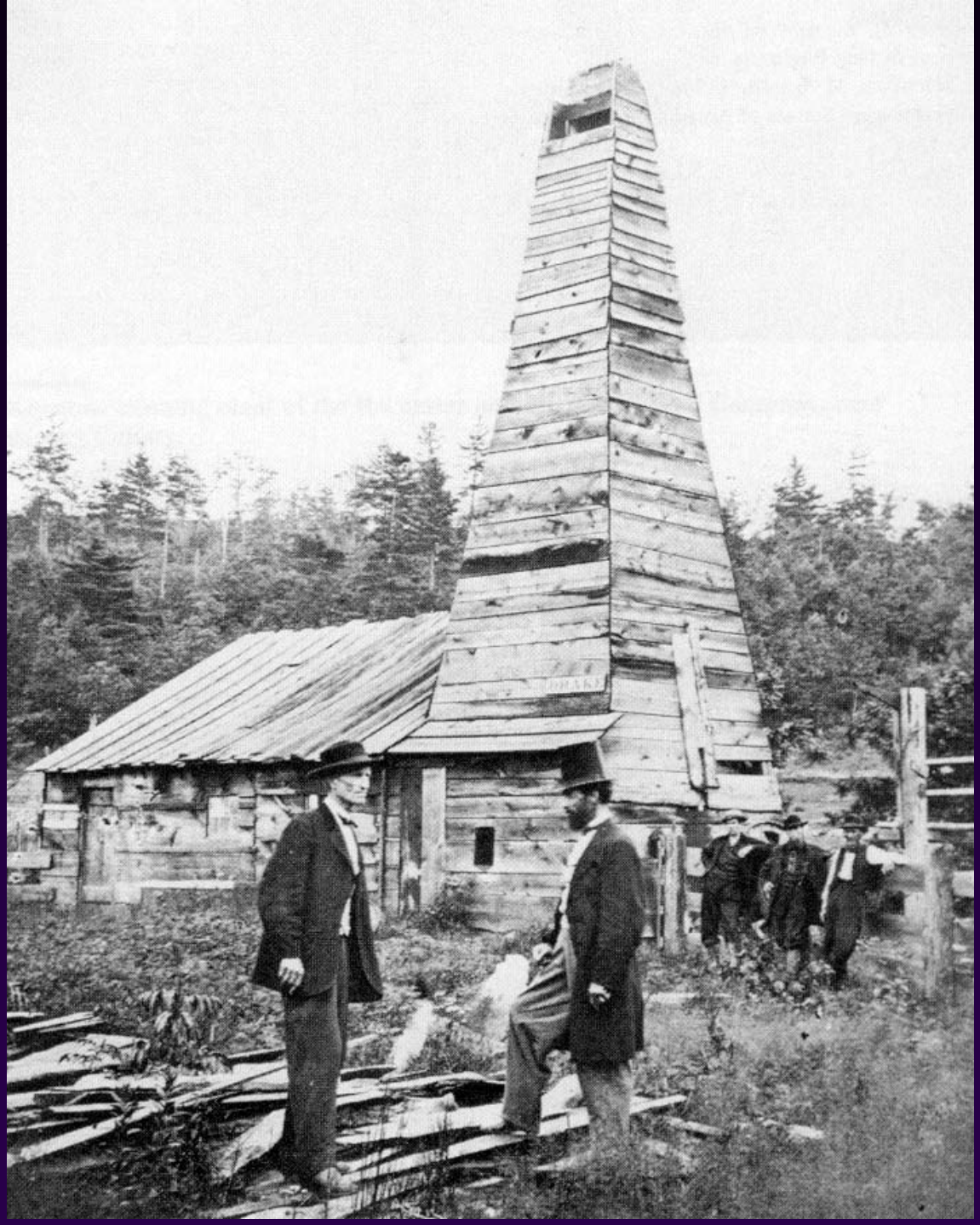
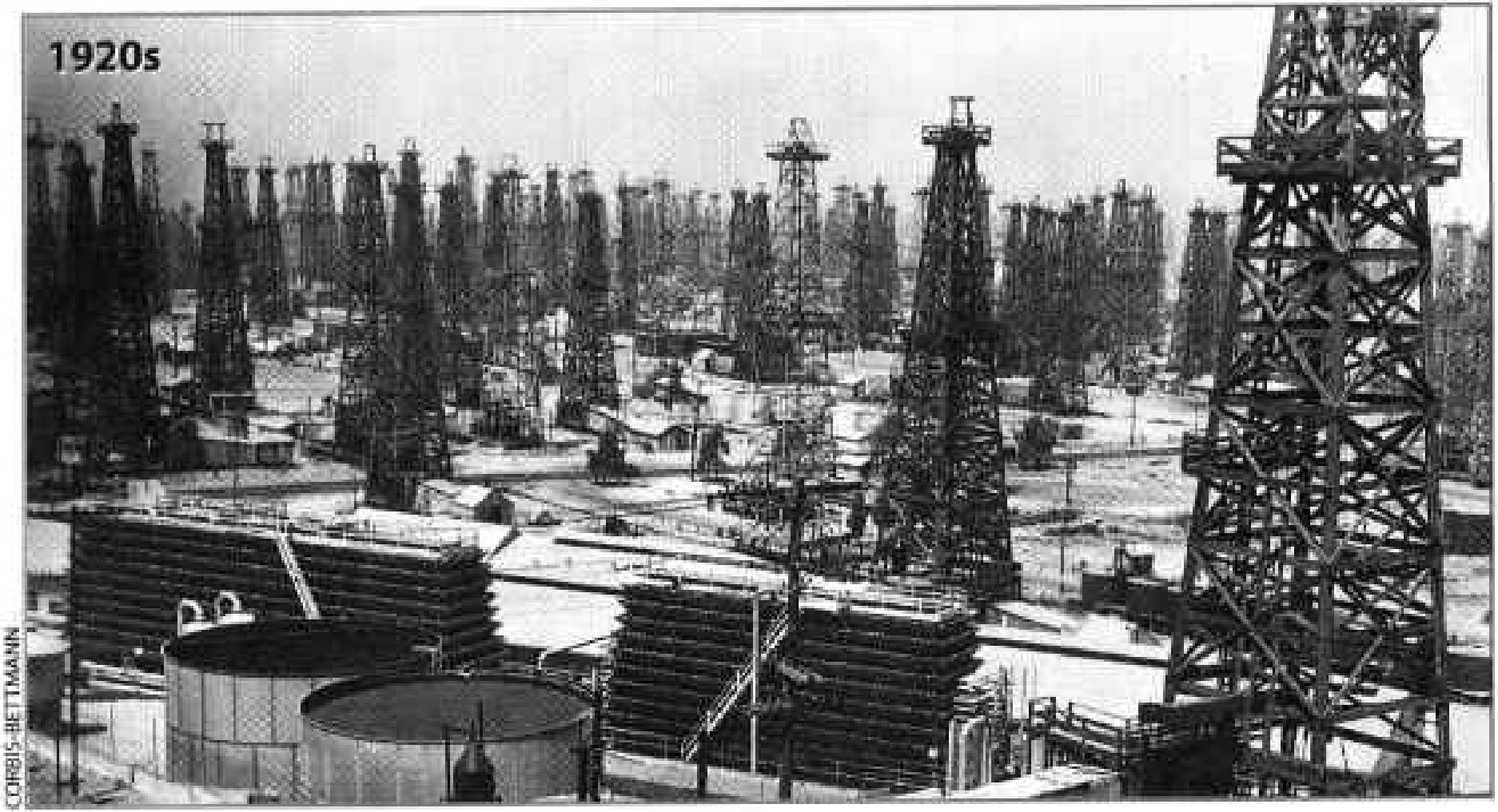
Outline 16:
The Mesozoic World:
Formation of Oil Deposits
(with a side trip to the Devonian Marcellus Shale)

The first commercial oil well was drilled by “Colonel” Edwin Drake in Titusville, Pennsylvania, in 1859.

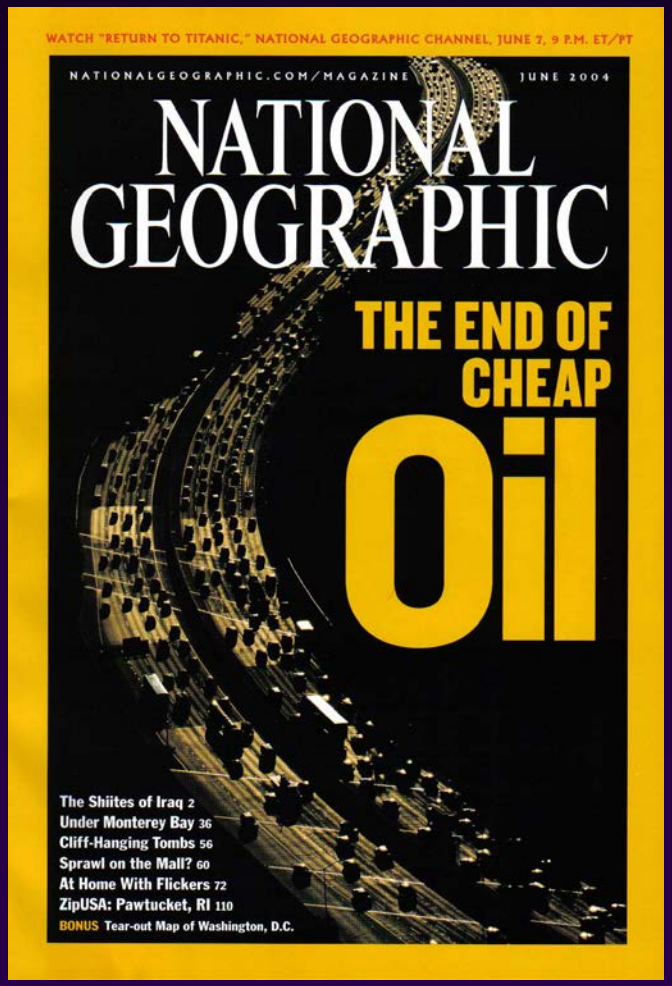


Los Angeles in the 1920s

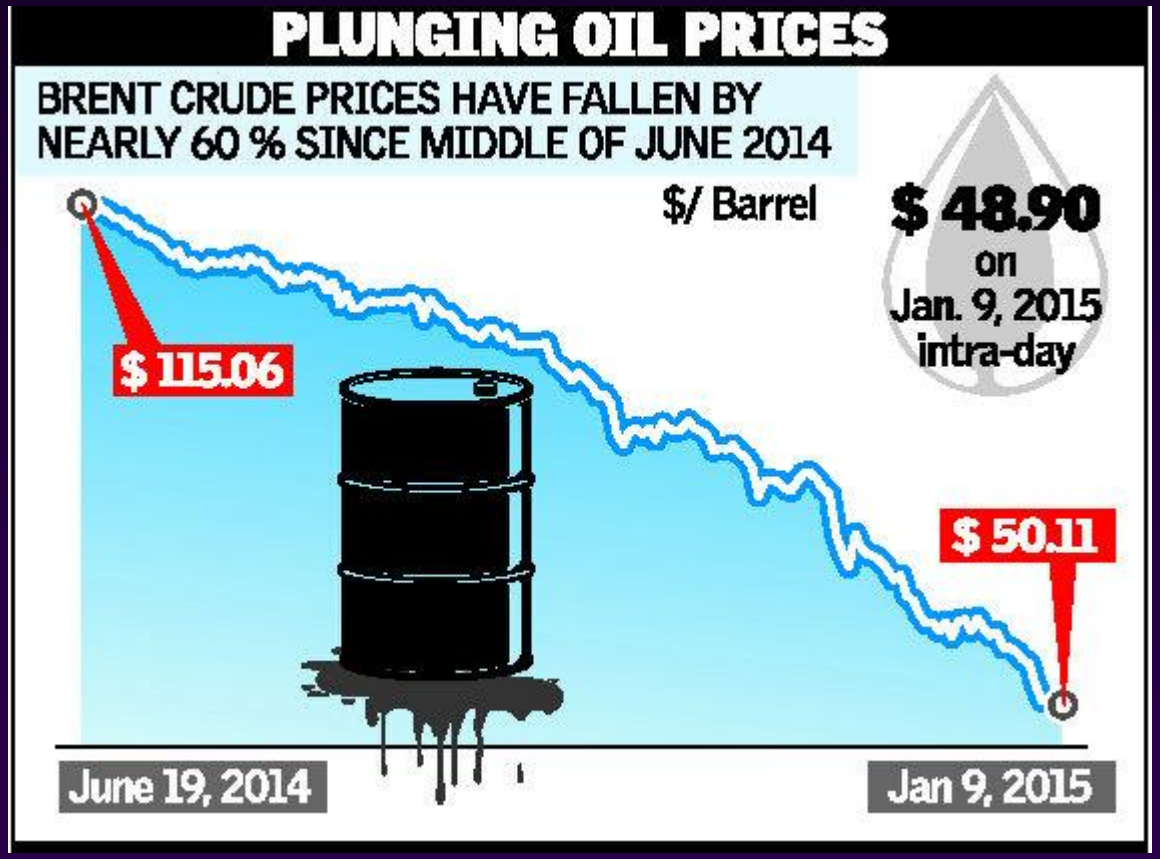


Are we running out of oil, or not? What happened between these years?

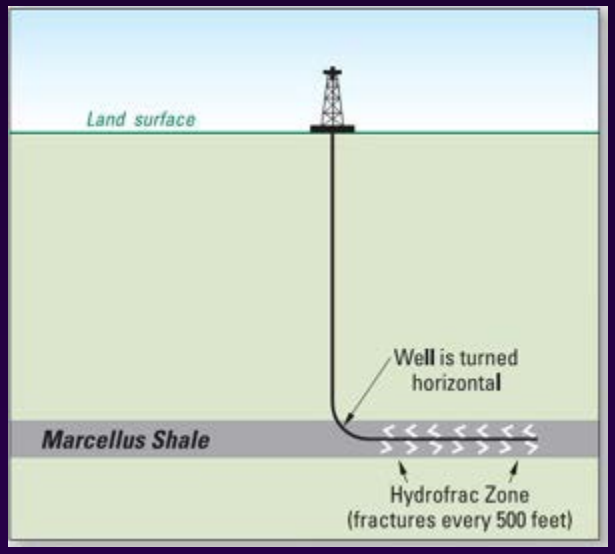
2004



2015



Horizontal Drilling and Hydrofracking



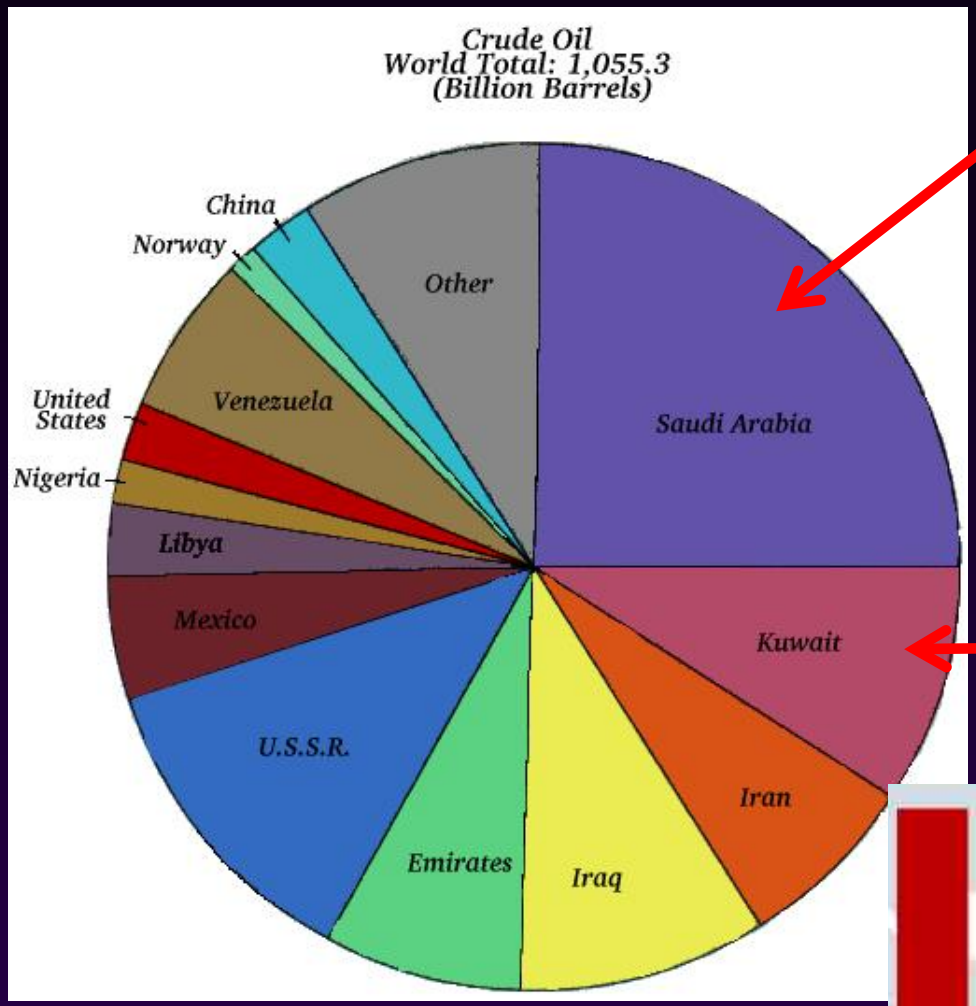
We will come back to this.

Facts about Oil Deposits

- 70% are Mesozoic in age
- 20% are Cenozoic in age
- 10% are Paleozoic in age
- What's so special about the Mesozoic?

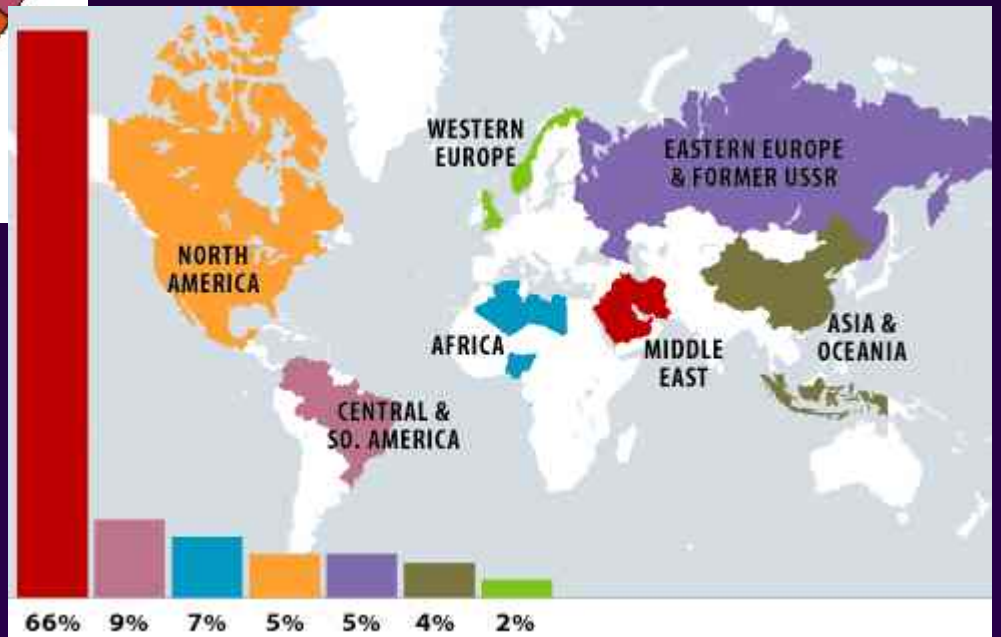
Facts about Oil Deposits

- The majority of the world's oil reserves are in the Middle East around the Persian Gulf.
- What's so special about the Persian Gulf area?



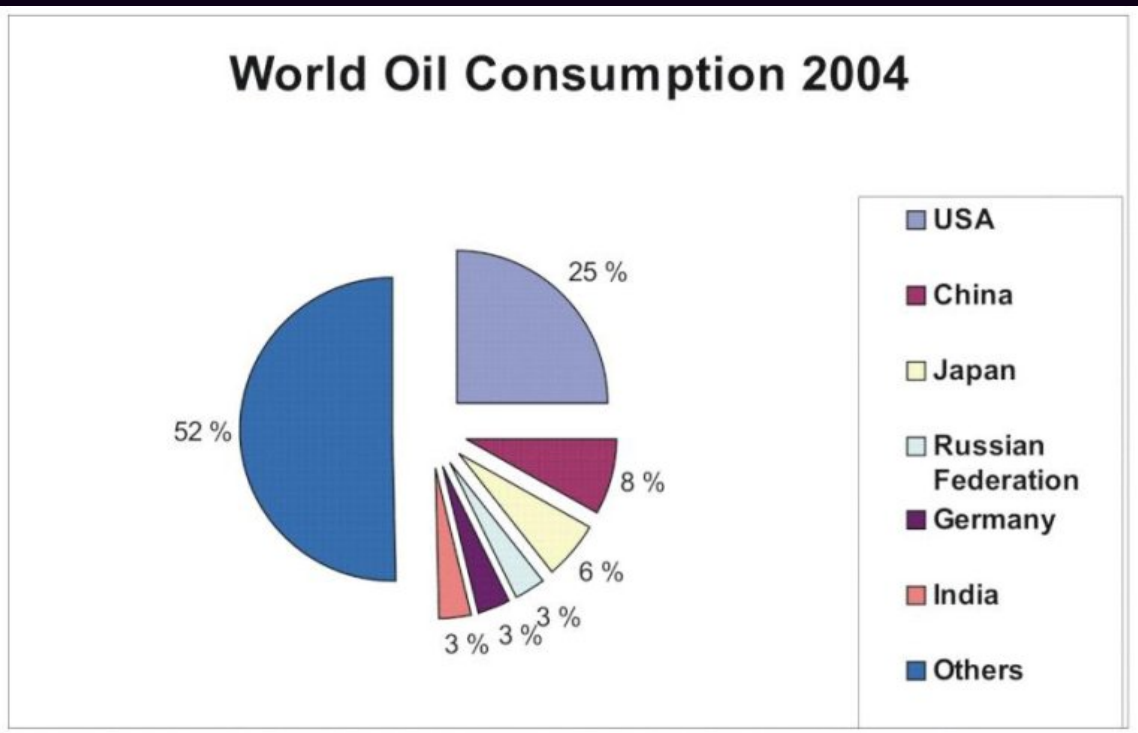
Less than 10% of the population of USA

Less than 1% of the population of USA



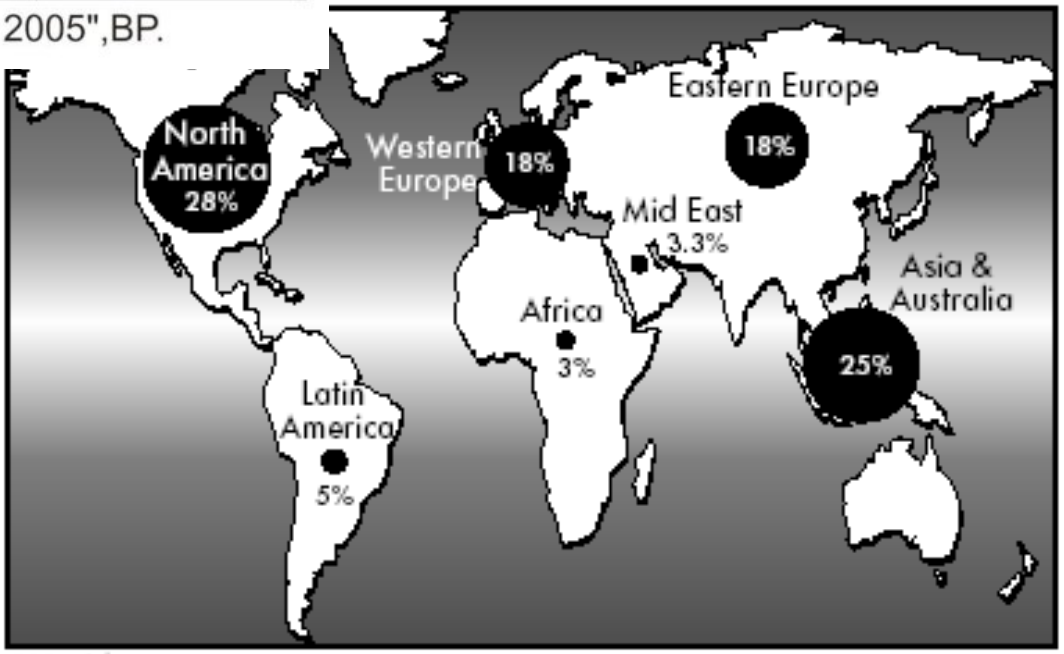
Conventional Oil Reserves

Consumption



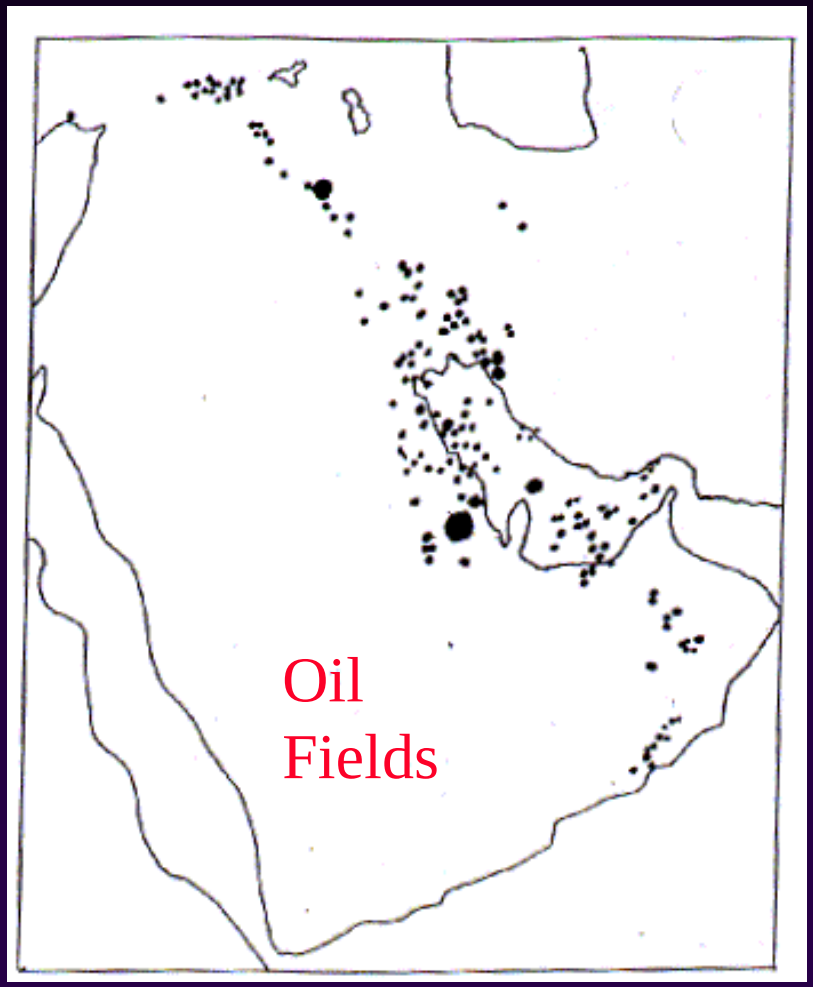
Source: "Statistical Review of World Energy 2005",BP.

If India or China consumed at the same rate as the U.S., that would use the total available world oil supply!



World energy consumption


0 100 200 300 mi
0 200 400 km
TURKEY
TURKMENISTAN
Caspian Sea
SYRIA
Karkuk
IRAN
IRAQ
JORDAN
Ahvāz
Marūn
Majnūn
Āghā Jārī
Al-Rumaylah North
Al-Rumaylah
Gach Sārān
Al-Rawdatayn
KUWAIT
ARABIAN-IRANIAN BASIN
ZAGROS FOLD BELT
Persian Gulf
Al-Buqān
Al-Zuluf
Saffāniyyah
Manīfah
Al-Qatīf
Al-Barrī
Abu Sa'fah
Abqaiq
QATAR
Umm Al-Shā'if
Khurayṣ
Gulf of Oman
Al-Ghawār
Al-Zakum
UNITED ARAB EMIRATES
Būḥaṣā
SAUDI ARABIA
Al-Shabah
Red Sea
OMAN
ERITREA
YEMEN
Arabian Sea
ETHIOPIA
DJIBOUTI
Gulf of Aden
Supergiant oil fields
©2004 Encyclopaedia Britannica, Inc.


Oil Fields

Oil Reserves:
1 trillion barrels (2007)

- Saudi Arabia 20%
- Iran 10%
- Iraq 9%
- Kuwait 8%
- UAE 7%
- Other 1%
- Middle East 55%

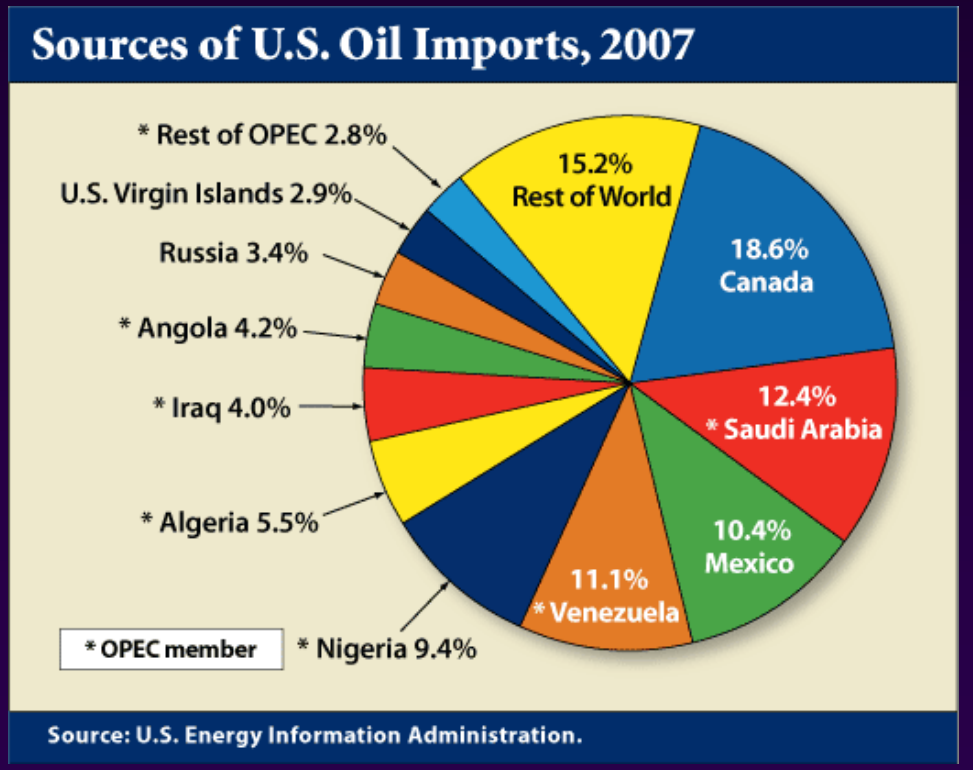
- Asia/Australia 8%
- South America 7%
- Africa 7%
- Russia 5%
- Europe 1%
- USA 2%
- Canada/Mexico 15%

(USA consumes 25% of world oil)

Alberta Tar Sands – a major source of oil at high prices for the Keystone Pipeline

Major U.S. Oil Suppliers, 2010
(We import 55% of our oil)

- Canada, 28%
- Mexico, 13%
- Nigeria, 11%
- Saudi Arabia, 10%
- Venezuela, 9%
- Algeria, 6%
- Russia, 4%



How long will the reserves last?

Current annual worldwide consumption is 25 billion barrels (BB) per year. Divide that into the 2007 reserves:

$$\frac{1{,}000{,}000{,}000{,}000 \text{ barrels}}{25{,}000{,}000{,}000 \text{ barrels/yr}} = 40 \text{ years!!!}$$

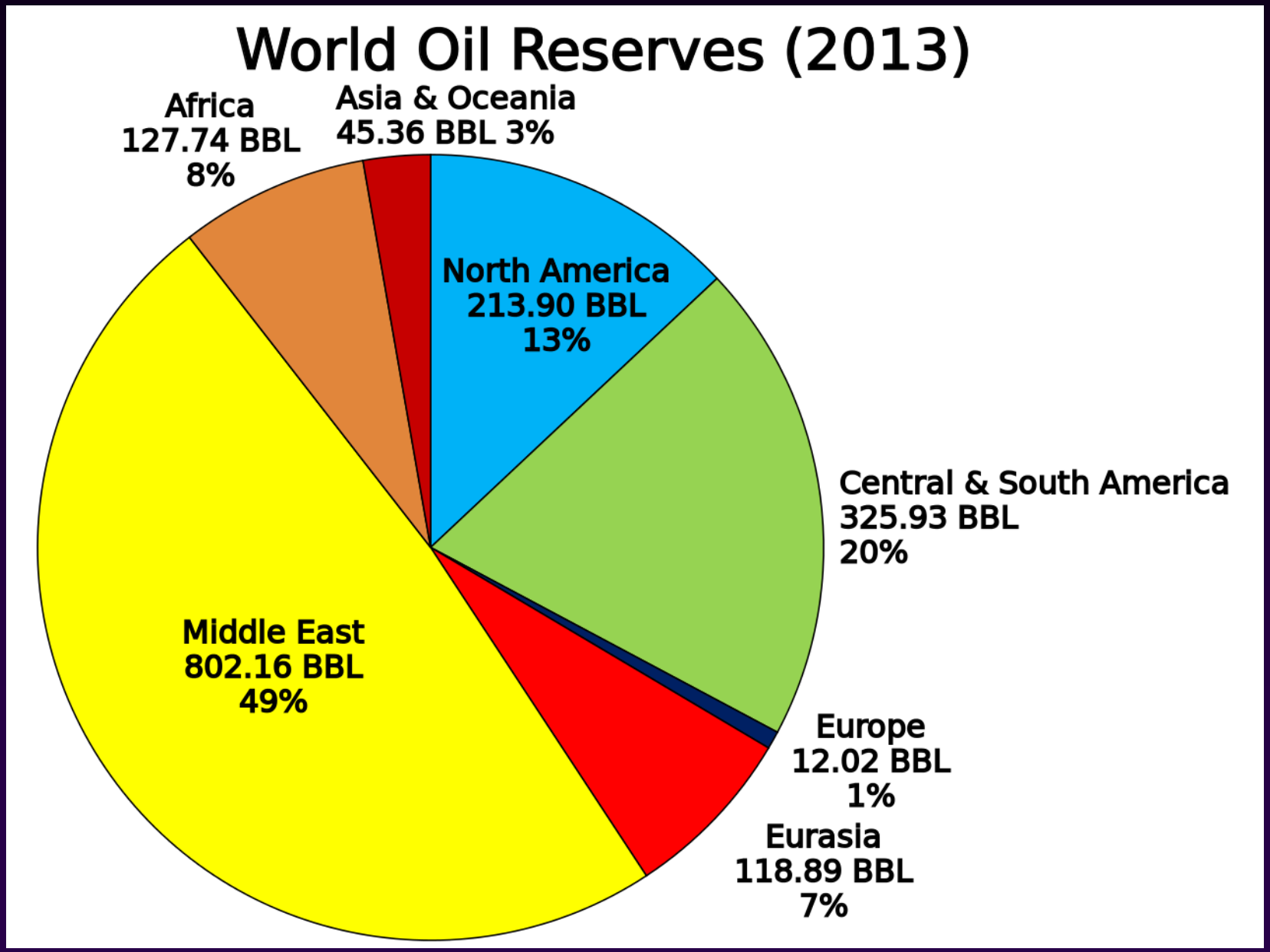
(70MB/day)

This assumes no increased consumption and no new discoveries.

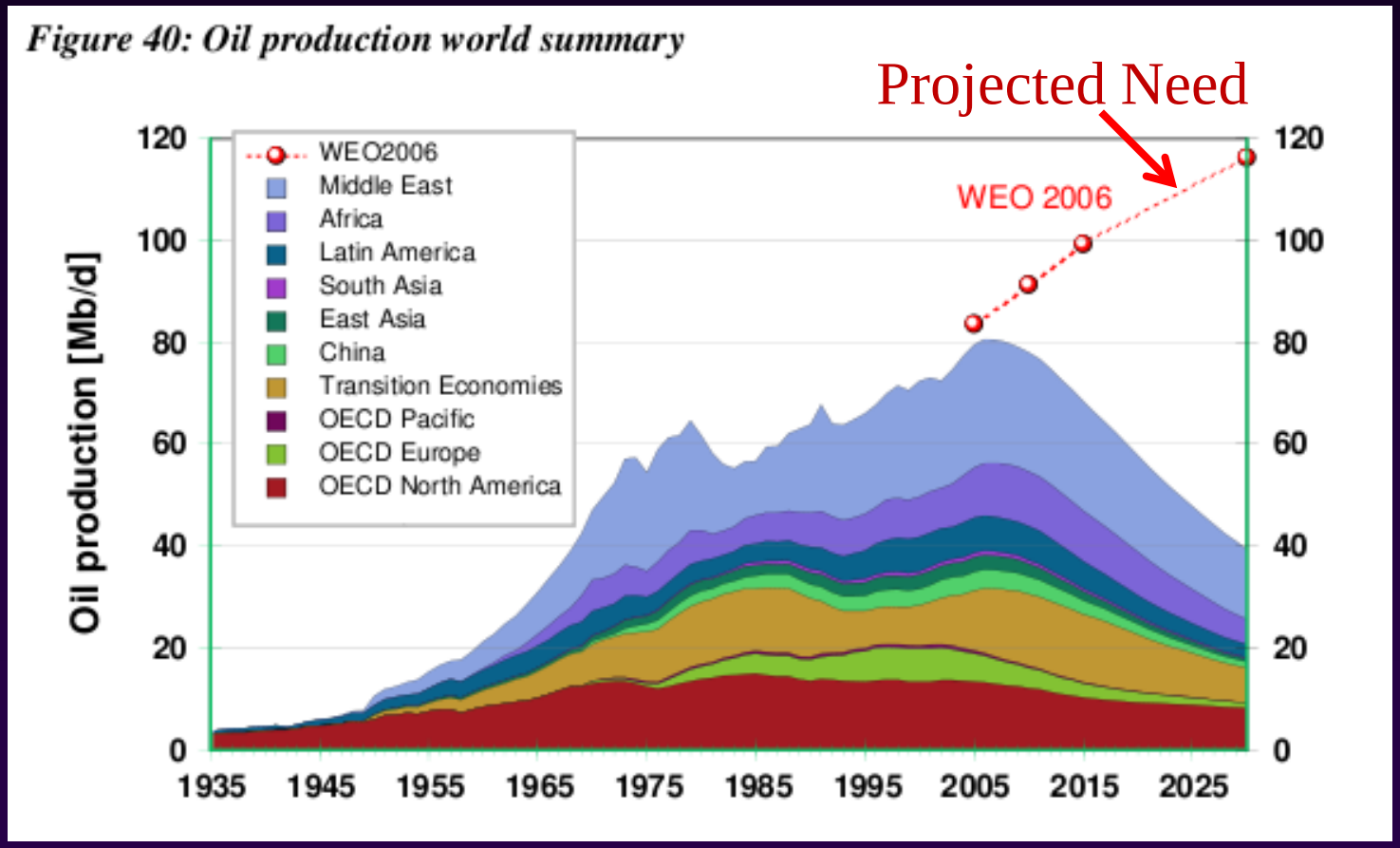
How much oil is undiscovered?

- Hard to know, but scientific estimates in 1996 suggest that 2/3 of commercial oil have already been found. Estimates in 2000 suggest only ½ has been found.
- The remaining oil will be harder to find and will require the abilities of talented geologists.
- Horizontal drilling is a game changer. Previous estimates are being revised upwards.

Reserves calculated to be 1.6 Trillion barrels in 2013



Is Oil Production near its Peak? Probably not.

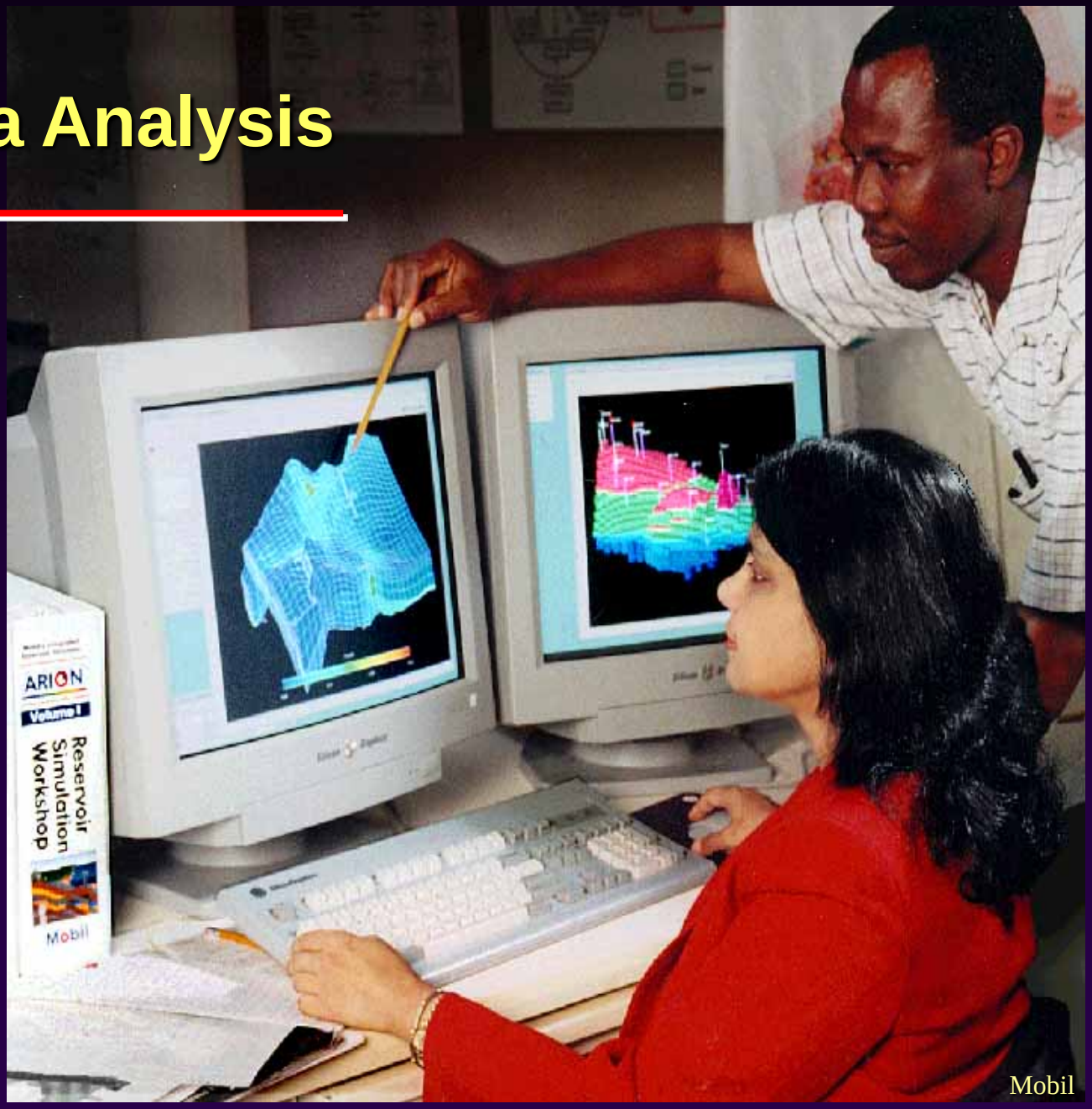


Geologic Mapping and Sampling

- Gravity
- Magnetics
- Seismic Reflection
- Geologic Mapping

American Petroleum Institute, 1986

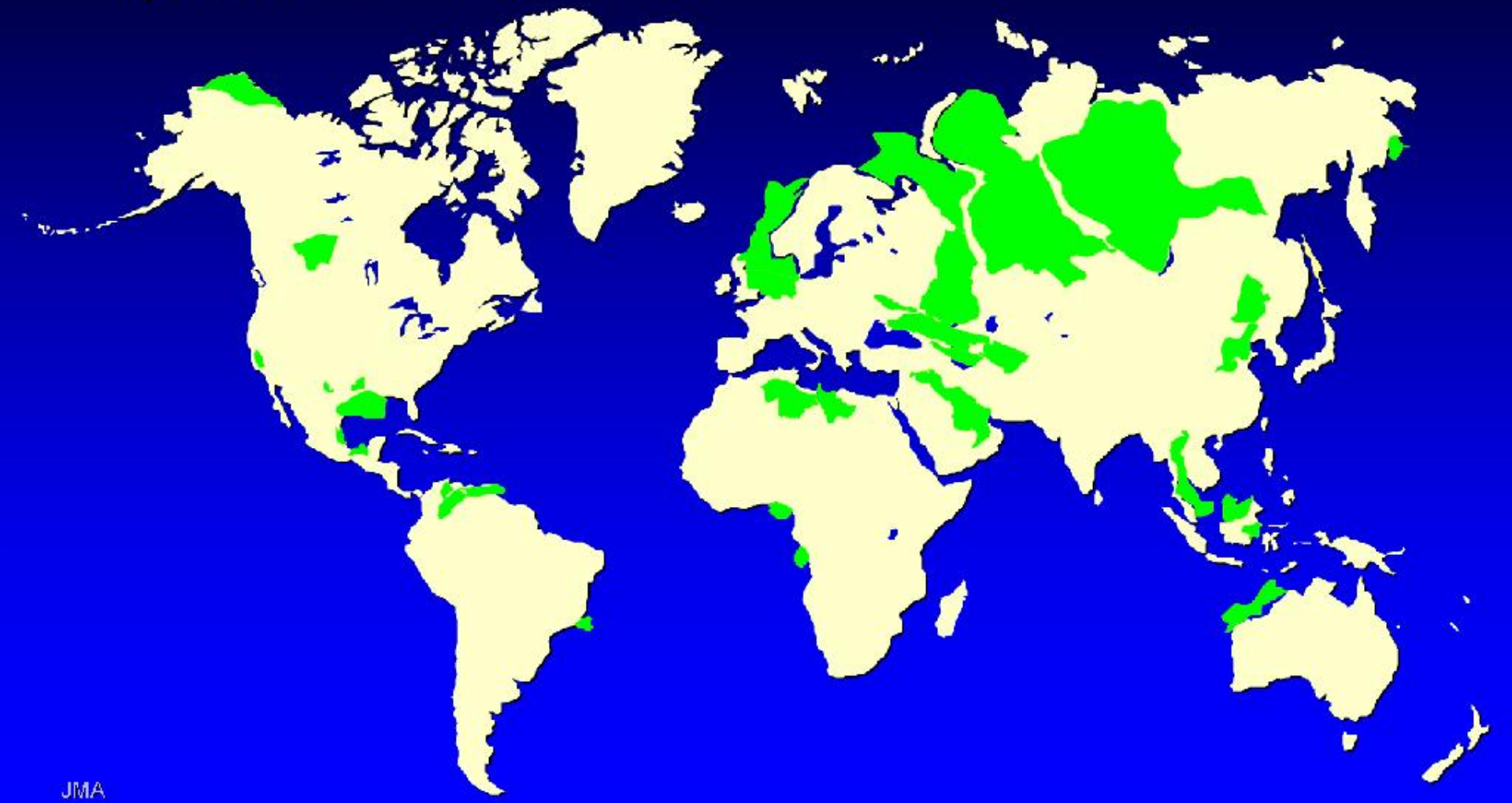
Geologic Data Analysis



Mobil

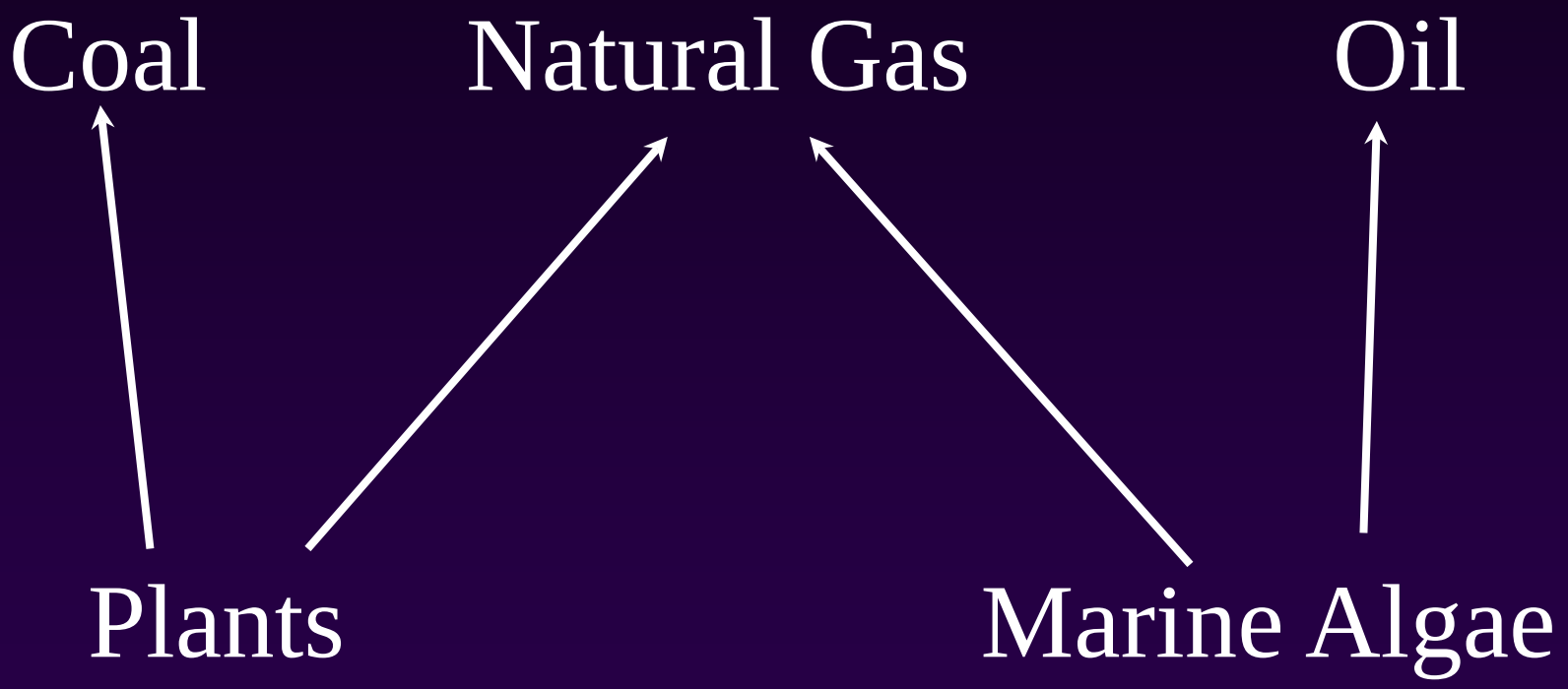
Largest Hydrocarbon Basins

by Ultimate Potential

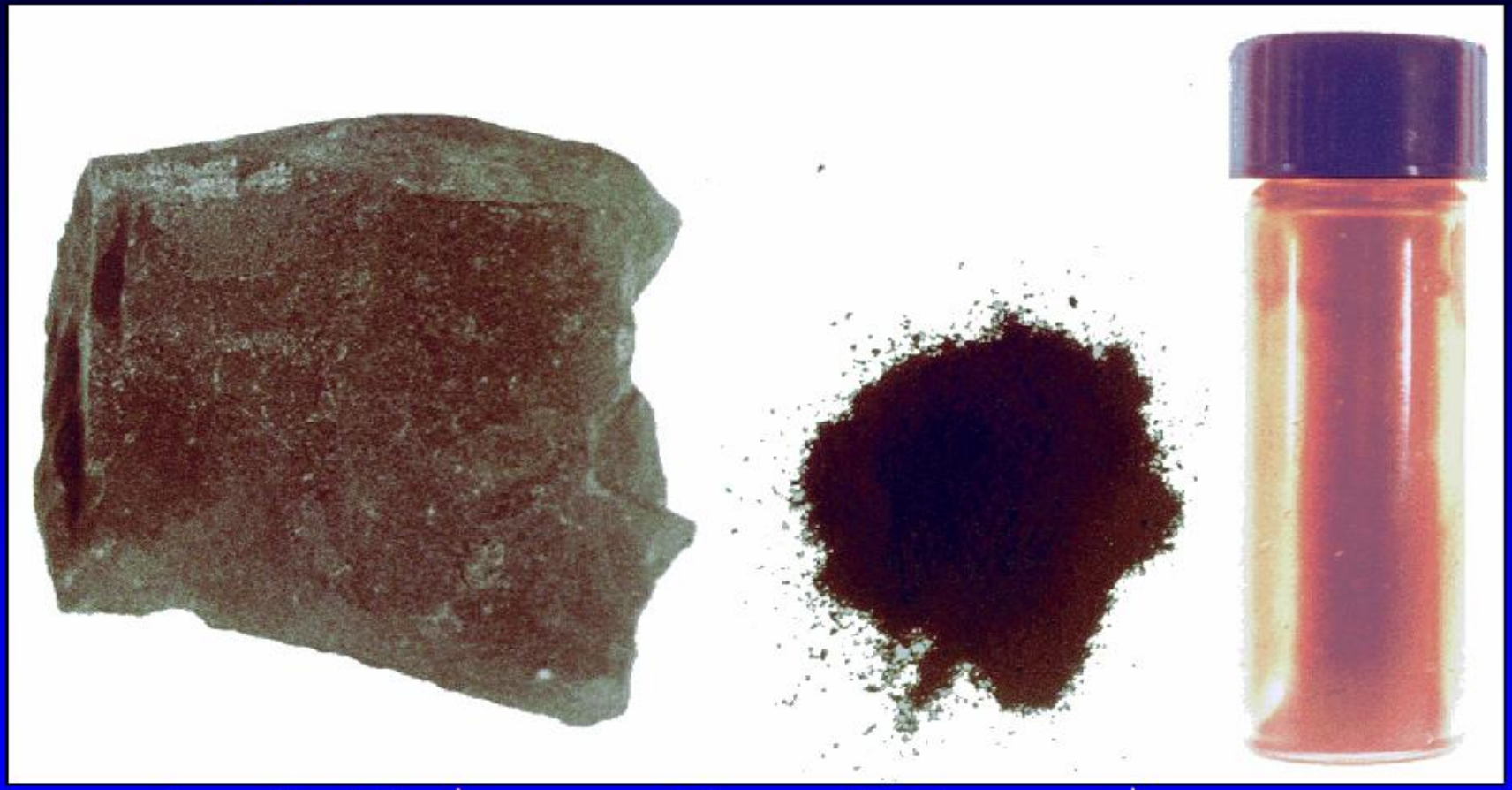


JMA

Origin of Fossil Fuels



The Origin of Petroleum



Organic-rich Source Rock → Thermally Matured Organic Matter → Oil

JMA

Source Rock for Petroleum

LOMPOC Quarry Sample
Monterey Formation, CA

Measured Values

Total Organic Carbon	Hydrogen Index
3.39	378

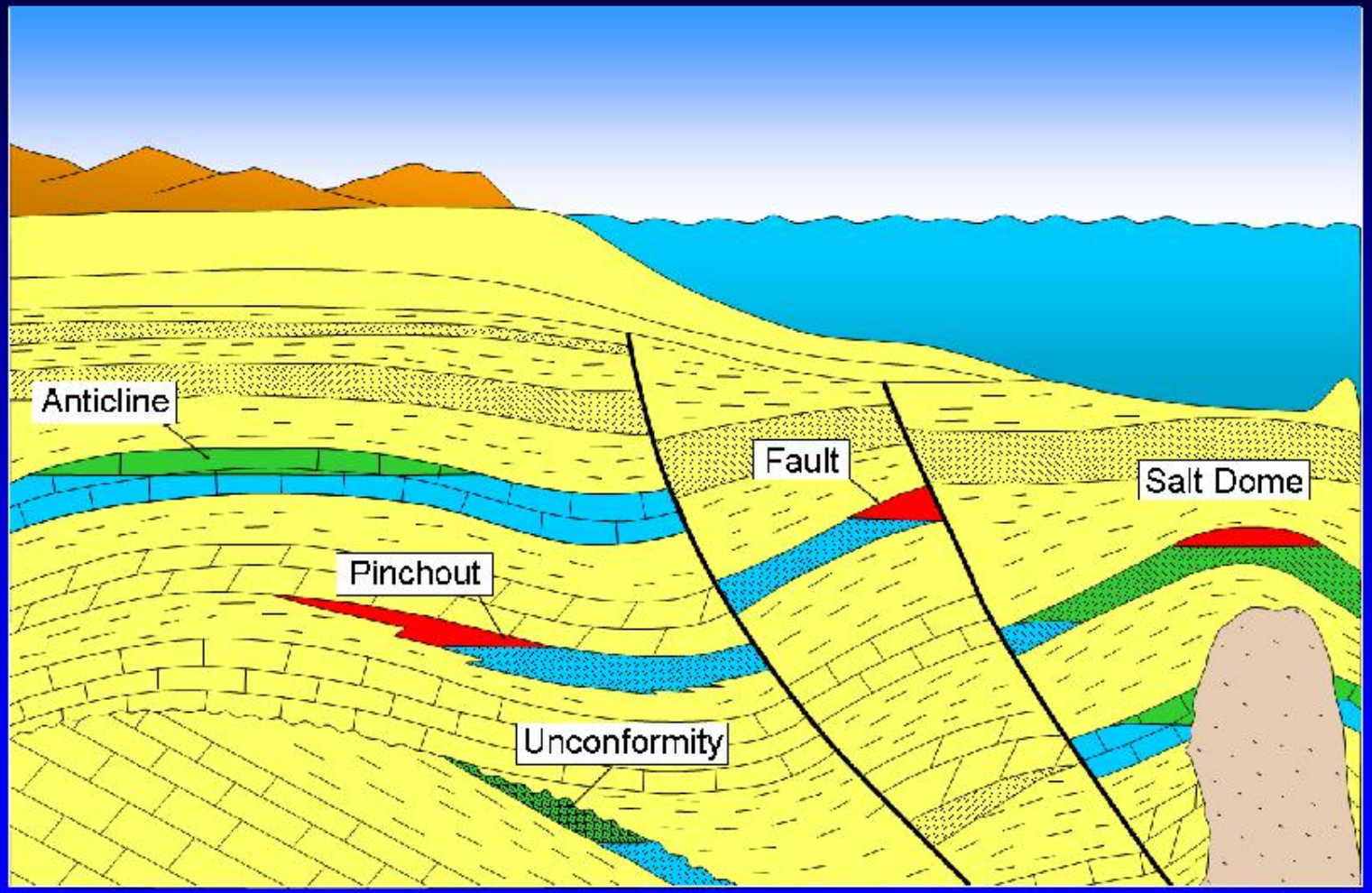
In-Place Petroleum S_1	Pyrolytically Generated Petroleum S_2
2.24	12.80

JMA

Production of Oil and Gas

1. Need source materials: marine plankton
2. Burial of source materials to “cook” it.
3. Reservoir rock: porous sandstone or limestone (reefs)
4. Seal for reservoir: shale or salt
5. Trap: a structural trap or a facies trap.

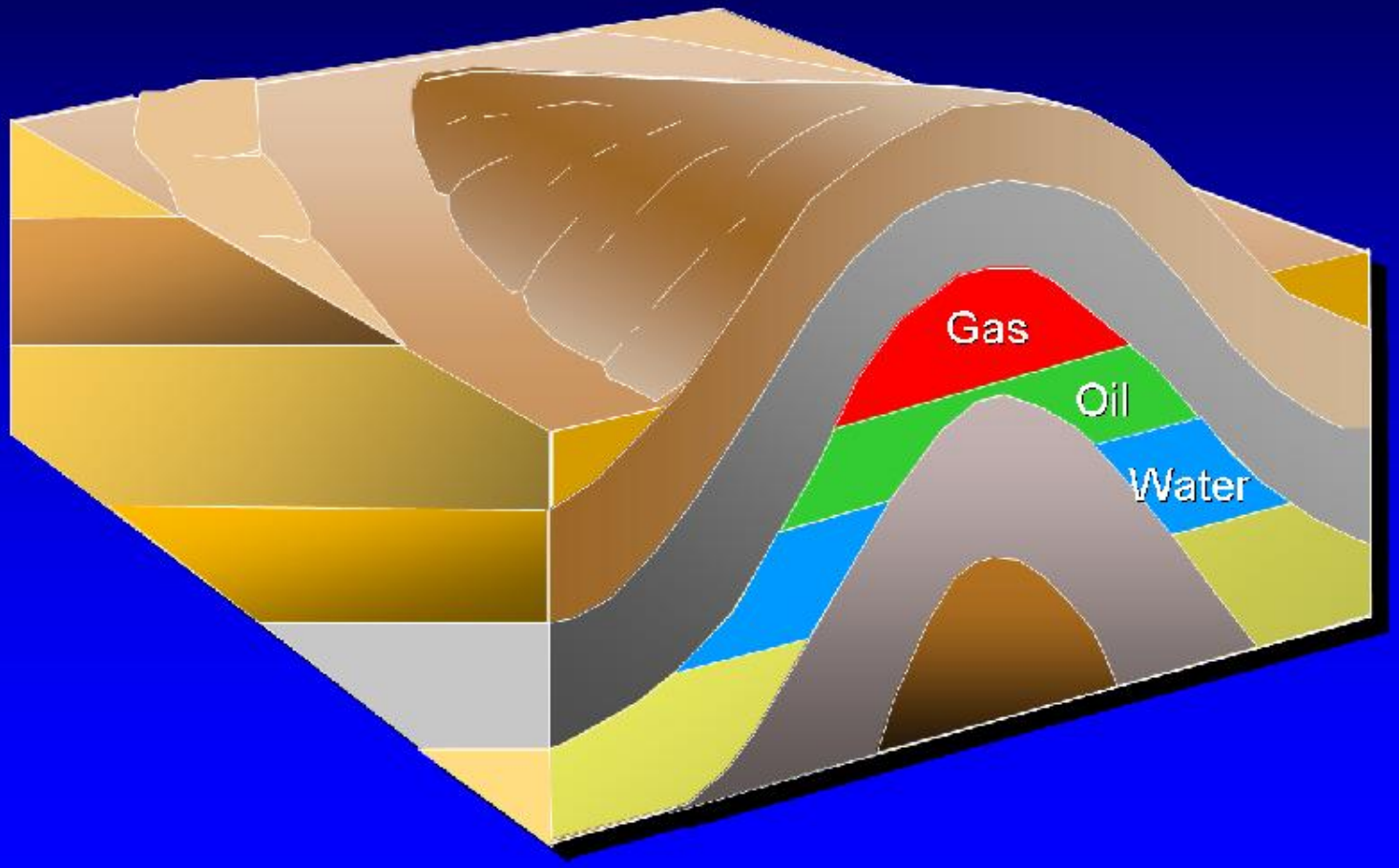
Hydrocarbon Trap Types



American Petroleum Institute, 1986

Anticlinal Theory

Petroleum Accumulates in Structural Closure

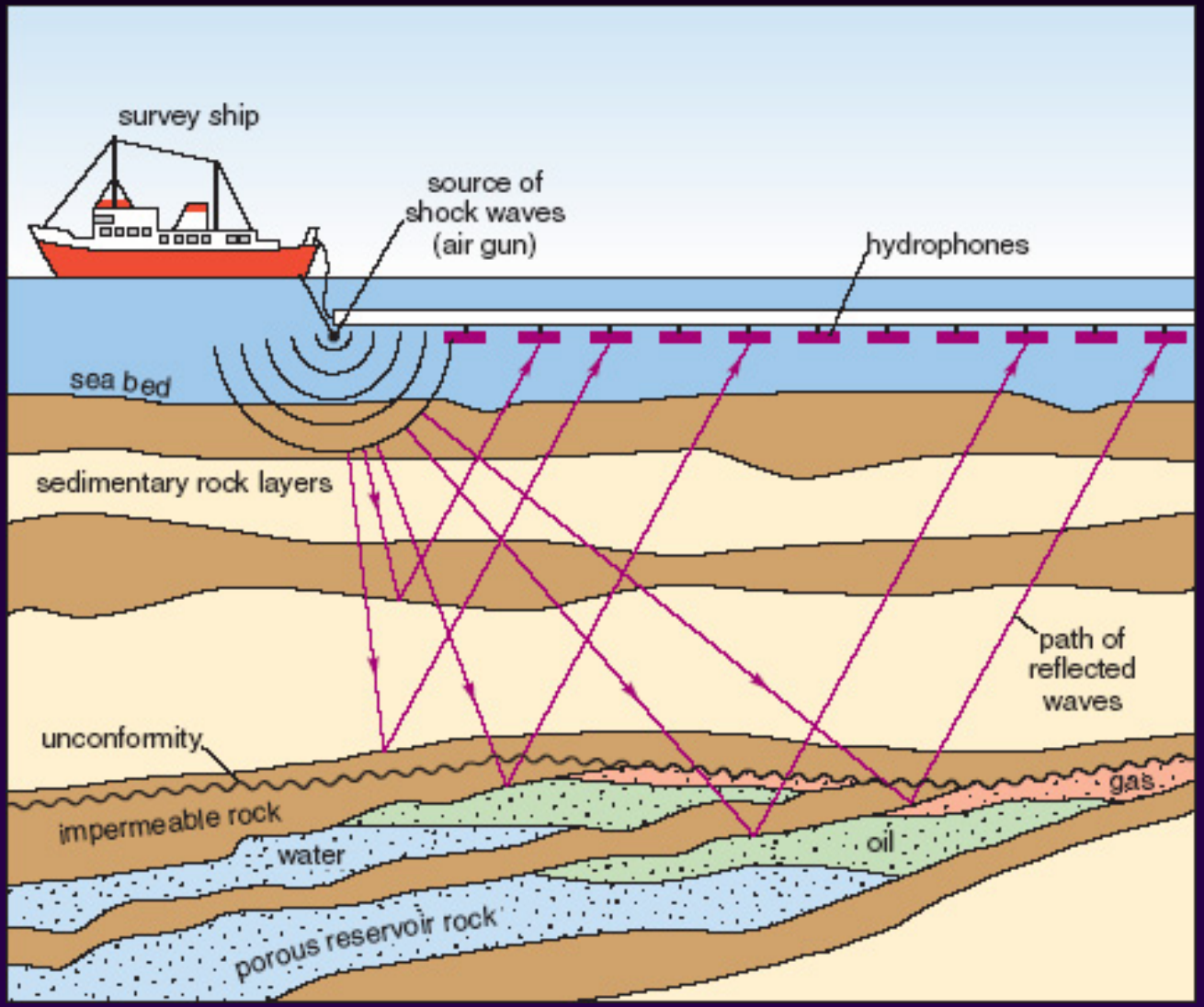


JMA

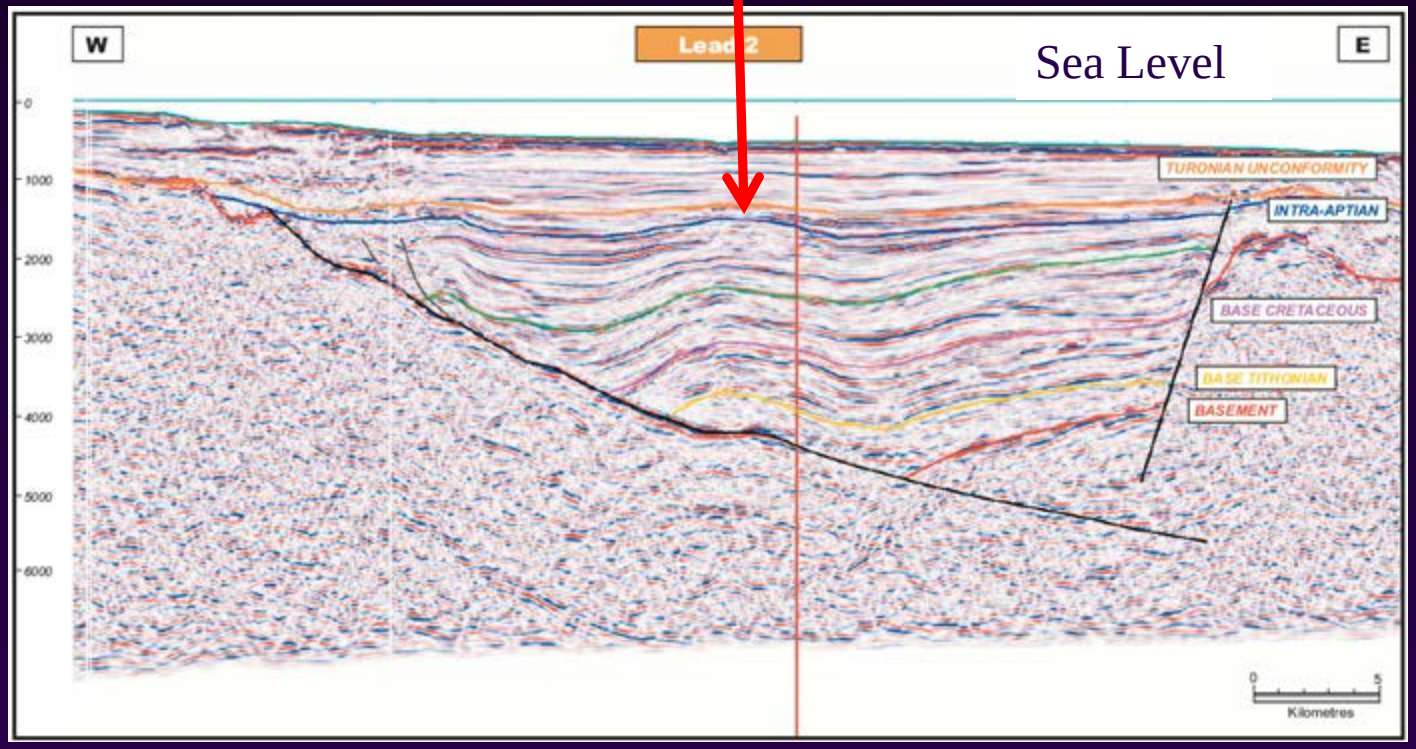
Production of Oil and Gas

- Maximum burial depths:
  - oil: 25,000 ft (5 miles)
  - gas: 35,000 ft (7 miles)
- Drilling technology is limited to 35,000 ft, which is the effective limit of fluid hydrocarbons.

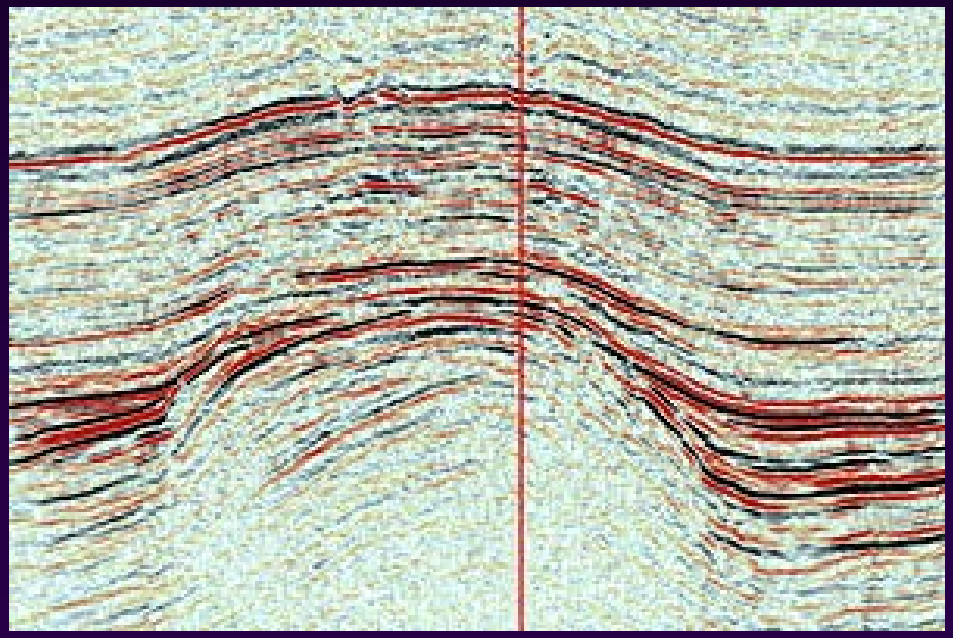
Exploring for Petroleum: Collecting Seismic Reflection Data

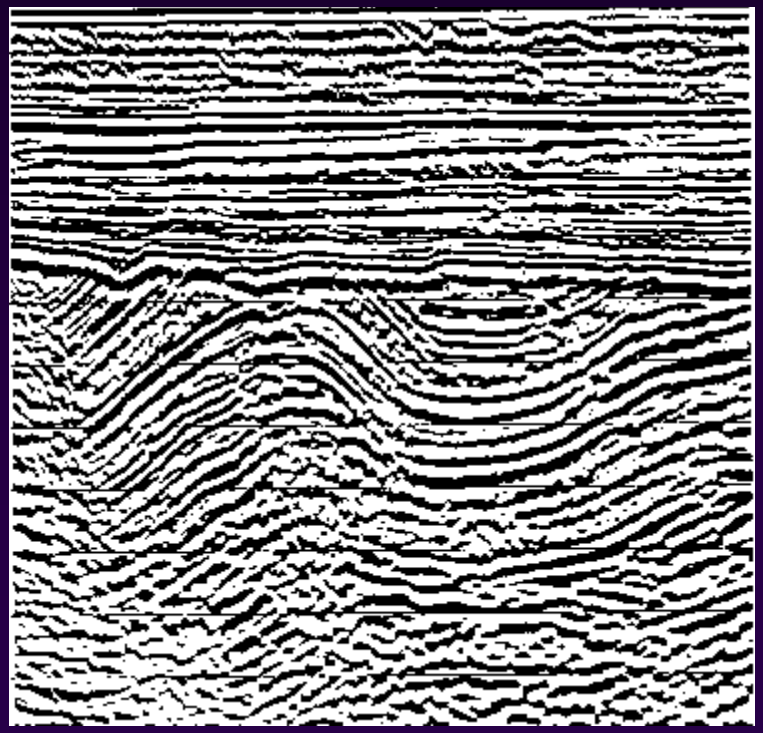


Geology of a continental shelf revealed by seismic reflection data. Folded layers trap oil and gas.

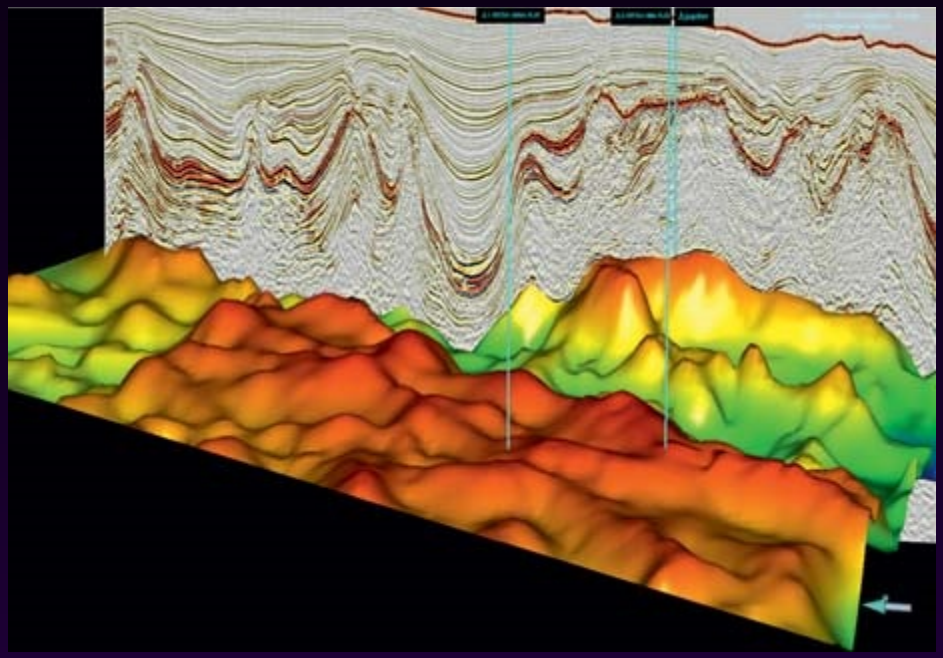


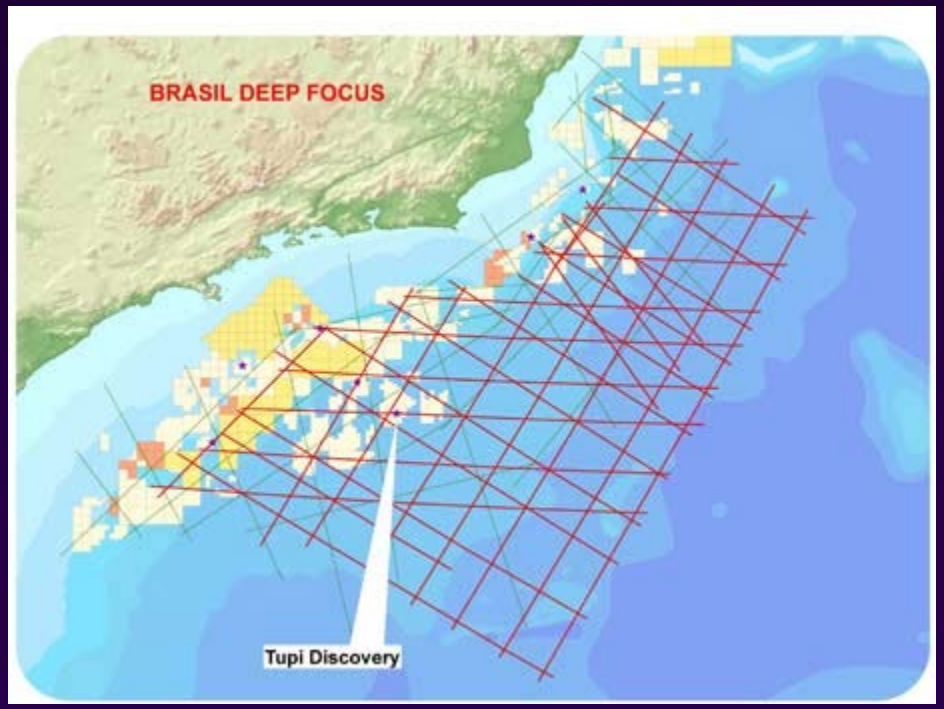
Other examples of seismic lines showing traps for oil and gas deposits.



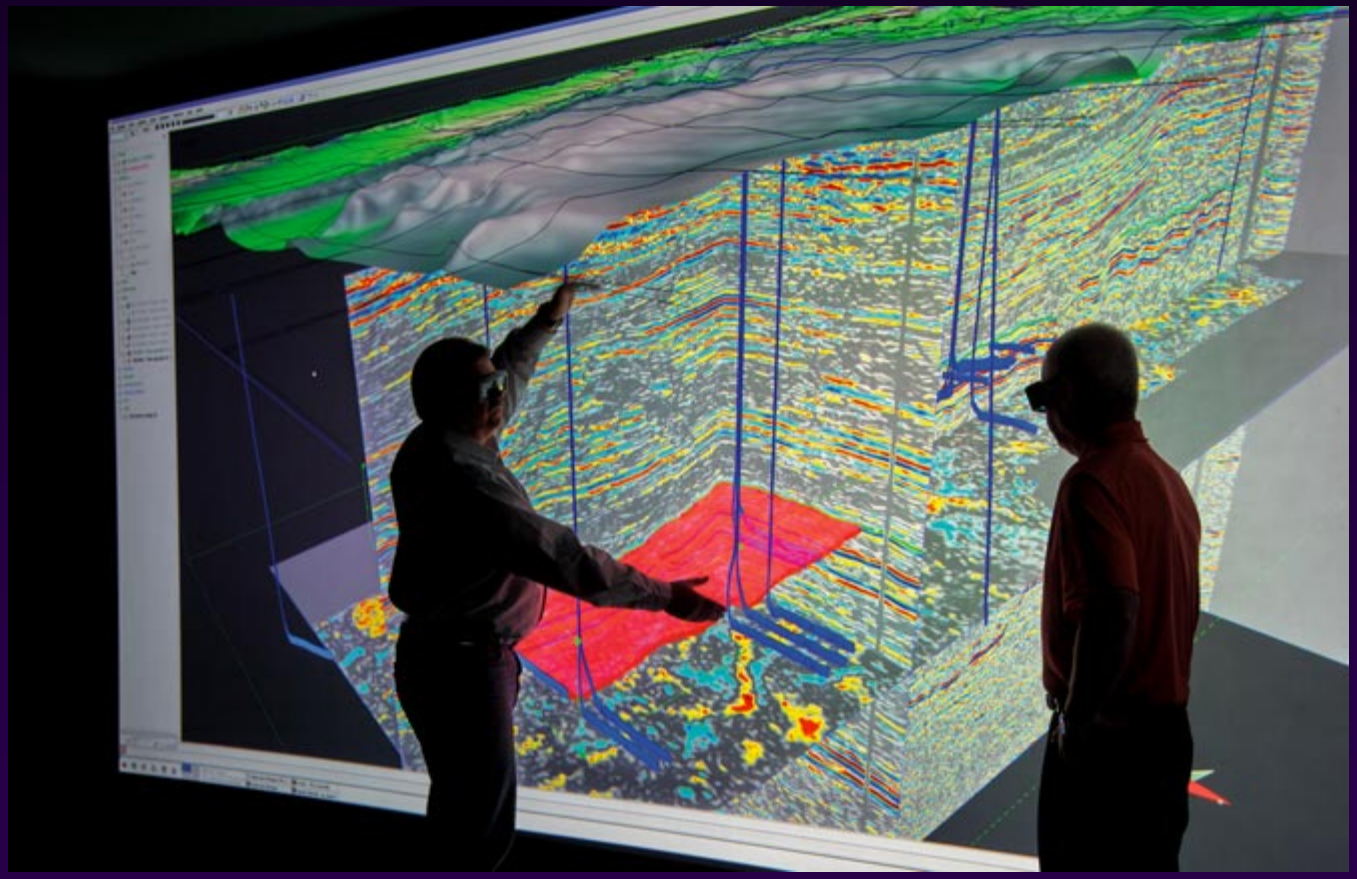


3 D Seismic Imaging off the SE coast of Brazil. Major oil discovery in 2010.





3D Seismic Imaging of the Marcellus Shale in Pennsylvania

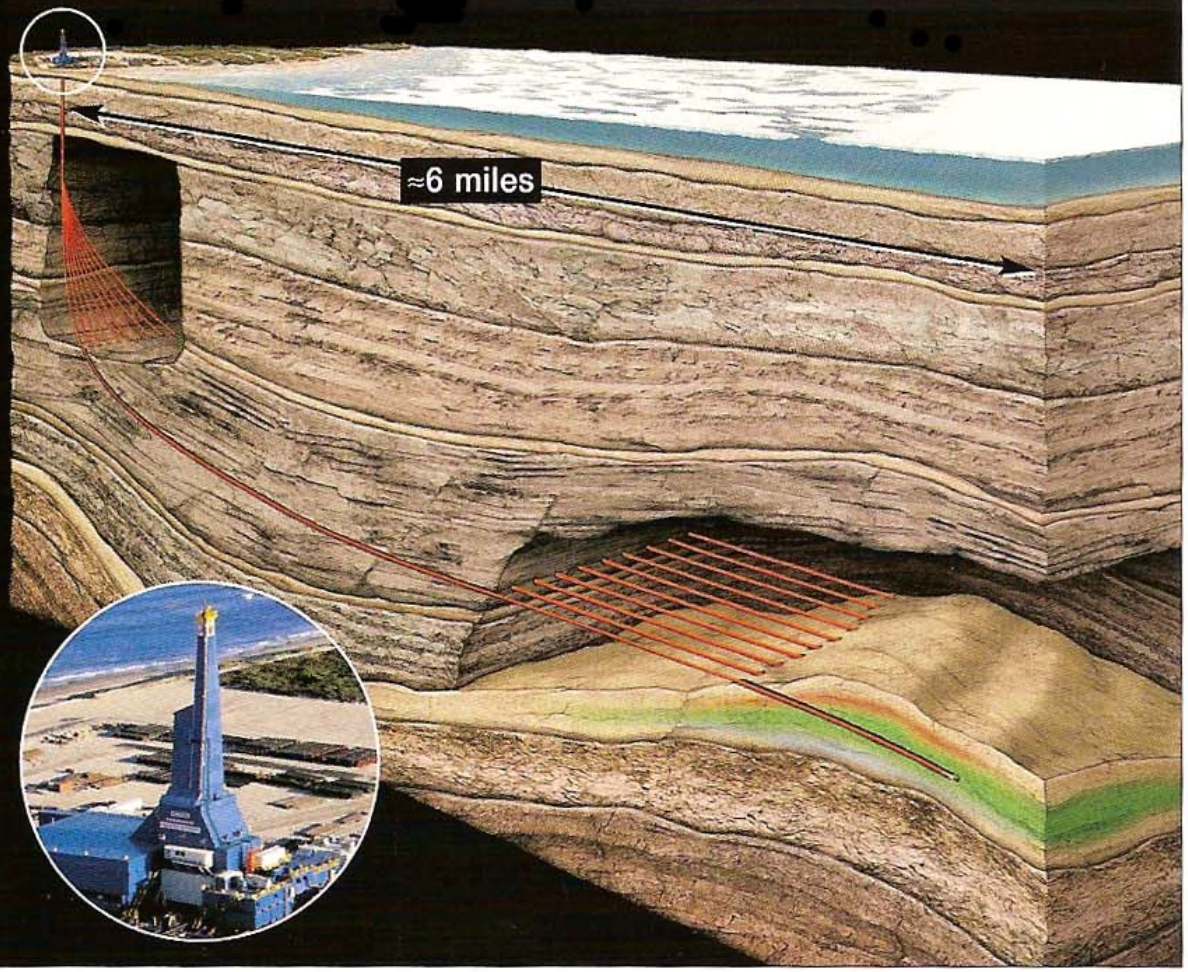


Horizontal production wells from directional drilling. Common practice today, even in WV

We continue to set new industry benchmarks in drilling and completions.

Above – ExxonMobil is improving well production rates and reducing well-related problems using technologies validated by learnings in the laboratory and the field.

Right – ExxonMobil engineers use an integrated suite of technologies to drill and complete complex extended-reach wells.



Deep Gas Well: 8,000 ft in WV

Drilling the Devonian-age Marcellus Shale in the Appalachian Basin

See an Industry Video

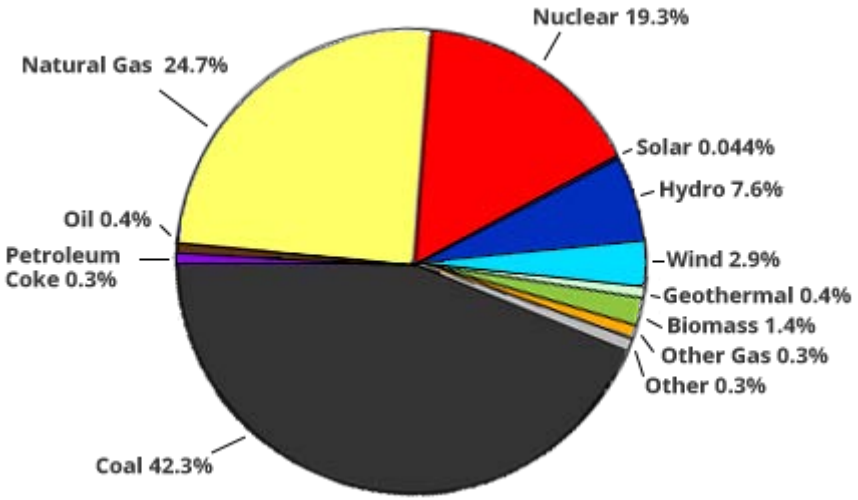
http://www.youtube.com/watch?v=VY34PQUiwOQ

60 Minutes Story

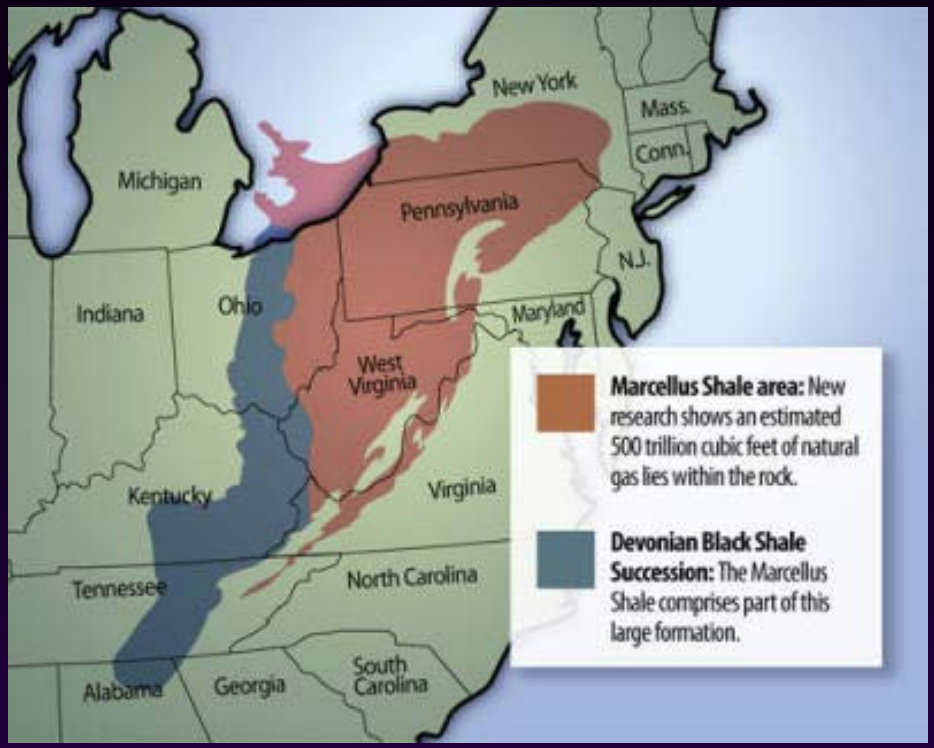
https://www.youtube.com/watch?v=UuGrawkuA2s

Shale Gas is an Energy Game-Changer

Shale Gas is Displacing Coal for Generating Electricity



Source: Energy Information Administration, year 2011 data. / U.S. Environmental Protection Agency
https://www.eia.gov/



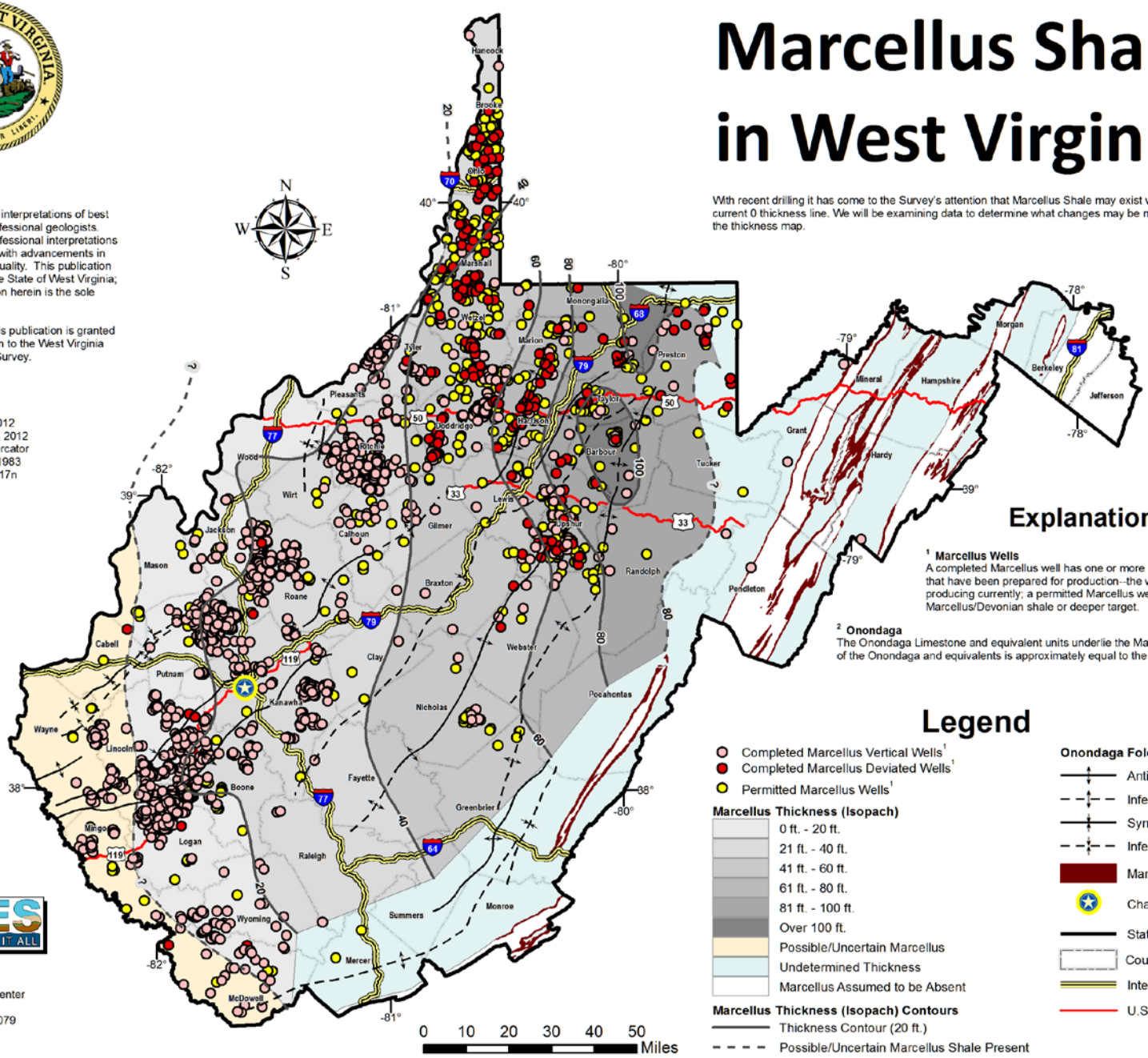
Extent of Devonian black shales

Marcellus Shale link

Black shale on outcrop

Marcellus Shale in West Virginia

With recent drilling it has come to the Survey's attention that Marcellus Shale may exist west of the current 0 thickness line. We will be examining data to determine what changes may be needed to the thickness map.



Explanations

[1] Marcellus Wells
A completed Marcellus well has one or more zones in the Marcellus that have been prepared for production--the well may or may not be producing currently; a permitted Marcellus well is one with a Marcellus/Devonian shale or deeper target.

[2] Onondaga
The Onondaga Limestone and equivalent units underlie the Marcellus Shale. The top of the Onondaga and equivalents is approximately equal to the base of the Marcellus.

Legend

- Completed Marcellus Vertical Wells[1]
- Completed Marcellus Deviated Wells[1]
- Permitted Marcellus Wells[1]

Marcellus Thickness (Isopach)

- 0 ft. - 20 ft.
- 21 ft. - 40 ft.
- 41 ft. - 60 ft.
- 61 ft. - 80 ft.
- 81 ft. - 100 ft.
- Over 100 ft.
- Possible/Uncertain Marcellus
- Undetermined Thickness
- Marcellus Assumed to be Absent

Marcellus Thickness (Isopach) Contours

- Thickness Contour (20 ft.)
- Possible/Uncertain Marcellus Shale Present

Onondaga Fold Axis[2]

- Anticline
- Inferred Anticline
- Syncline
- Inferred Syncline
- Marcellus Outcrop
- Charleston, WV
- State Boundary
- County Boundaries
- Interstate Highways
- U.S. Highways

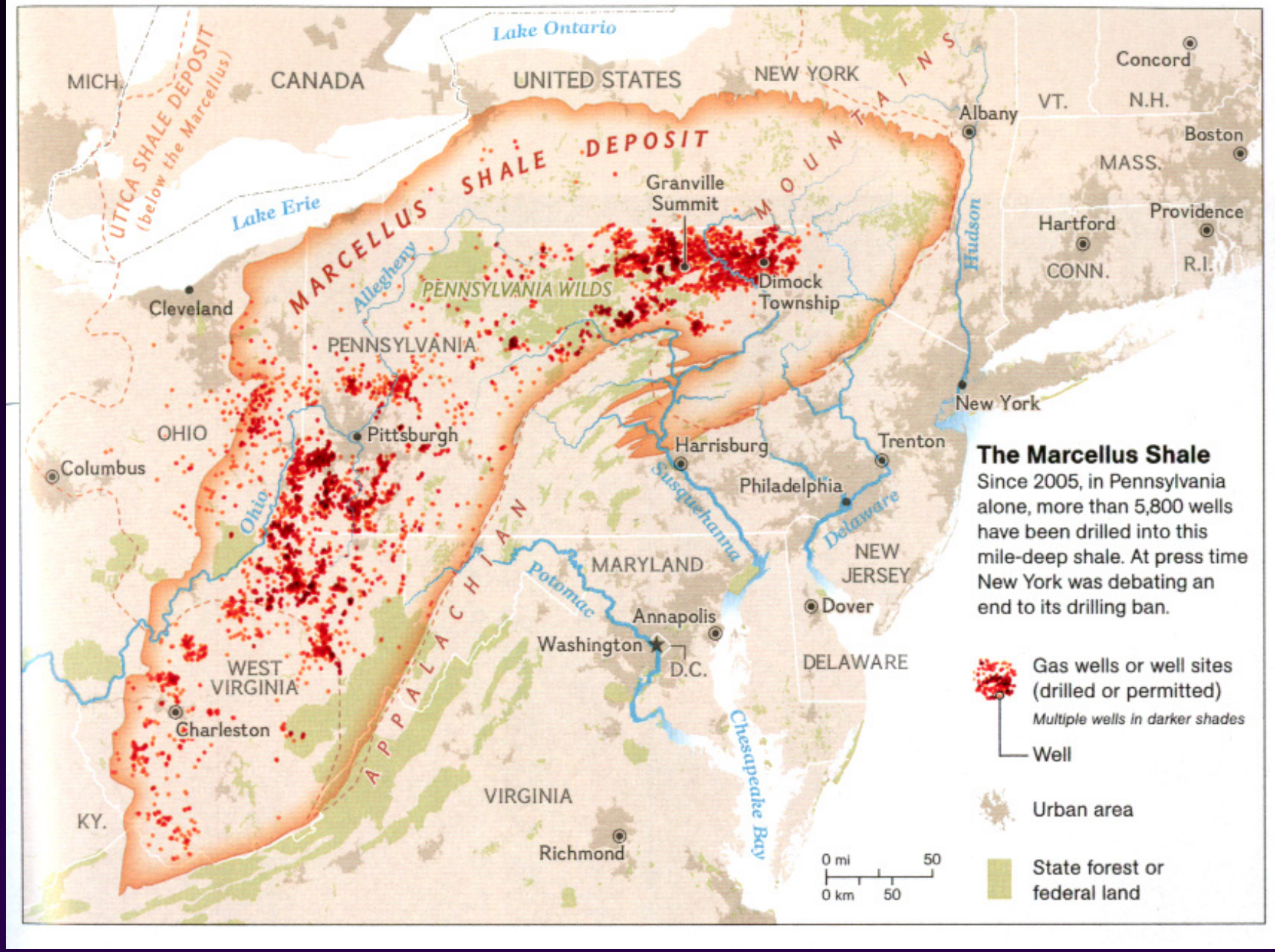
Publications Policy:

This publication represents interpretations of best available data made by professional geologists. As in all research work, professional interpretations may vary, and can change with advancements in both technology and data quality. This publication is offered as a service of the State of West Virginia; proper use of the information herein is the sole responsibility of the user.

Map Date: October 23, 2012
Data Date: September 25, 2012
Projection: Transverse Mercator
Horizontal Datum: NAD 1983
Coordinate System: UTMz17n
Map Scale: 1:2,000,000
(for full 8.5" x 11" display)

WVGES
GEOLOGY UNDERLIES IT ALL

West Virginia Geological and Economic Survey
Mont Chateau Research Center
1 Mont Chateau Road
Morgantown, WV 26508-8079
Phone: (304) 594-2331
www.wvgs.wvnet.edu



National Geographic, Dec. 2012

THE SHALE BOOM

The technology for pulling natural gas from deep shale, refined in the 1990s in Texas, has since spread to other "plays"—parts of a shale basin where large quantities of gas have been found. More than a third of U.S. gas now comes from shale.

Richest shale deposits

Recoverable gas, in trillion cubic feet (tcf)
Total for continental U.S. **542***

1. Marcellus	**141**
2. Haynesville	**66**
3. Eagle Ford	**50**
4. Barnett-Woodford	**27**
5. Woodford	**24**

Shale play (active or expected drilling)

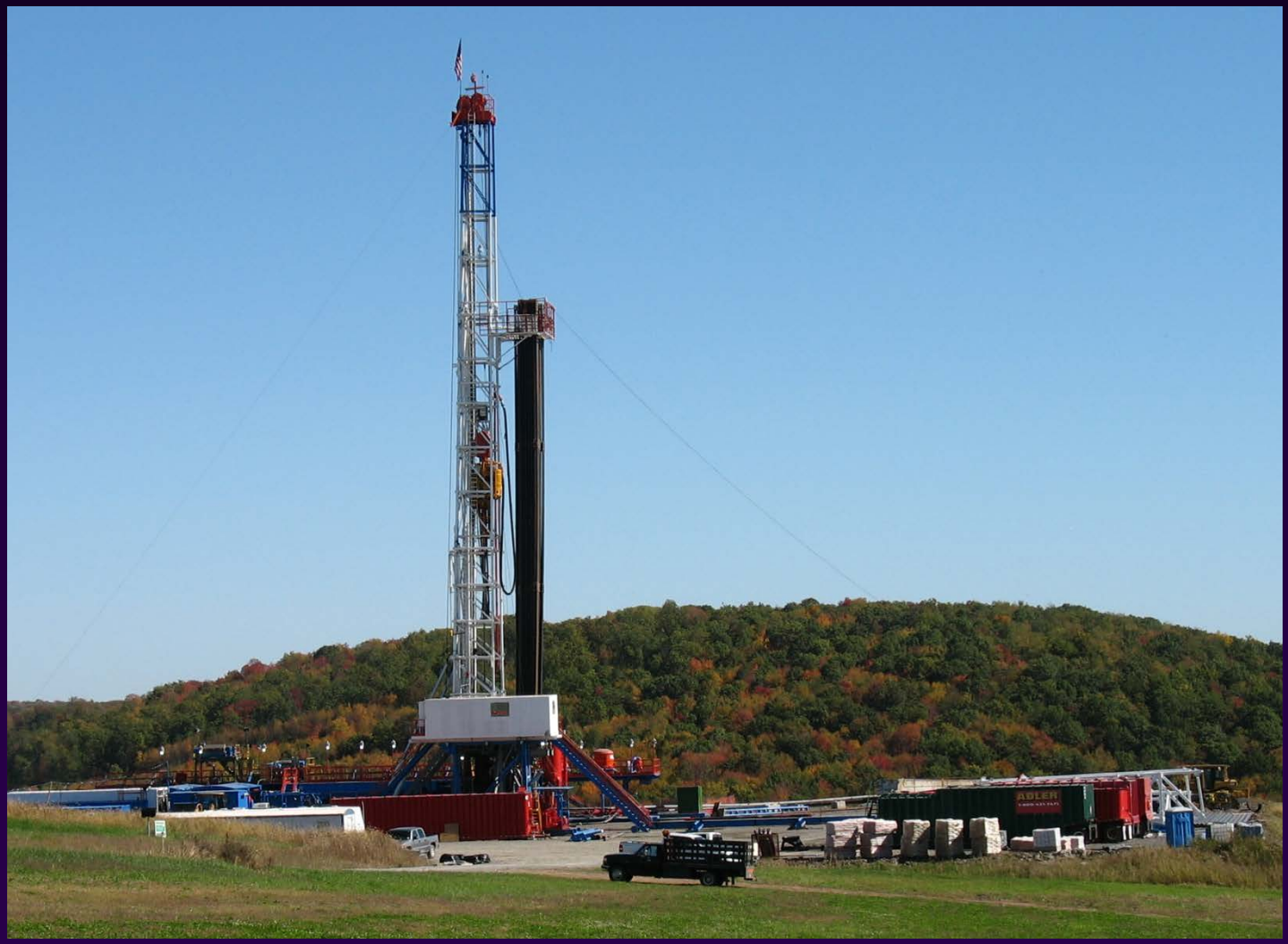
Shale basin (potential gas resource)

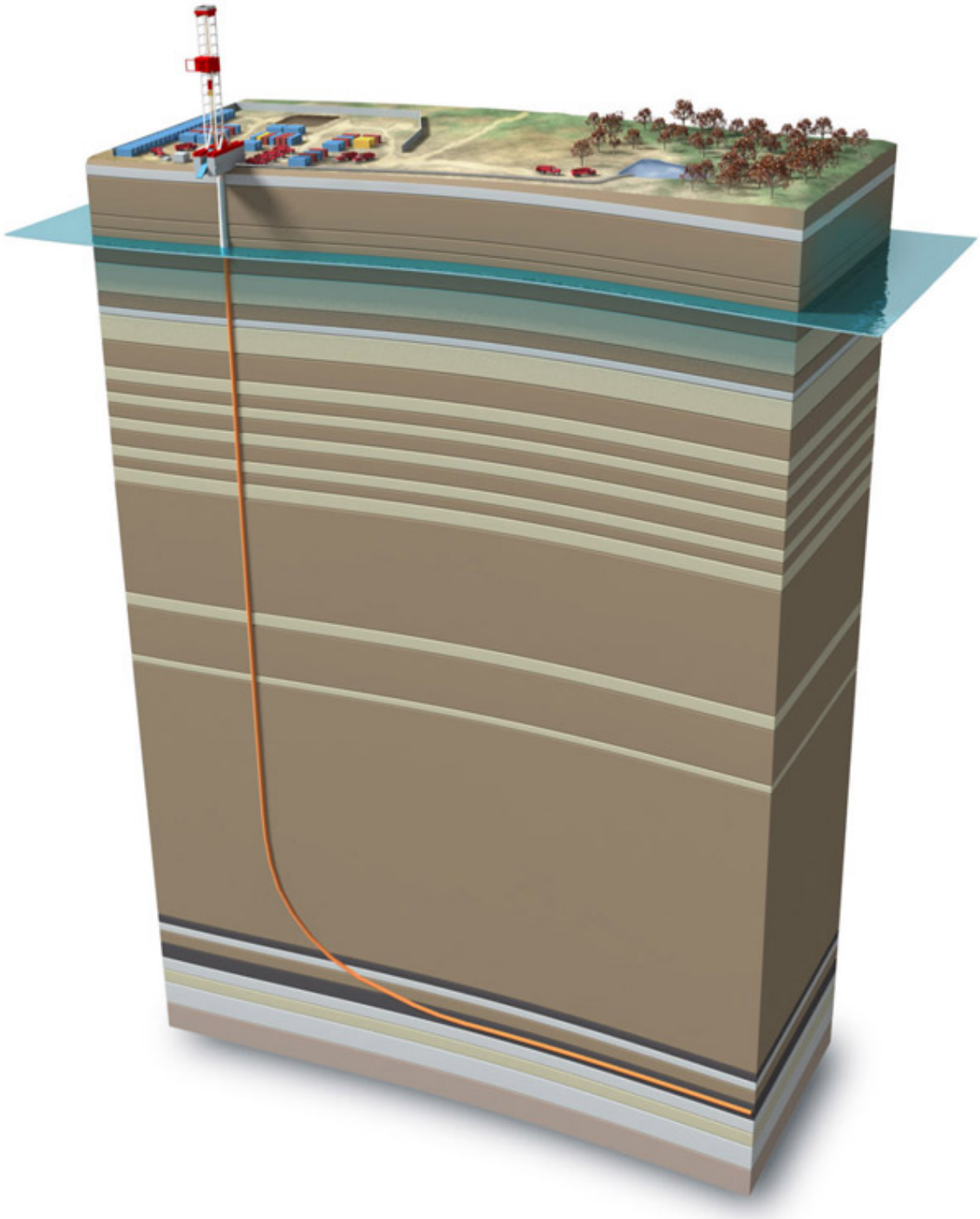
ONE TCF CAN HEAT 15 MILLION HOMES FOR A YEAR.
*TOTAL INCLUDES "PROVED RESERVES" AND "UNPROVED RESOURCES."

VIRGINIA W. MASON, NGM STAFF; ALEXANDER STEGMAIER, NG STAFF
SOURCES: U.S. EIA; FRACTRACKER; U.S. CENSUS BUREAU; STATISTICS CANADA

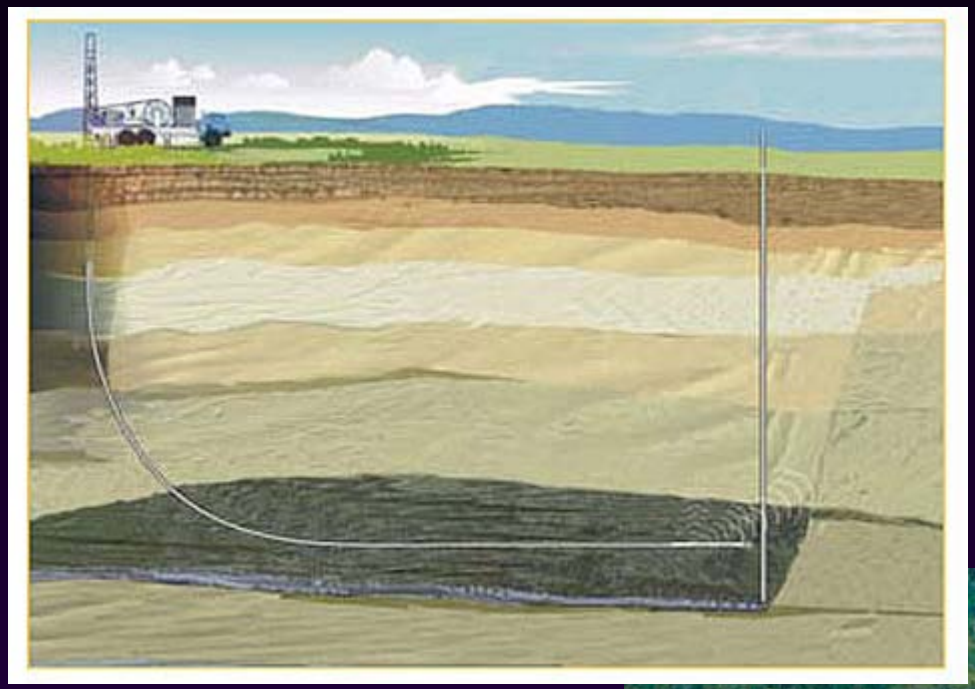
National Geographic, Dec. 2012

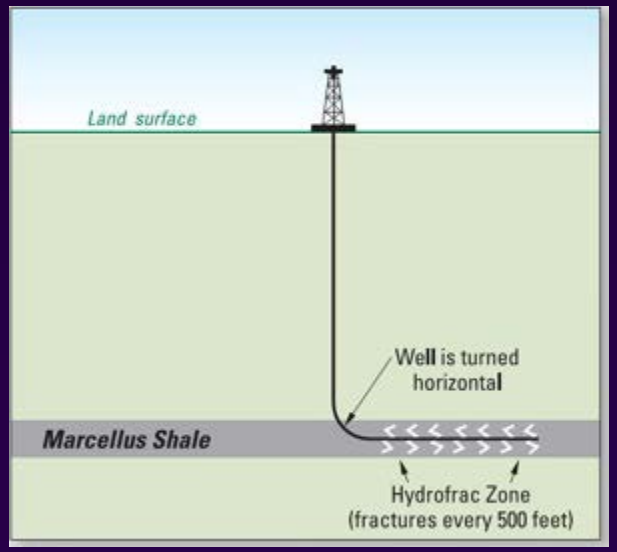
A drilling rig for a Marcellus gas well in the Appalachian Basin

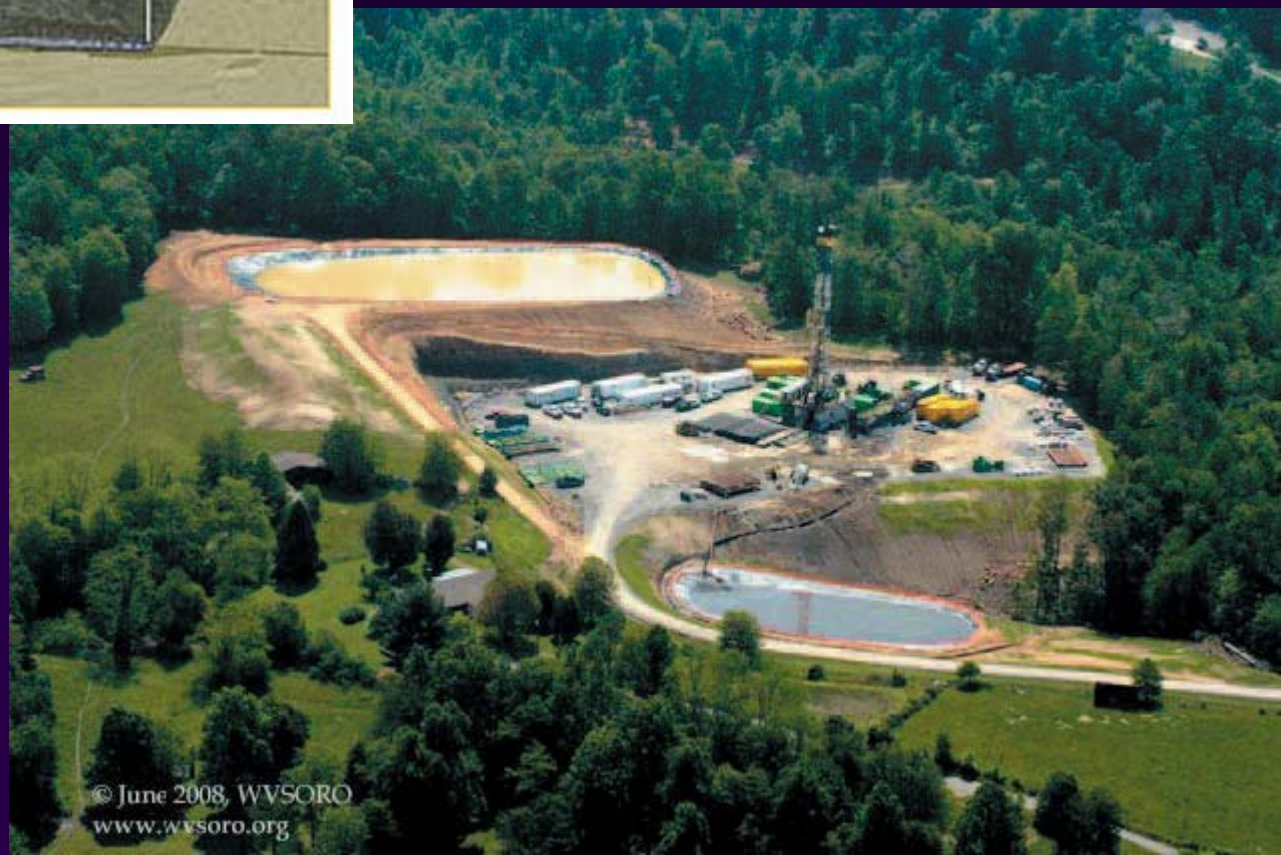




Horizontal Drilling and Hydrofracking operations



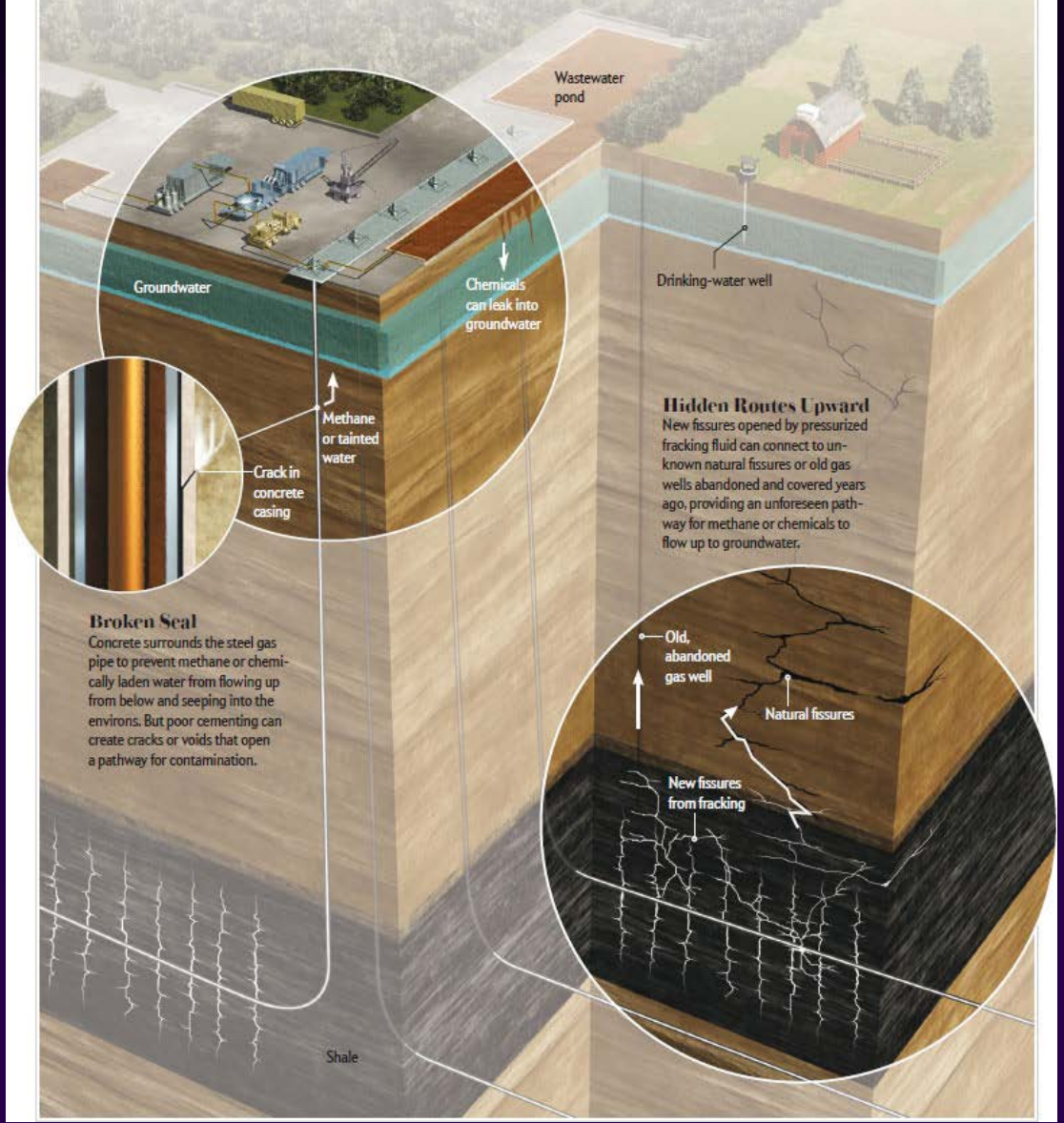




Fractures in Marcellus black shale

Risks to Drinking Water

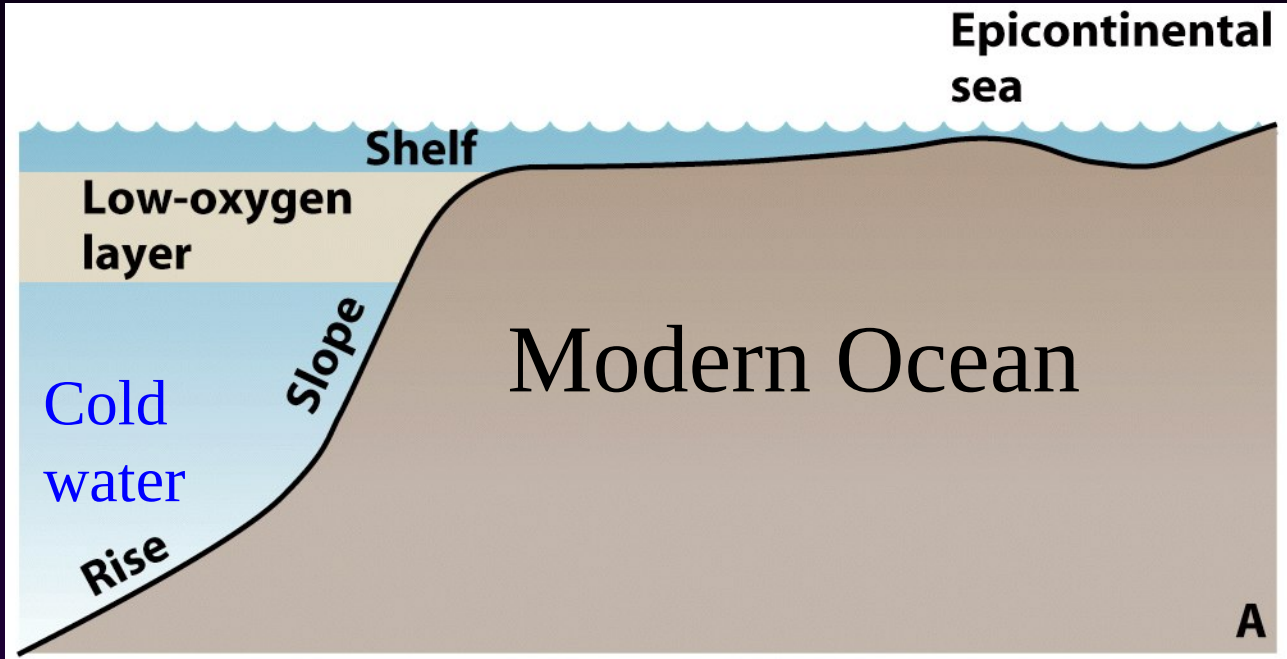
Once a drill pad and wastewater pond are established, a driller may sink a dozen wells or more to fully tap the shale gas. Three spots may have the greatest potential to contaminate groundwater. Chemical-laden wastewater ponds can leak or overflow (*center*), which happened in Pennsylvania in September because of flooding by Tropical Storm Lee. Concrete that encases the vertical pipe can crack (*inset, left*), and new fissures opened by the fracking can connect to natural fissures or old wells (*inset, right*).



WTF: Watch the Fracking

What's so special about the Mesozoic?

- The worldwide climate was tropical.
- Plankton were abundant in the ocean.
- Ocean bottoms were stagnant and anoxic, unlike today's ocean.
- Black, organic-rich muds accumulated to form later source rocks.



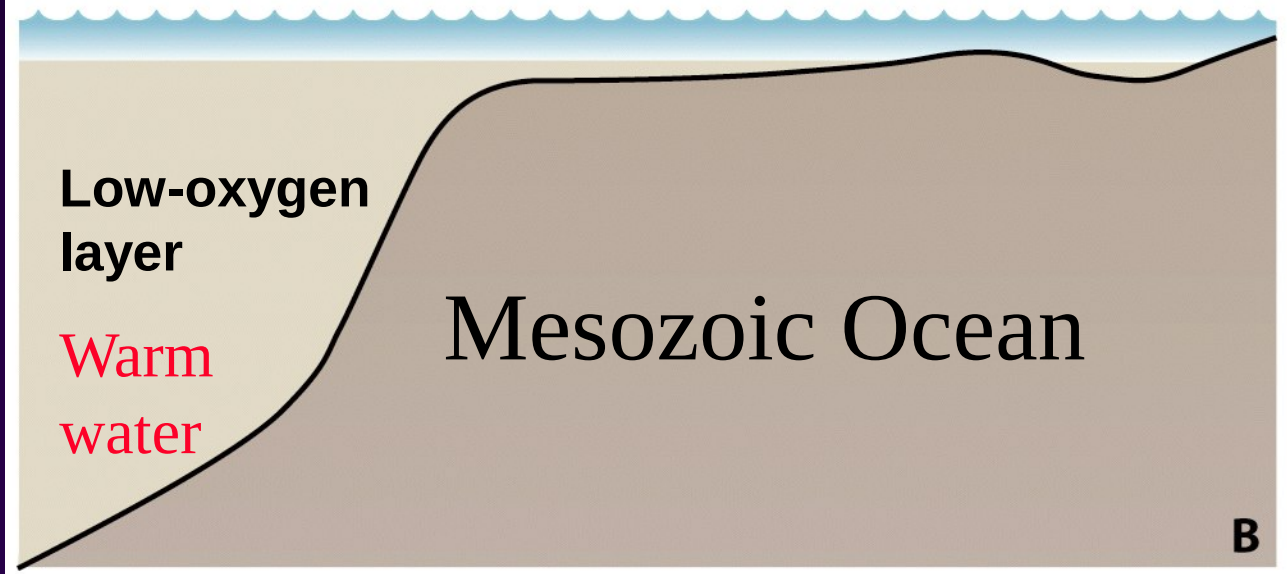
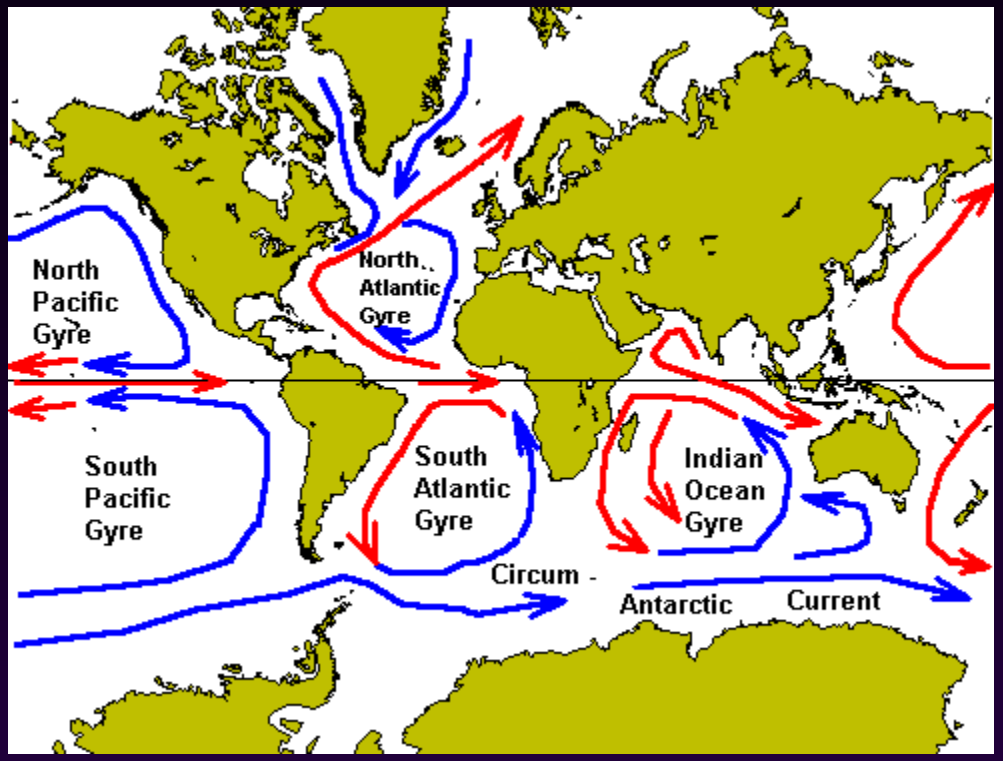
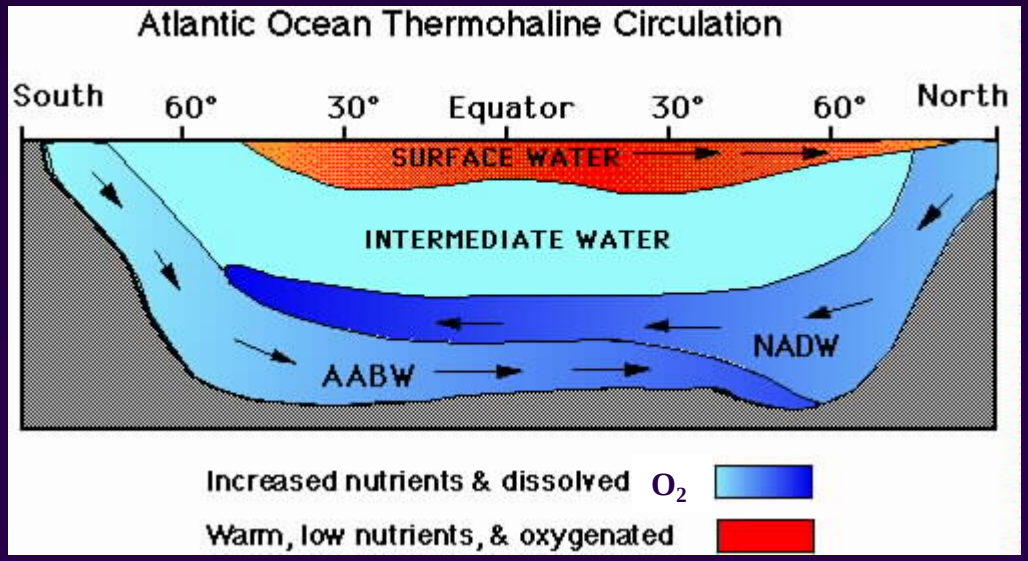


Figure 17-16
Earth System History, Second Edition





Modern oceans are well ventilated unlike during the Cretaceous when there was no cold, oxygenated water to sink near the poles.

What's so special about the Persian Gulf area?

- The Persian Gulf area was once on the edge of the Tethys Seaway.
- Tropical reefs were abundant.
- The Tethys was a particularly anoxic ocean.
- The closing of the Tethys produced numerous structural traps.

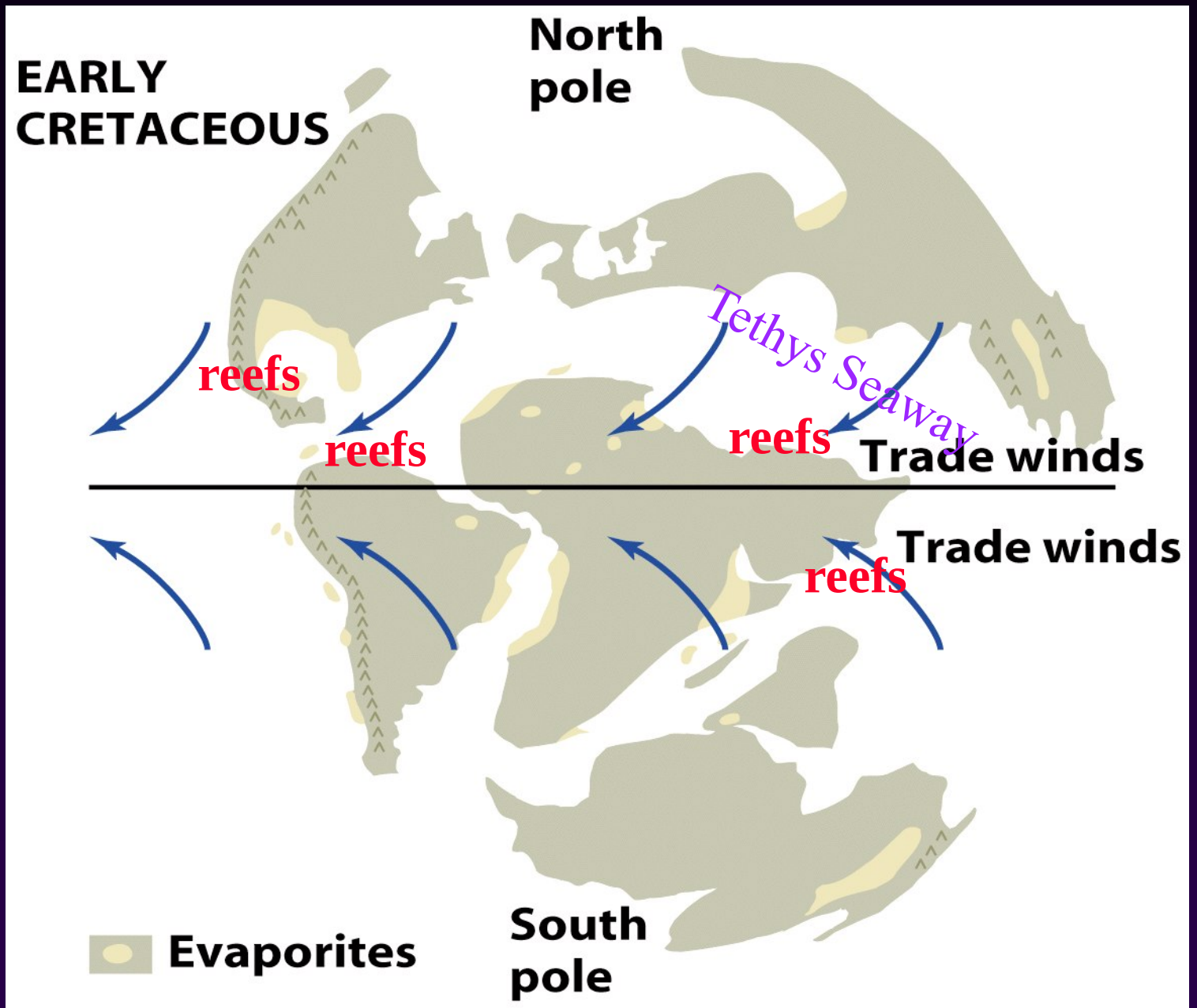


Figure 17-14
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Reefs: Excellent reservoir rocks

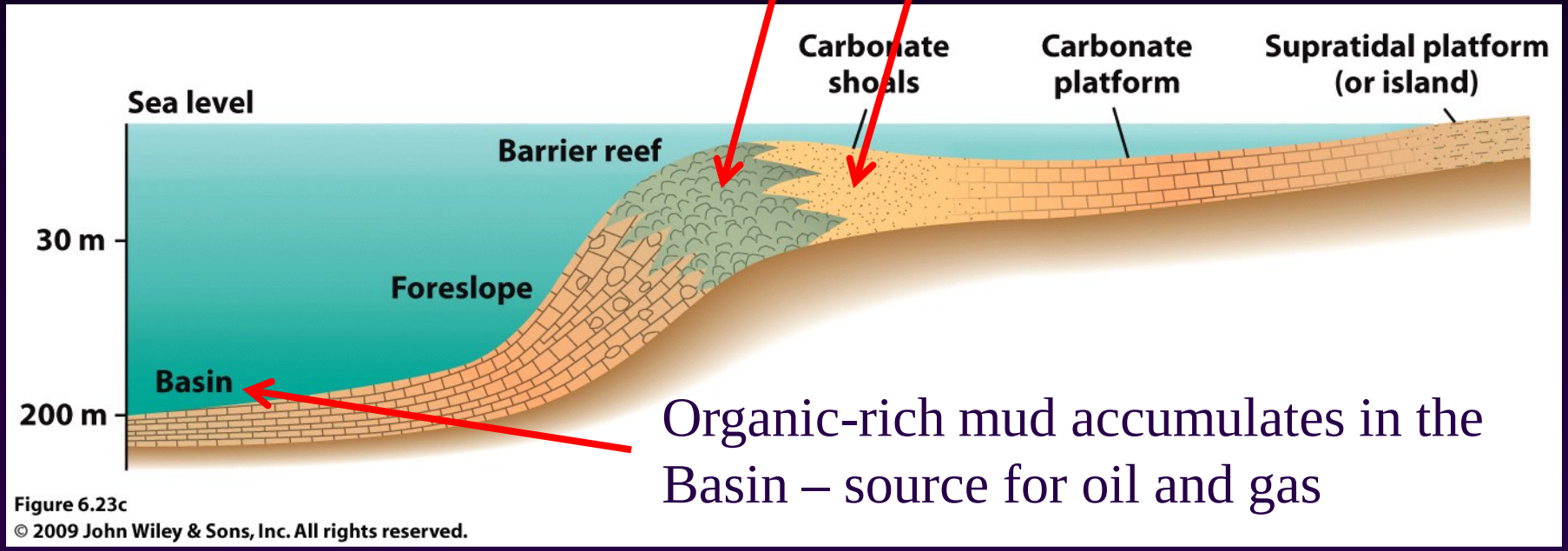
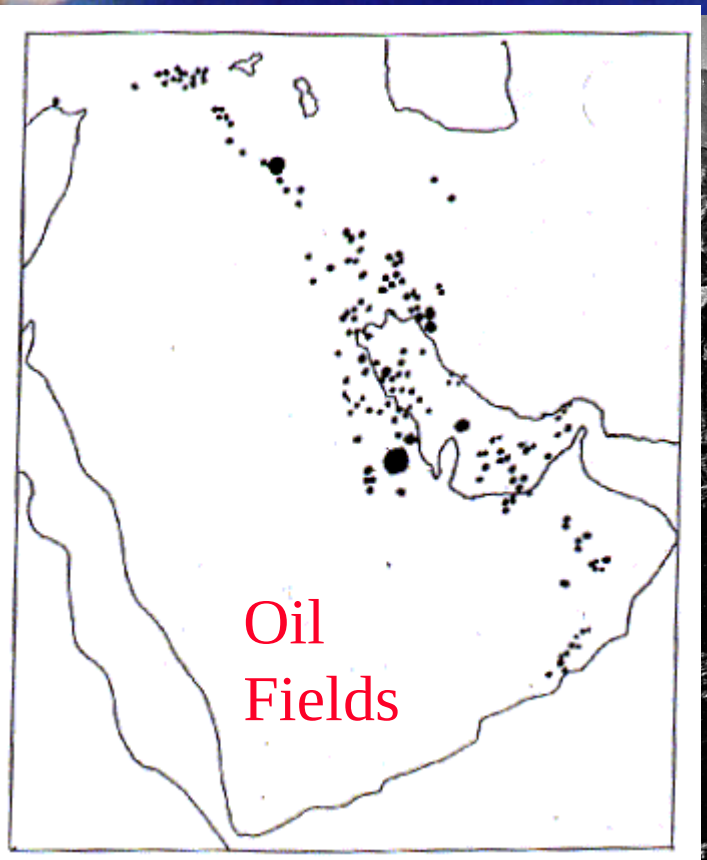


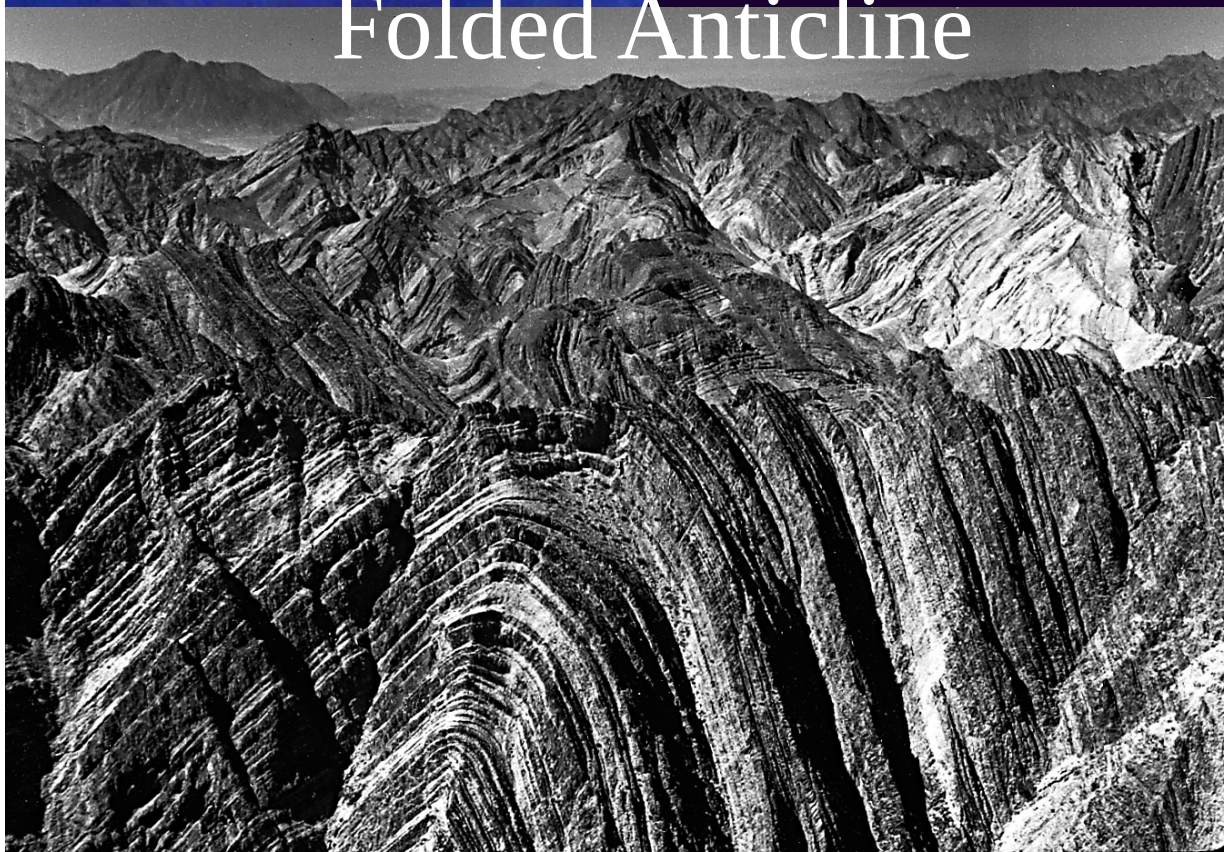
Figure 6.23c

Organic-rich mud accumulates in the Basin – source for oil and gas

Persian Gulf Region



Folded Anticline




Iran
Qatar
Saudi Arabia
UAE
Tectonic plates in the Persian Gulf
Photograph by Jacques Descloitres, MODIS Land Rapid Response Team, NASA/GSFC
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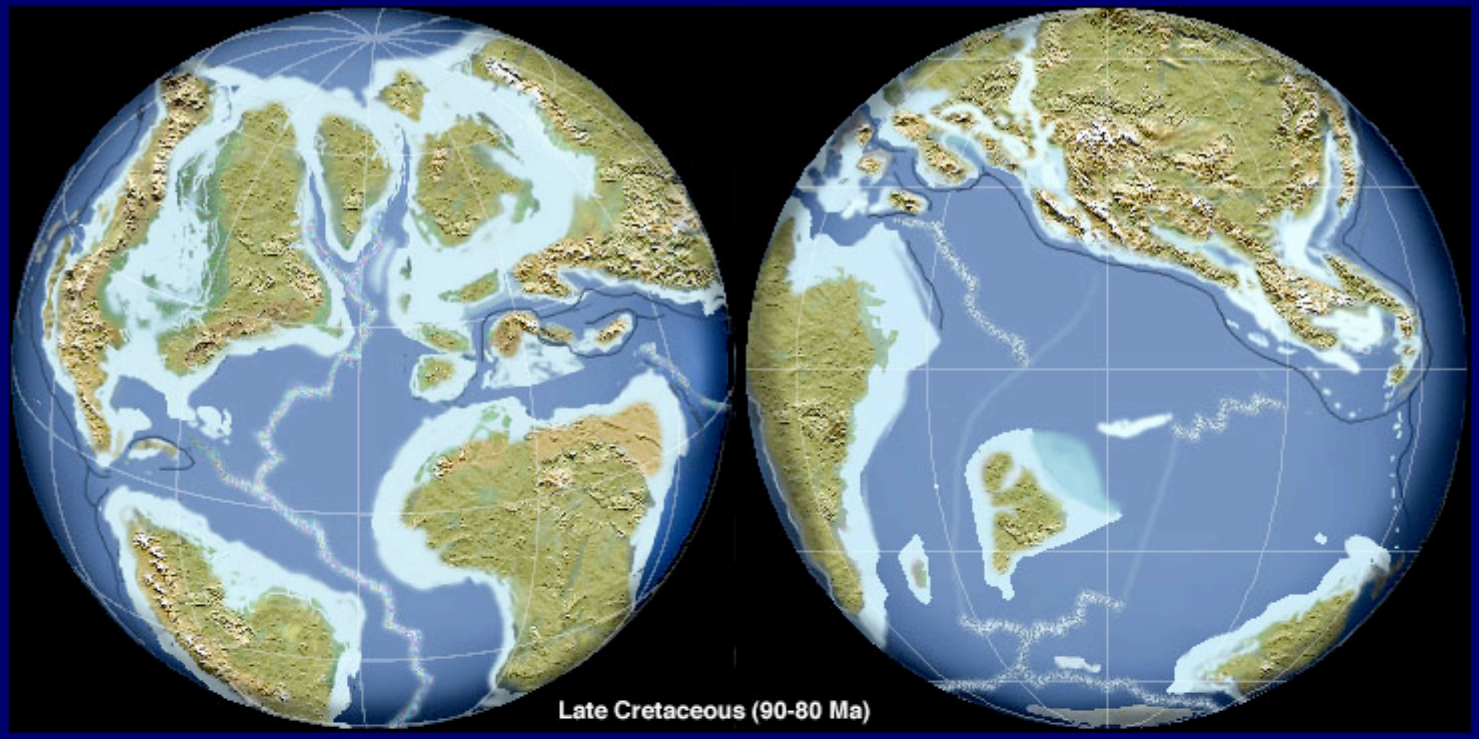
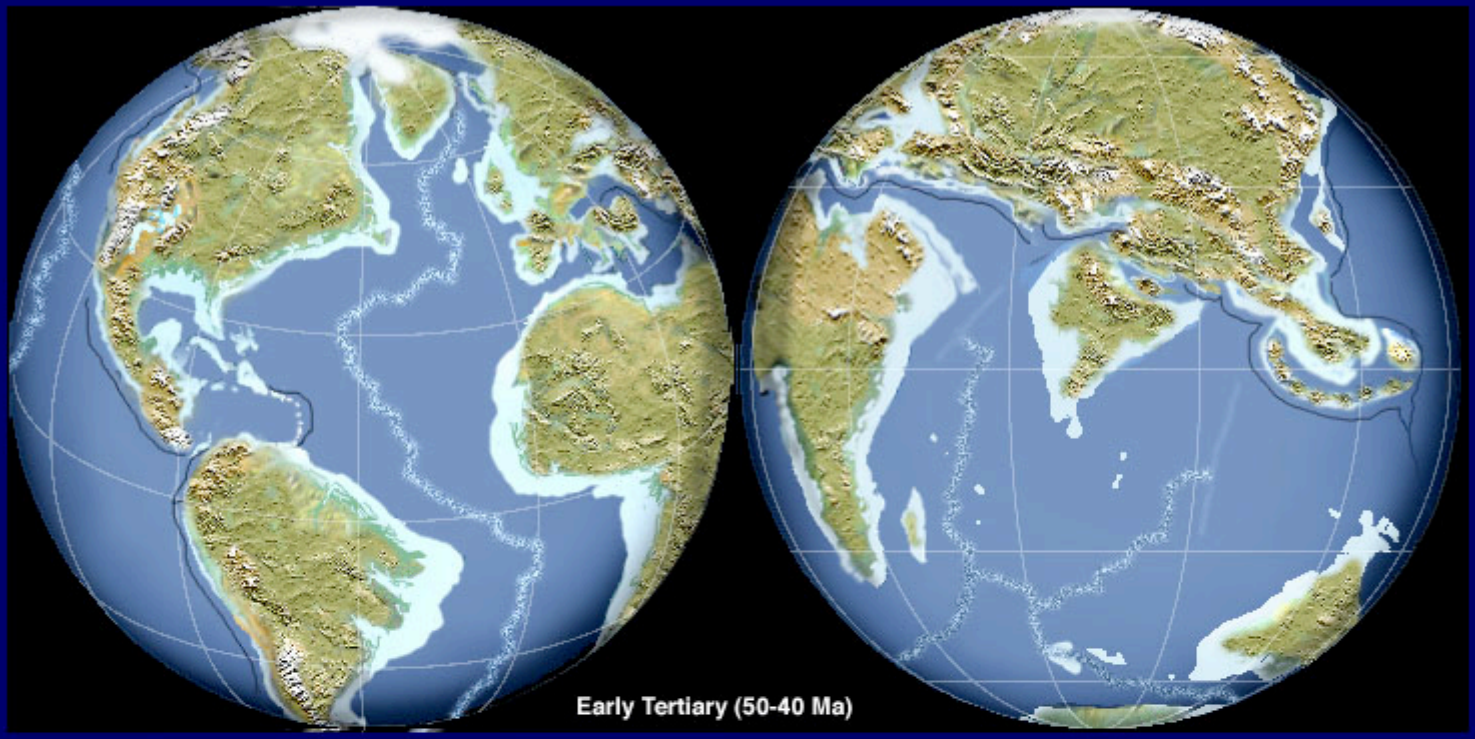
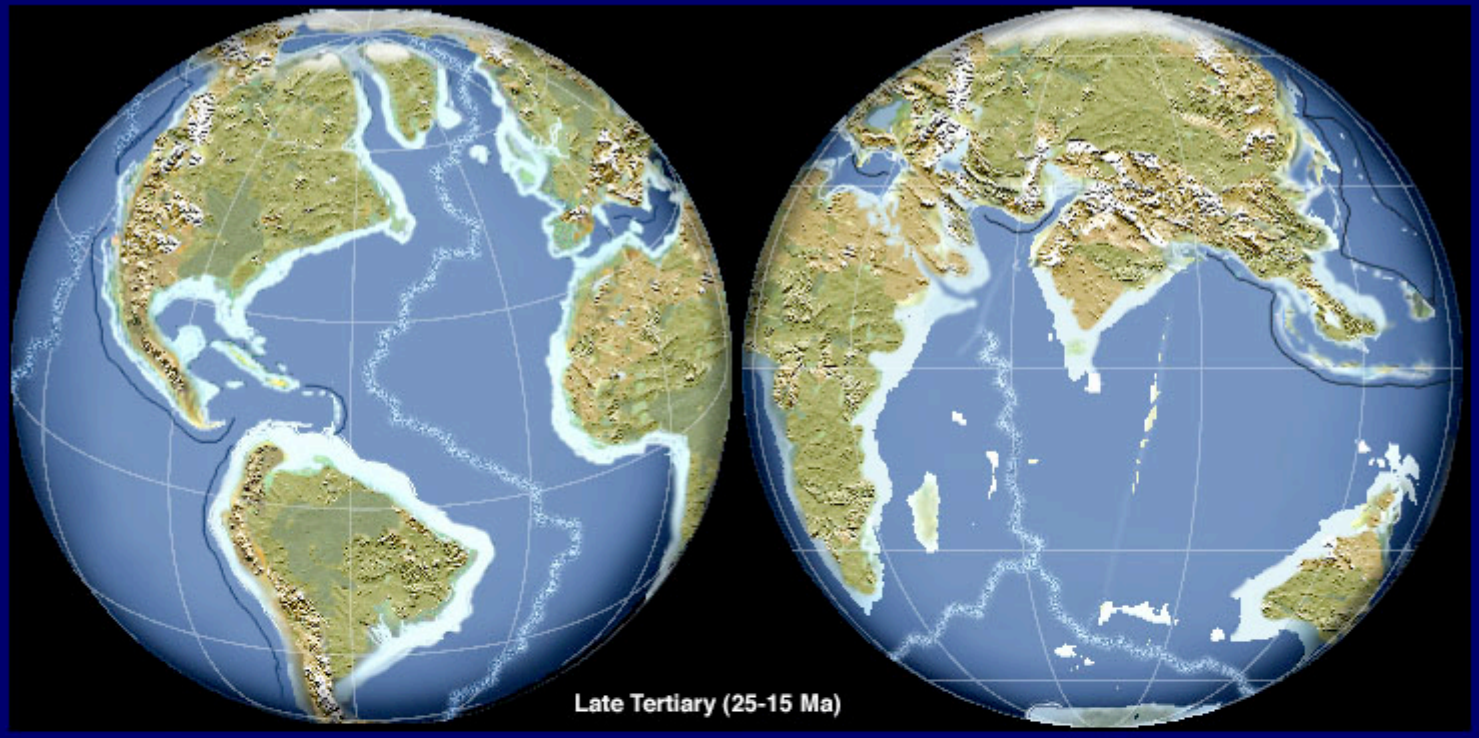


Late Cretaceous 80 Ma



Late Eocene 40 Ma



Early Miocene 20 Ma