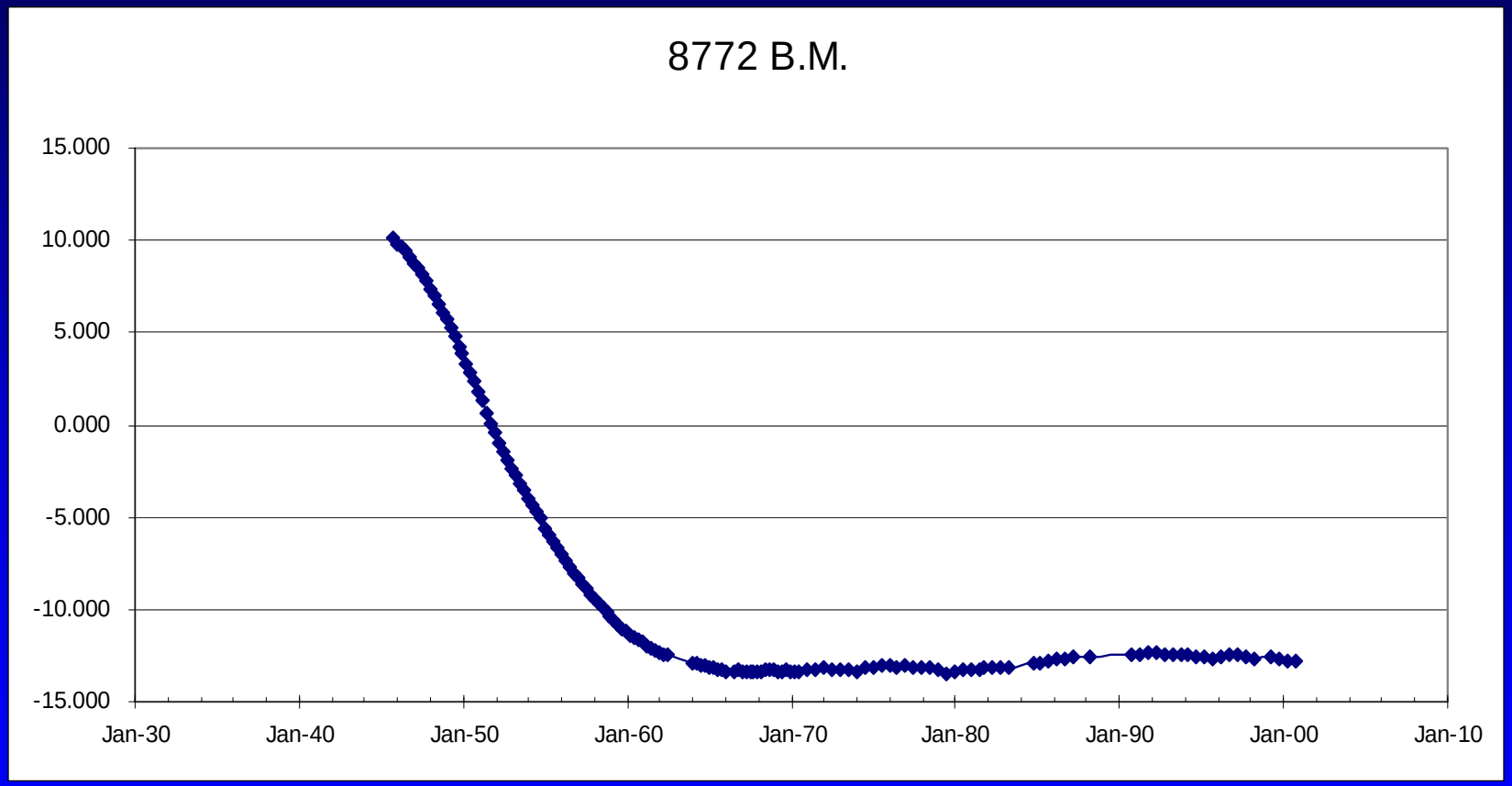
Benchmark


8772 B.M.
15.000
10.000
5.000
0.000
-5.000
-10.000
-15.000
Jan-30
Jan-40
Jan-50
Jan-60
Jan-70
Jan-80
Jan-90
Jan-00
Jan-10

Subsidence

- Subsidence is still a threat to areas overlying oil producing areas
- Constant monitoring of elevations, pressures, production, and injection is ongoing and will continue to be a necessity for many years, even after the oil fields are depleted

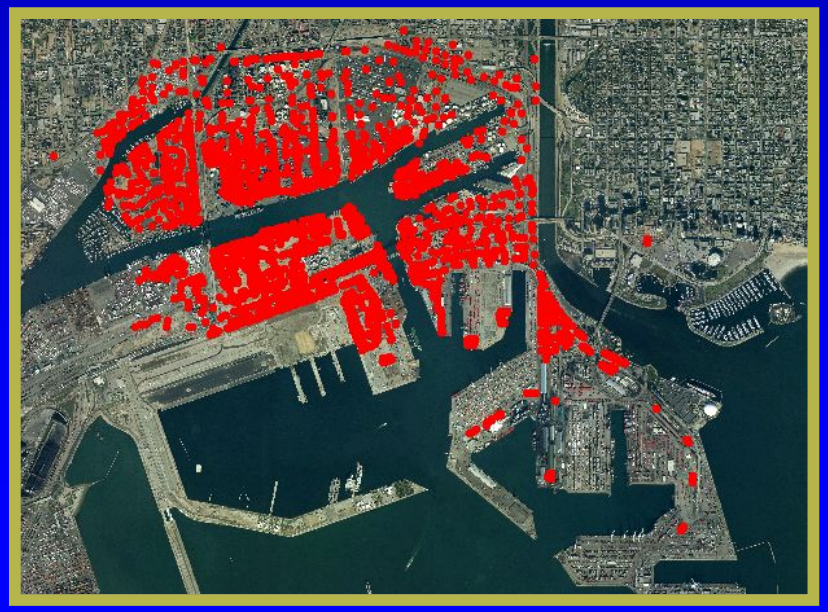
Terminal Island

1922

2003

Active Wells

Injection Wells



Abandoned Wells

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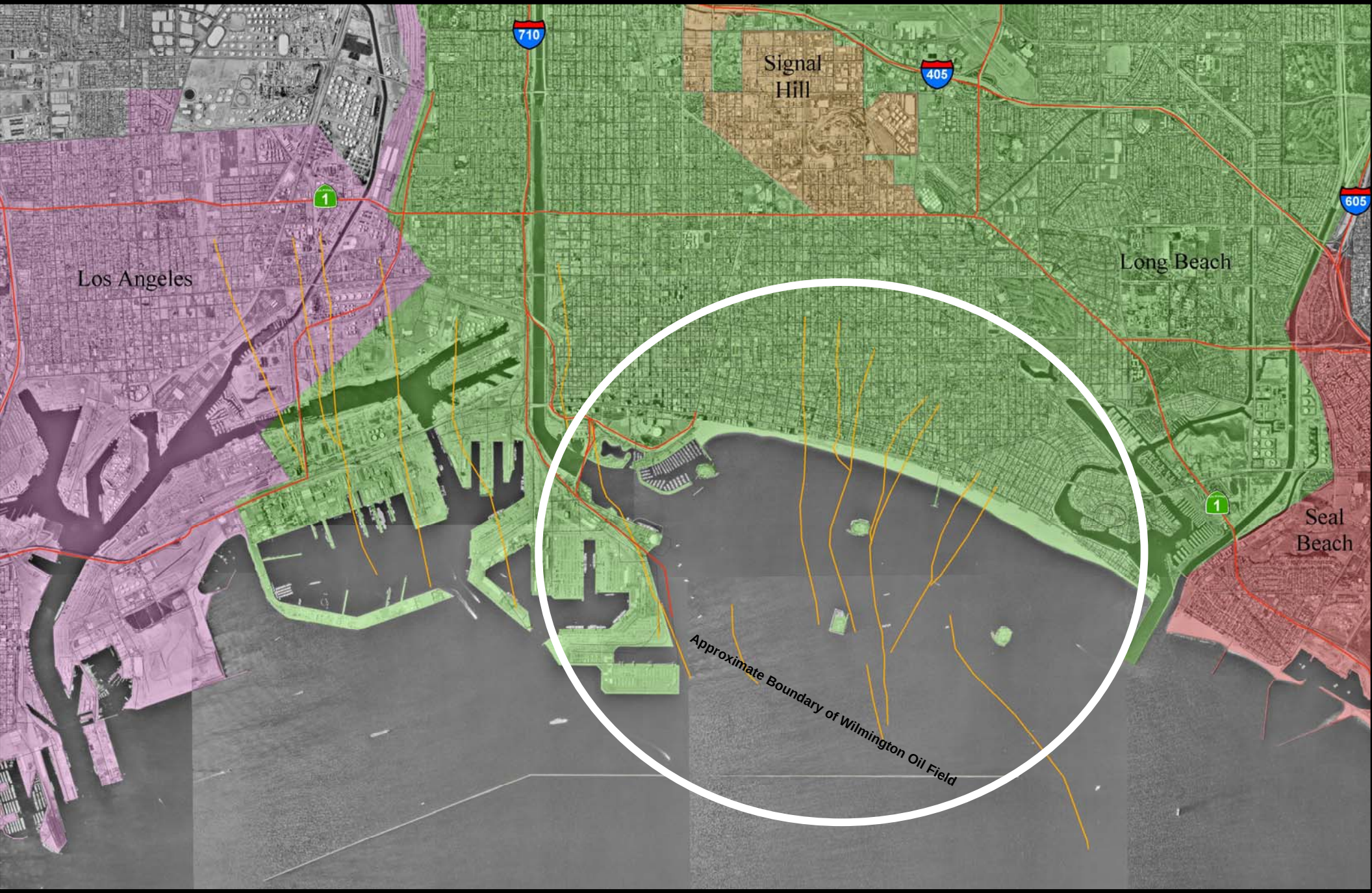
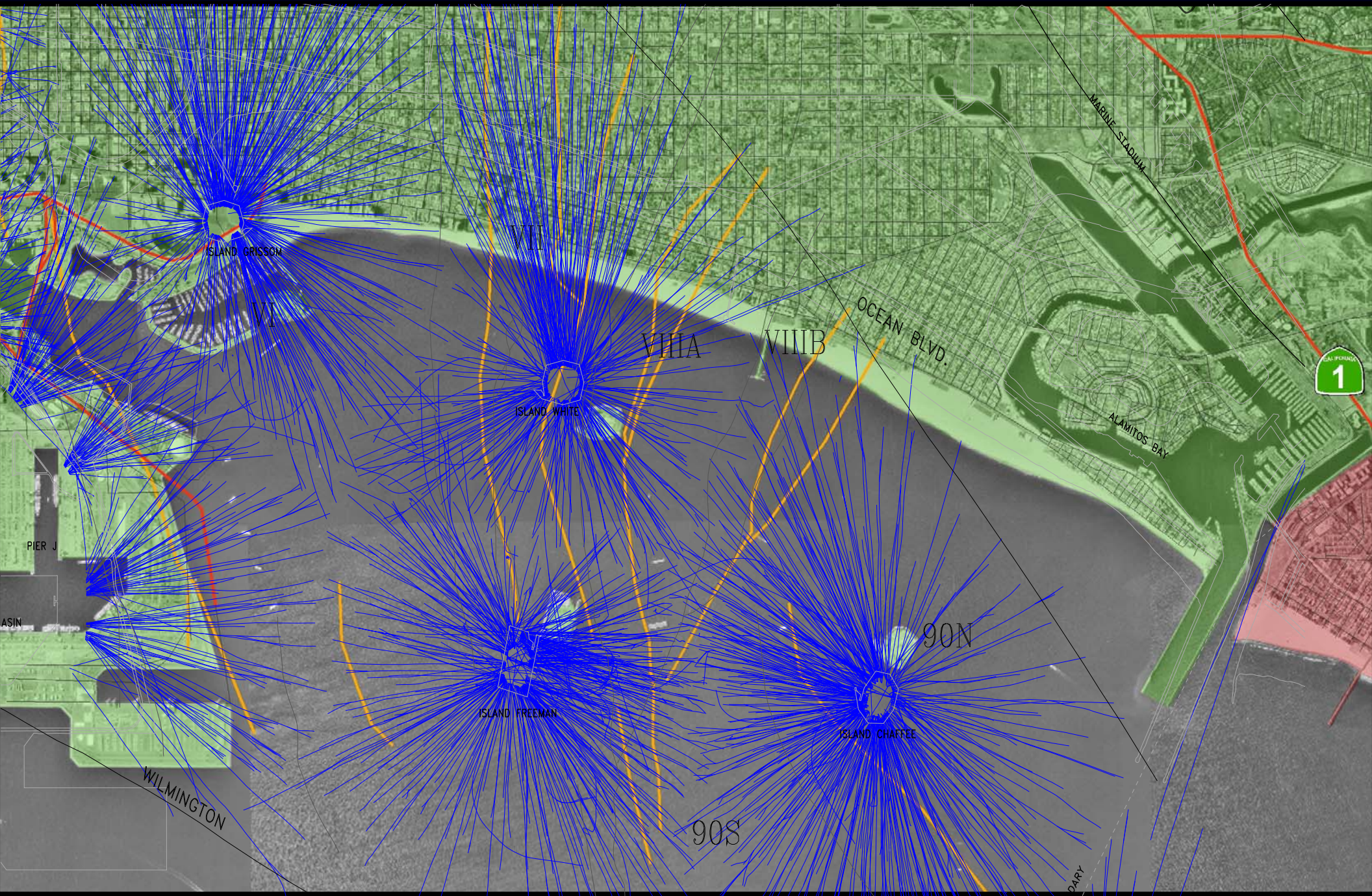
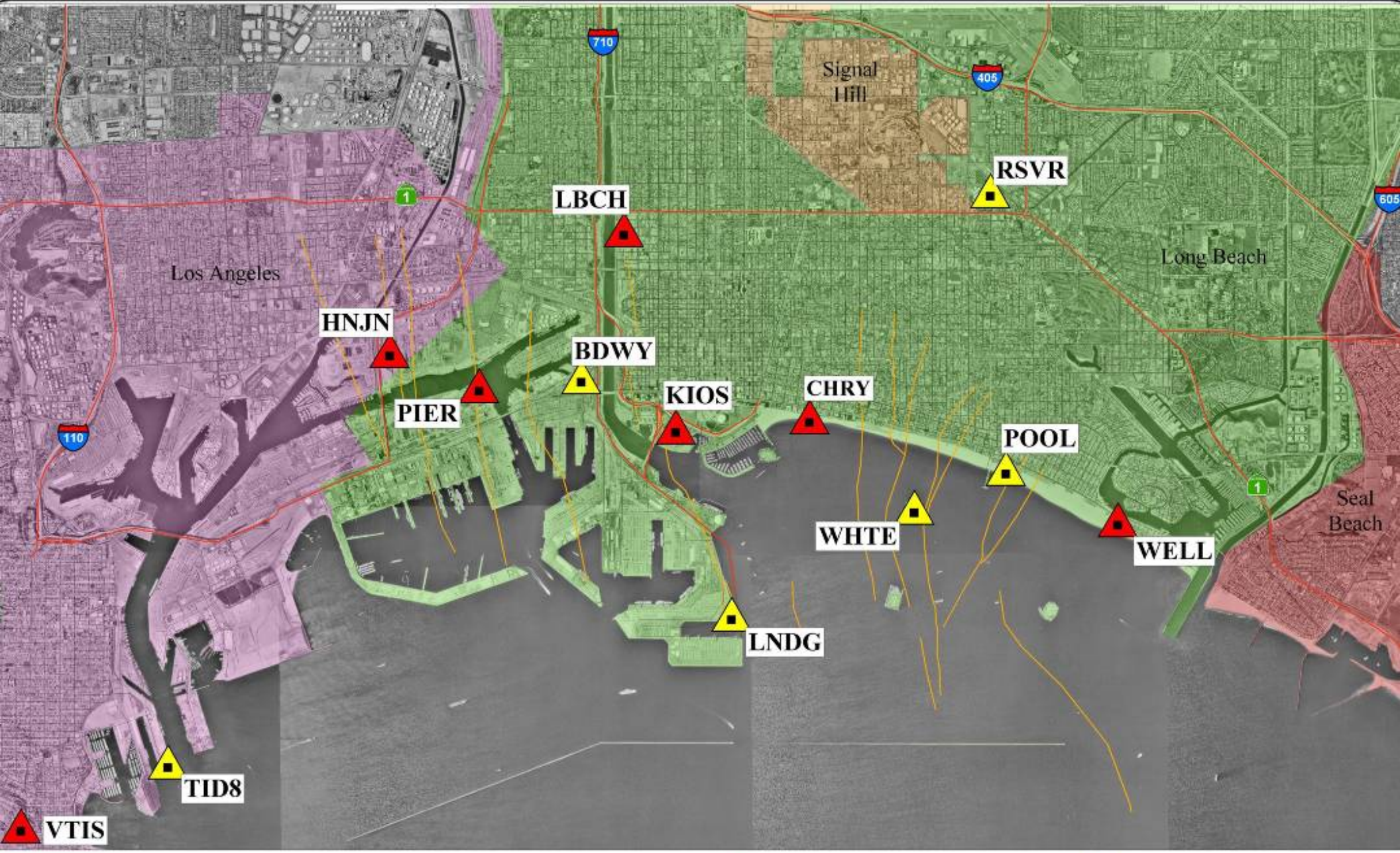

710
Signal Hill
405
605
Long Beach
Los Angeles
1
1
Seal Beach
Approximate Boundary of Wilmington Oil Field


ISLAND GRISSOM
VI
VII
VIIIA
VIIIB
ISLAND WHITE
OCEAN BLVD.
MARINE STADIUM
ALAMITOS BAY
1
PIER J
ASIN
90N
ISLAND FREEMAN
ISLAND CHAFFEE
WILMINGTON
90S



Long Beach GPS Network, 2003

Phase 1 - Fixed GPS Sites

Phase 2 - Fixed GPS Sites

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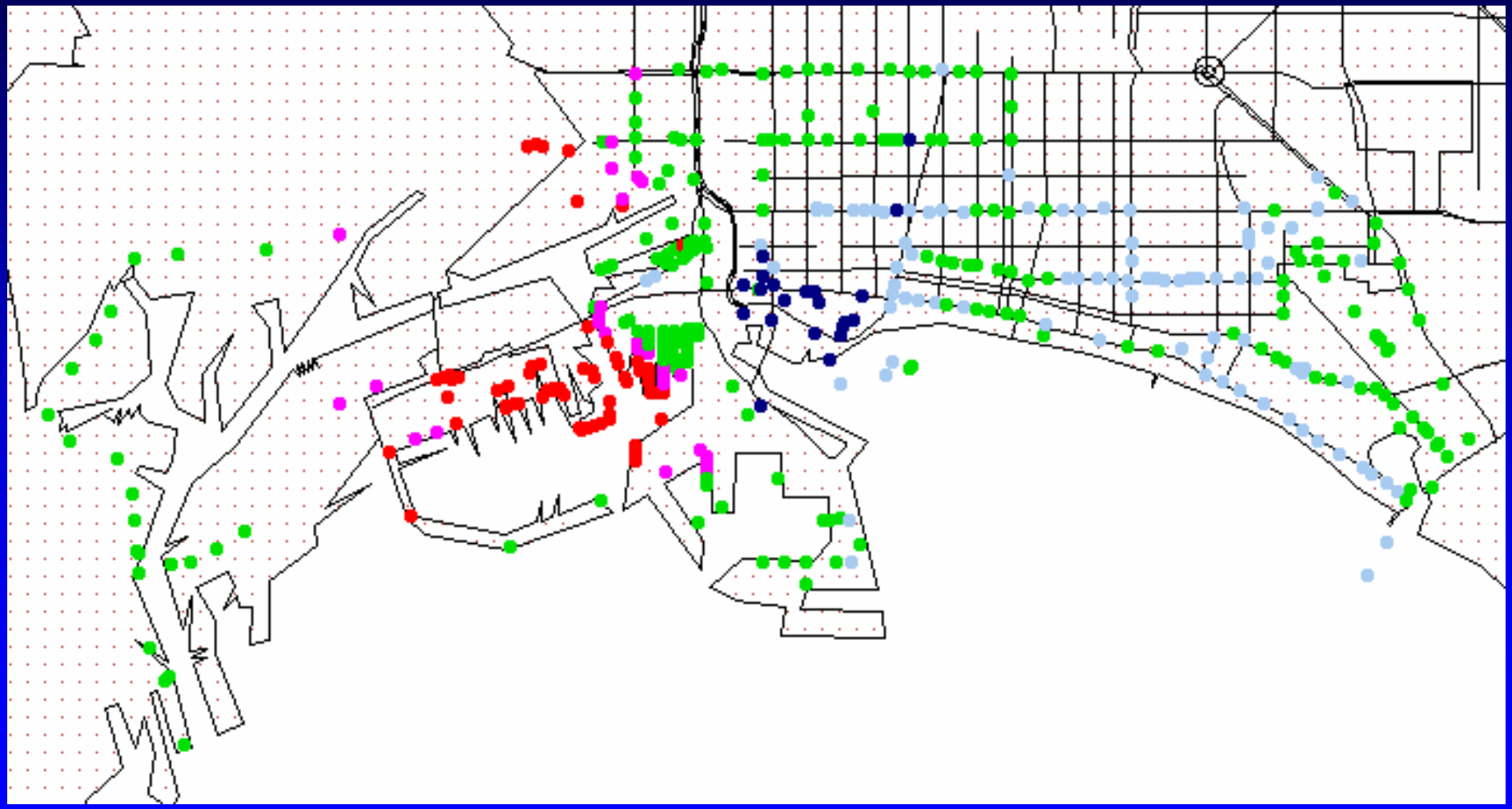
Subsidence Measurement Tools

- **Global positioning satellites (GPS)**
  - Fixed locations
  - Mobile survey
    - Reduce time to conduct survey
      - Not constrained to line of sight
      - Less benchmarks surveyed
    - Reduce time to calculate elevations
    - Cost savings
    - Same or better accuracy
    - Additional information – xy changes

Benchmark Locations in Long Beach



Benchmark Locations in Long Beach

Wilmington Oil Field

More than 6000 wells drilled

Production from 1,200 wells:

Oil	40,370	bbl oil per day
Water	1,005,870	bbl water per day

Water Injection from 600 wells:

1,121,412 bbl water per day

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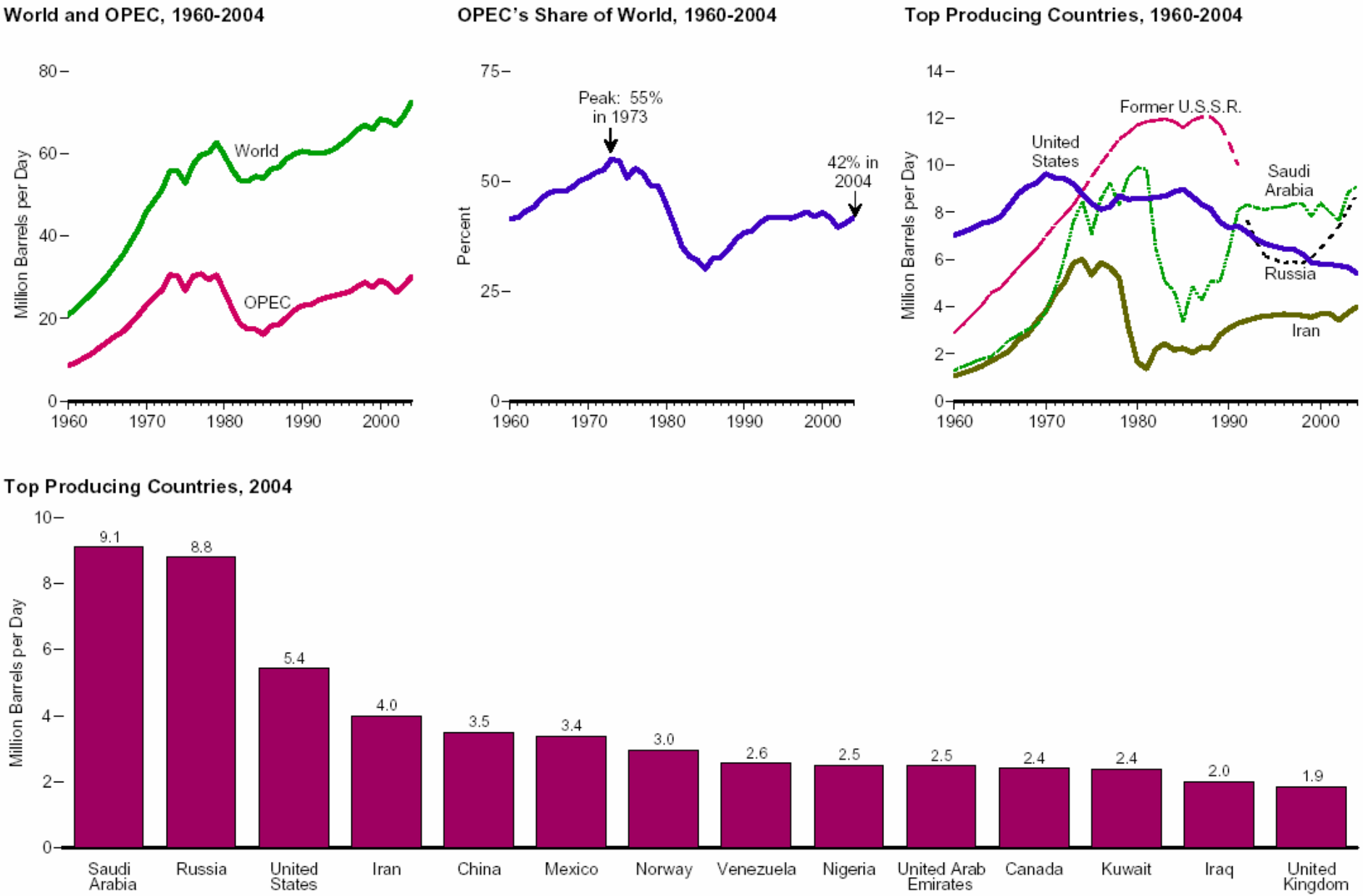
Or – why are my gasoline bills so high and how do I tell my kids that they cannot drive the car anymore.

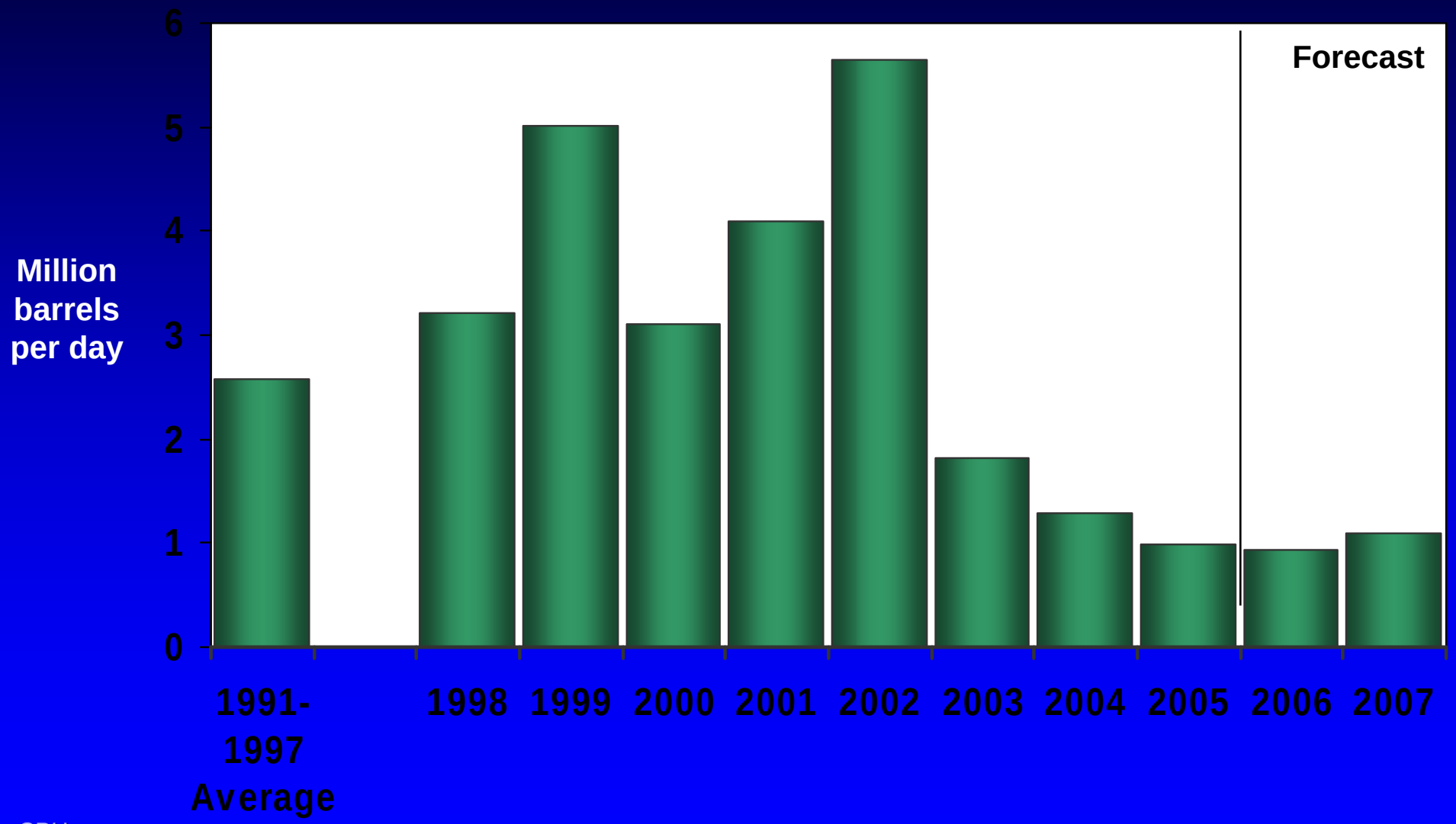
Why Has the Price of Oil Increased?

- Oil production capacity limits
  - Upswing in economy
  - China and India
  - Katrina
- Exchange rate
- Refining limitations
- Other

Figure 11.5 World Crude Oil Production



World Oil Surplus Production Capacity



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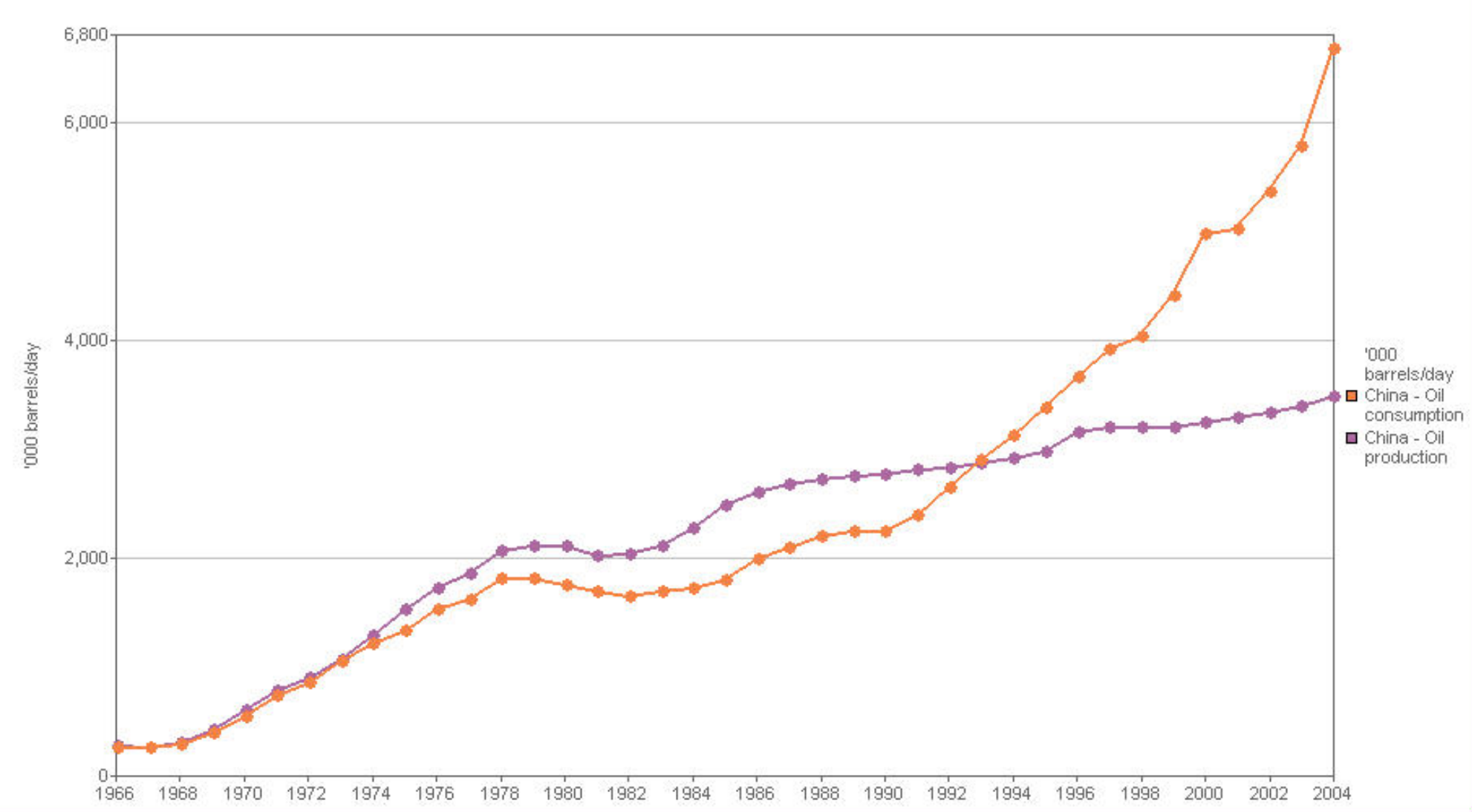
6,800
6,000
4,000
2,000
0
'000 barrels/day
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
'000 barrels/day
China - Oil consumption
China - Oil production

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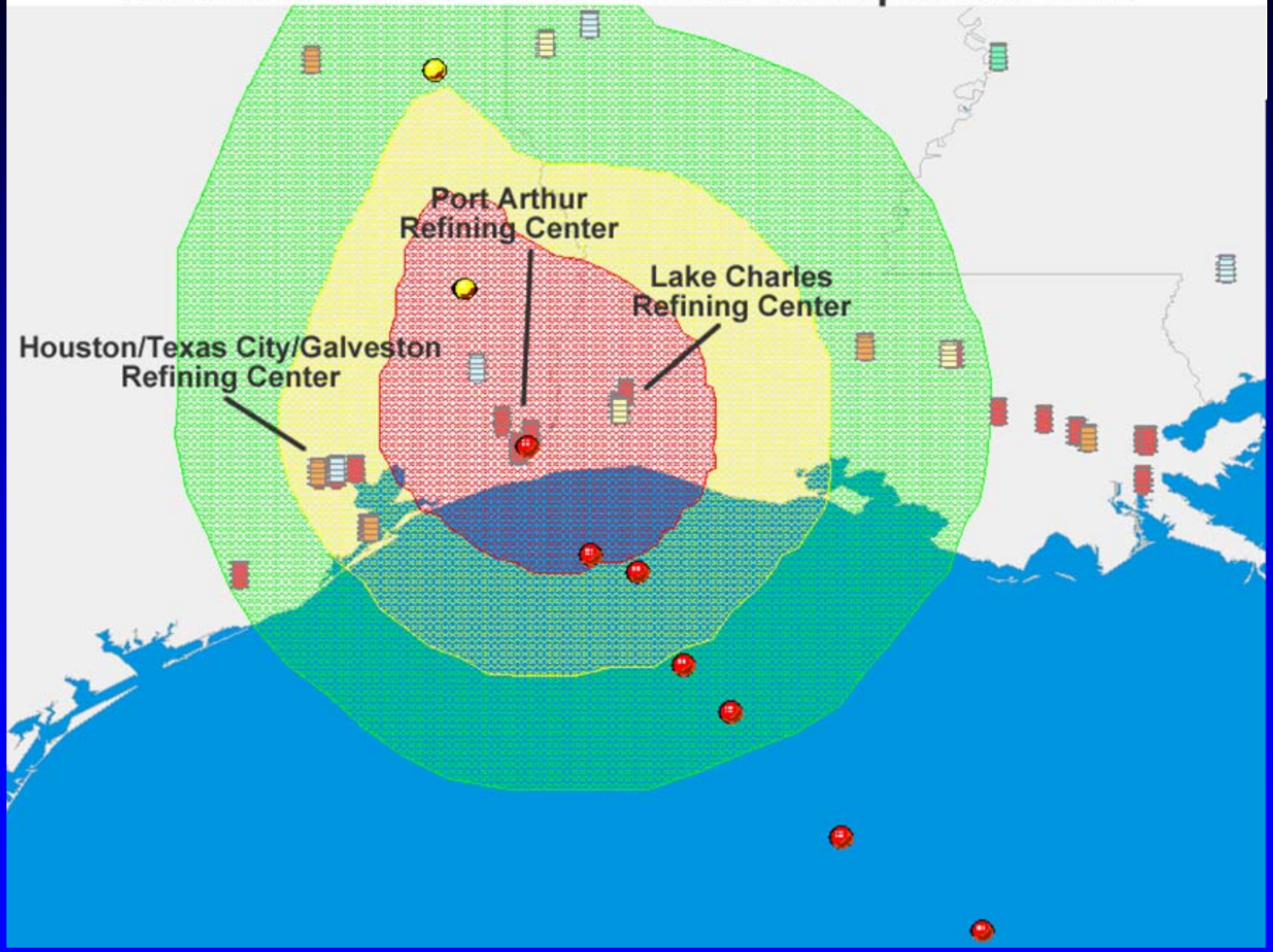
Hurricane Rita's Path at Landfall on September 24th



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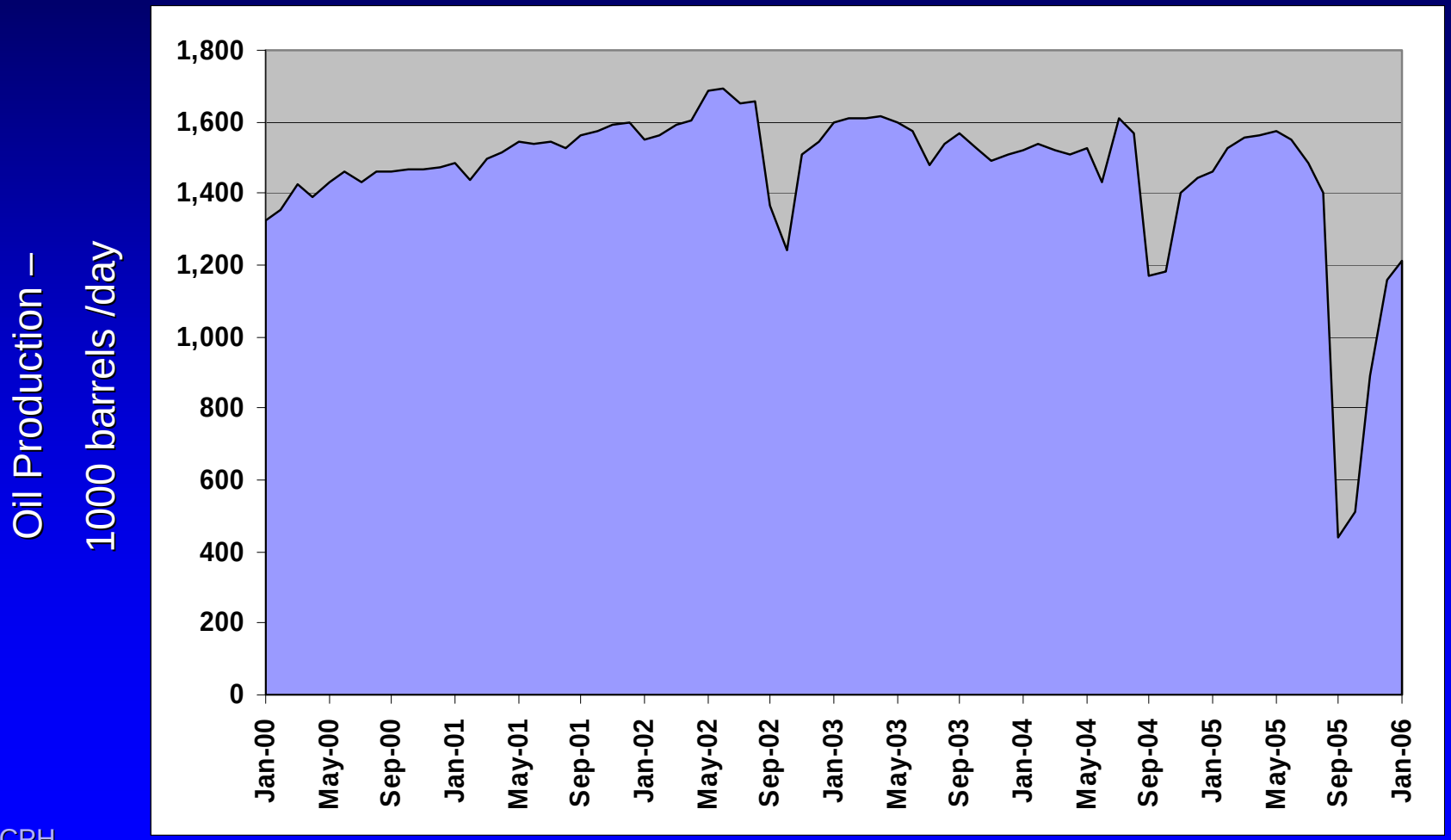
Katrina and Rita

- Lost production from Federal offshore fields
  - over 162 million barrels of crude oil
  - 784 billion cubic feet of natural gas production
  - This amounts to about 30 percent and 21 percent respectively of a normal years production

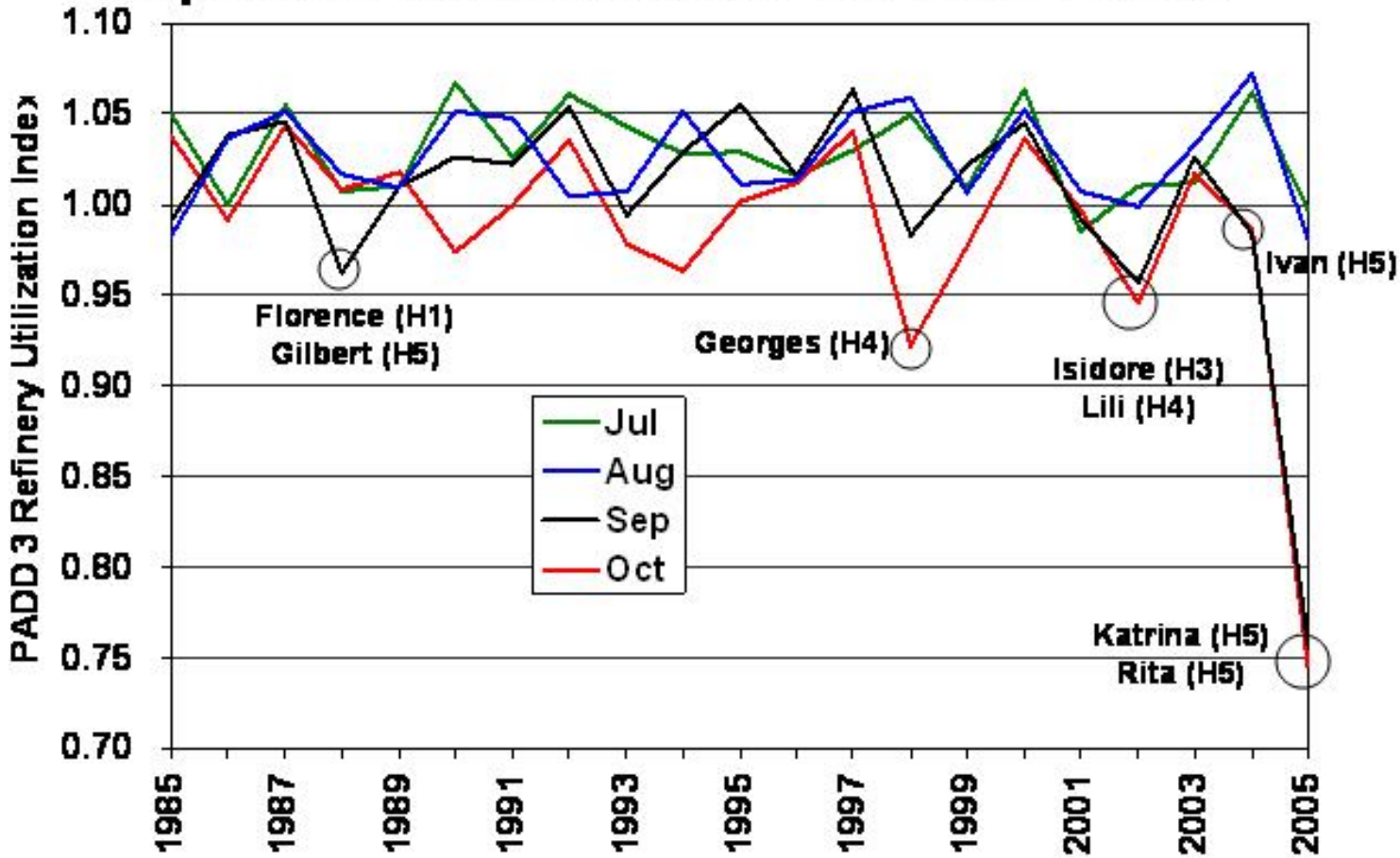
Katrina and Rita

- Upstream impacts to Gulf production
  - Louisiana Offshore Oil Port had to temporarily stop accepting shipments during both hurricanes.
  - onshore refineries and natural gas processing facilities suffered heavy damage.
  - Nearly 2 million barrels per day of refinery capacity were shut down, due to either direct damage or interruption of power supplies.
  - As much as 4.9 million barrels per day of refining capacity (nearly 29 percent of U.S. refining capacity and over 60 percent of refining capacity in the Gulf Coast region) were shut down. Some of the shutdowns were precautionary, ahead of the storms.
  - Several refineries were damaged extensively, thus keeping them shut down for a relatively long time. For example, even as late as October 10, 2005, more than 2 million barrels per day of refining capacity were still shut down.

Effects of hurricanes – offshore Gulf



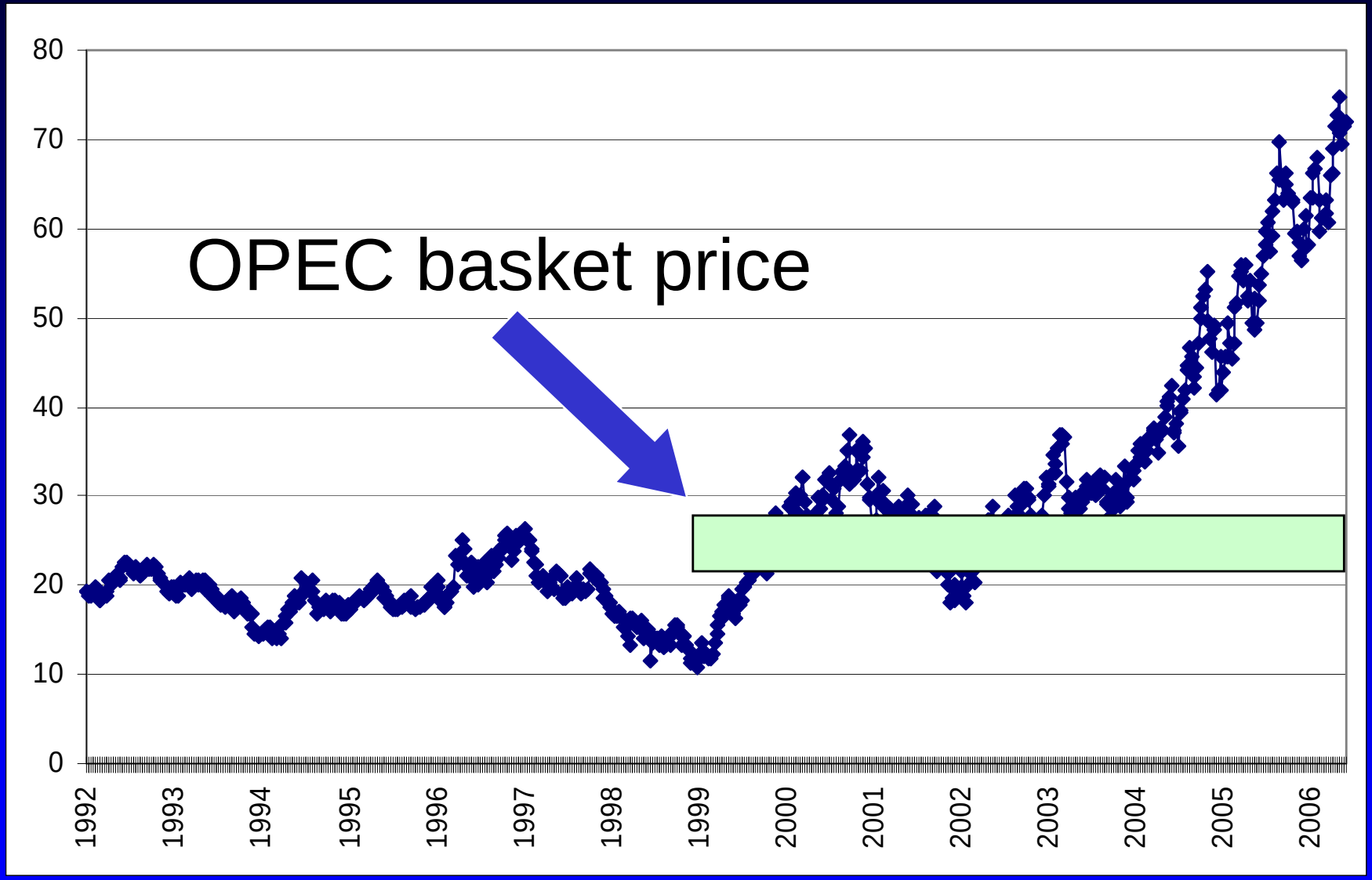
Hurricanes in 1988, 1998, 2002, 2004, and 2005 Impacted Refineries on the Gulf Coast



Note: The Refinery Utilization Index is calculated by taking the ratio of the refinery utilization in a given month divided by the average utilization for January through June in the same year.

Source: EIA Petroleum Navigator database.

Oil Price


OPEC basket price
80
70
60
50
40
30
20
10
0
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006

EURO versus the dollar

US Oil Consumption (Millions bbl/day)
Millions of Barrels per Day
25
20
15
10
5
0
1956
1958
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
Year
http://calculatedrisk.blogspot.com/

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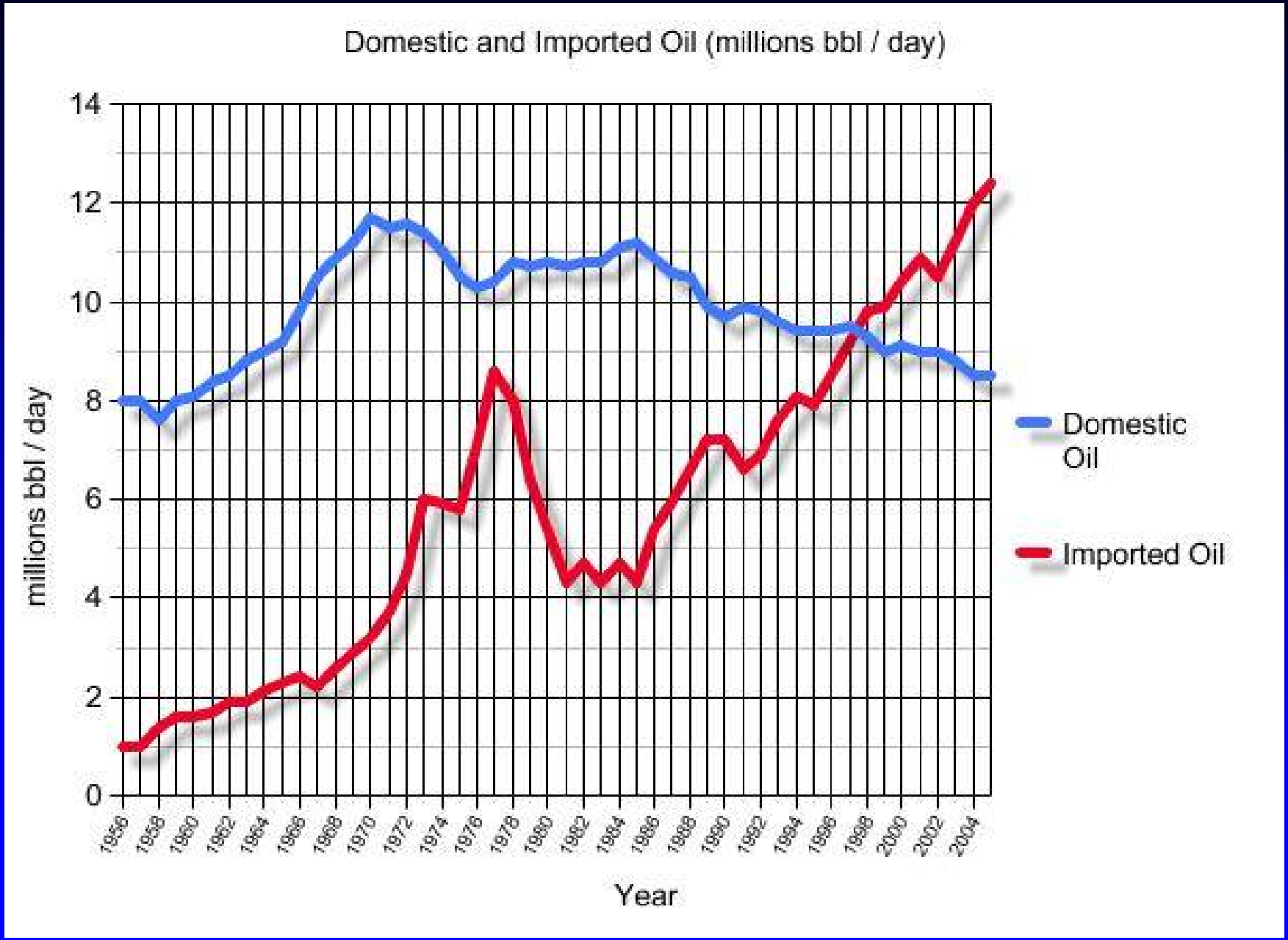
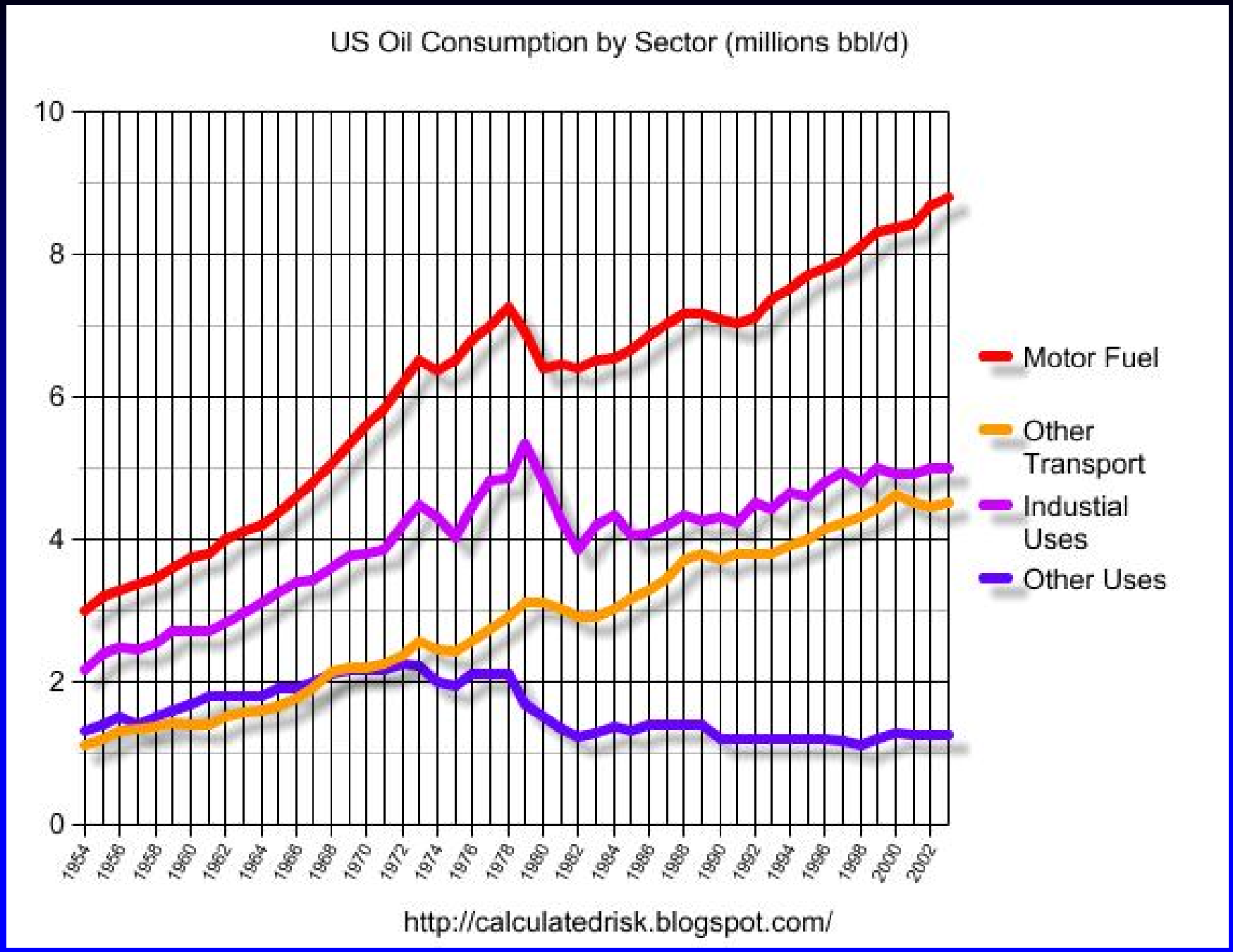
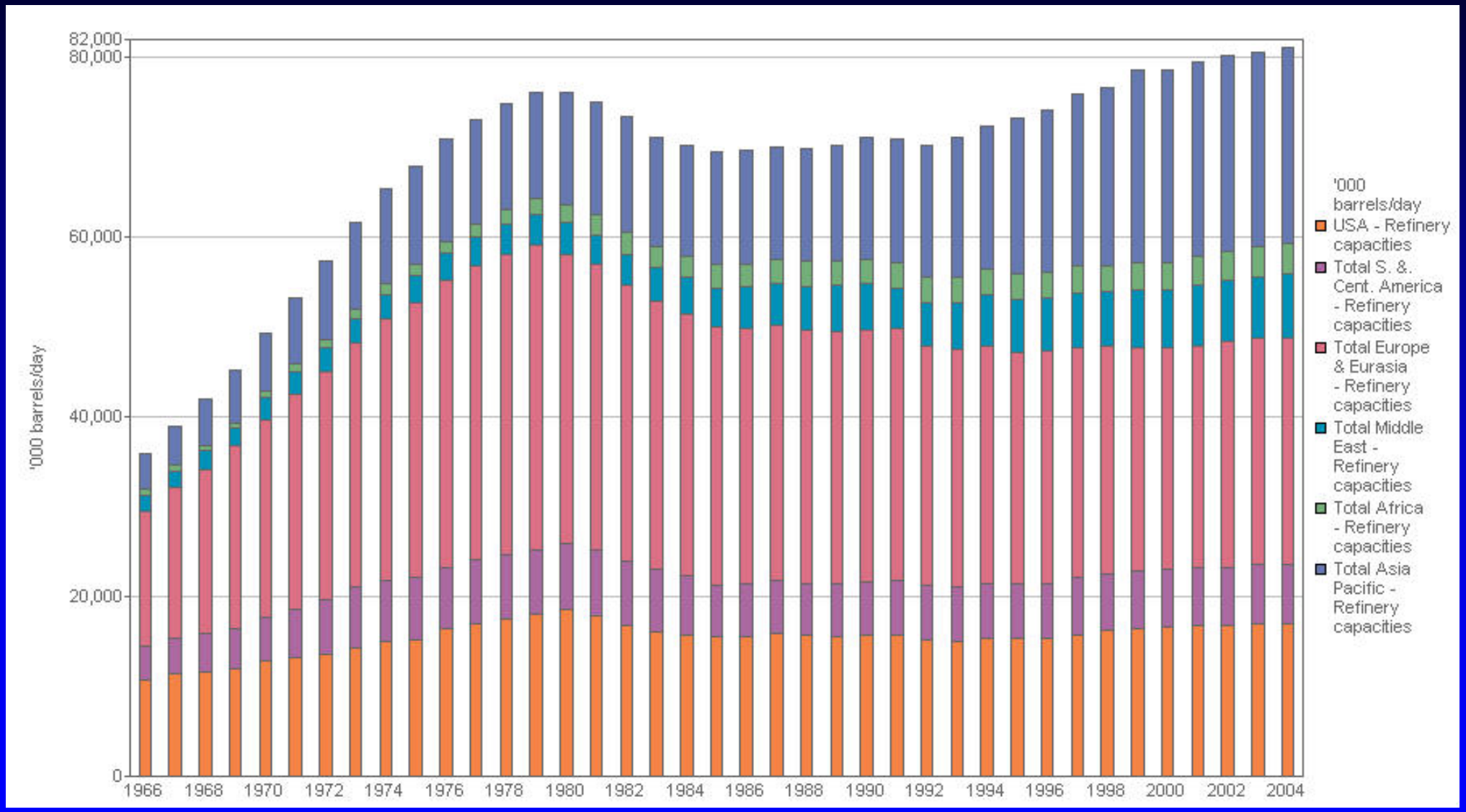

Domestic and Imported Oil (millions bbl / day)
millions bbl / day
14
12
10
8
6
4
2
0
1956
1958
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
Year
Domestic Oil
Imported Oil

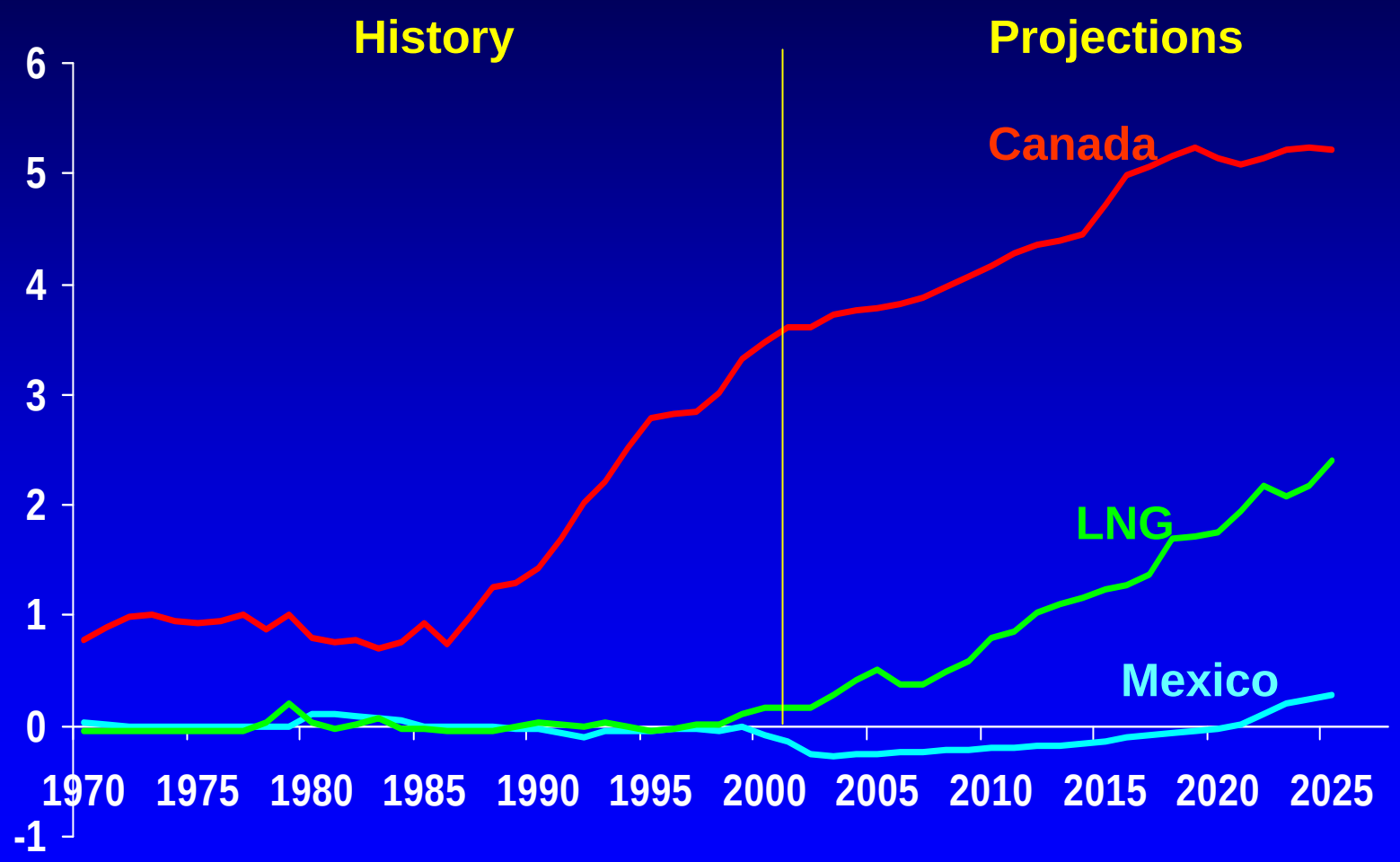
CPH


US Oil Consumption by Sector (millions bbl/d)
10
8
6
4
2
0
1954
1956
1958
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
Motor Fuel
Other Transport
Industial Uses
Other Uses
http://calculatedrisk.blogspot.com/


82,000
80,000
60,000
40,000
20,000
0
'000 barrels/day
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
'000 barrels/day
USA - Refinery capacities
Total S. &. Cent. America - Refinery capacities
Total Europe & Eurasia - Refinery capacities
Total Middle East - Refinery capacities
Total Africa - Refinery capacities
Total Asia Pacific - Refinery capacities

CPH

Net U.S. Imports of Natural Gas, 1970-2025 (trillion cubic feet)



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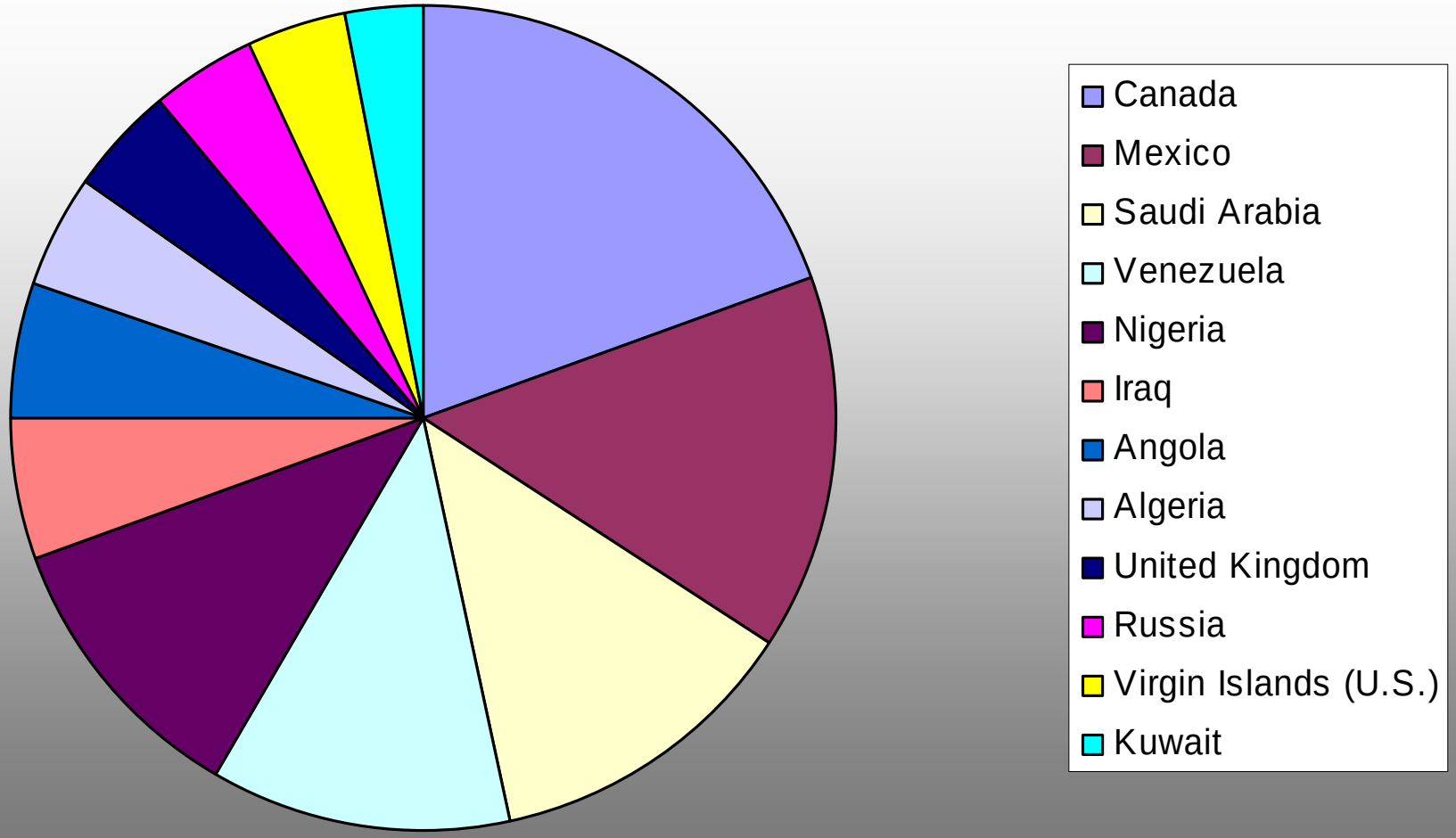
Source: EIA

What Will the Price of Oil Be…?


Canada
Mexico
Saudi Arabia
Venezuela
Nigeria
Iraq
Angola
Algeria
United Kingdom
Russia
Virgin Islands (U.S.)
Kuwait

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Who Sets the Price of Oil

- Up to 1974 – oil companies set the price
- Up to 1981/2004 - OPEC
- Currently
  - Traders – free market
    - New York Mercantile Exchange (NYMEX),
    - International Petroleum Exchange in London
    - Singapore International Monetary Exchange (SIMEX)
  - OPEC can have influence over the market
  - FEAR

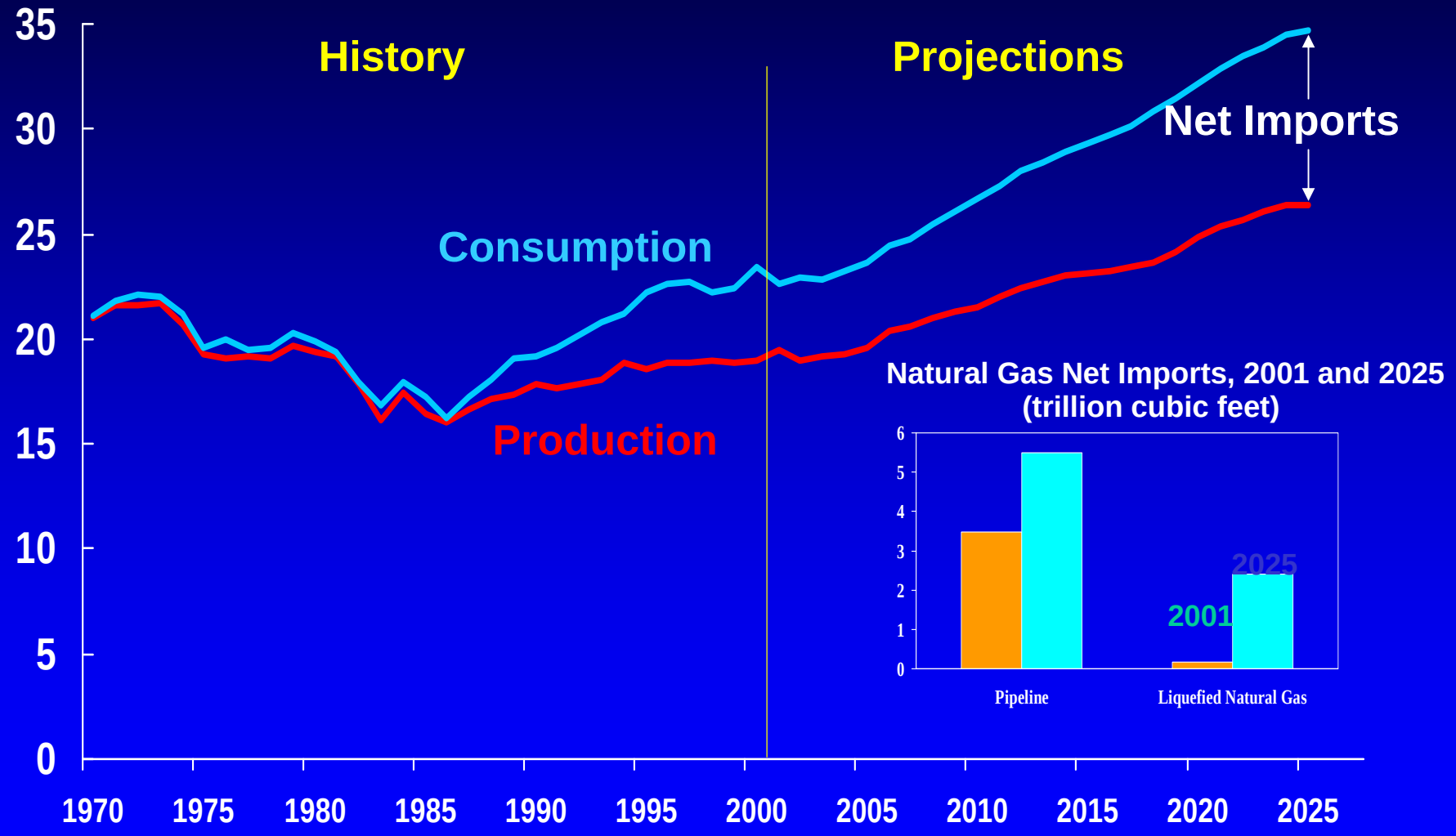
Current Market Conditions

- World economy still strong
- China still growing
- Refinery capacity (US) has limited or no growth potential
- Peak oil?

What Can Change the Situation?

- Oil Shale
- Coal
- Natural Gas
- Nuclear
- Conservation
  - Alternative fuels
- Recession

Natural Gas Production, Consumption, and Imports, 1970 - 2025 (trillion cubic feet)



Source: EIA

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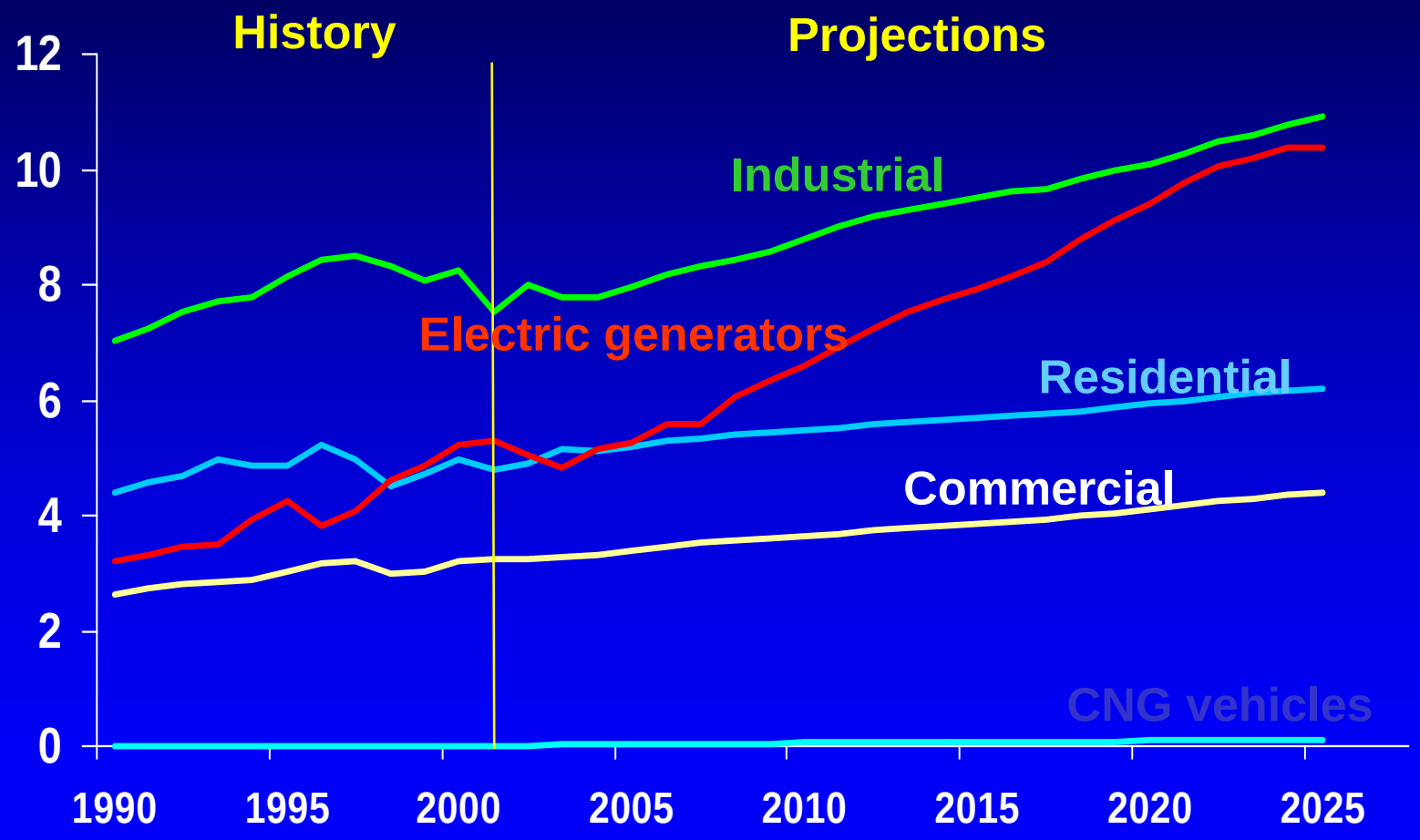
U.S. Natural Gas Consumption by Sector, 1990-2025

(trillion cubic feet)



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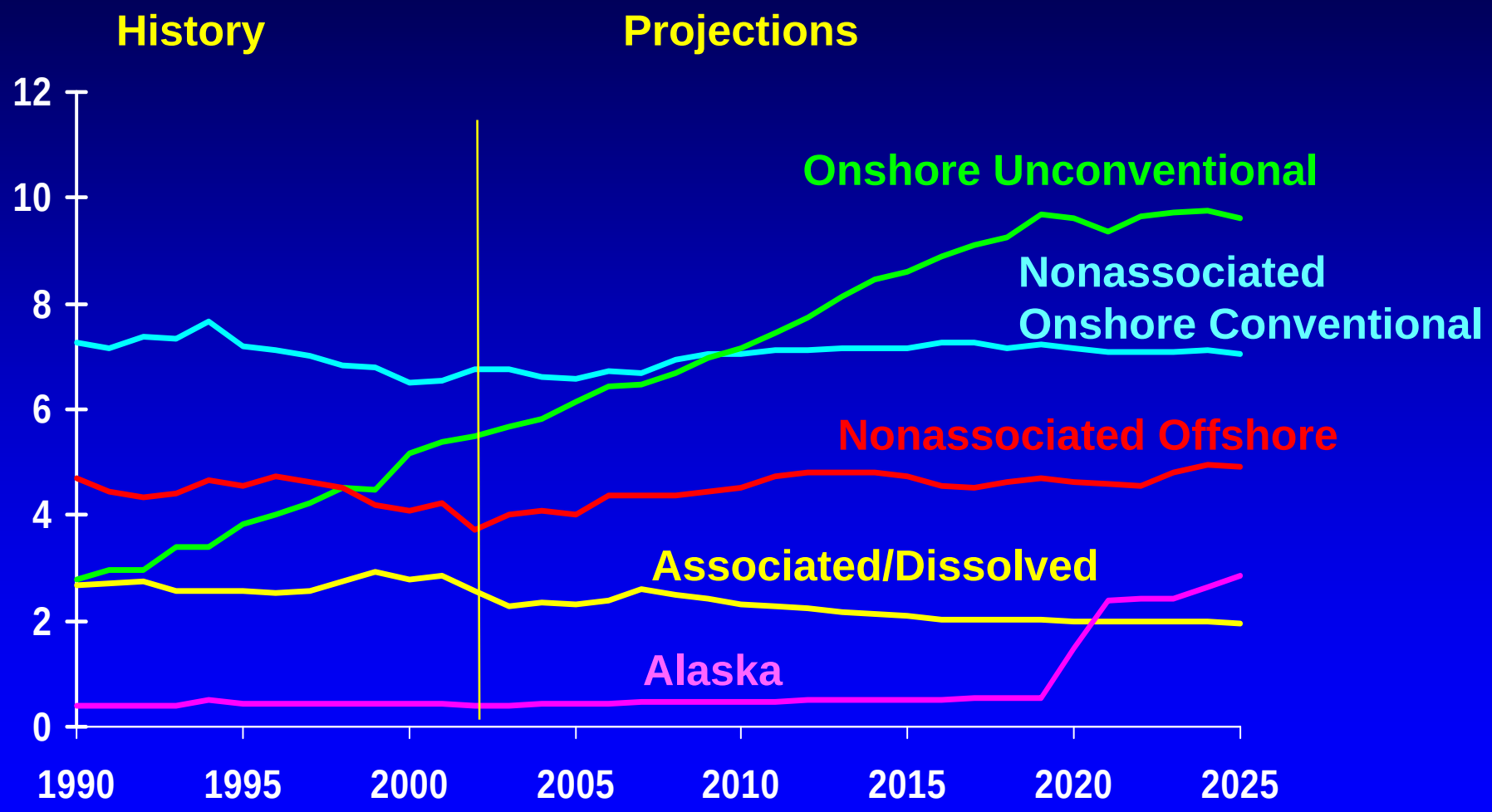
Source: EIA

U.S. Dry Natural Gas Production, 1990 - 2025 (trillion cubic feet)



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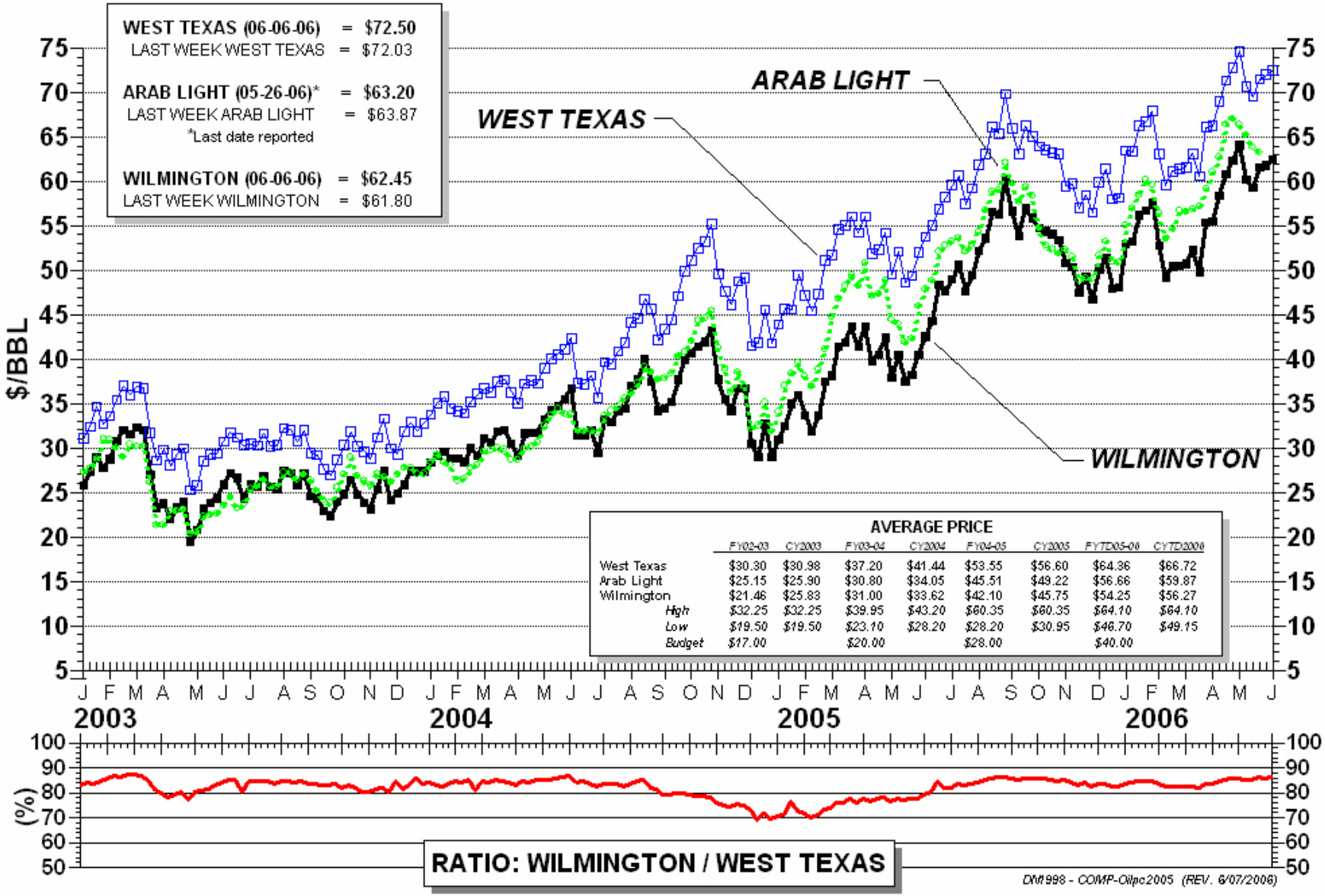
Source: EIA

OIL PRICE COMPARISON

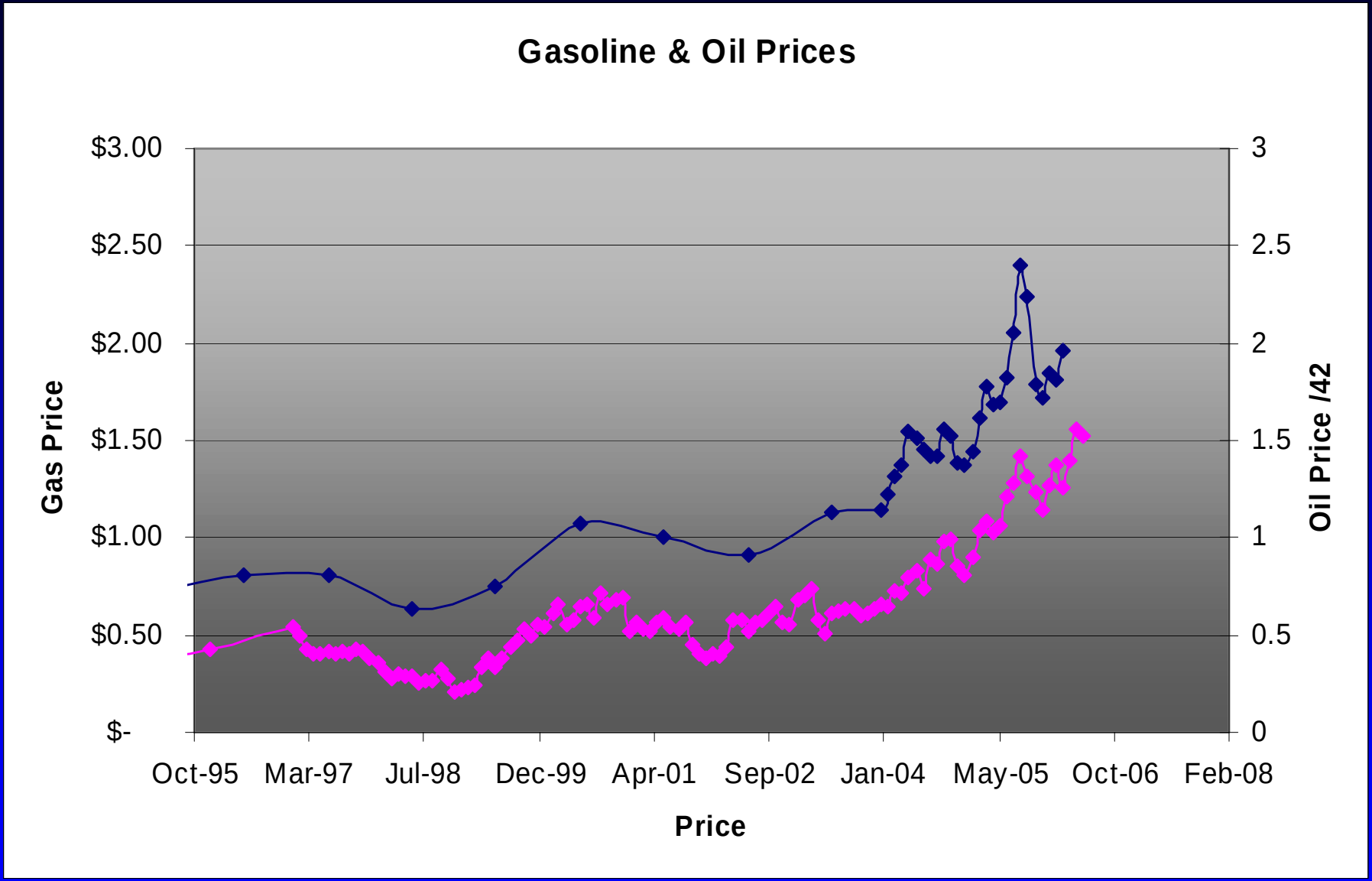
LONG BEACH GAS & OIL DEPARTMENT - OIL OPERATIONS BUREAU

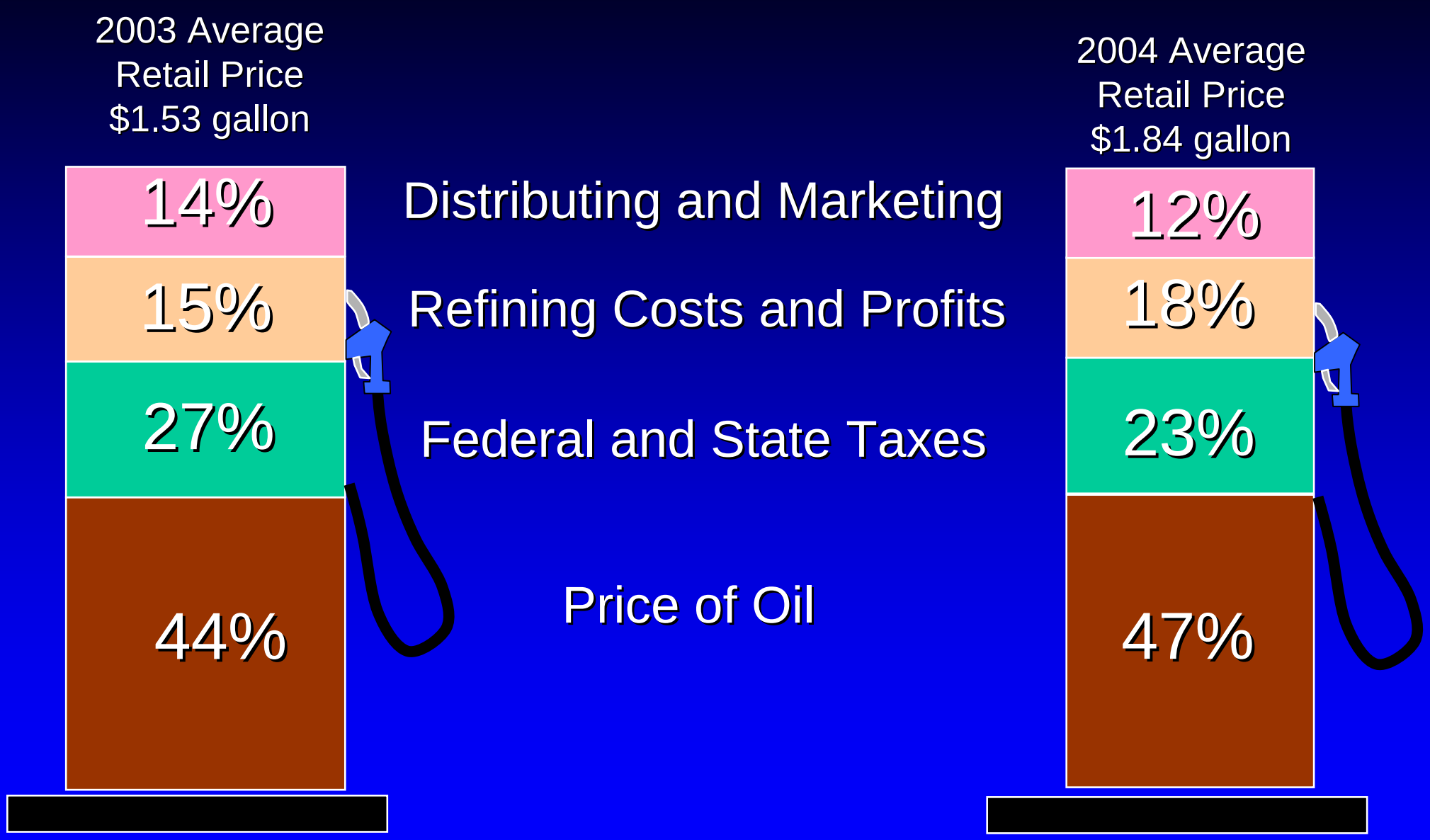


AVERAGE PRICE

	FY02-03	CY2003	FY03-04	CY2004	FY04-05	CY2005	FYTD05-06	CYTD2006
West Texas	$30.30	$30.98	$37.20	$41.44	$53.55	$56.60	$64.36	$66.72
Arab Light	$25.15	$25.90	$30.80	$34.05	$45.51	$49.22	$56.66	$59.87
Wilmington	$21.46	$25.83	$31.00	$33.62	$42.10	$45.75	$54.25	$56.27
High	*$32.25*	*$32.25*	*$39.95*	*$43.20*	*$60.35*	*$60.35*	*$64.10*	*$64.10*
Low	*$19.50*	*$19.50*	*$23.10*	*$28.20*	*$28.20*	*$30.95*	*$46.70*	*$49.15*
Budget	*$17.00*		*$20.00*		*$28.00*		*$40.00*	

PRICE6~1.JPG


Gasoline & Oil Prices
$3.00
$2.50
$2.00
$1.50
$1.00
$0.50
$-
Gas Price
3
2.5
2
1.5
1
0.5
0
Oil Price /42
Oct-95
Mar-97
Jul-98
Dec-99
Apr-01
Sep-02
Jan-04
May-05
Oct-06
Feb-08
Price


2003 Average
Retail Price
$1.53 gallon
2004 Average
Retail Price
$1.84 gallon
14%
15%
27%
44%
12%
18%
23%
47%
Distributing and Marketing
Refining Costs and Profits
Federal and State Taxes
Price of Oil

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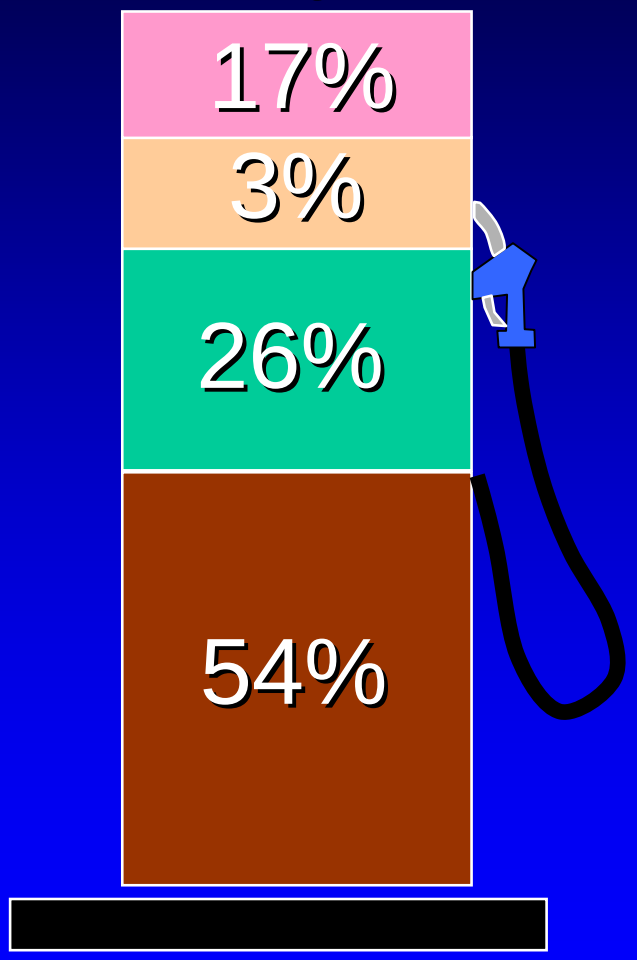
2006 Average
Retail Price
$2.74 gallon

Distributing and Marketing

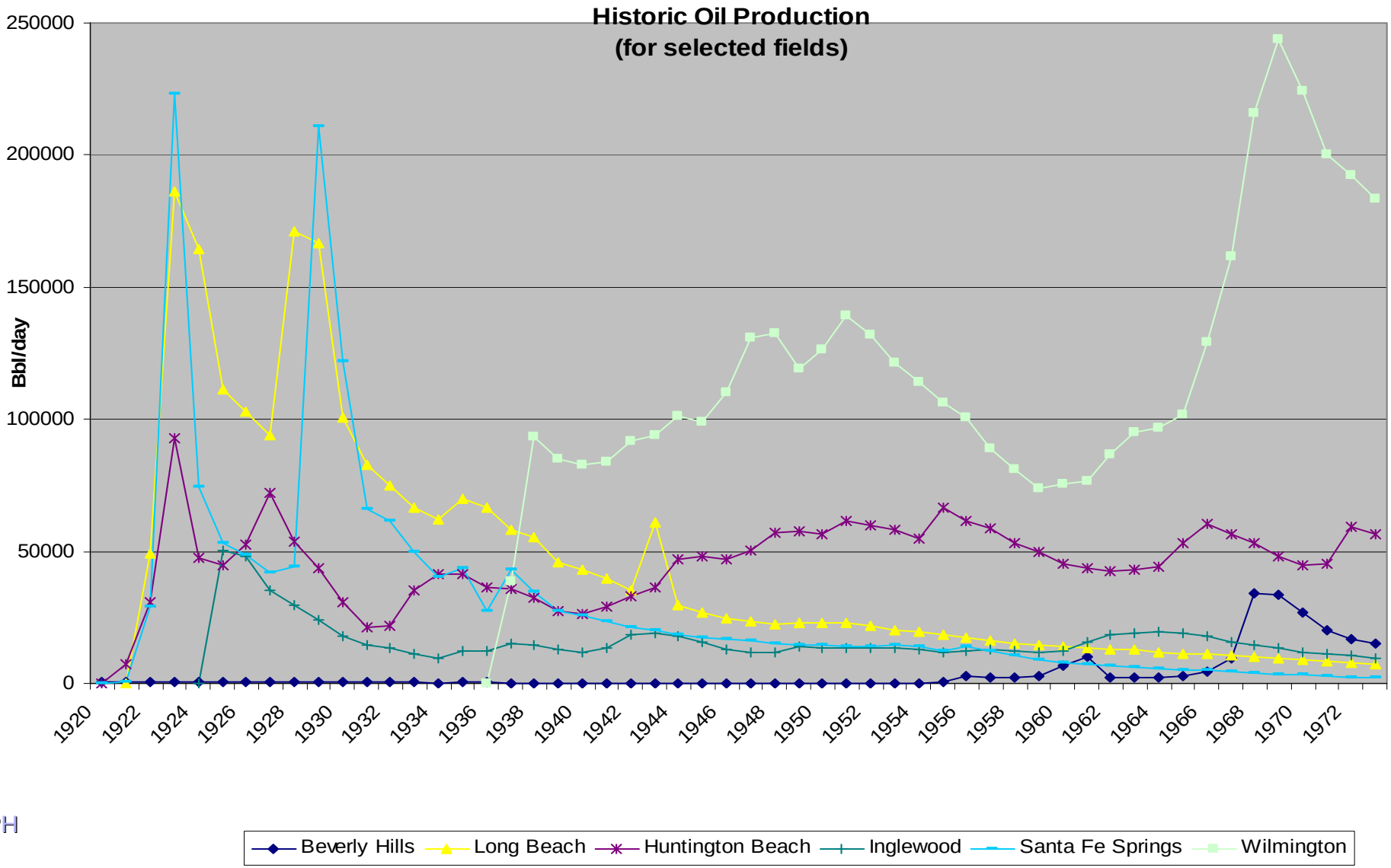
Refining Costs and Profits

Federal and State Taxes

Price of Oil



Oil Production in the LA Basin



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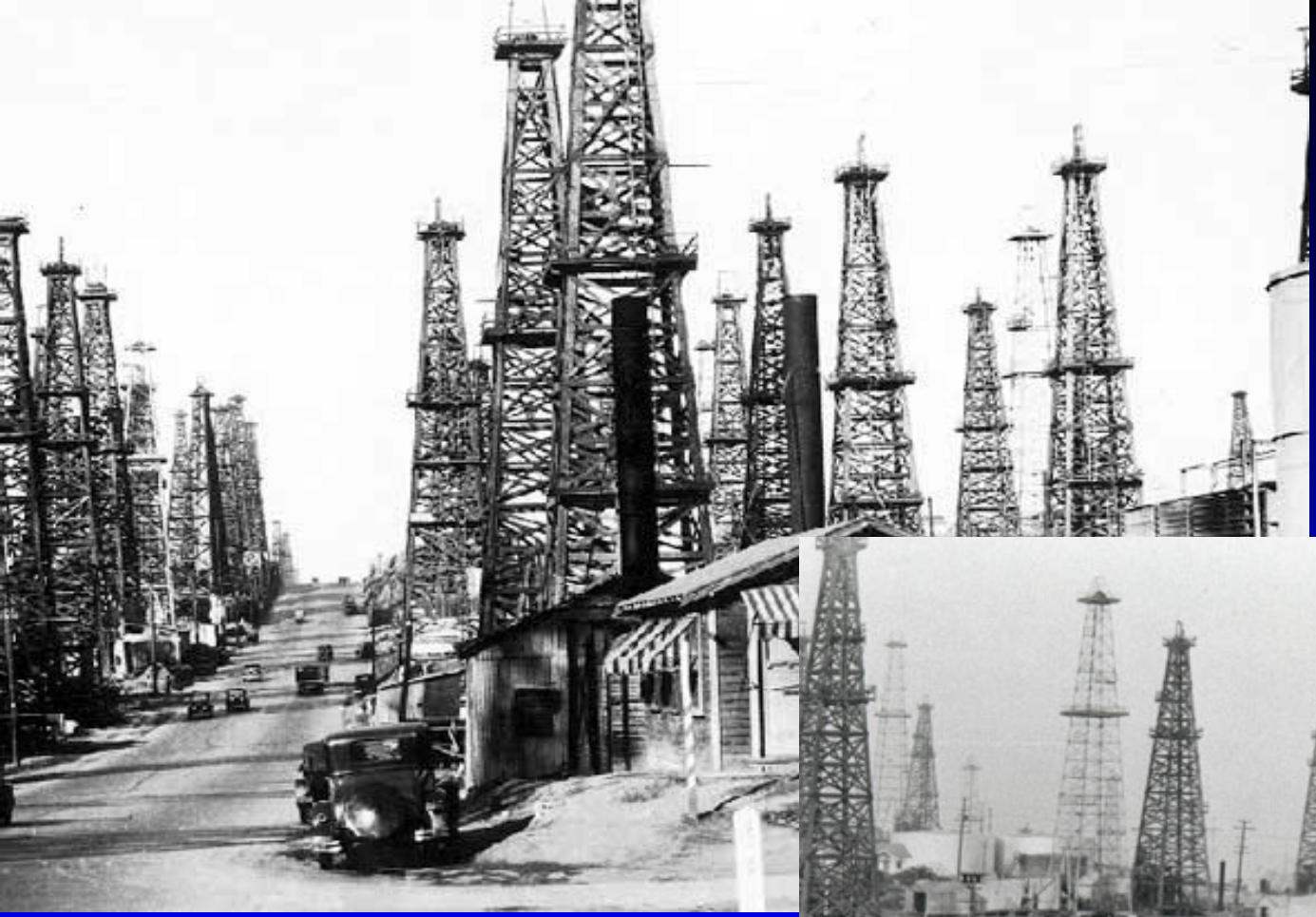

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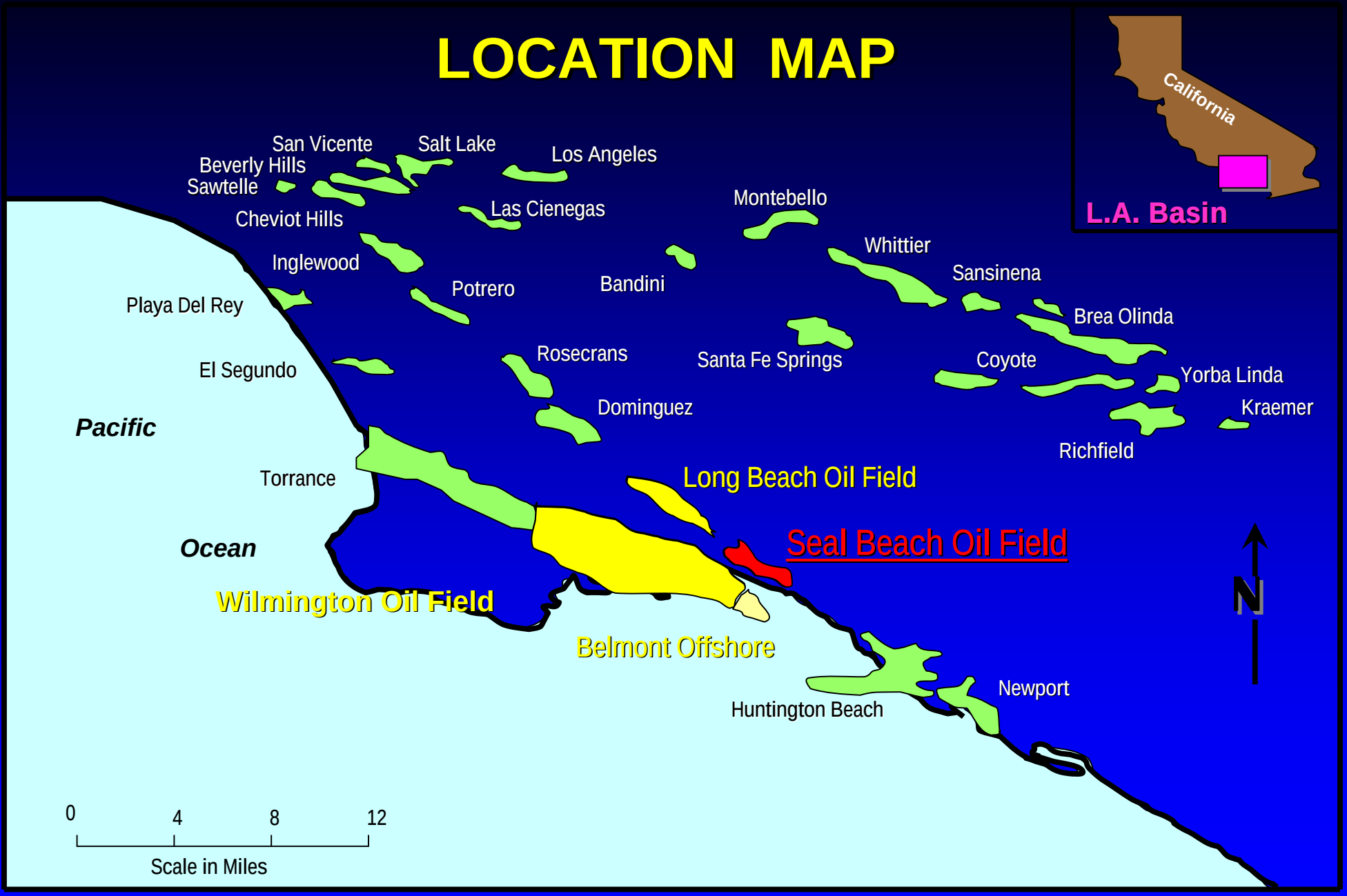
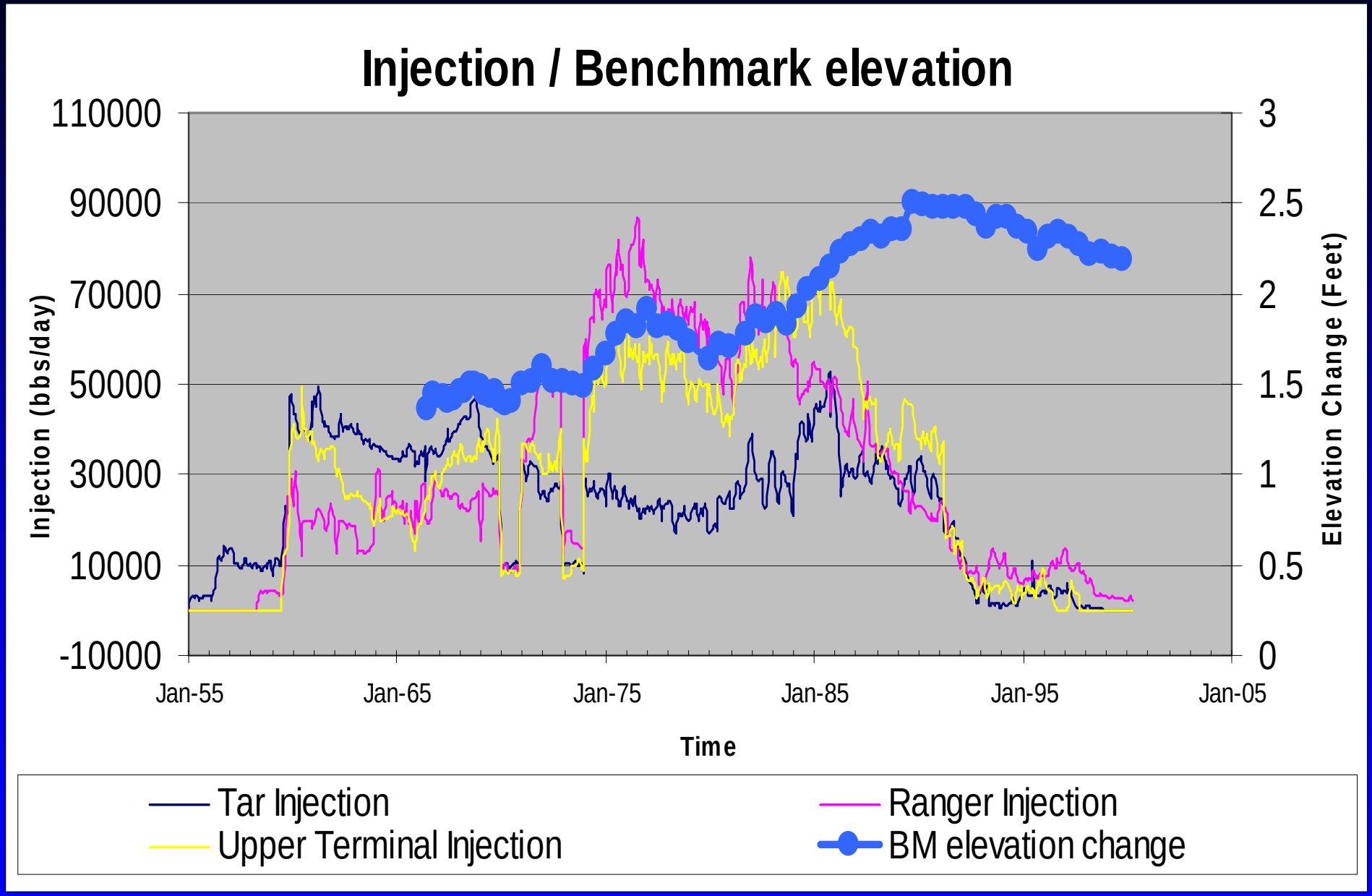
LOCATION MAP




Injection / Benchmark elevation
110000
90000
70000
50000
30000
10000
-10000
Injection (bbs/day)
3
2.5
2
1.5
1
0.5
0
Elevation Change (Feet)
Jan-55
Jan-65
Jan-75
Jan-85
Jan-95
Jan-05
Time
Tar Injection
Ranger Injection
Upper Terminal Injection
BM elevation change

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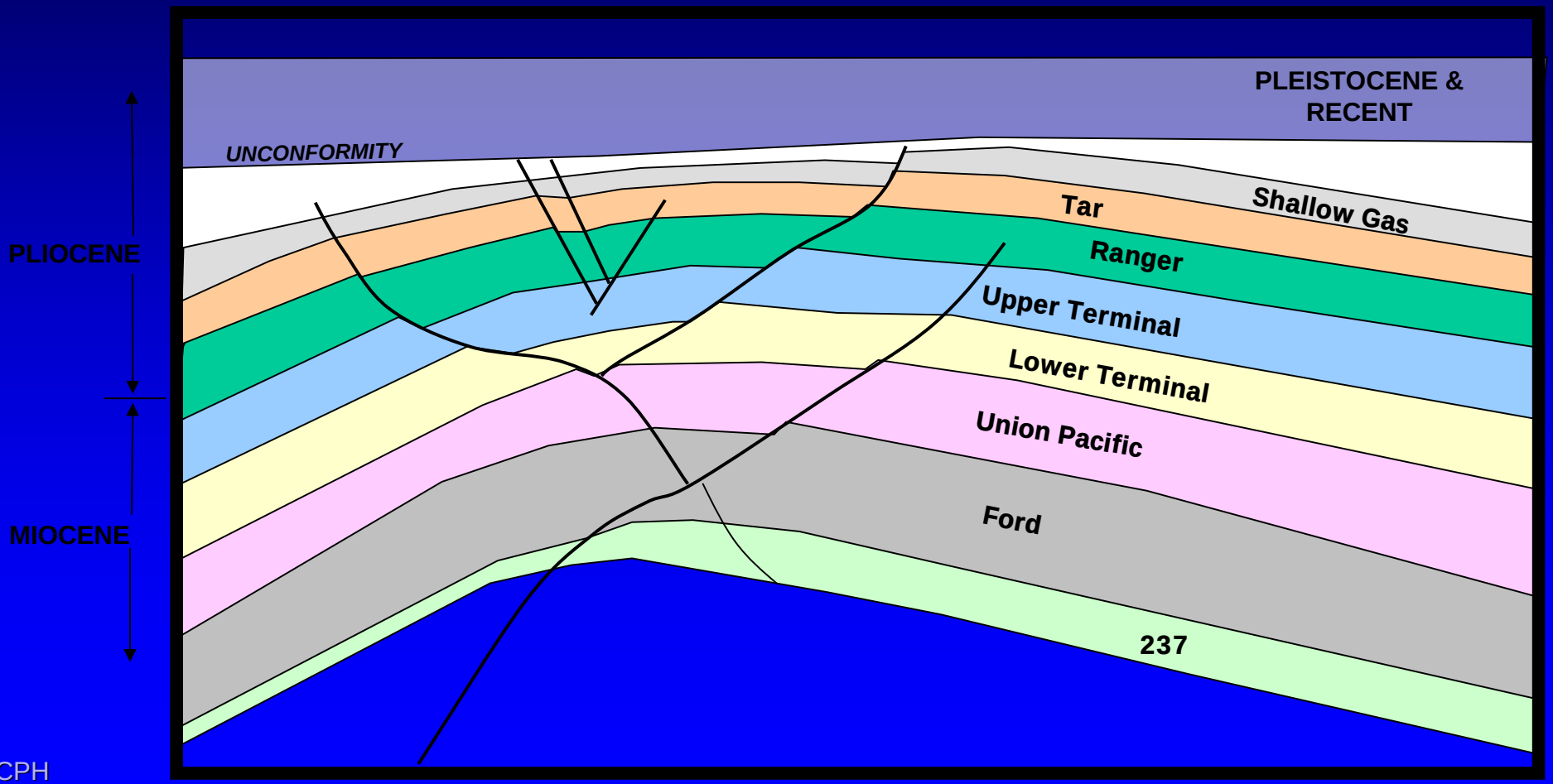
Definition of Problem

NE – SW TRANSVERSE CROSS SECTION



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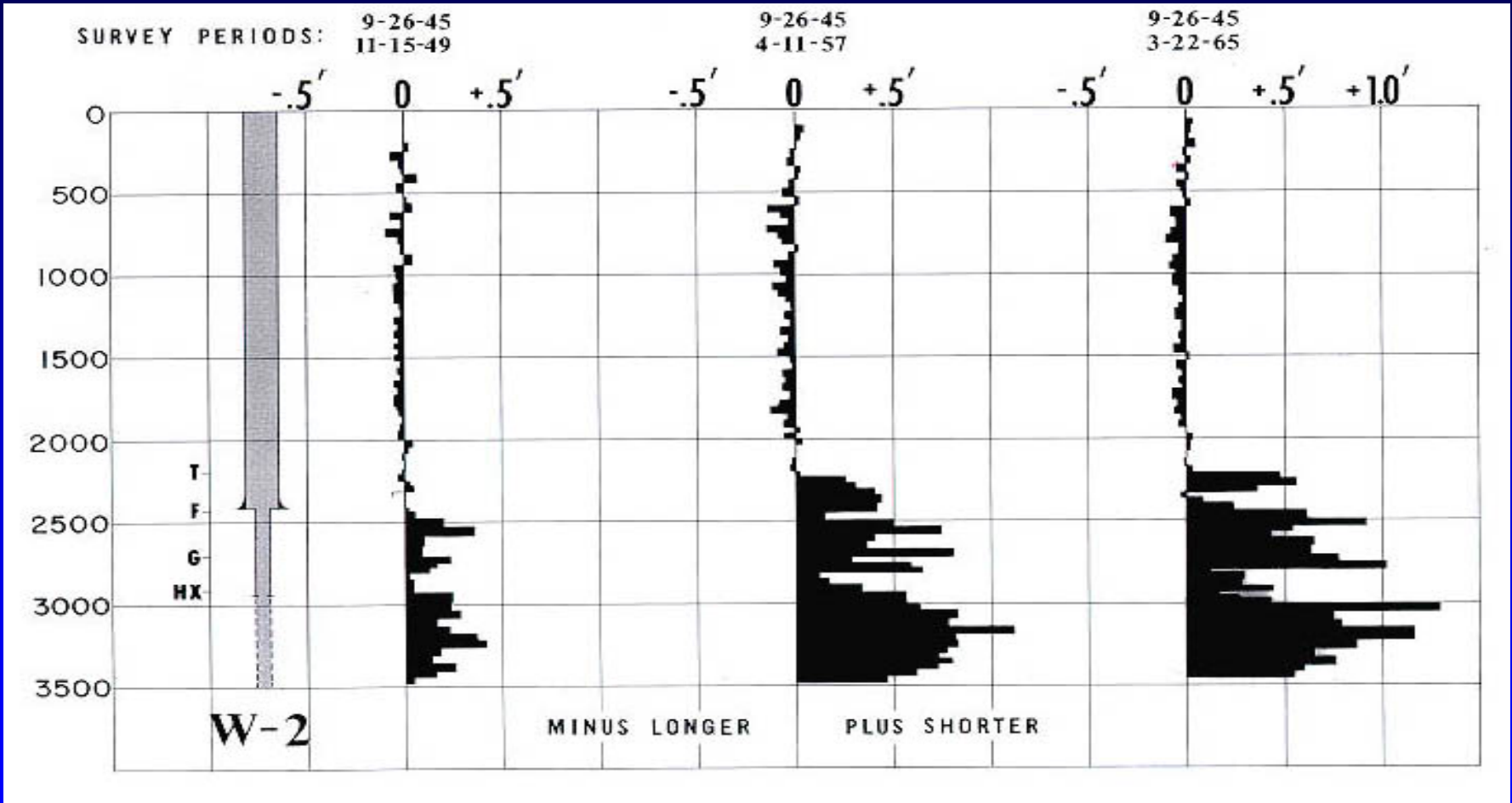
Location of Compacting Strata

- Direct measurement
  - Collar counting
    - Locate the recessed area between coupled casing joints in oil wells with a magnetic locator connected to a cable odometer at the surface
    - Determine casing joint lengths by the difference between collar locations
    - Compare current joint lengths with original lengths and those measured in prior collar surveys

Identification of Compacting Strata

- Casing joints
  - 14 meters in length
    - Shortened as much as 36 cm.
- Varying compaction measured in Tar, Ranger, Upper Terminal, and Lower Terminal zones.

Joint Length changes Over Time as a Function of Depth and Zone



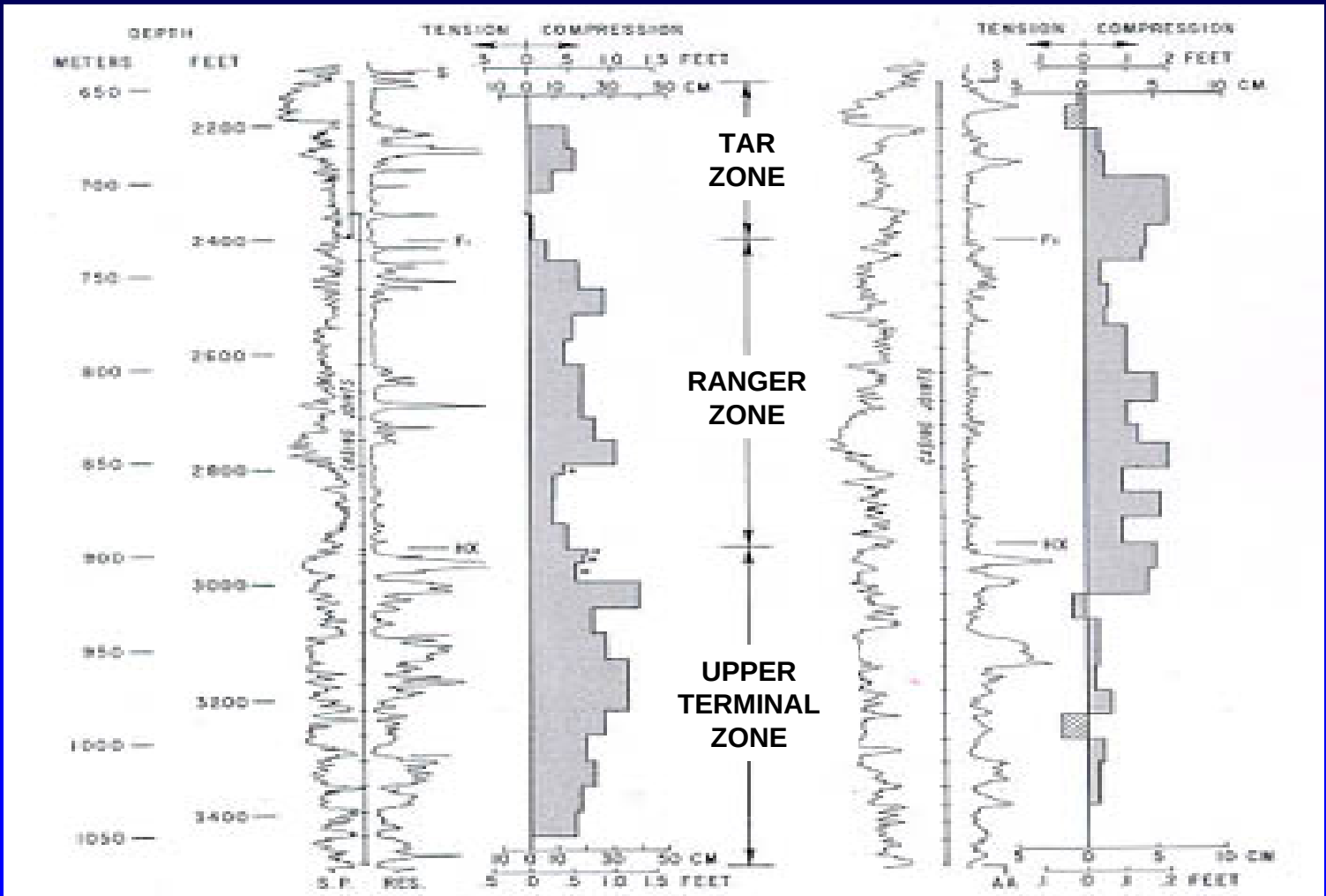
Casing Compression Near Center Of Maximum Subsidence

Well W-2

11-45 to 3-65

Well W-279

3-59 to 3-65



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Prerequisites for Subsidence

- Reservoir fluid pressures must be lowered.
- Reservoir rocks must be compactable (un-cemented) and unable to effectively resist deformation upon a transfer of load from the fluid phase to the grain and grain contacts.
- Overburden must lack internal self support.
  - Cannot support itself in place without support from the compacting underlying rock.

If Conditions Are Meet

- The closer the compacting reservoir rock is to the surface the larger the impact.
- The larger the area of reservoir affected, the larger the area affect at surface.
- The greater the amount of compaction in the reservoir, the greater the surface impact
- Results
  - Increase in the grain to grain pressure as fluid pressures are lowered
  - Consolidation and compaction of reservoir rock
  - Surface subsides as overburden deforms downward