Oil and Natural Gas

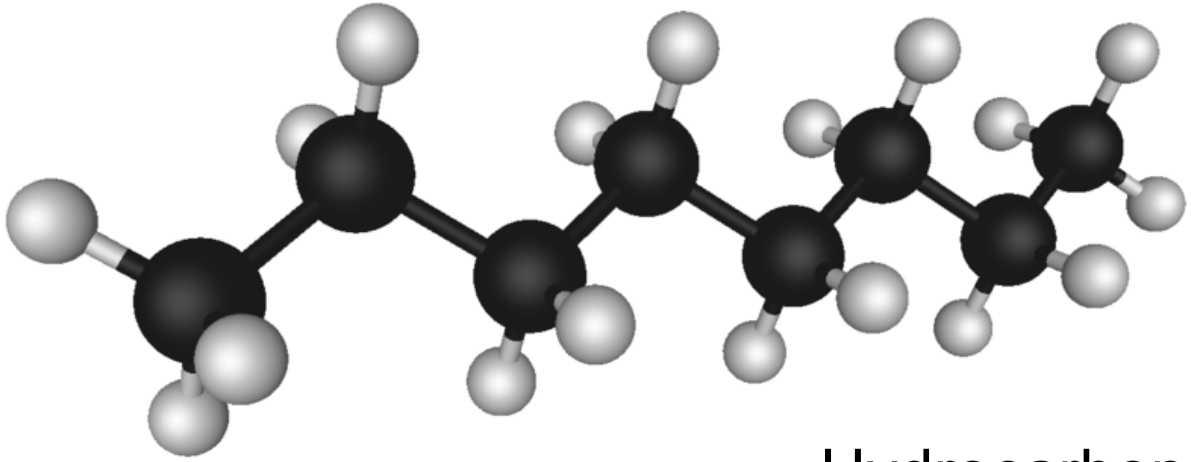
Adam Simon
University of Michigan


Unleaded
Regular
87
Unleaded
Mid-Grade
89
Unleaded
Premium
93
1.999
2.199
2.399
$ Price per Gallon (including tax)
$ Price per Gallon (including tax)
$ Price per Gallon (including tax)
MINIMUM OCTANE RATING
(R+M)/2 METHOD
87
PUSH HERE
MINIMUM OCTANE RATING
(R+M)/2 METHOD
89
PUSH HERE
MINIMUM OCTANE RATING
(R+M)/2 METHOD
93
PUSH HERE
Take Receipt Here
Wayne

Global oil consumption fills the University of Michigan stadium every 40 minutes.

107,000 people

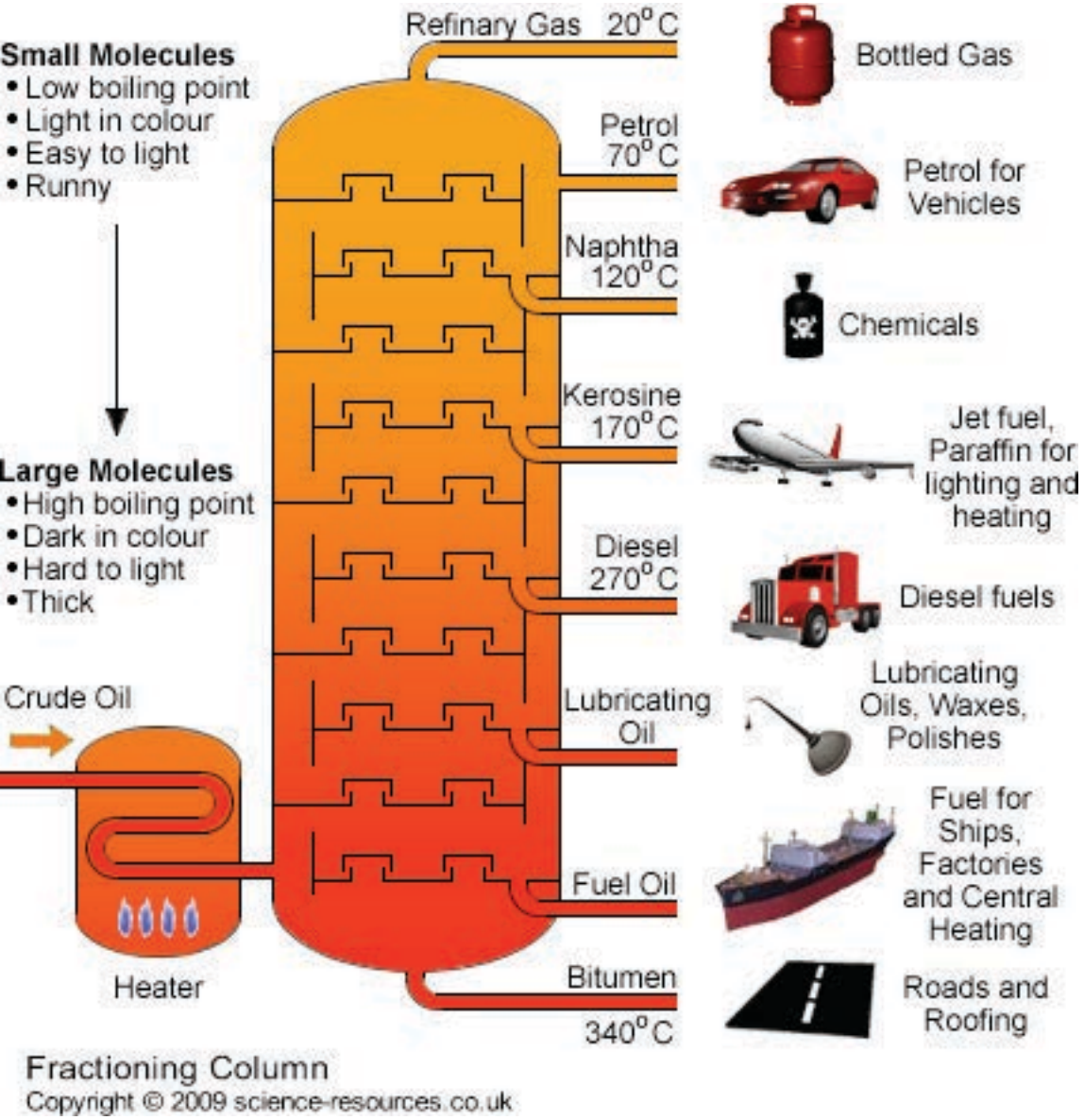
Crude Oil



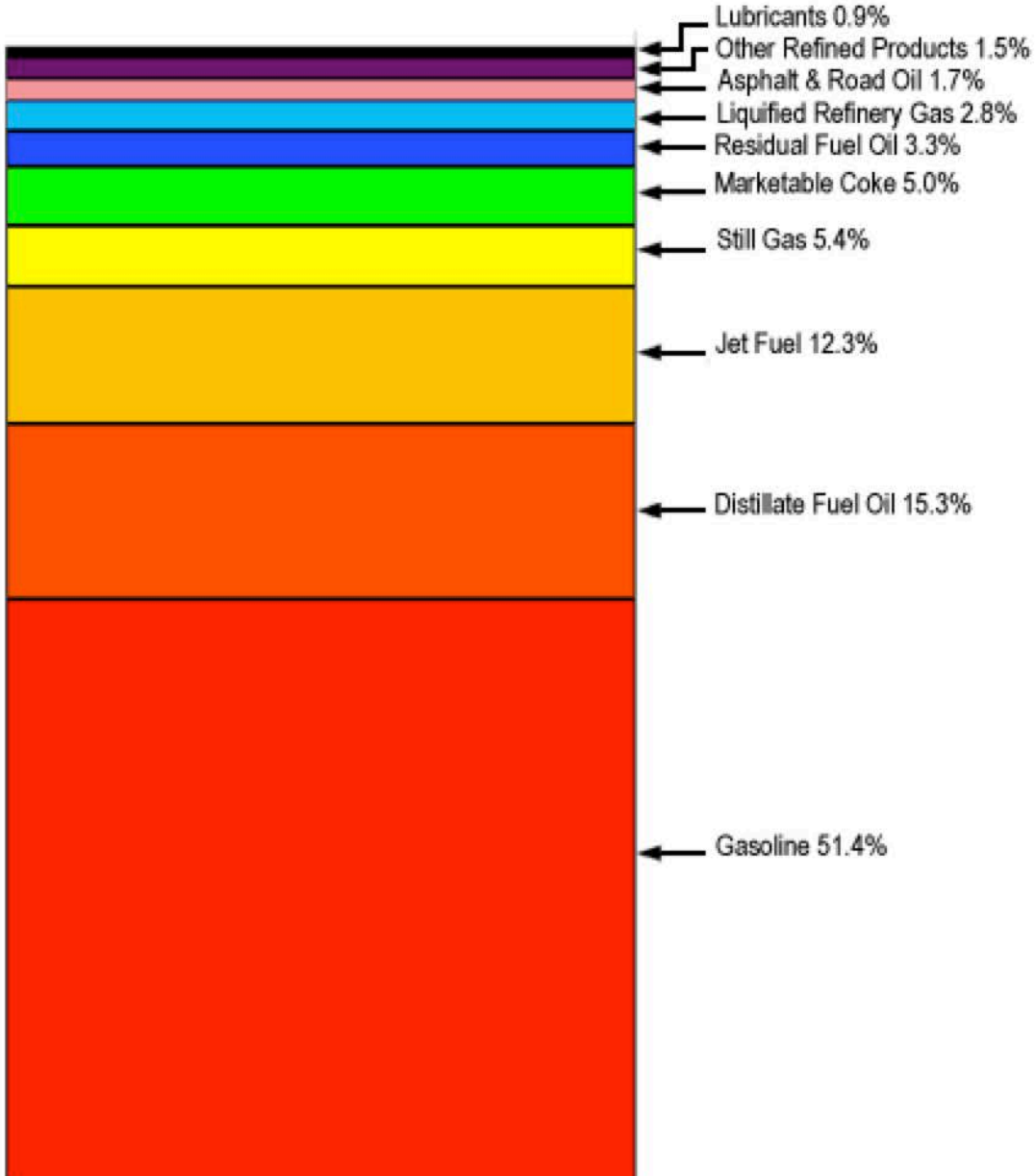
Hydrocarbon

- Oil and natural gas are made of a mixture of different hydrocarbons.
- As the name suggests these are large molecules made up of hydrogen atoms attached to a backbone of carbon.

Distillation (‘cracking’)

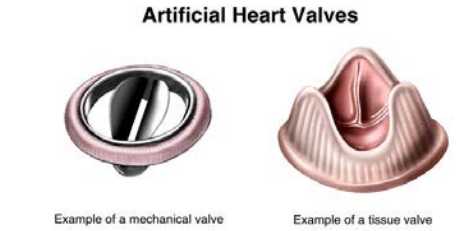


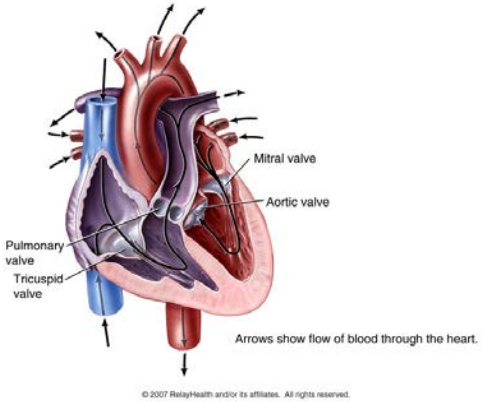
~75% used for planes, trains, cars, ships



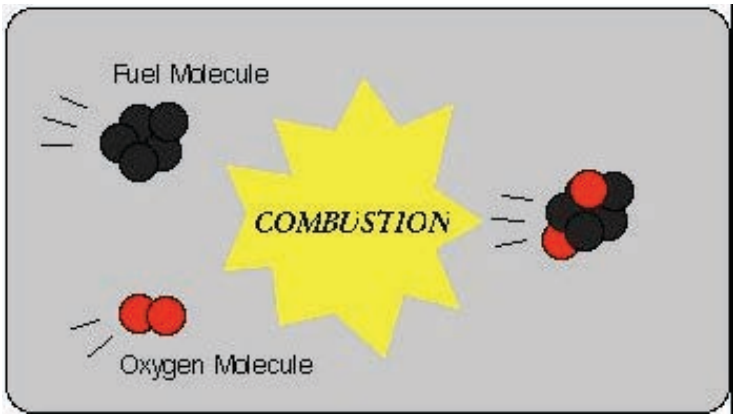
Product	Percent of Total
Finished Motor Gasoline	51.4%
Distillate Fuel Oil	15.3%
Jet Fuel	12.3%
Still Gas	5.4%
Marketable Coke	5.0%
Residual Fuel Oil	3.3%
Liquefied Refinery Gas	2.8%
Asphalt and Road Oil	1.7%
Other Refined Products	1.5%
Lubricants	0.9%

OSSIL FUELS – CURRENT USE





Gasoline is a mixture of various hydrocarbons (e.g., octane) and additives



---------- What the engine needs ----------

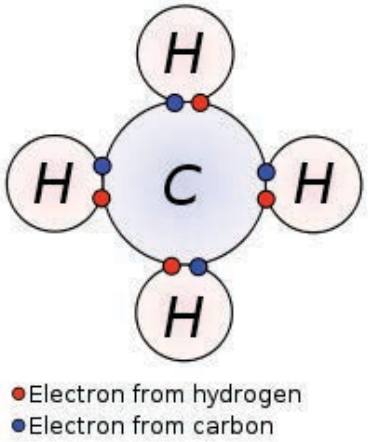
---------- Products of combustion ----------

$$C_8H_{18} + 12.5\ O_8 \Rightarrow 8\ CO_2 + 9\ H_2O$$

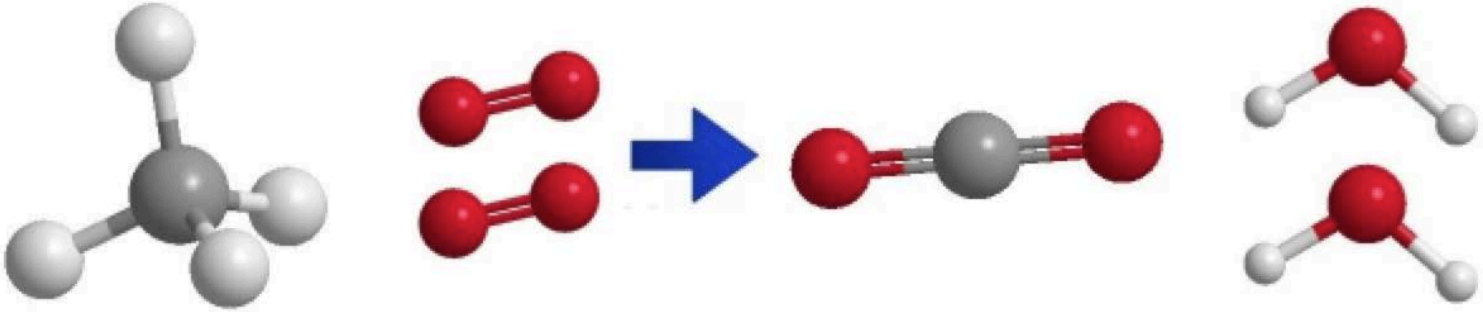
Isooctane Oxygen Carbon dioxide Water

+ ENERGY

Covalent Bonds: Electron Sharing



$$CH_4 + 2\,O_2 = CO_2 + 2\,H_2O + \text{ENERGY}$$

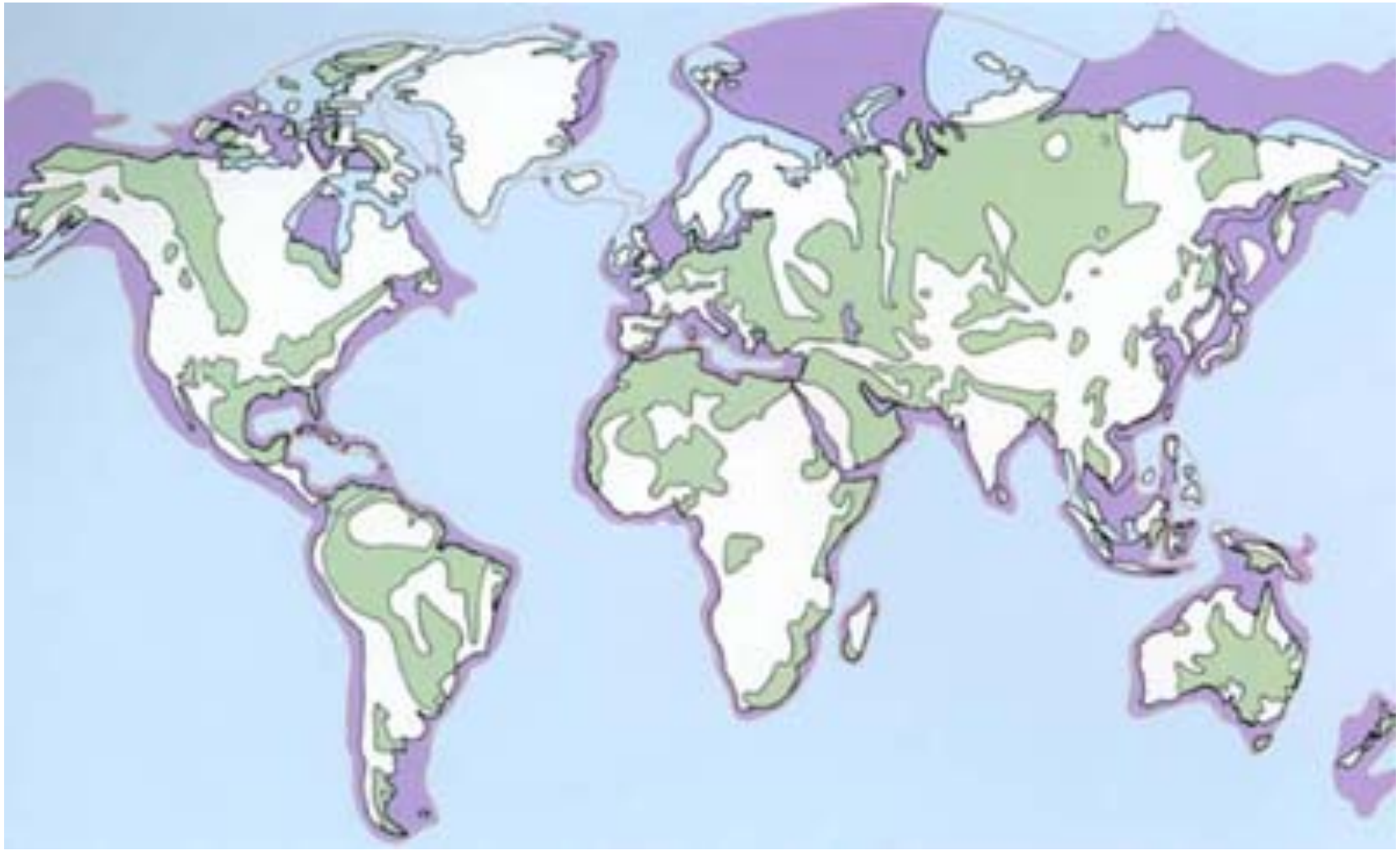


Used to synthesize ammonia, the primary fertilizer that delivers nitrogen to crops.

simple hydrocarbons (natural gas, gasoline) burn easily, can be stored and transported efficiently, and generate energy

Energy density

wood	15 MJ/kg	4 kWh
coal	24 MJ/kg	7 kWh
heating oil	38 MJ/kg	10 kWh
gasoline	45 MJ/kg	12 kWh
methane	55 MJ/kg	15 kWh

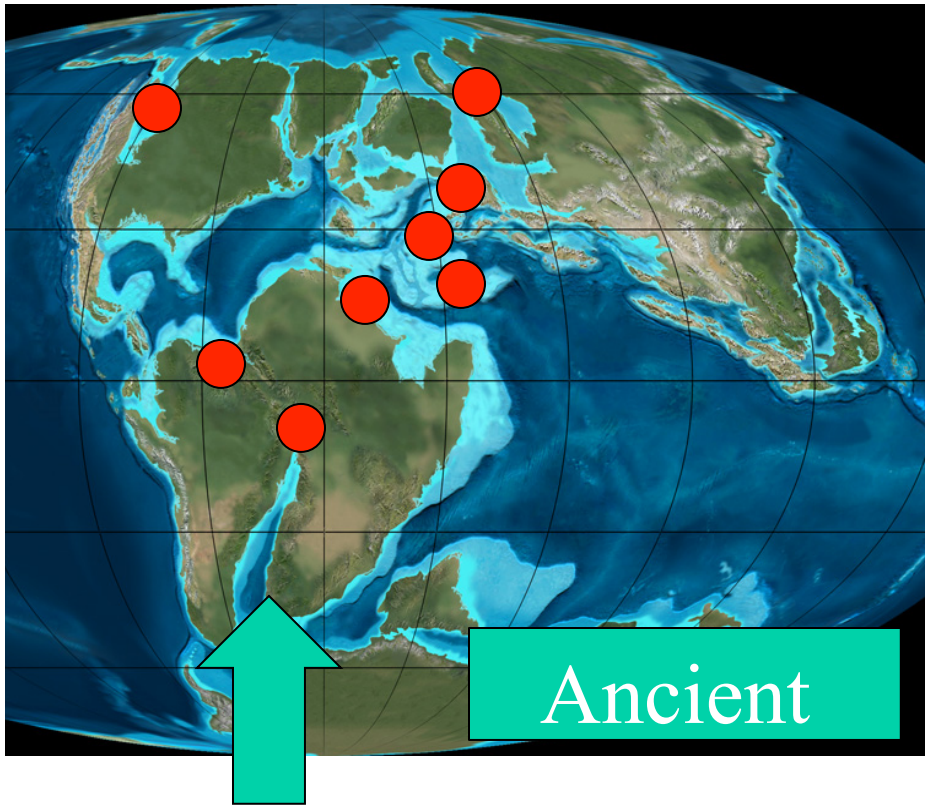


Global Sedimentary Basins

onshore basins; offshore basins

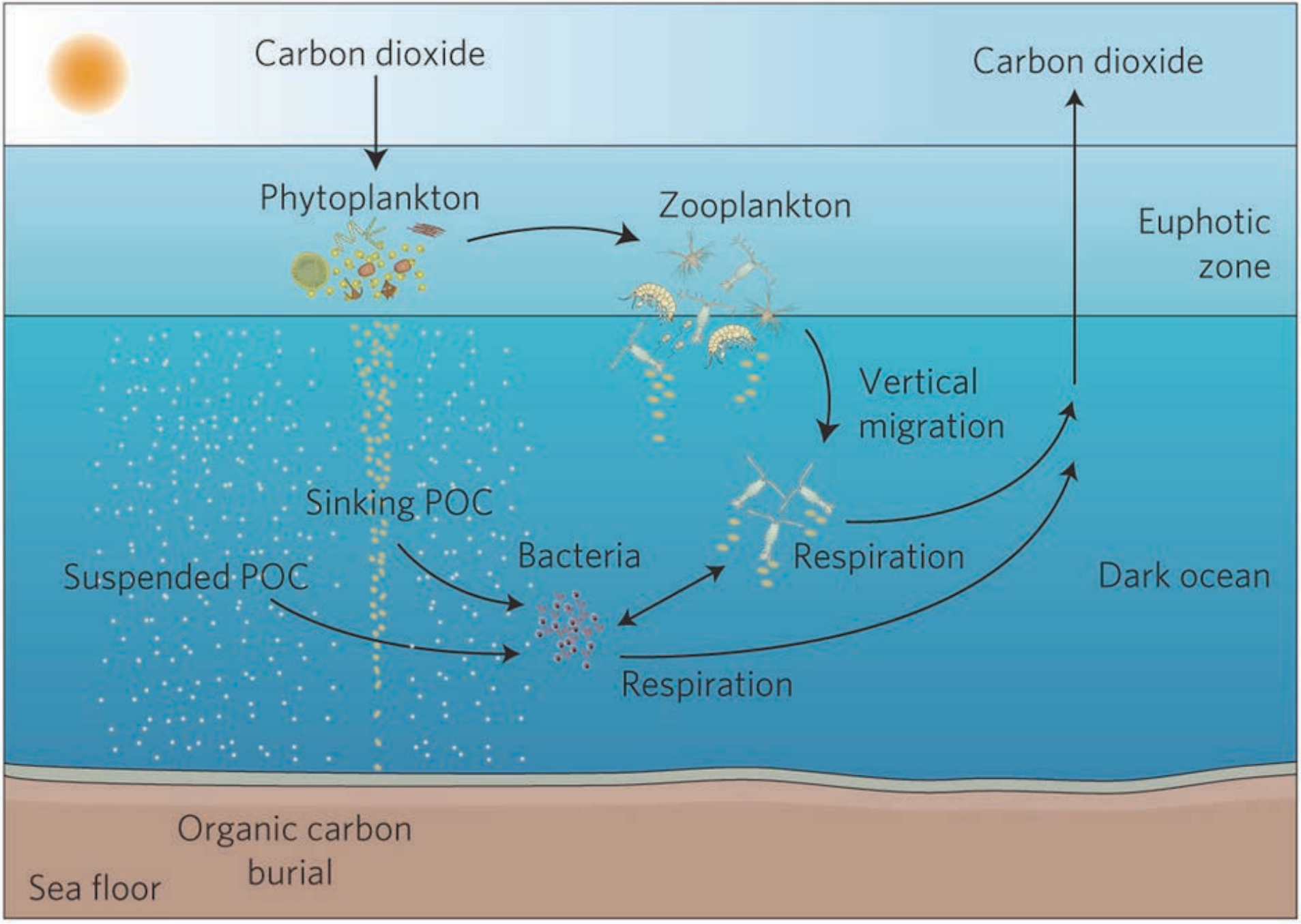
think ‘rivers’, shallow seas/oceans

Ancient Earth



- During mid-Mesozoic times around 150 million years ago, conditions were just right to build up huge thicknesses of Black Shale.

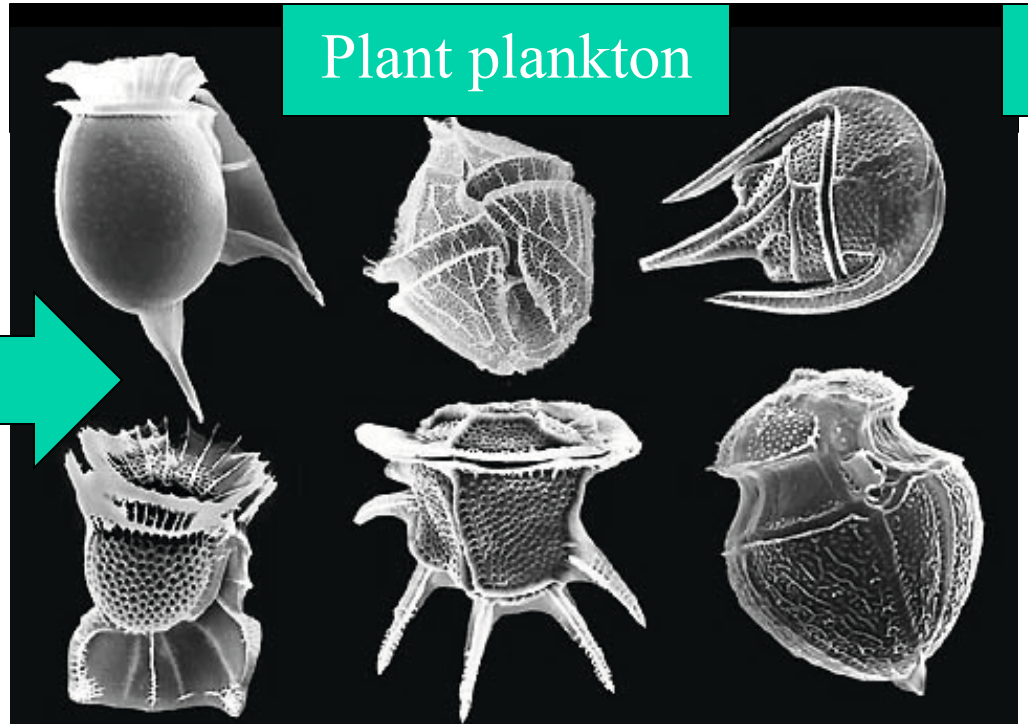
The world's main oil deposits all formed in warm shallow seas where plankton bloomed but bottom waters were deoxygenated


Carbon dioxide
Carbon dioxide
Phytoplankton
Zooplankton
Euphotic zone
Vertical migration
Sinking POC
Bacteria
Respiration
Suspended POC
Dark ocean
Respiration
Organic carbon burial
Sea floor

Plankton

$CaCO_3$

10,000 of these bugs would fit on a pinhead!

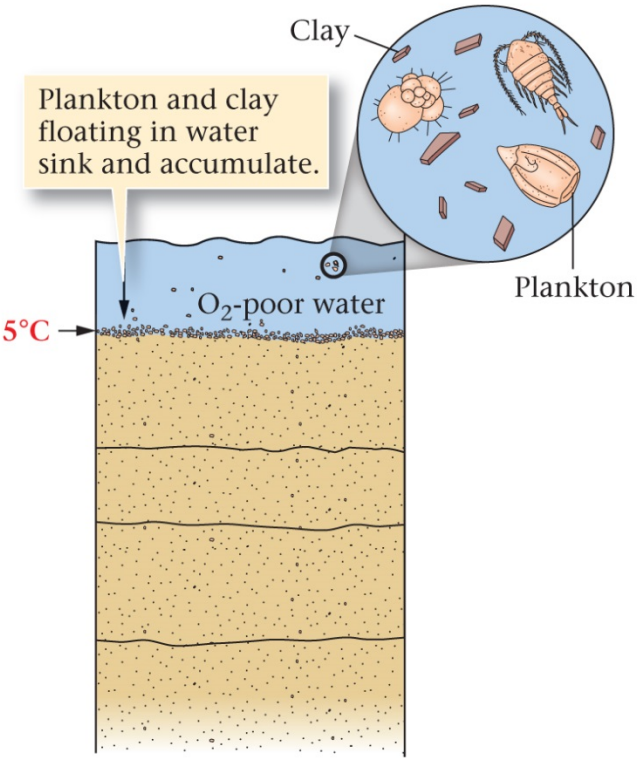


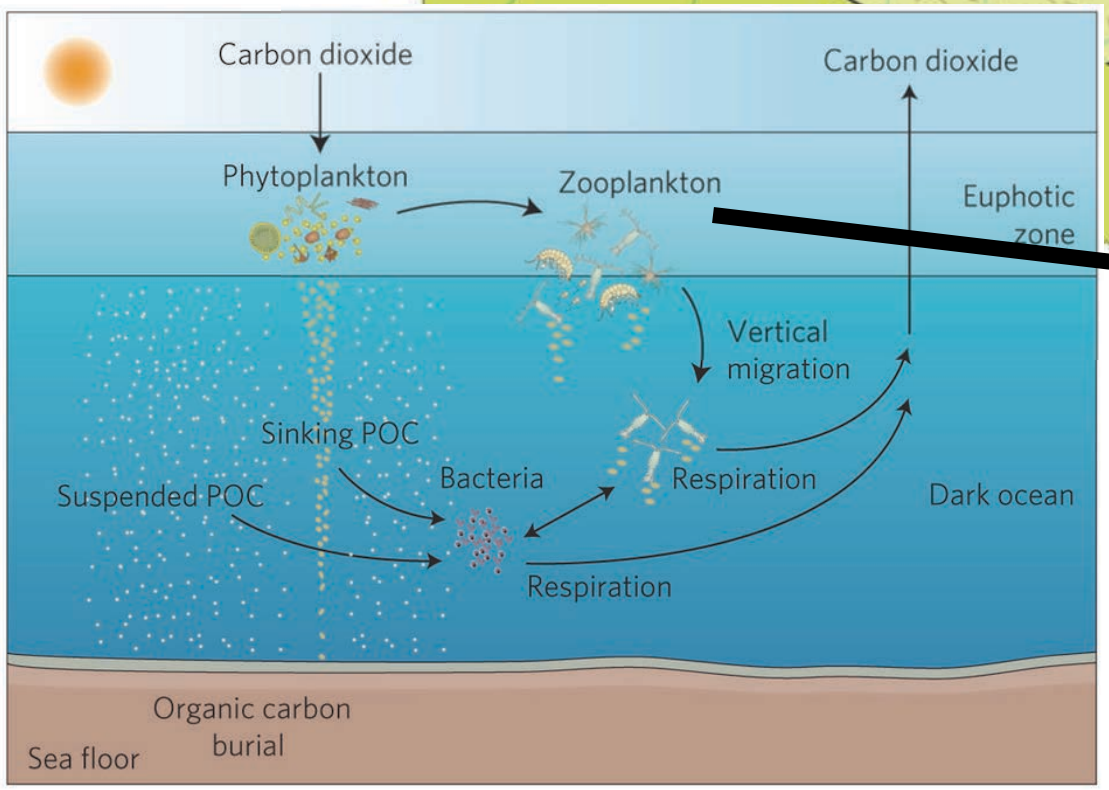
- Oil and natural gas start life as microscopic plants and animals that live in the ocean.

Dinoflagellate bloom

- Today, most plankton can be found where deep ocean currents rise to the surface
- This upwelling water is rich in nutrients and causes the plankton to bloom
- Blooms of certain plankton called dinoflagellates may give the water a red tinge

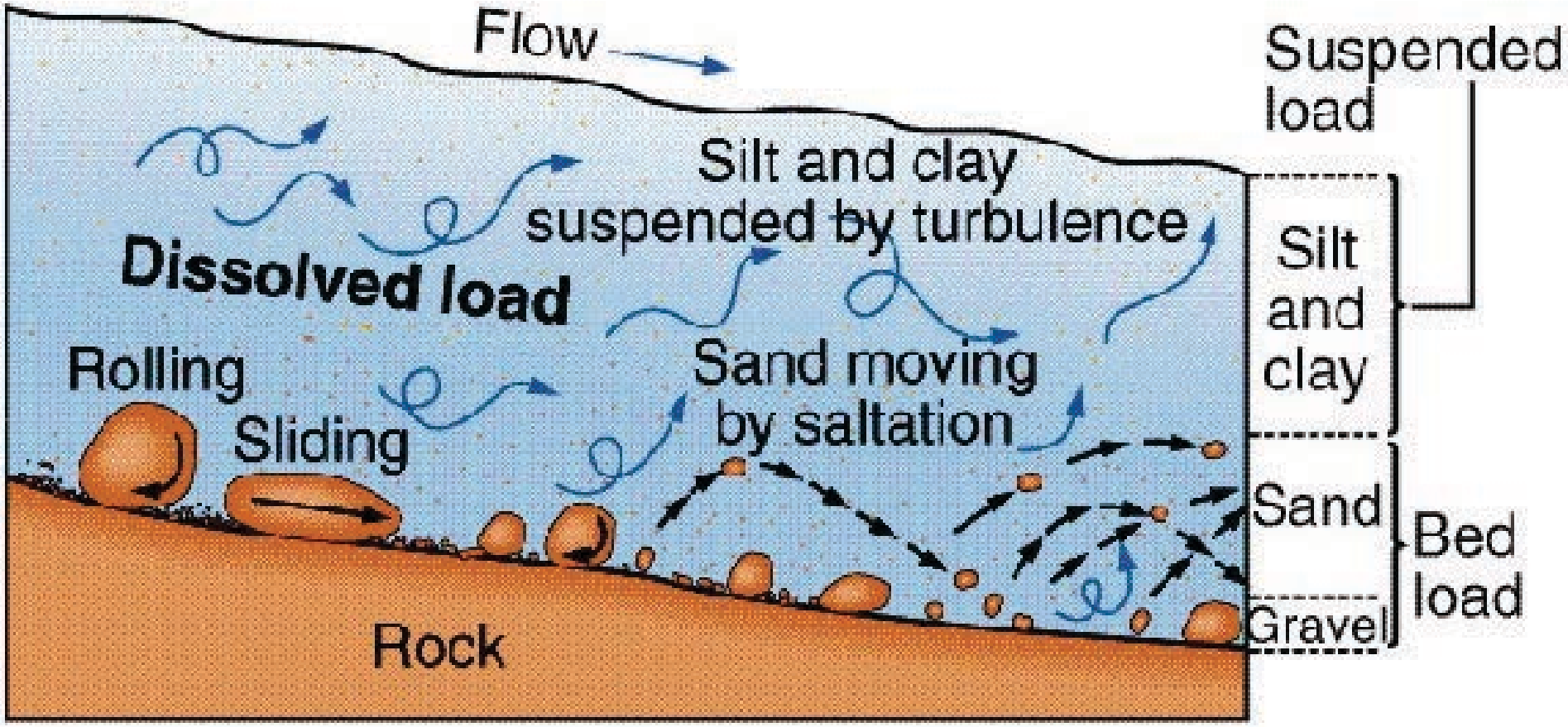
Formation of hydrocarbons from baking of
organic matter (decomposed from plankton, diatoms etc.)
into kerogen → oil, gas

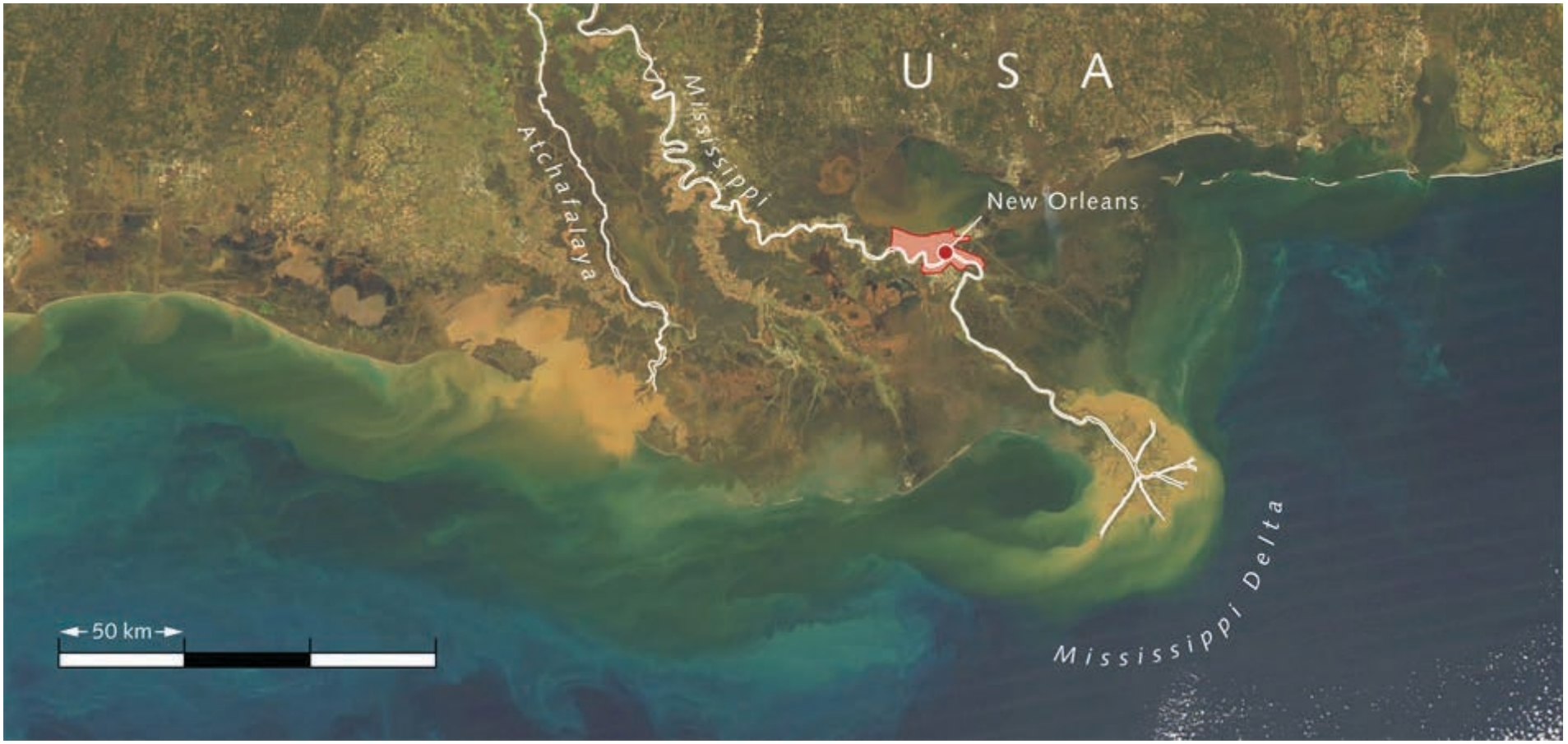


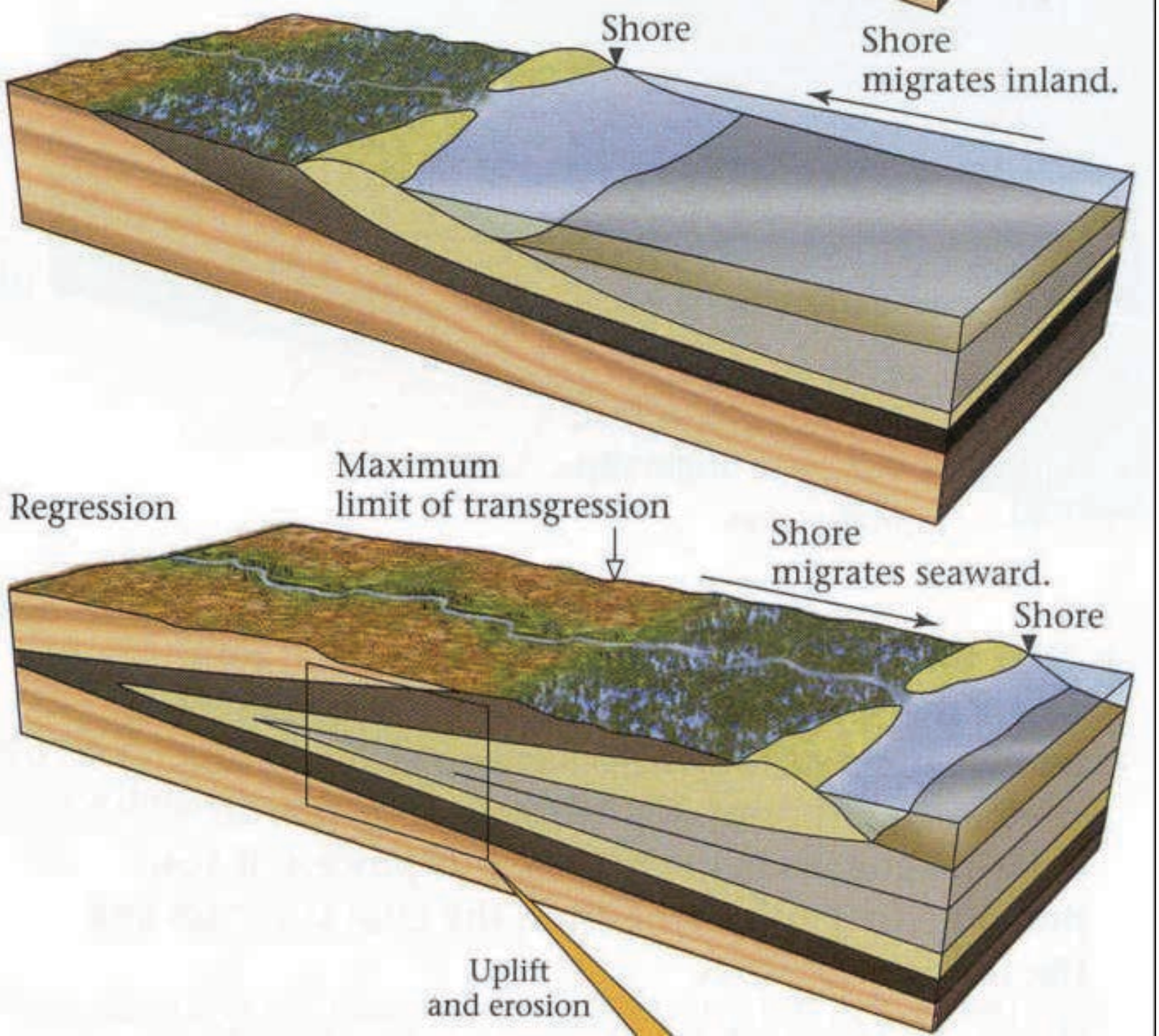


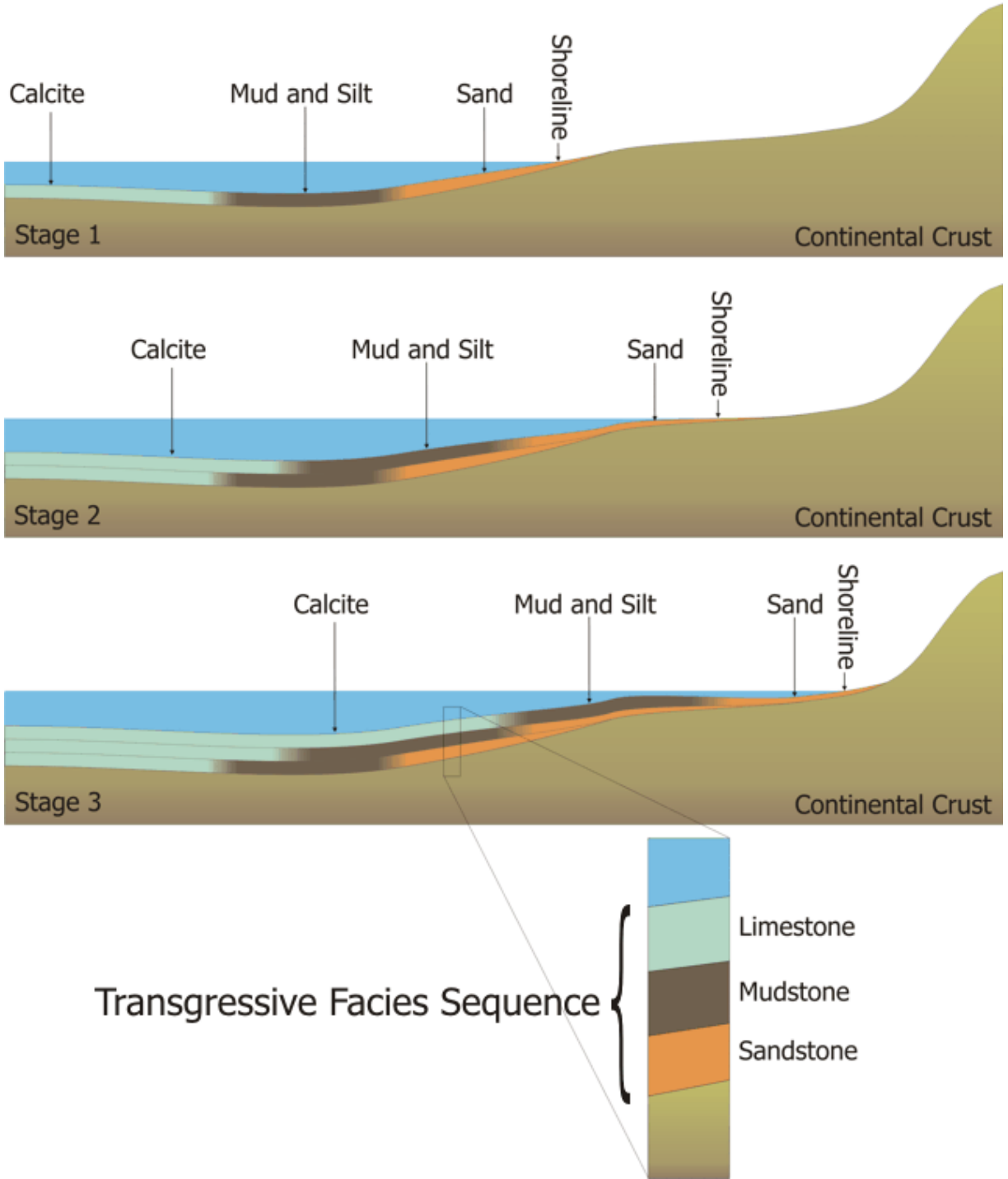
Gulf of Mexico

Contents of a Stream Bed

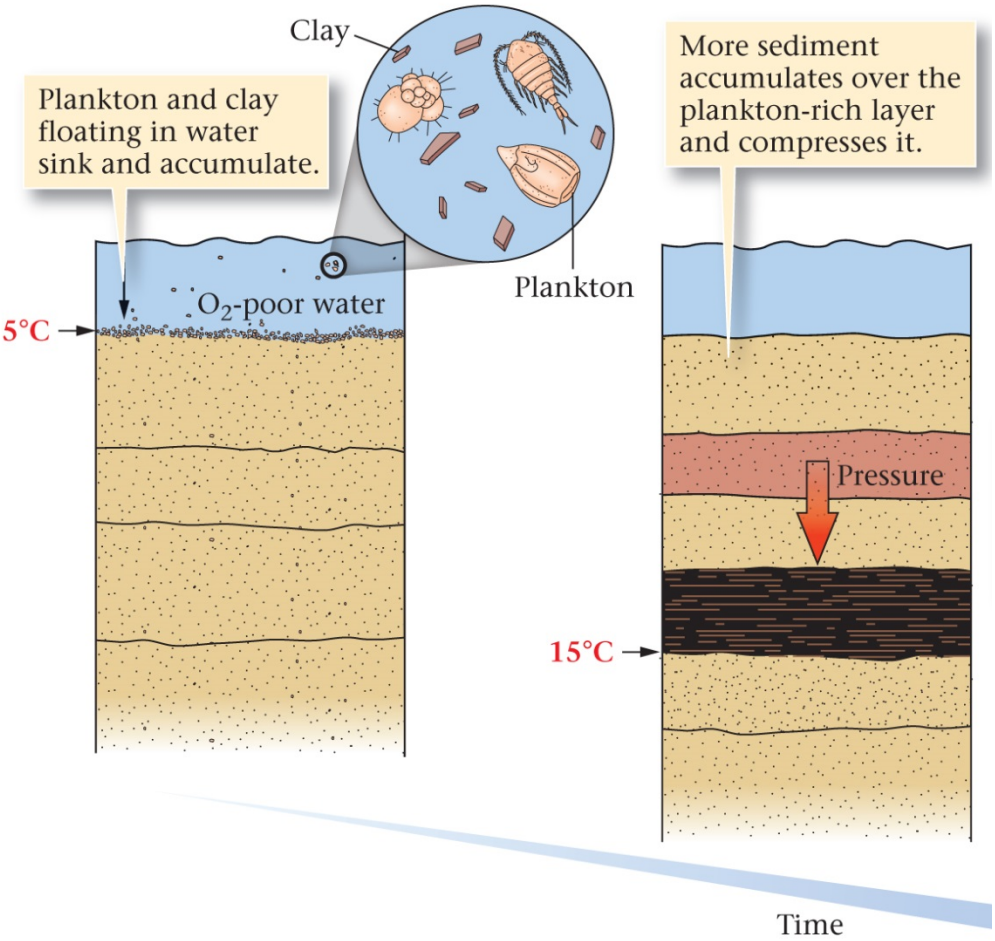



U S A
Mississippi
Atchafalaya
New Orleans
Mississippi Delta
50 km

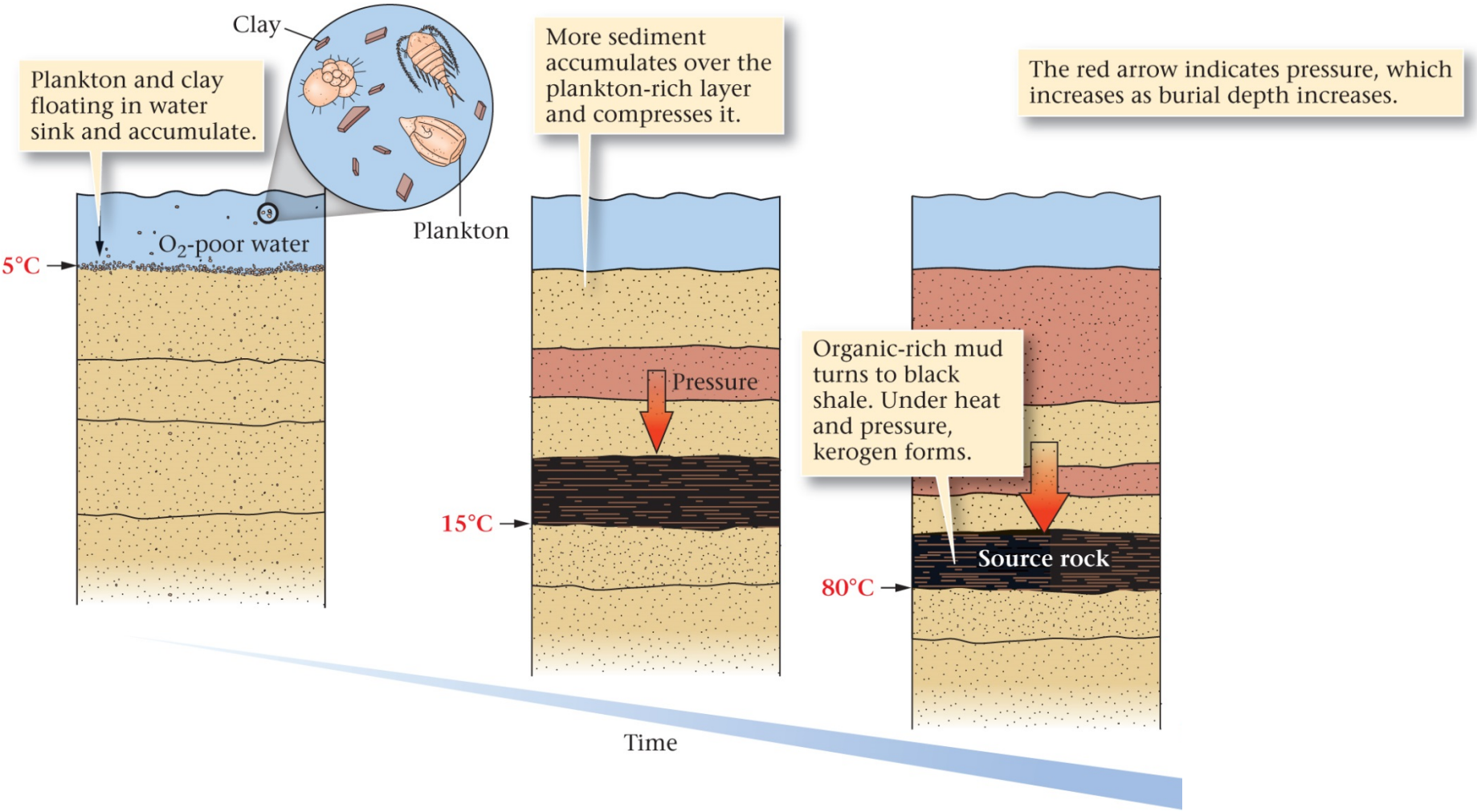

Shore
Shore
migrates inland.
Regression
Maximum
limit of transgression
Shore
migrates seaward.
Shore
Uplift
and erosion


Calcite
Mud and Silt
Sand
Shoreline
Stage 1
Continental Crust
Calcite
Mud and Silt
Sand
Shoreline
Stage 2
Continental Crust
Calcite
Mud and Silt
Sand
Shoreline
Stage 3
Continental Crust
Transgressive Facies Sequence
Limestone
Mudstone
Sandstone

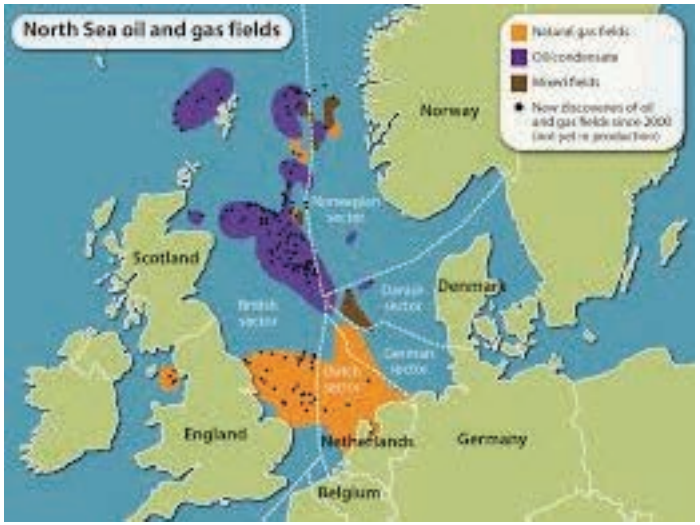
Formation of hydrocarbons from baking of organic matter (decomposed from plankton, diatoms etc.) into kerogen → oil, gas



Formation of hydrocarbons from baking of organic matter (decomposed from plankton, diatoms etc.) into kerogen → oil, gas

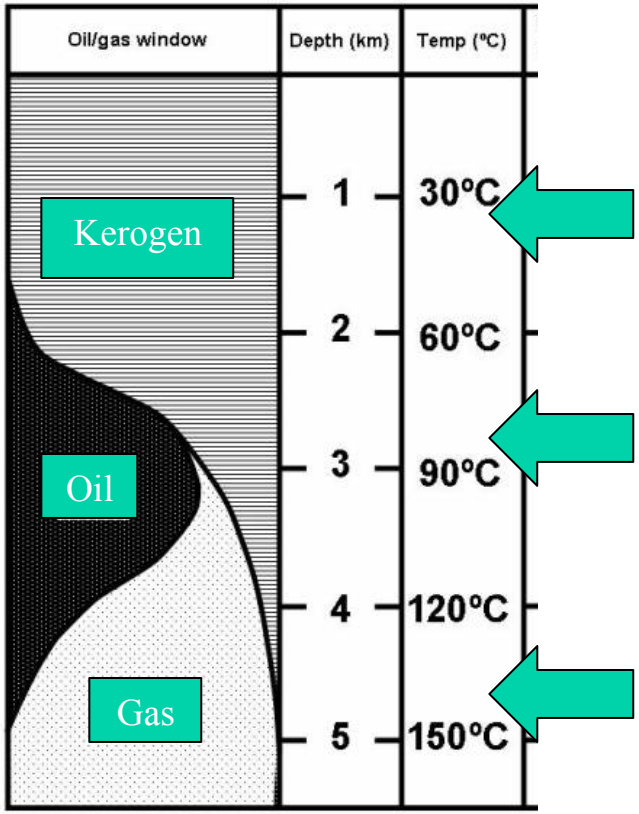


Black Shale = Source Rock



The Kimmeridge Clay is a Black Shale with up to 50% organic matter. It is the main source rock for the North Sea Oil & Gas Province.

Thermal Maturation (Cooking)



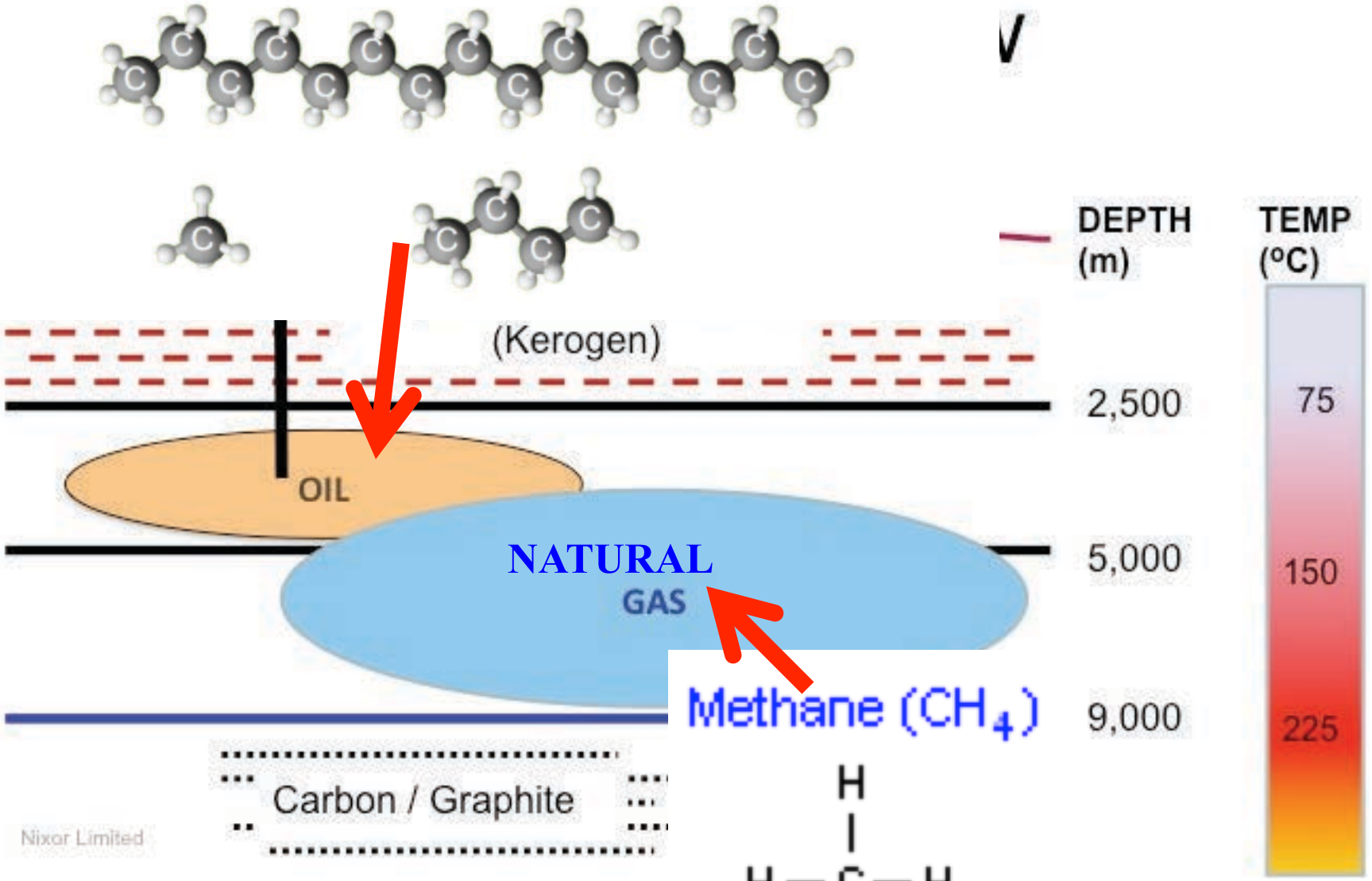
As Black Shale is buried, it is heated.

Organic matter is first changed by the increase in temperature into kerogen, which is a solid form of hydrocarbon

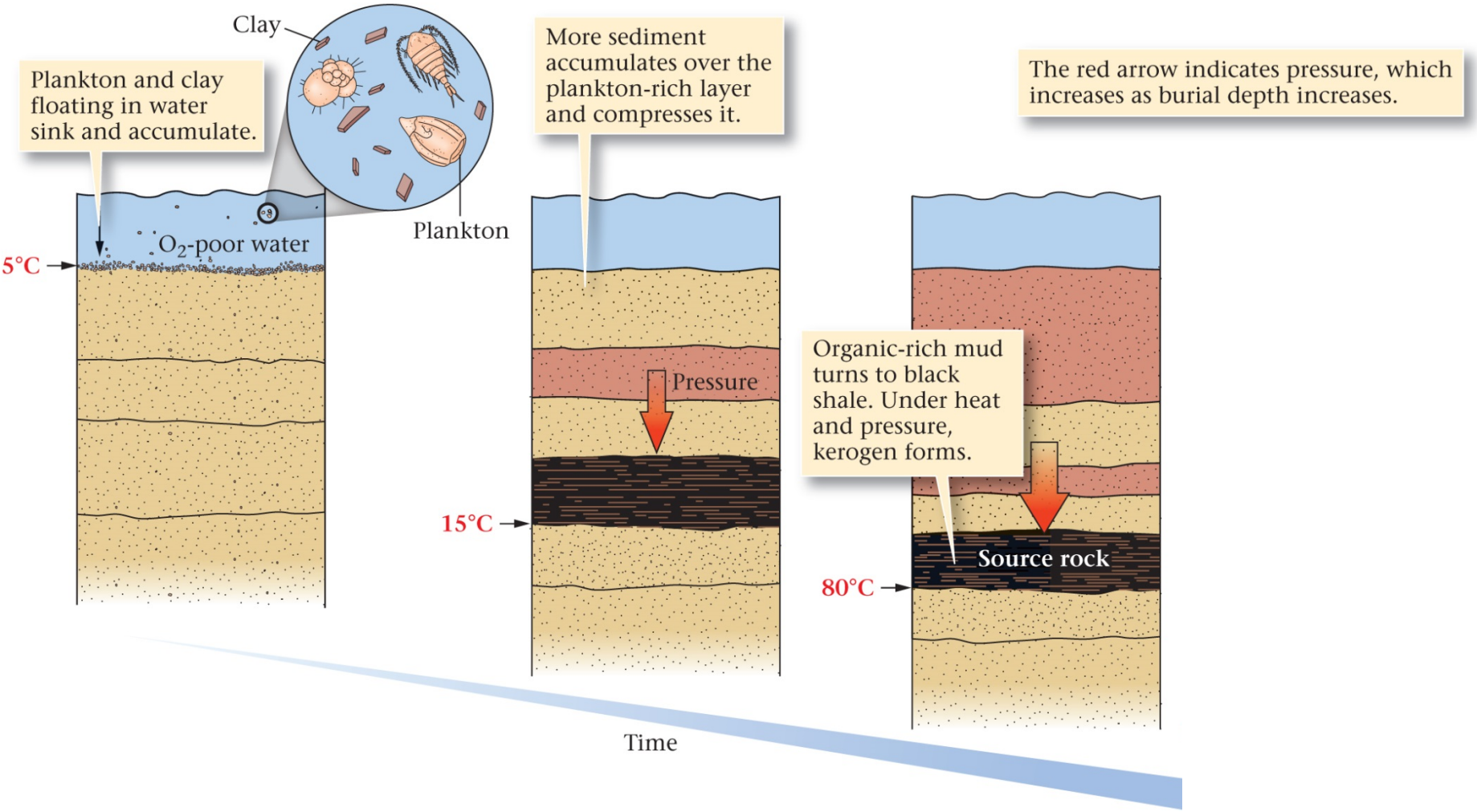
Around 90°C, it is changed into a liquid state, which we call oil

Around 150°C, it is changed into a gas

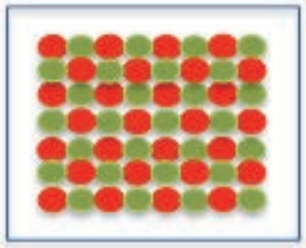
A rock that has produced oil and gas in this way is known as a Source Rock


(Kerogen)
OIL
NATURAL
GAS
Carbon / Graphite
Nixor Limited
DEPTH
(m)
2,500
5,000
9,000
TEMP
(°C)
75
150
225
Methane (CH_4)

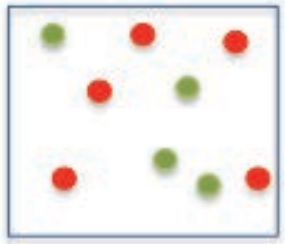
Formation of hydrocarbons from baking of organic matter (decomposed from plankton, diatoms etc.) into kerogen → oil, gas



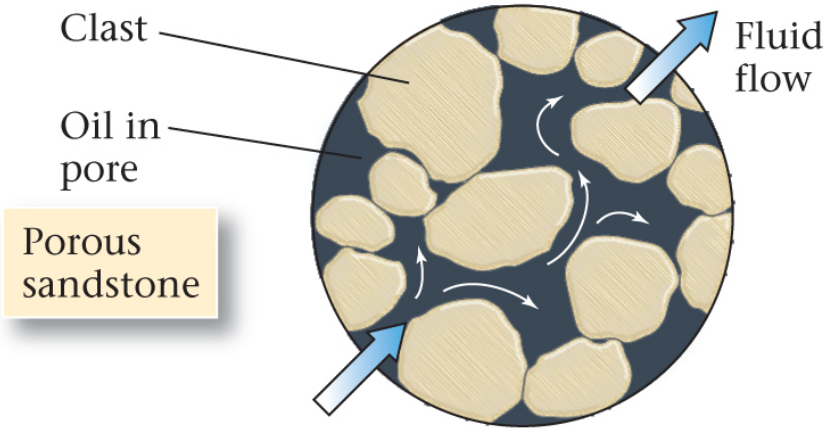
Oil/gas migration



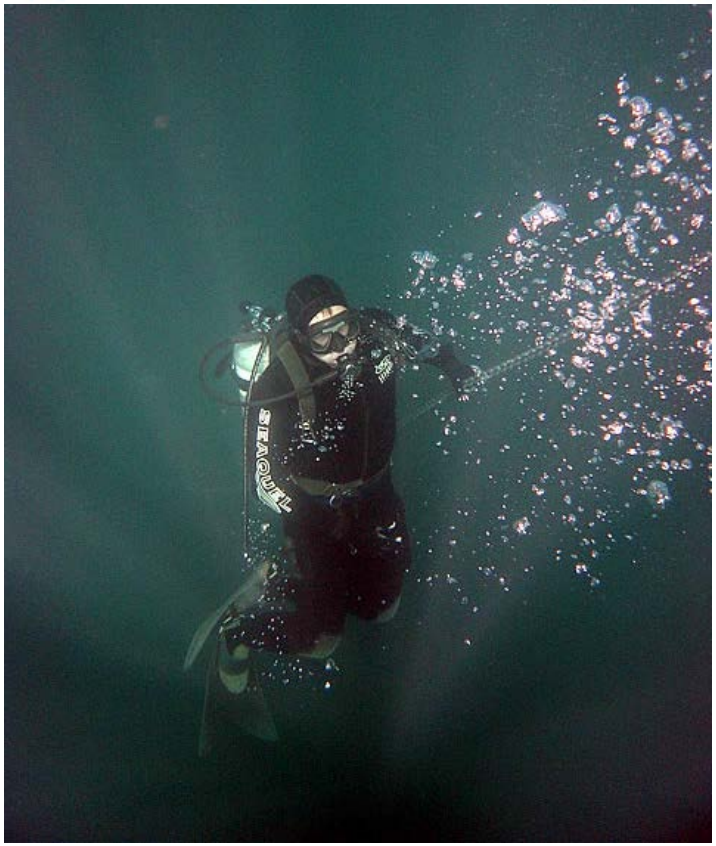
High Density



Low Density

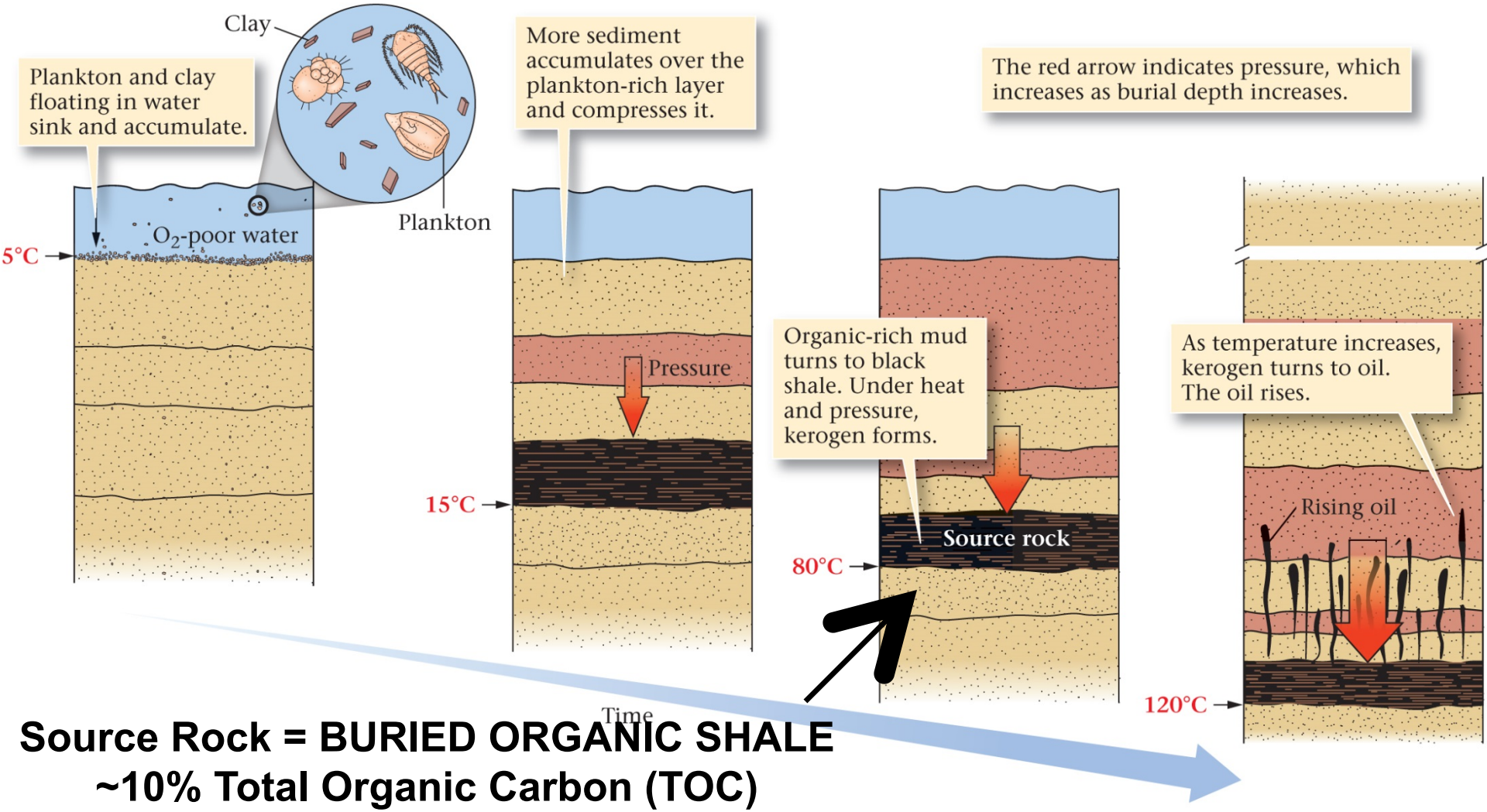


(a)



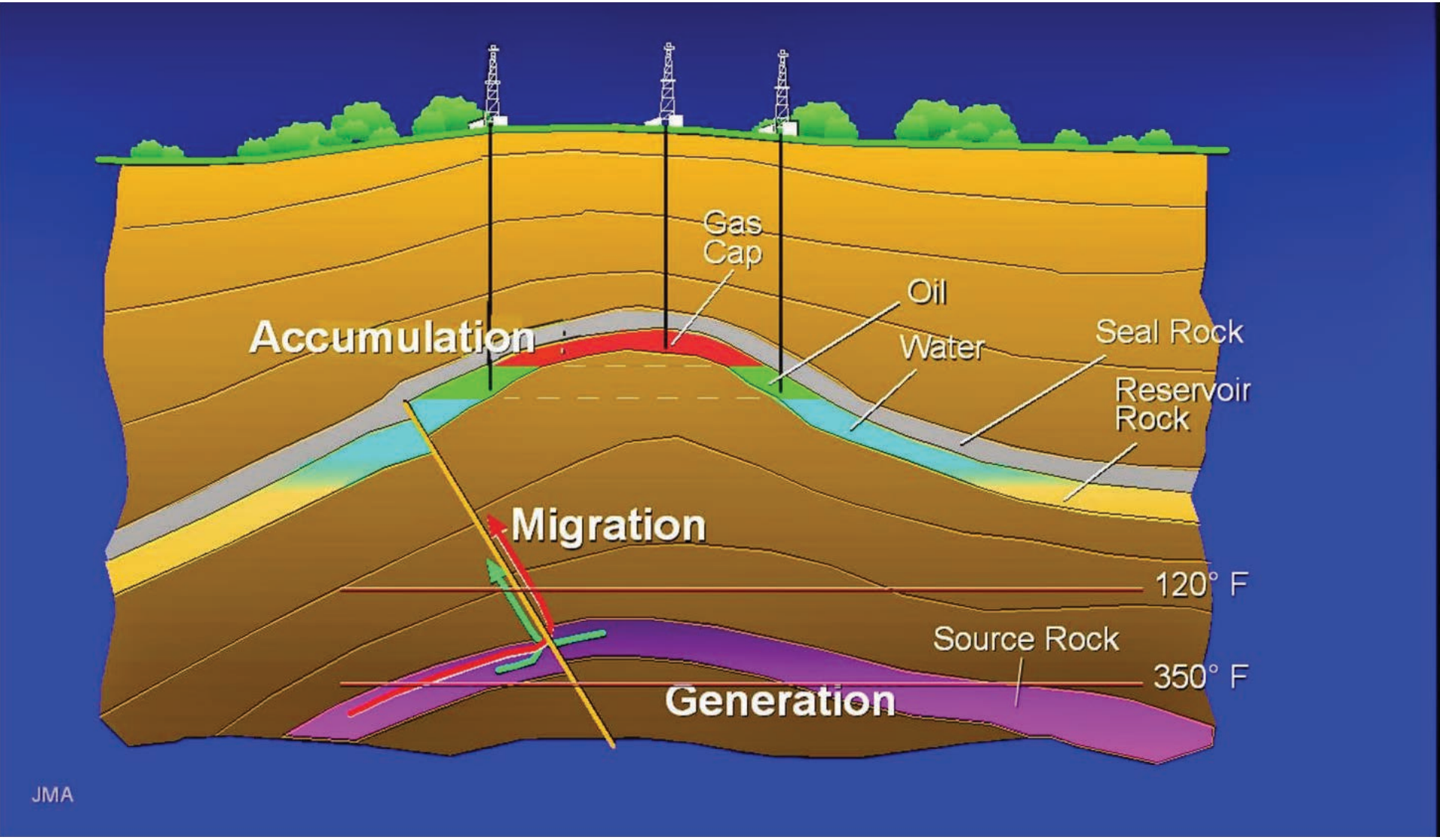
- Hot oil and gas are less dense than the source rock in which they occur
- Oil and gas migrate upwards up through the rock in much the same way that the air bubbles of an underwater diver rise to the surface

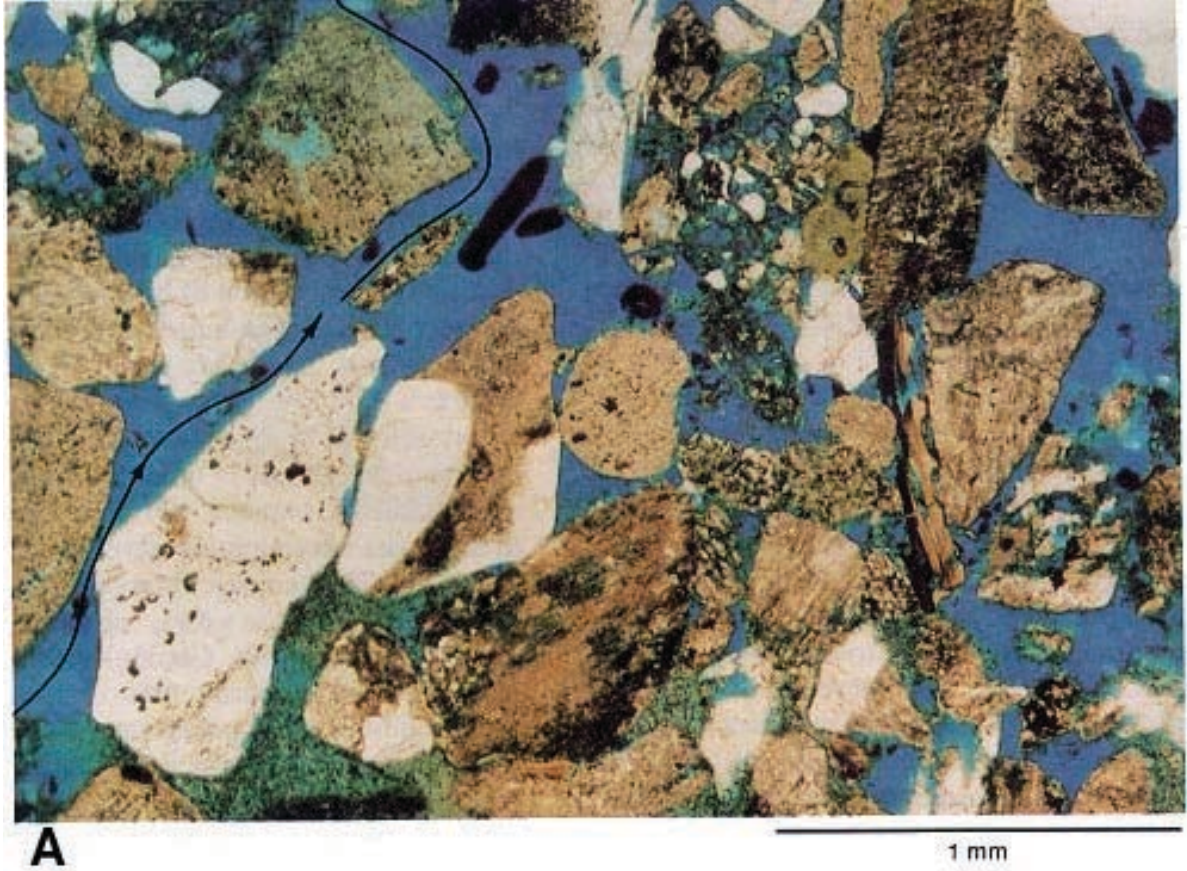
Formation of hydrocarbons from baking of organic matter (decomposed from plankton, diatoms etc.) into kerogen → oil, gas



Source Rock = BURIED ORGANIC SHALE
~10% Total Organic Carbon (TOC)

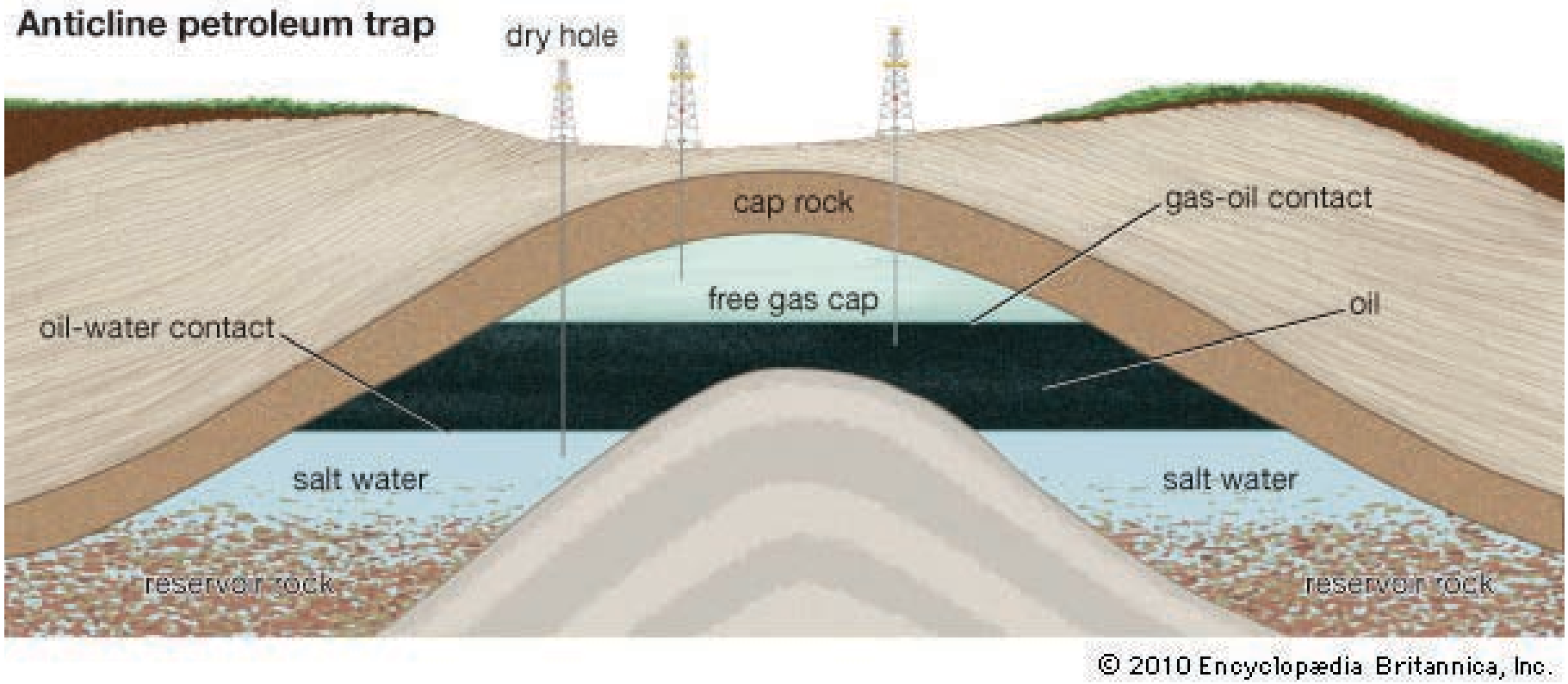
Formation of an oil and natural gas “trap”





A magnified image of a sandstone. The rock sample was injected with blue-colored epoxy that is seen here filling pores which are interconnected (permeable). The sample is exceedingly porous and permeable. The grains are loosely packed and there is very little cement filling the space between the grains. The arrow indicates possible pathways for fluid movement.

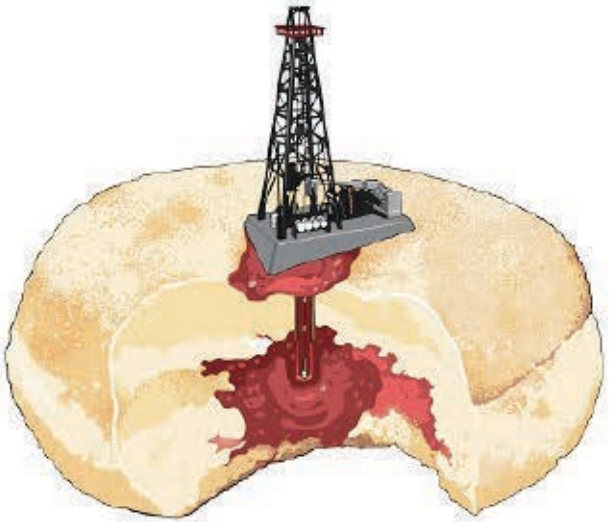
Formation of an oil and natural gas “trap”



CONVENTIONAL RESERVOIRS

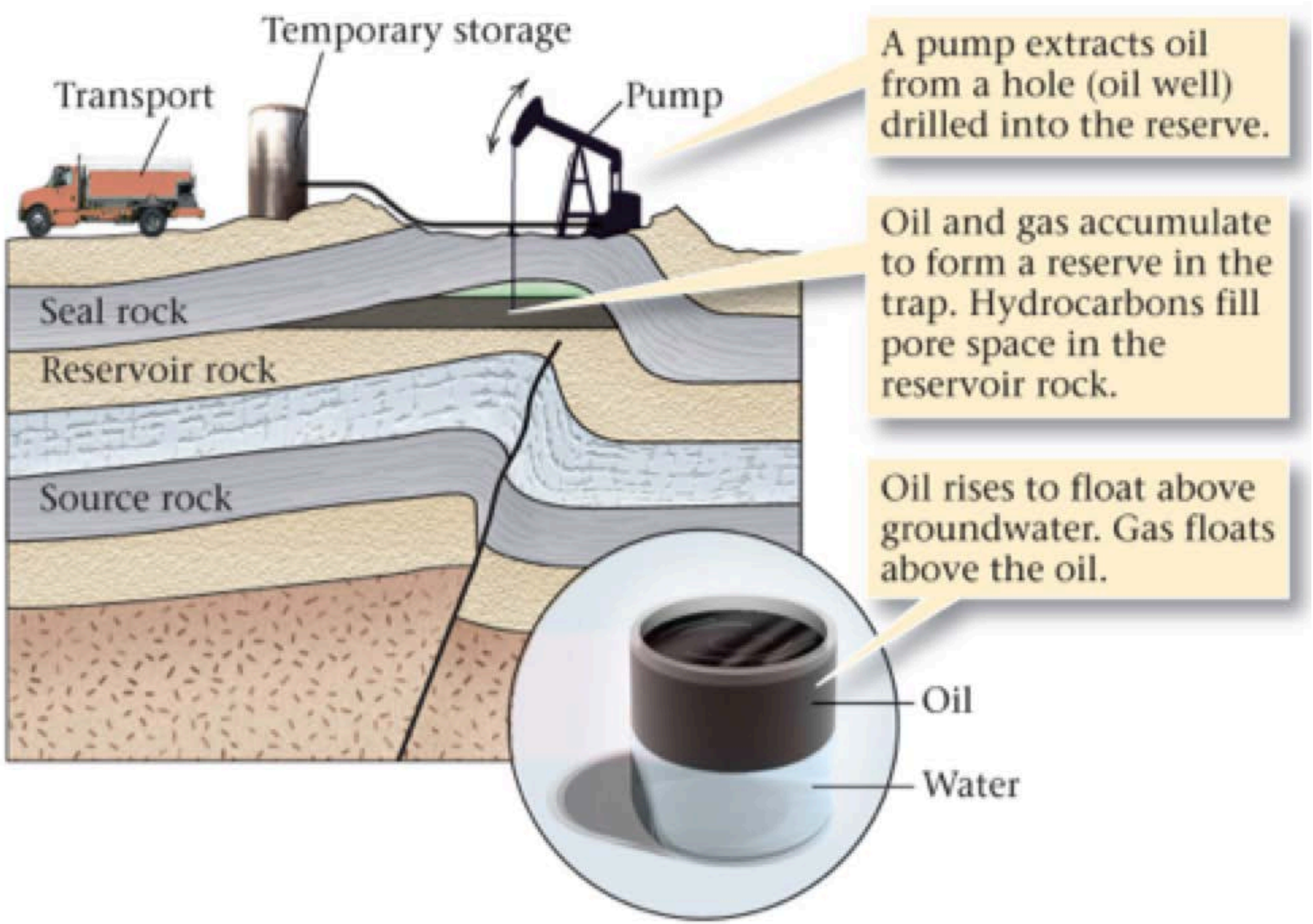
Jelly Donut

Conventional Drilling

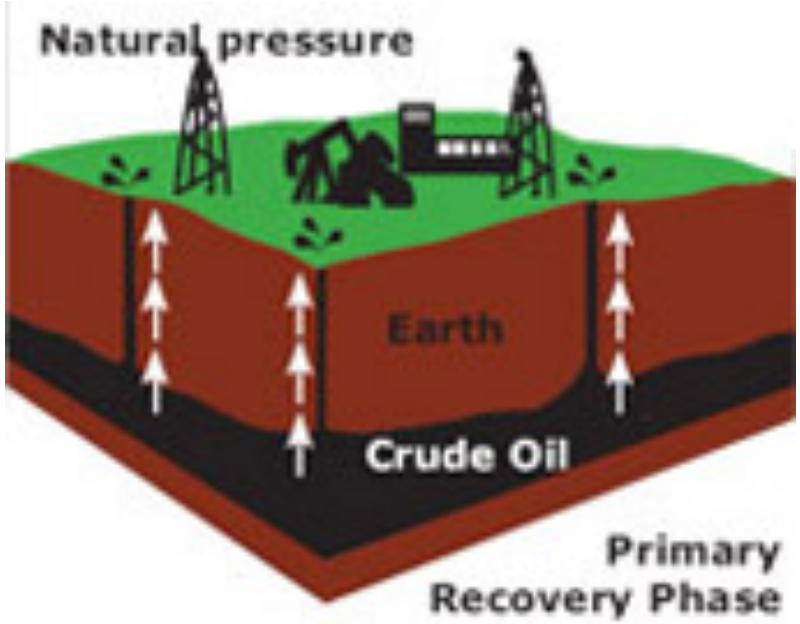


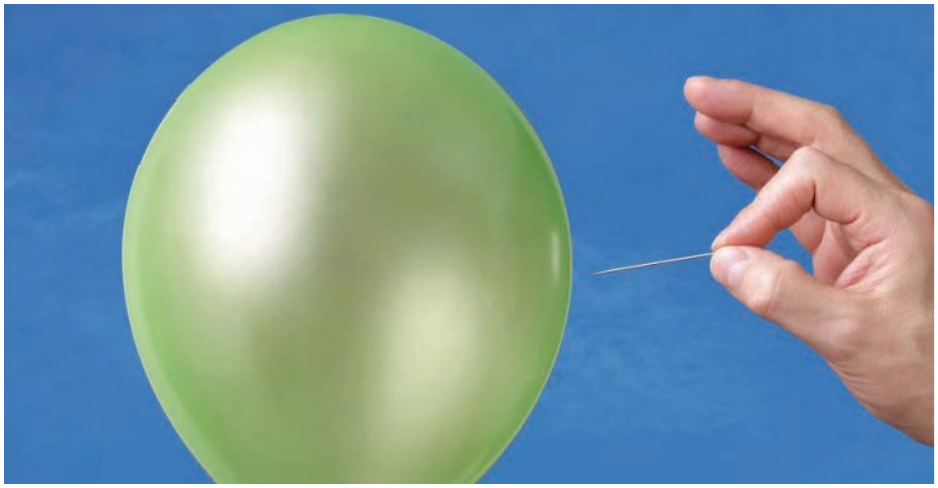
conventional oil/gas reservoir

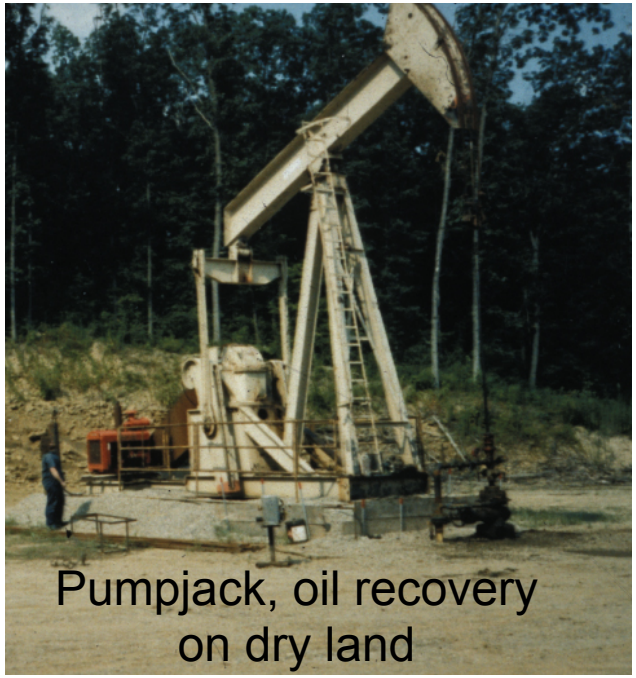
structural oil and gas traps



Primary Oil Recovery



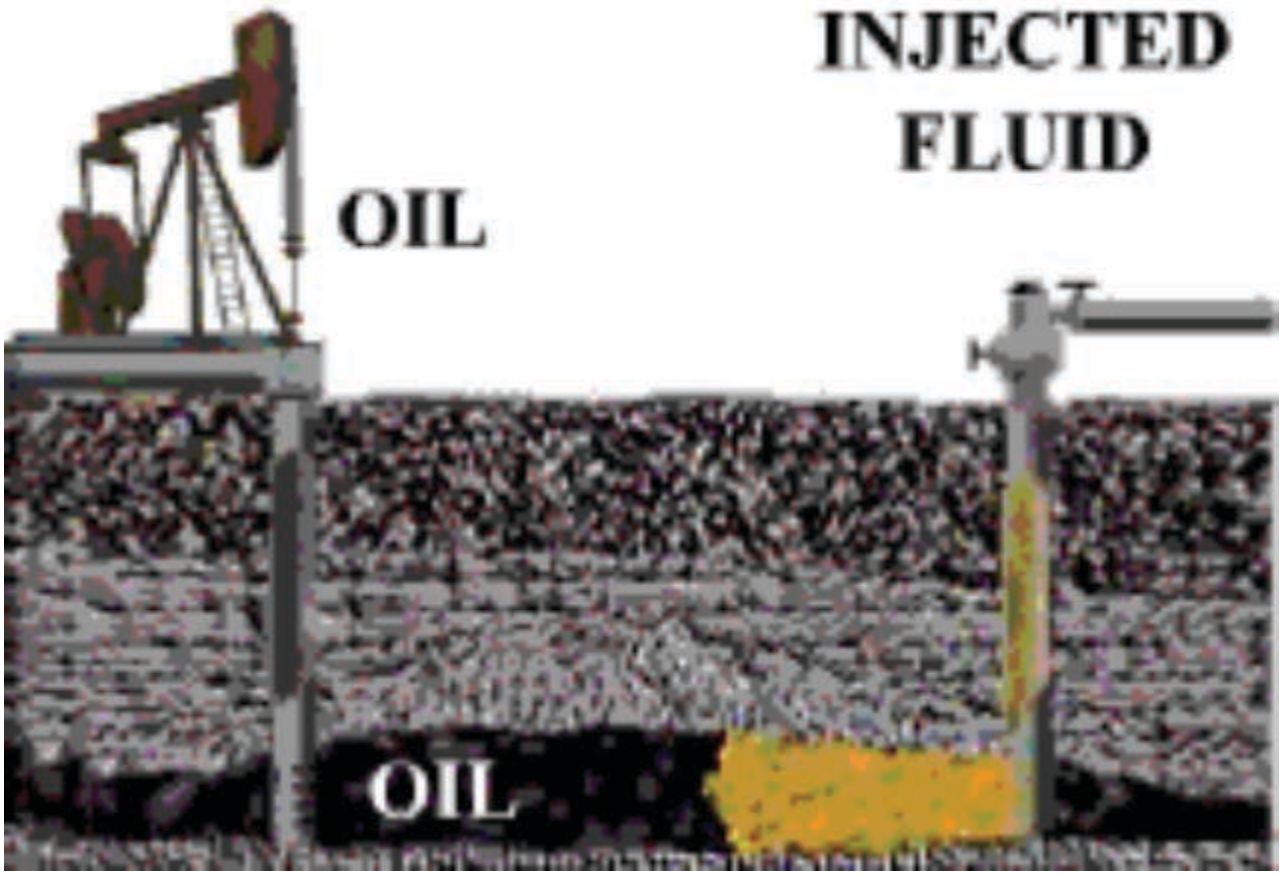



Pumpjack, oil recovery on dry land

Uses natural pressure of the reservoir to push crude oil to the surface

Allows about 5% to 10% of the oil in the reservoir to be extracted

Secondary Oil Recovery

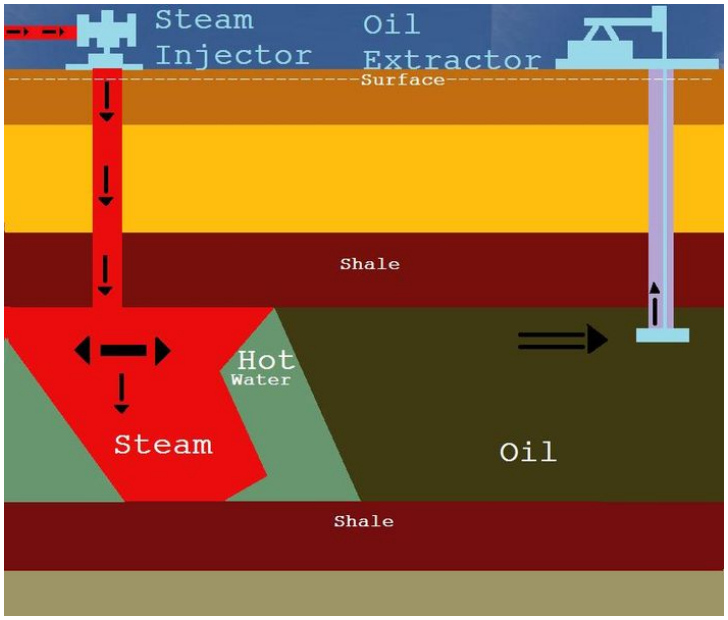


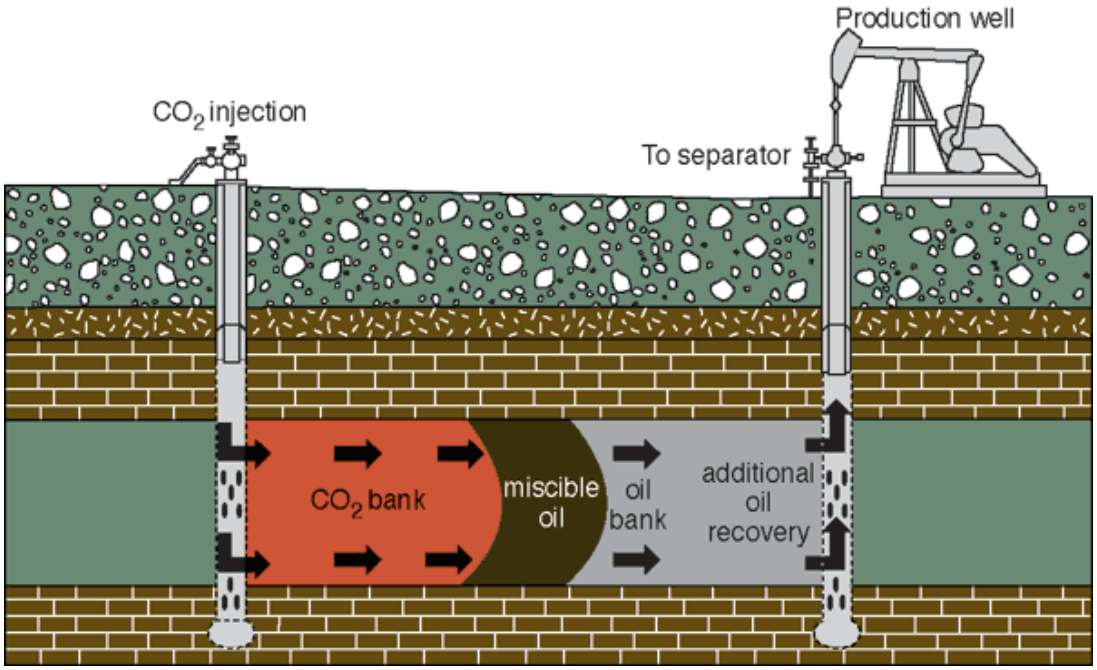
Injects **water** to drive the residual crude oil and gas remaining after the primary oil recovery phase to the surface wells

Allows additional 25% to 30% of the oil in the reservoir to be extracted

So after primary and secondary, ~50% oil remains in the ground

Tertiary “enhanced” Oil Recovery





Heat increases oil temperature;
Viscosity decreases;
Easier to pump out.

Liquid CO_2 forces oil out of tight pore spaces;

Tertiary recovery (average) about 25 %

Drill Conventionally

Jelly Donut

Conventional Drilling
Basic Vertical Penetration
Limited Formation Contact

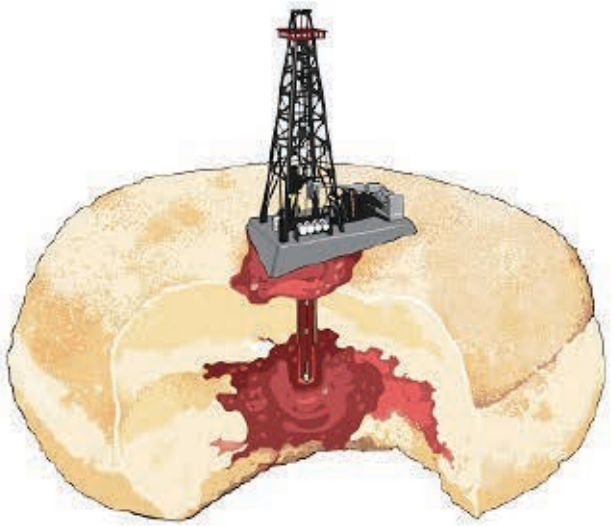
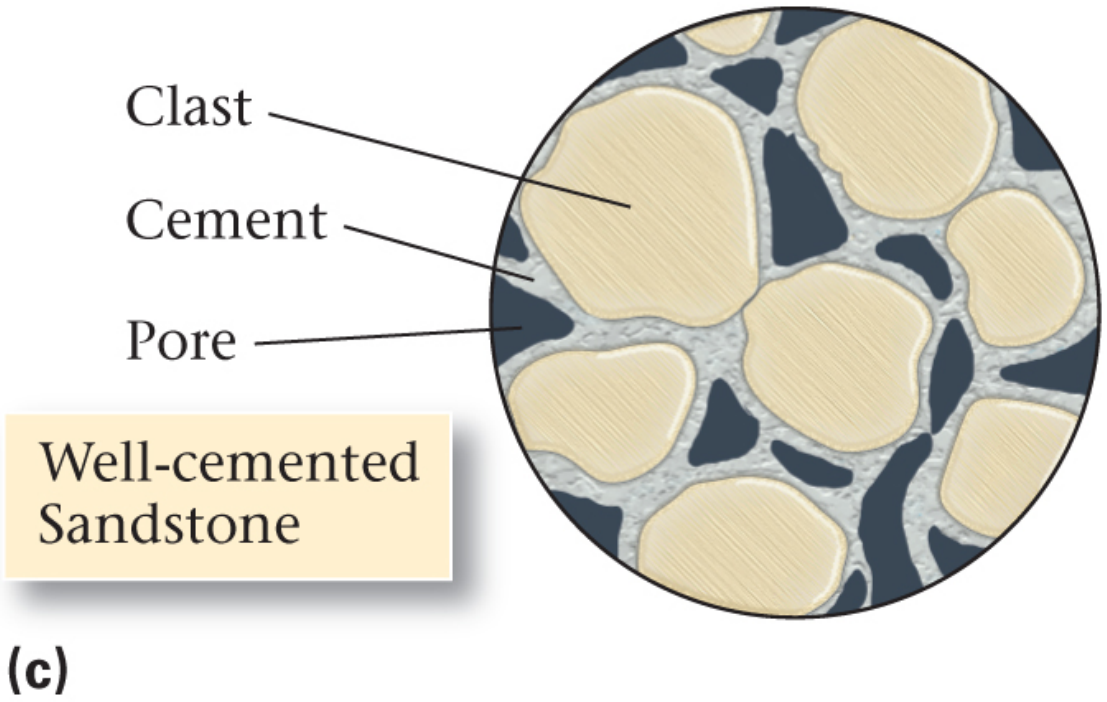


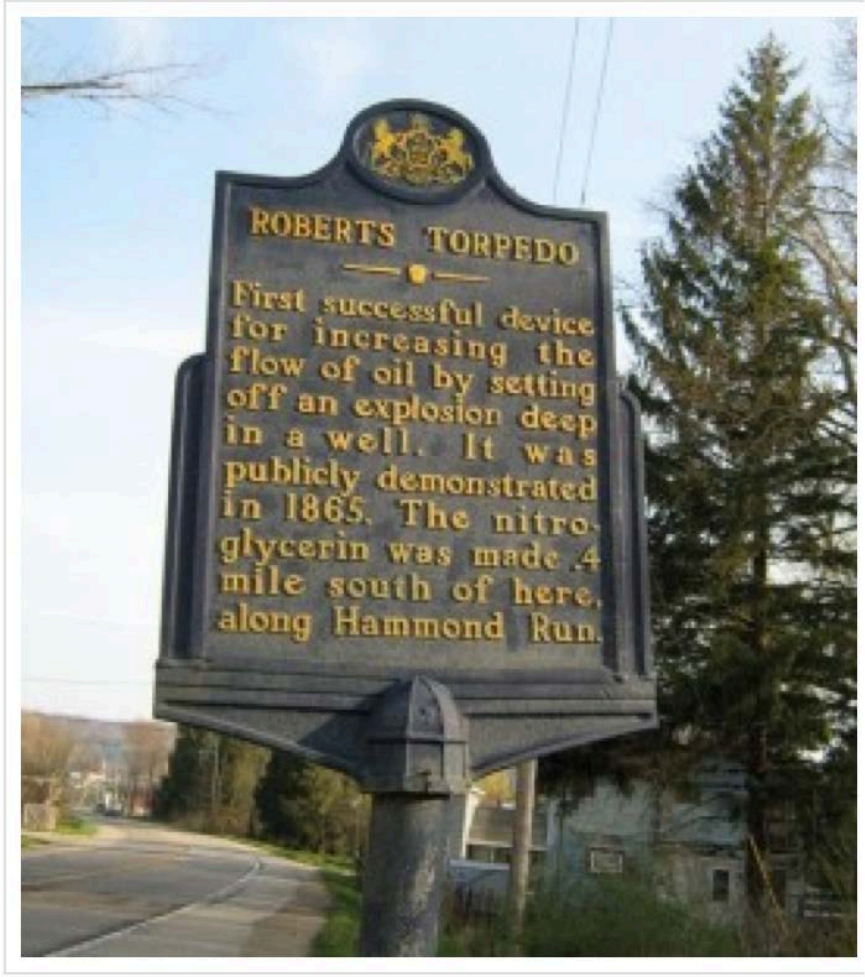
Illustration © James Scherrer 2014

East TX Field, WW II, 24 “big inch” pipe to City of Brotherly Love, and “thieves” 1930s, single wells > 20,000 b/day

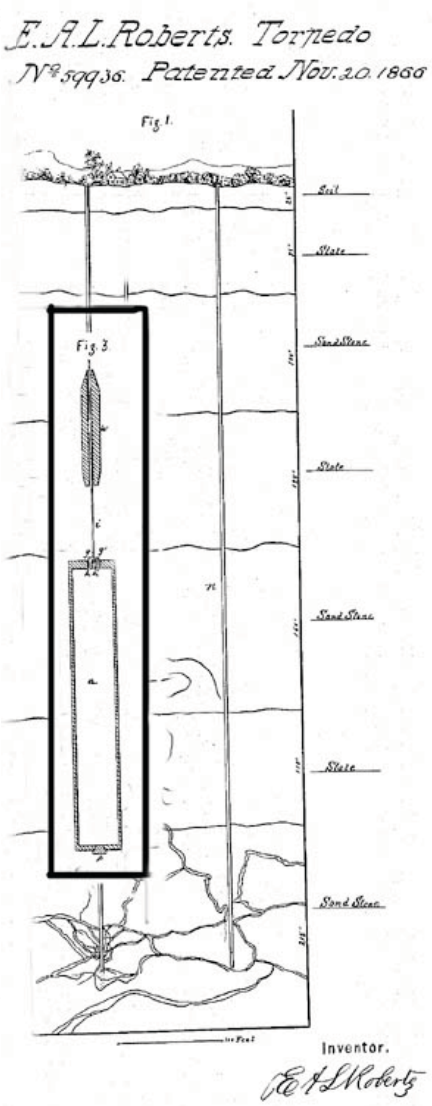
UNCONVENTIONAL RESERVOIR

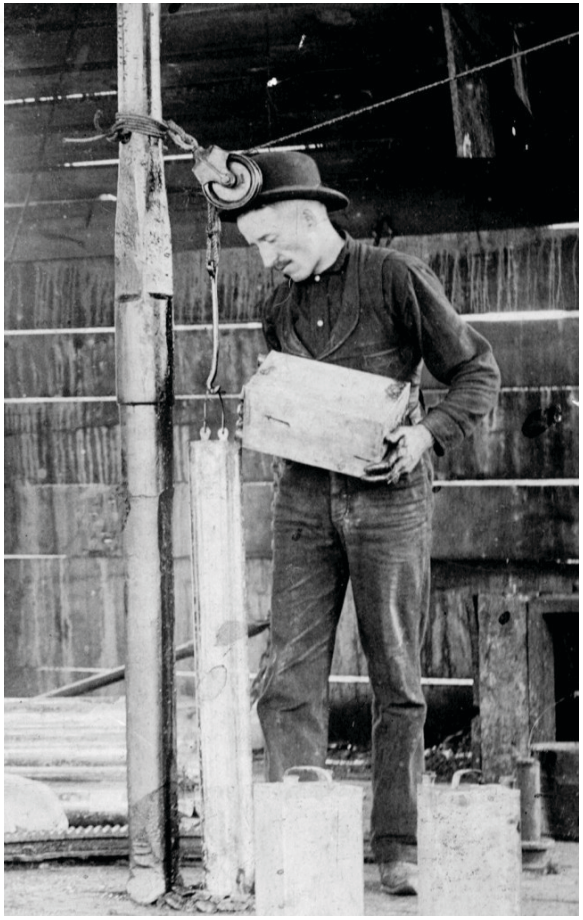


How could one extract oil from these isolated pores filled with oil, gas and water?



A Pennsylvania historical marker near Titusville notes the 1865 demonstration of the invention Union Col. E.A.L. Roberts.

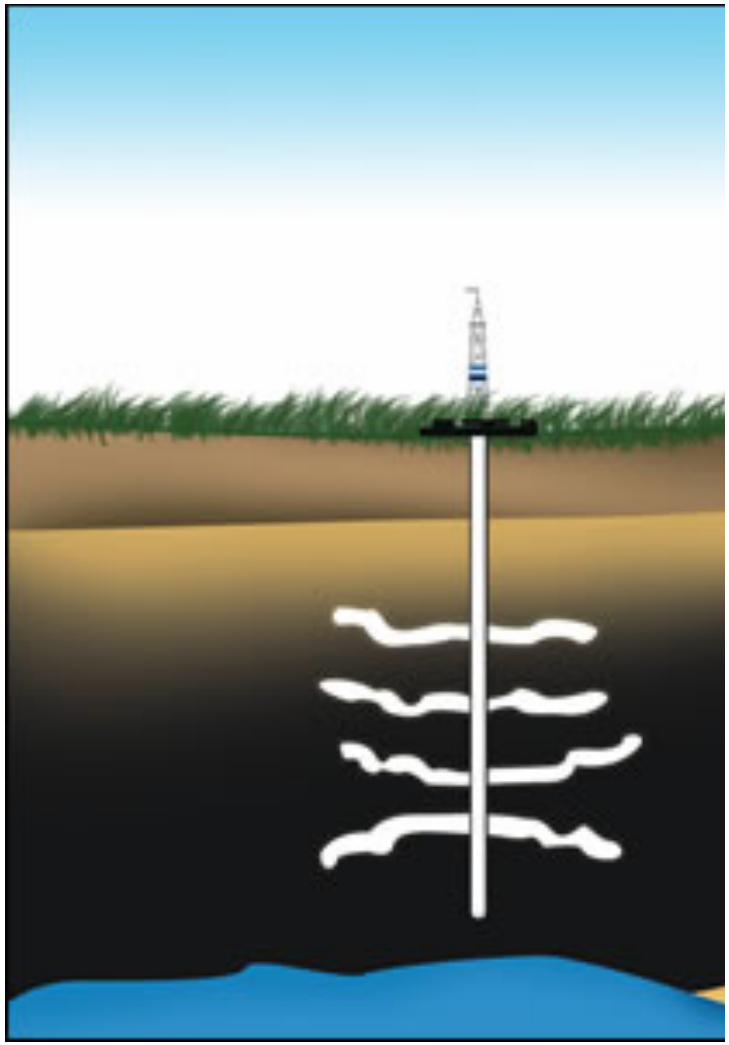




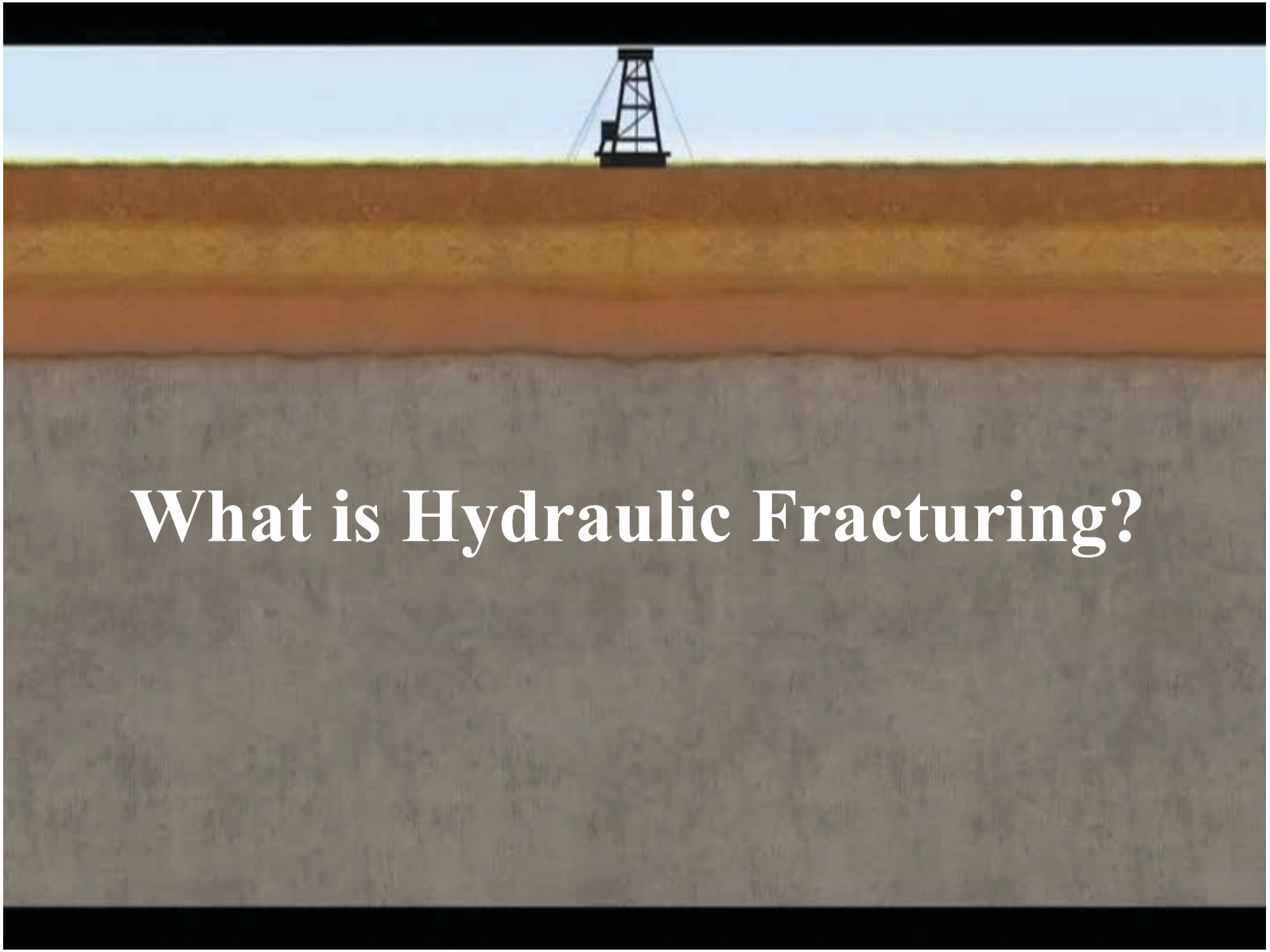
Pouring nitroglycerin was risky enough in the late 19th century oil patch. Doing it for an illegal well "shooting" led to the term "moonlighting,"

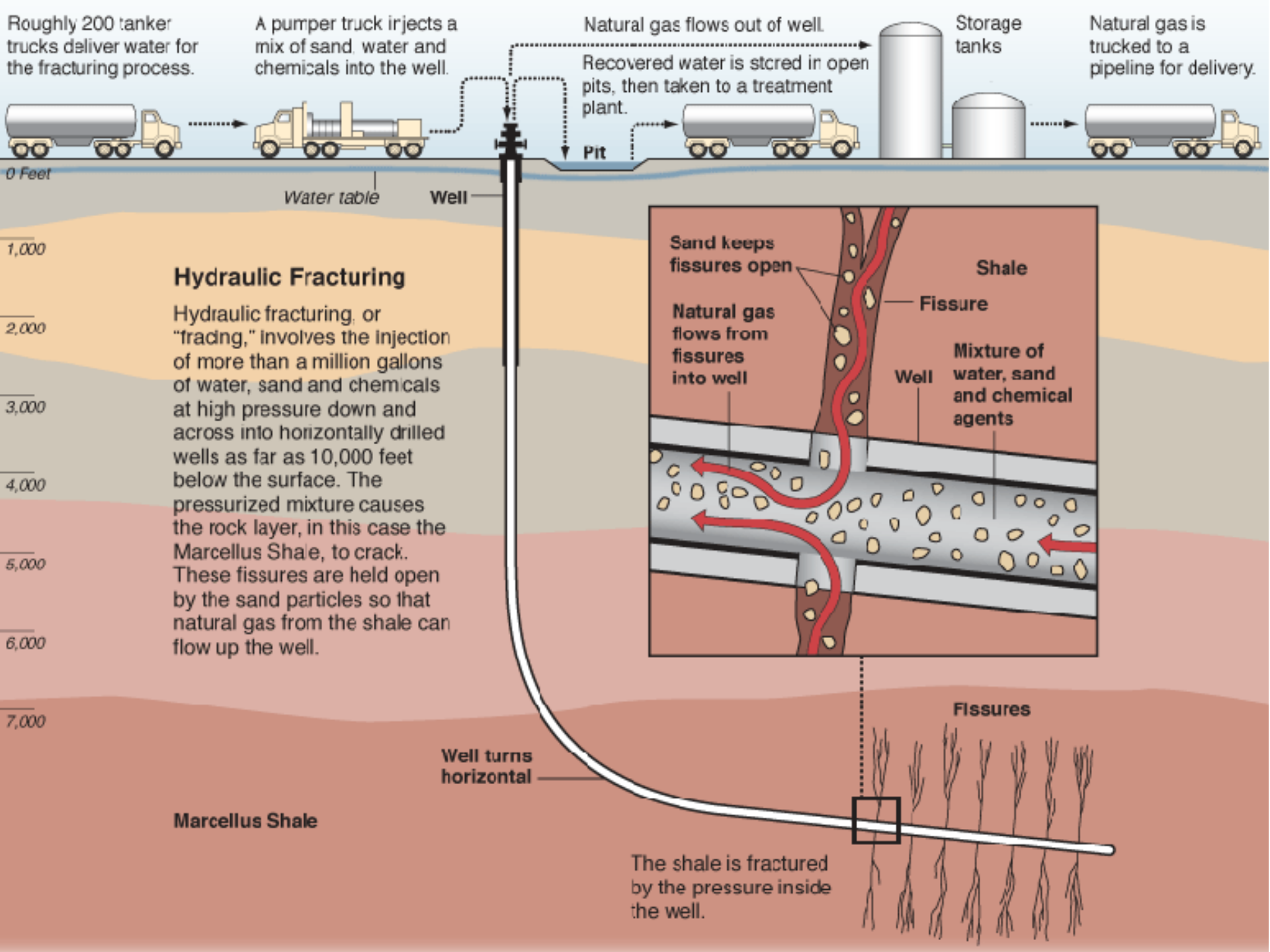
patents for "Improvement in Exploding Torpedoes in Artesian Wells" on April 25, 1865…production from some wells increased 1,200 percent within a week of being shot – and the Roberts Petroleum Torpedo Company flourished…$100 to $200 per torpedo and a royalty of one-fifteenth of the increased flow of oil.

UNCONVENTIONAL RESERVOIRS REQUIRE "ENHANCED PERMEABILITY" FRACKING



Fracking engineered and used starting in the 1860's to enhance permeability of vertical wells

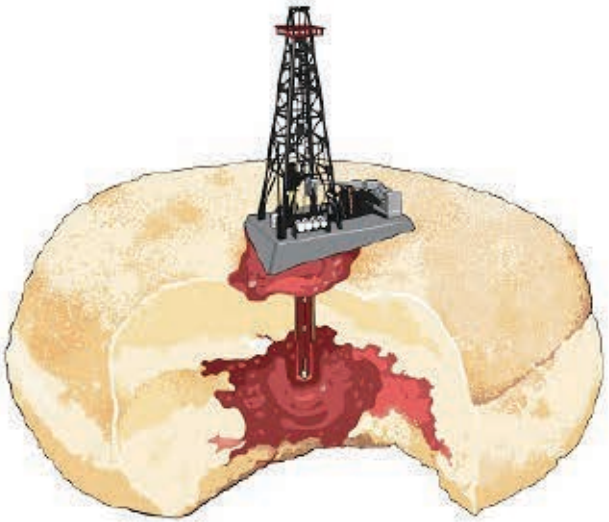

What is Hydraulic Fracturing?


Roughly 200 tanker trucks deliver water for the fracturing process.
A pumper truck injects a mix of sand, water and chemicals into the well.
Natural gas flows out of well.
Recovered water is stored in open pits, then taken to a treatment plant.
Storage tanks
Natural gas is trucked to a pipeline for delivery.
Pit
0 Feet
Water table
Well
1,000
2,000
3,000
4,000
5,000
6,000
7,000
Hydraulic Fracturing
Hydraulic fracturing, or "fracing," involves the injection of more than a million gallons of water, sand and chemicals at high pressure down and across into horizontally drilled wells as far as 10,000 feet below the surface. The pressurized mixture causes the rock layer, in this case the Marcellus Shale, to crack. These fissures are held open by the sand particles so that natural gas from the shale can flow up the well.
Sand keeps fissures open
Shale
Fissure
Natural gas flows from fissures into well
Well
Mixture of water, sand and chemical agents
Fissures
Well turns horizontal
Marcellus Shale
The shale is fractured by the pressure inside the well.

Drill Conventionally

Jelly Donut

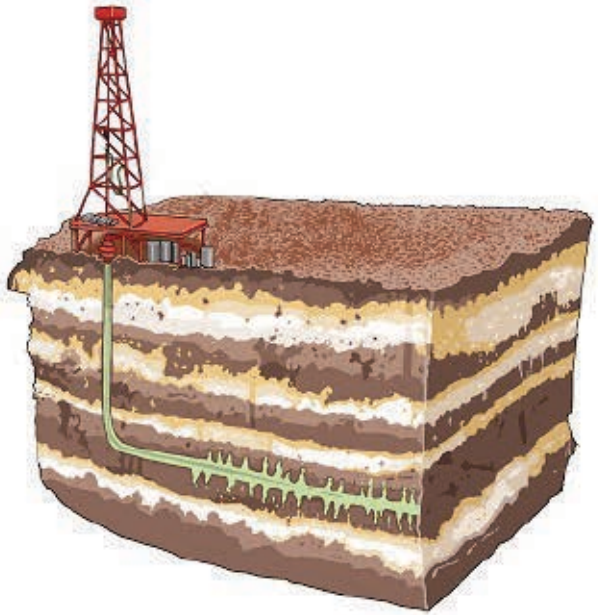
Conventional Drilling
Basic Vertical Penetration
Limited Formation Contact



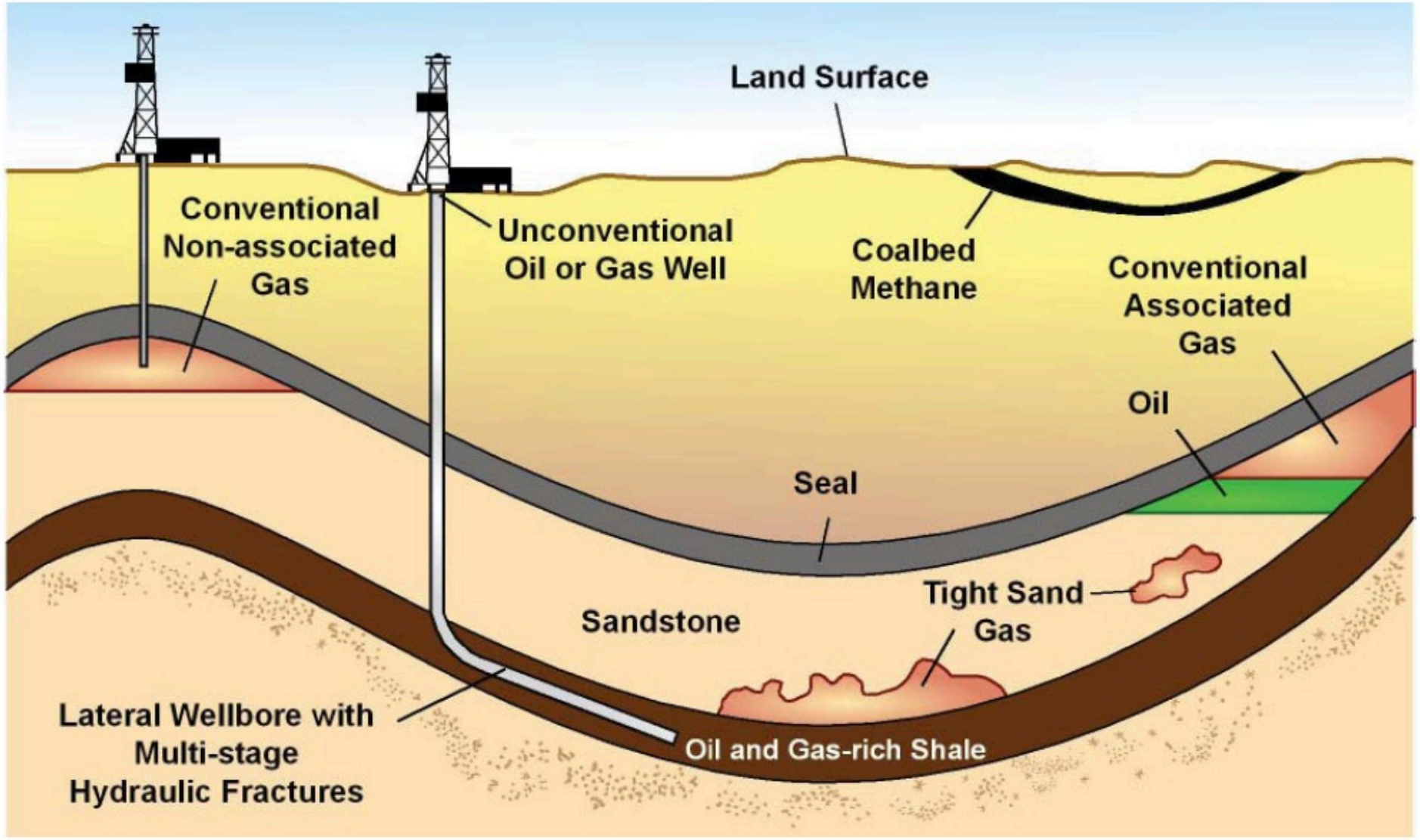
Drill Unconventionally

Tiramisu

Unconventional Drilling
More Sophisticated Horizontal Penetration
Extensive Formation Contact



The Geology of Conventional and Unconventional Oil and Gas

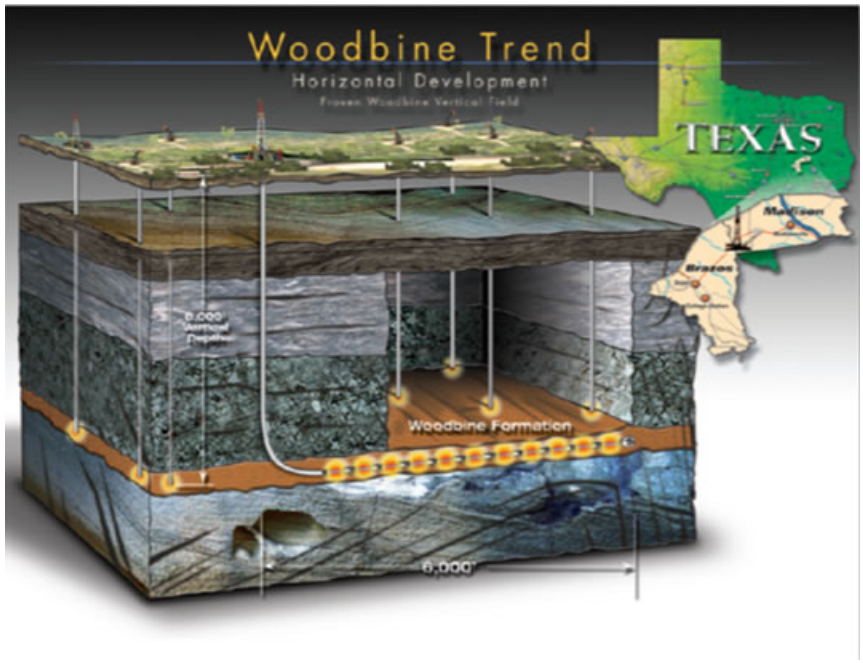


Source: EIA

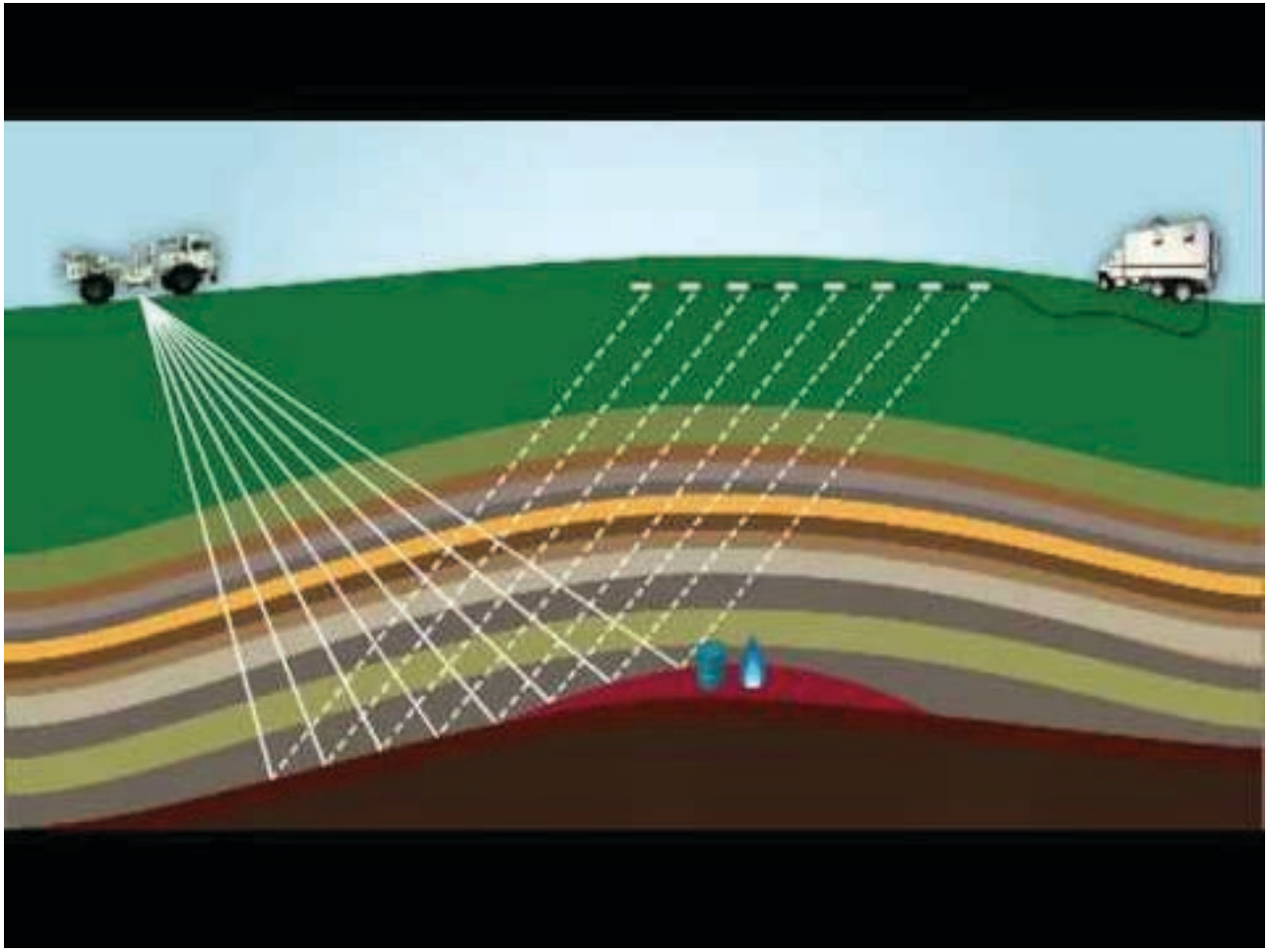
THEN

East TX Field, WW II, 24 “big inch” pipe to City of Brotherly Love, and “thieves” 1930s, single wells > 20,000 b/day

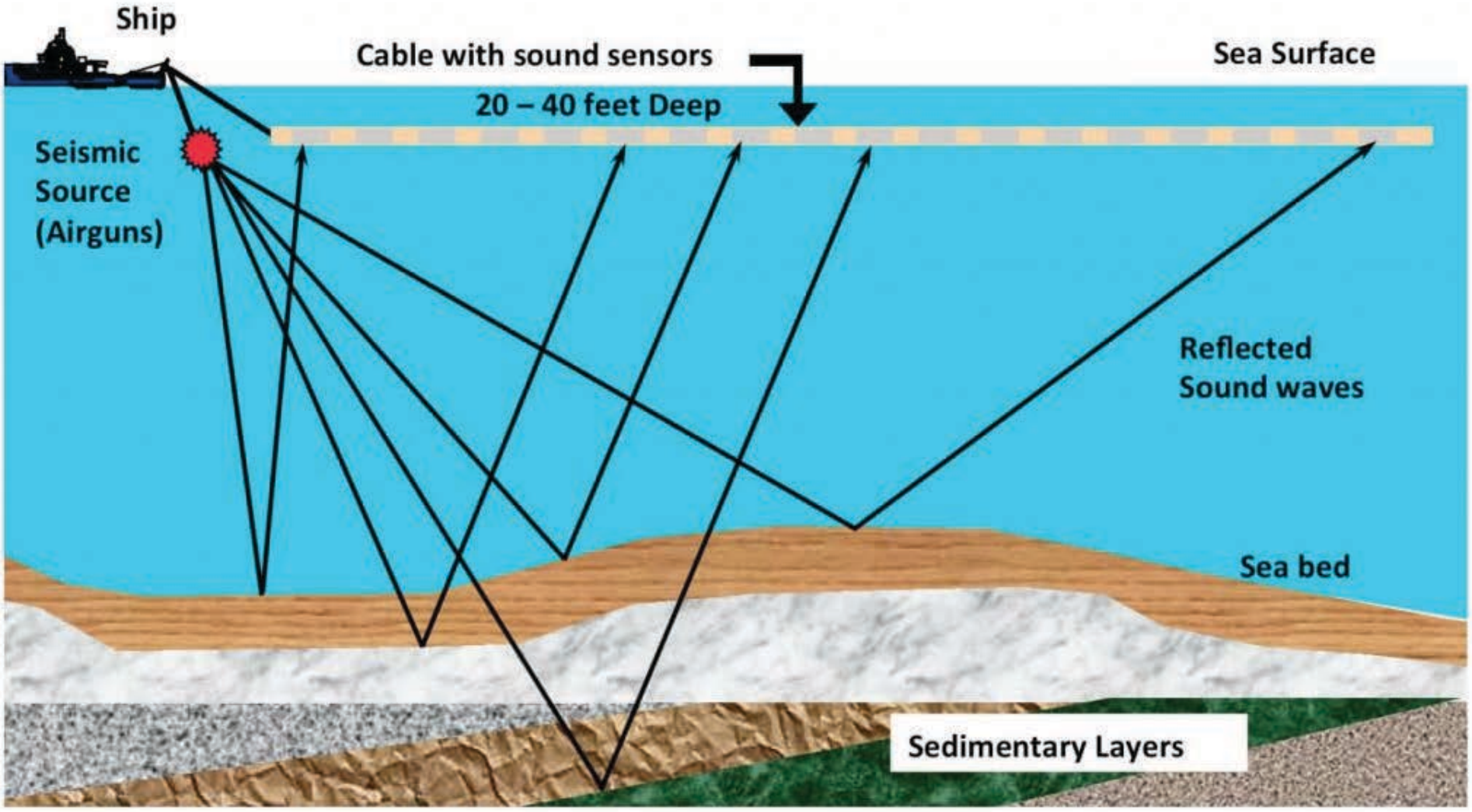
NOW

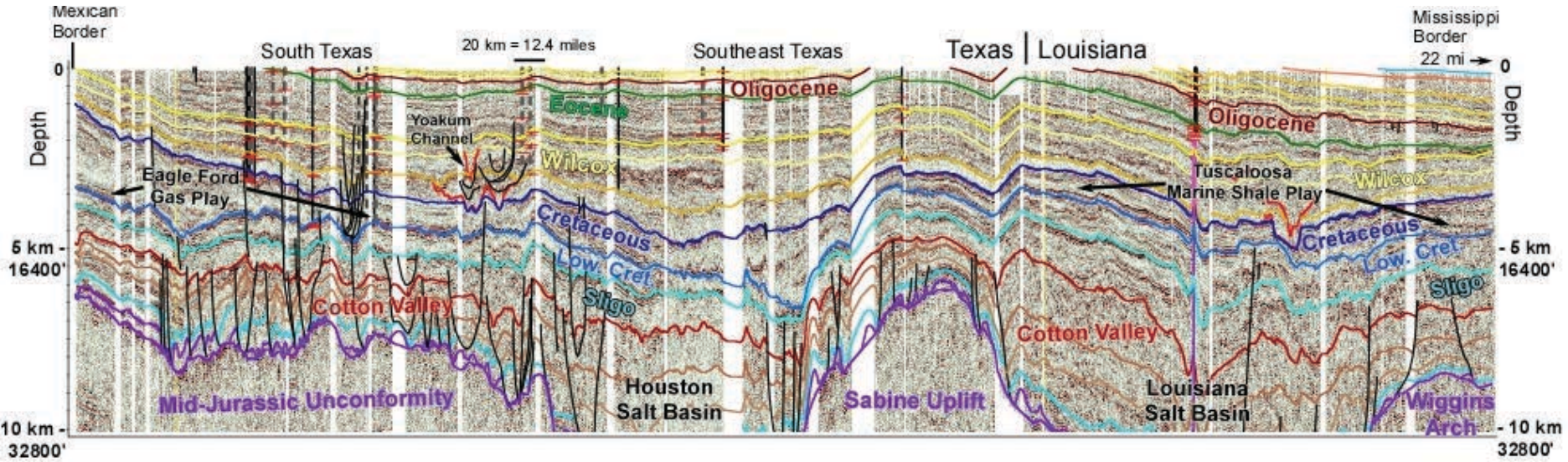


SEISMIC EXPLORATION



SEISMIC EXPLORATION




Mexican Border
South Texas
20 km = 12.4 miles
Southeast Texas
Texas | Louisiana
Mississippi Border
22 mi
0
Depth
Eocene
Oligocene
Yoakum Channel
Wilcox
Eagle Ford Gas Play
Tuscaloosa Marine Shale Play
Cretaceous
Low. Cret.
Sligo
Cotton Valley
Mid-Jurassic Unconformity
Houston Salt Basin
Sabine Uplift
Louisiana Salt Basin
Wiggins Arch
5 km - 16400'
10 km - 32800'

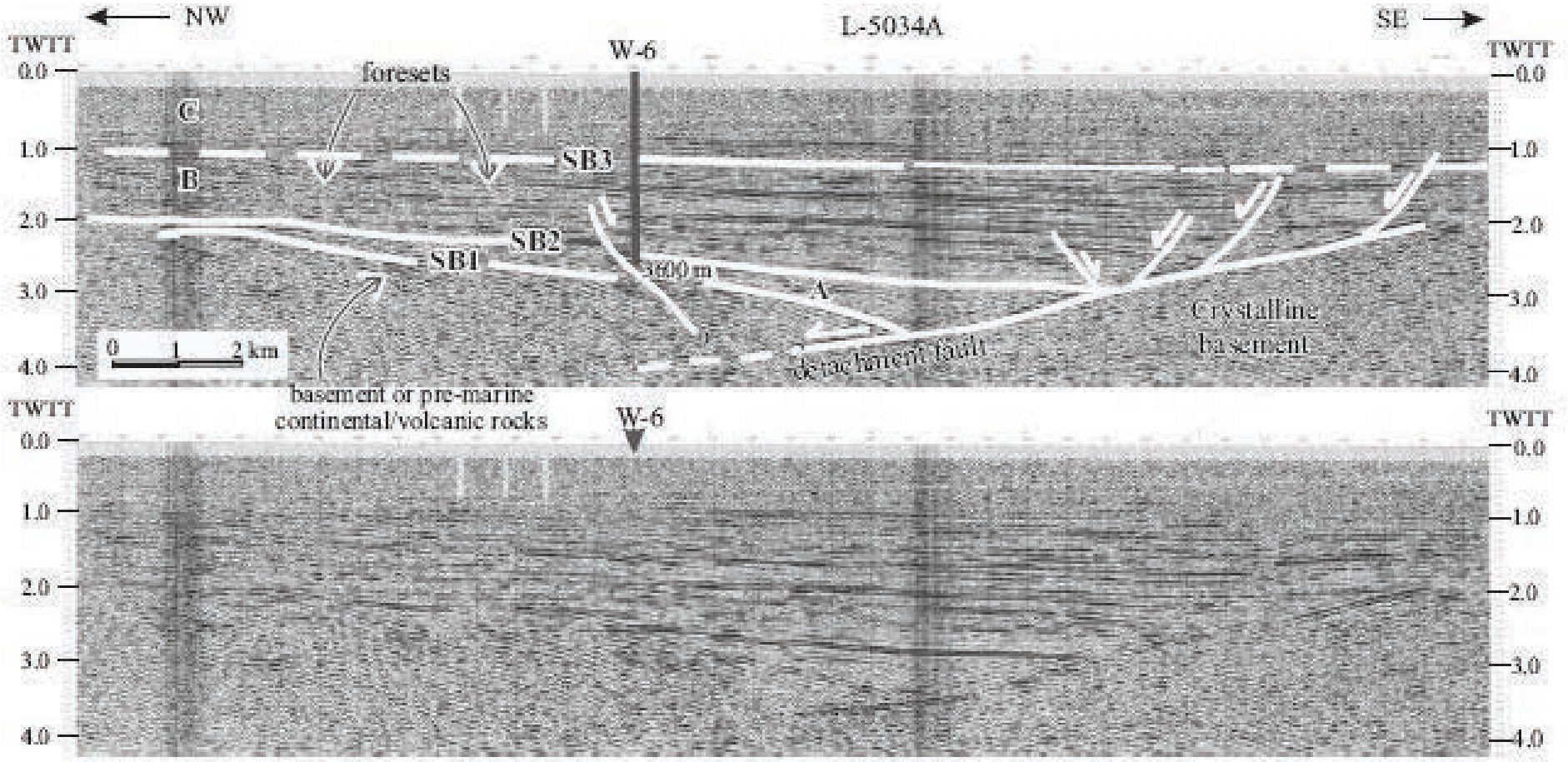
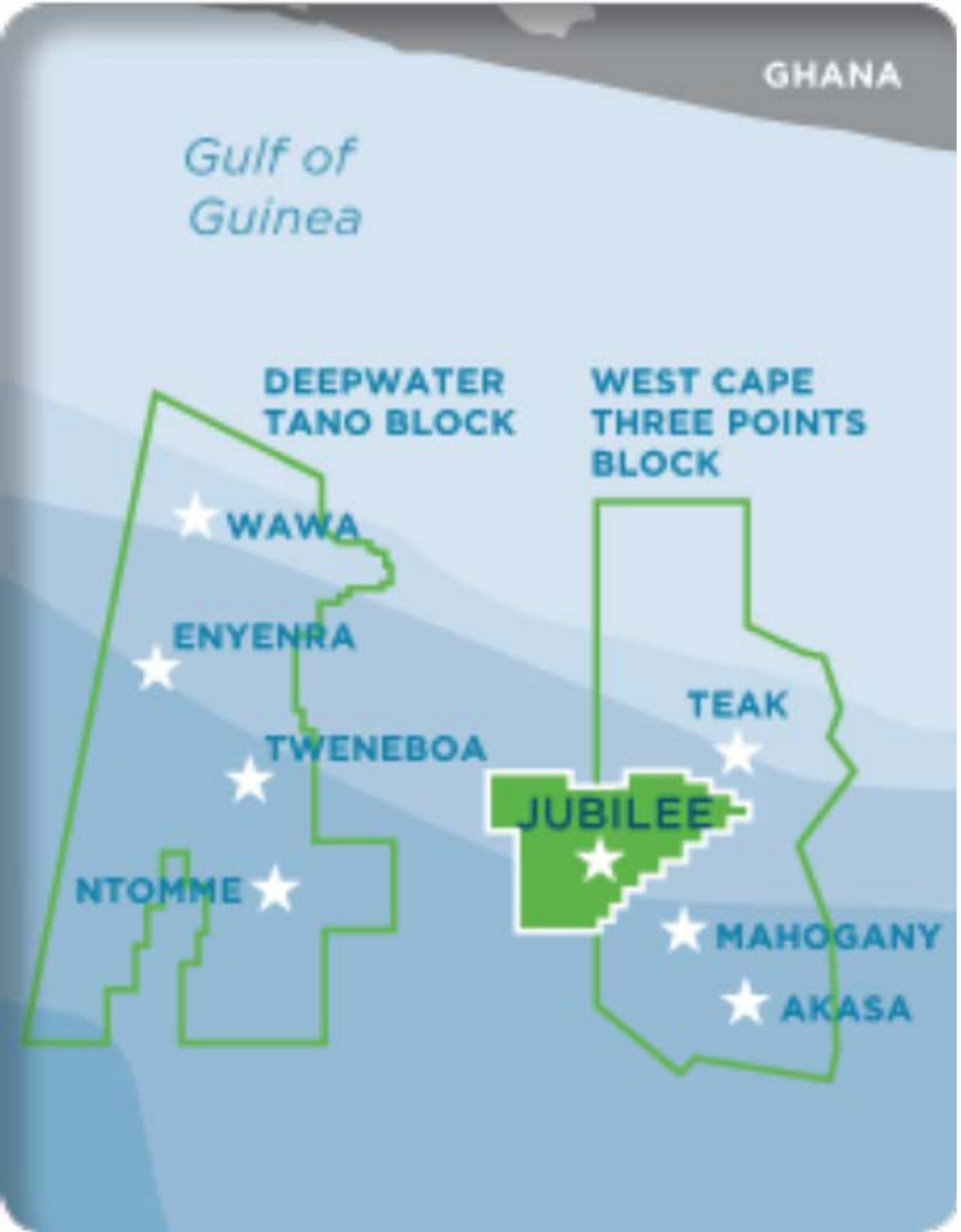
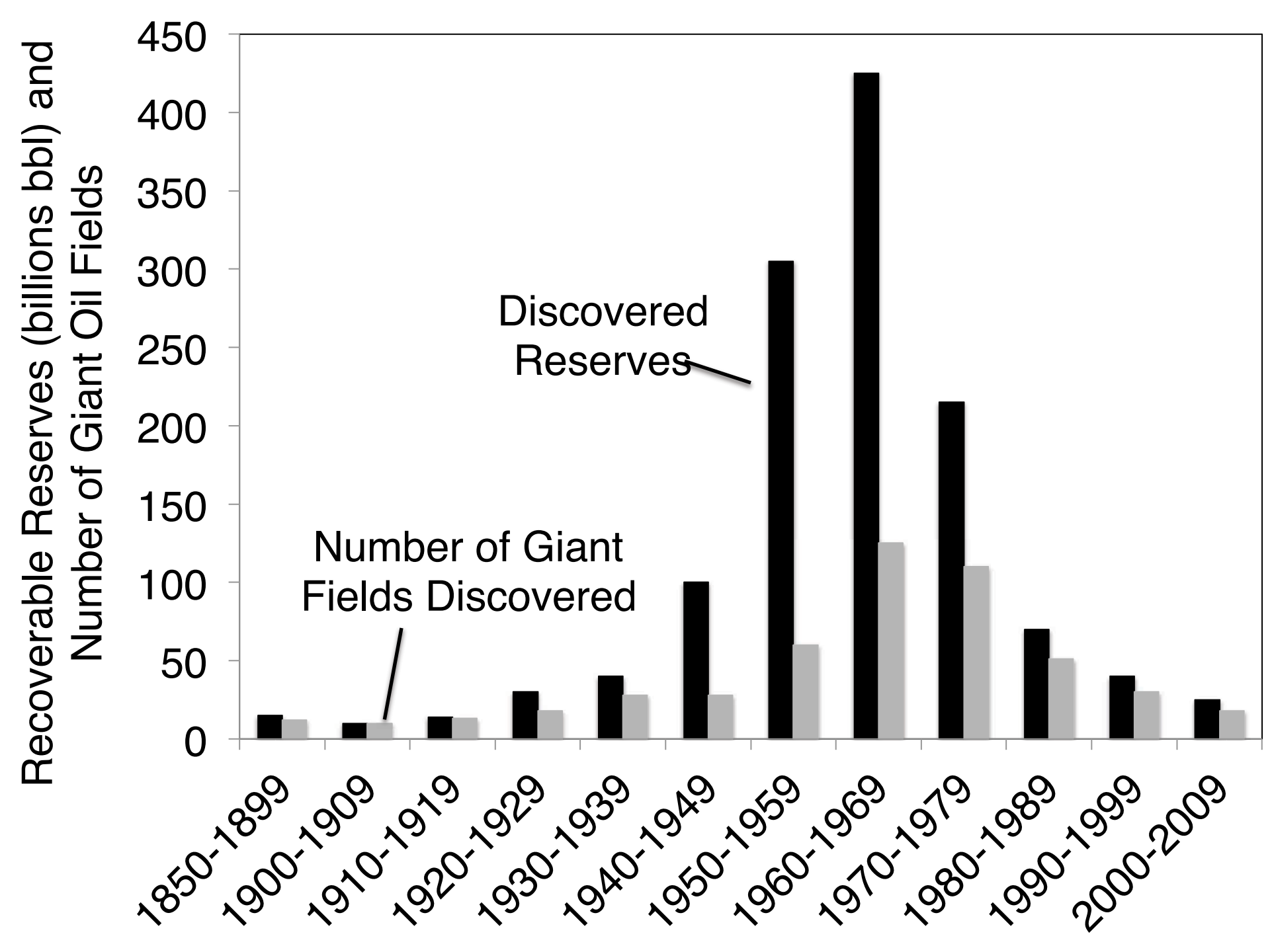


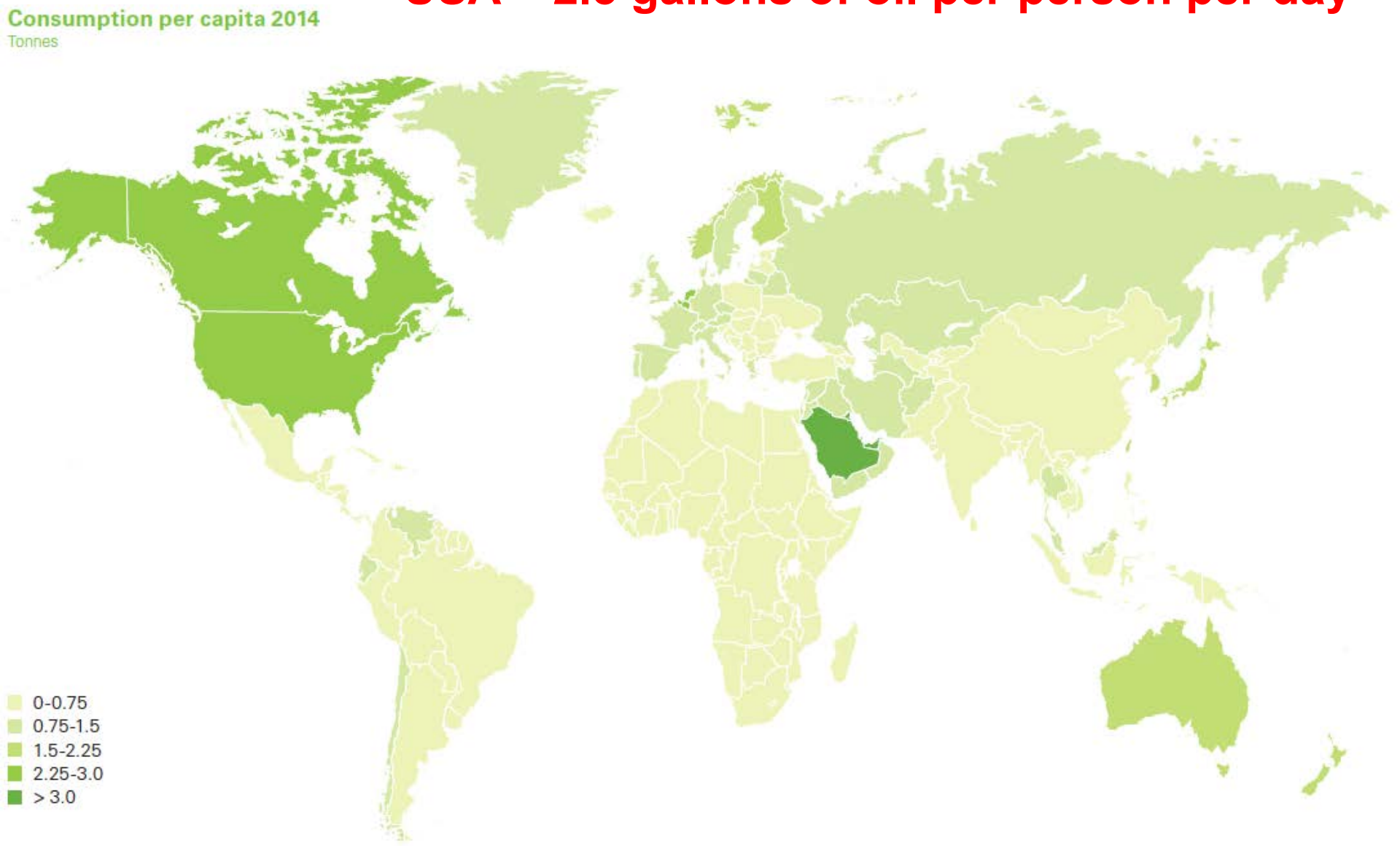
Figure 8. Seismic line L5034A and depth projection of well W-6. Seismic reflectors of sequence A appear to be in angular unconformity beneath SB2, and are cut by a strong acoustic reflector interpreted as a-top-to-the-northwest detachment fault. This detachment is SB1 and juxtaposes the sedimentary sequence and crystalline basement. Note that sequences B and C flatten upwards.



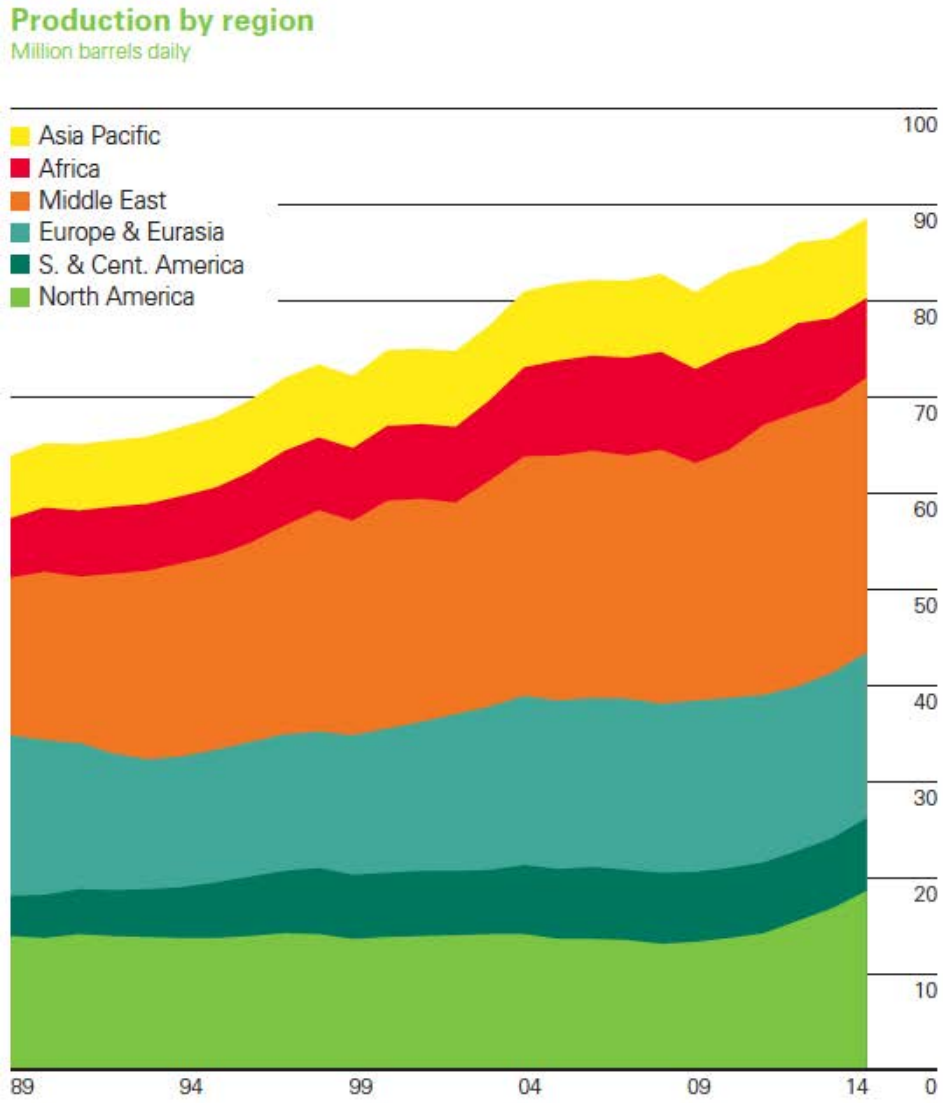
Oil and natural gas are not sustainable because we consume them at a much faster rate than nature produces them.

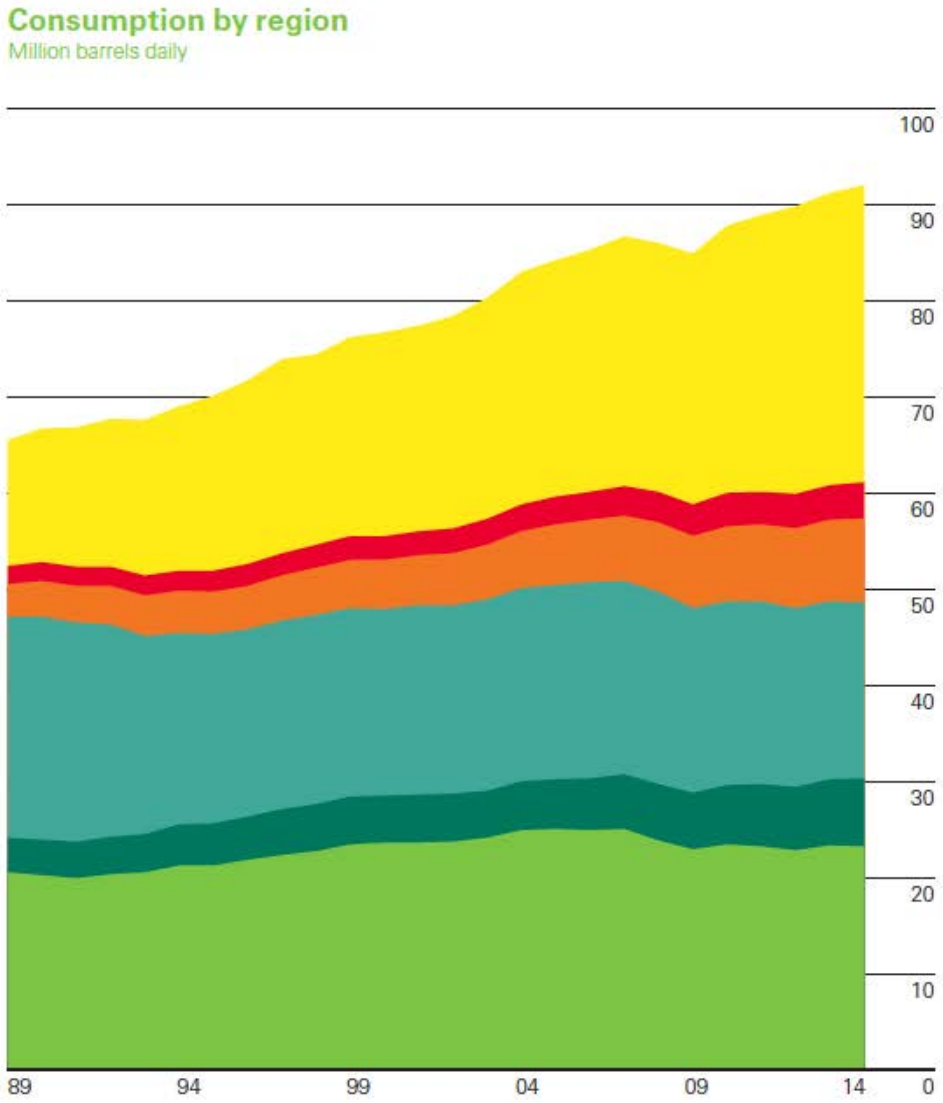

Recoverable Reserves (billions bbl) and Number of Giant Oil Fields
450
400
350
300
250
200
150
100
50
0
Discovered Reserves
Number of Giant Fields Discovered
1850-1899
1900-1909
1910-1919
1920-1929
1930-1939
1940-1949
1950-1959
1960-1969
1970-1979
1980-1989
1990-1999
2000-2009

USA = 2.5 gallons of oil per person per day



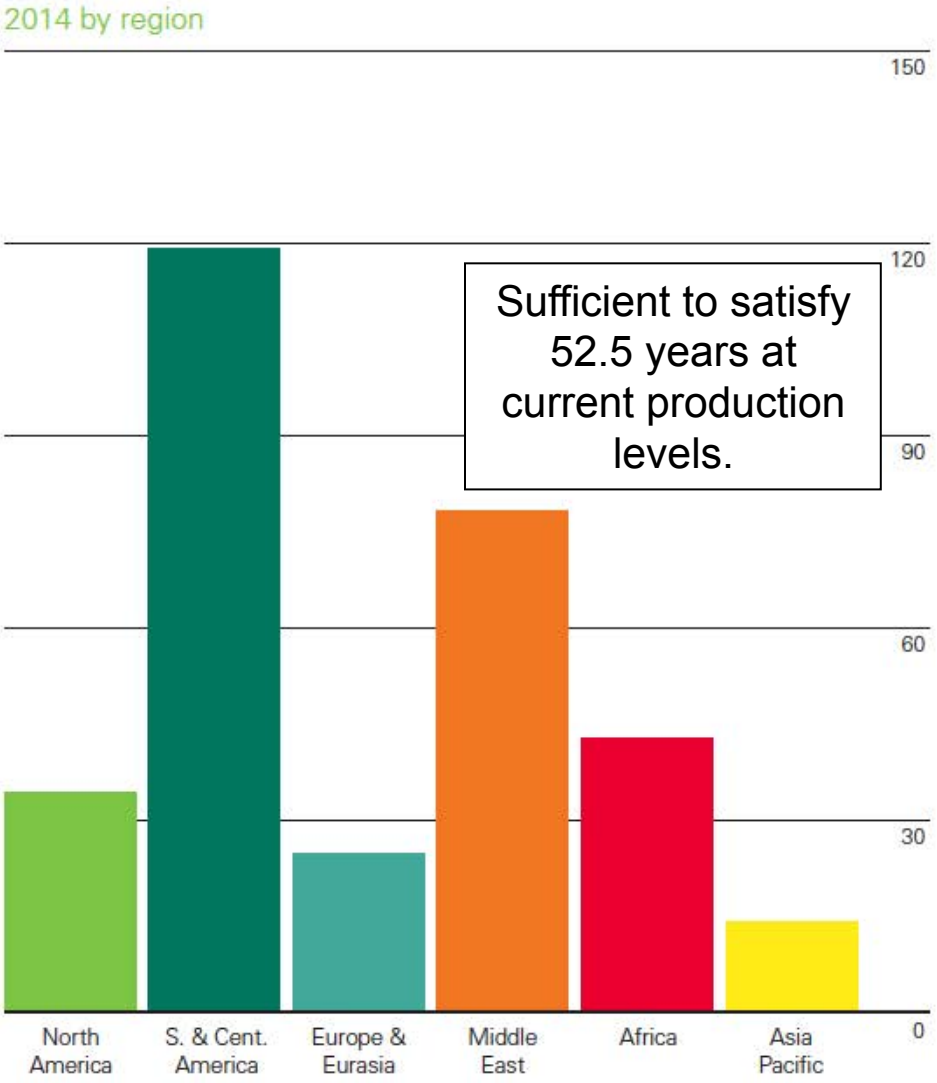
OIL – Production & Consumption Changes

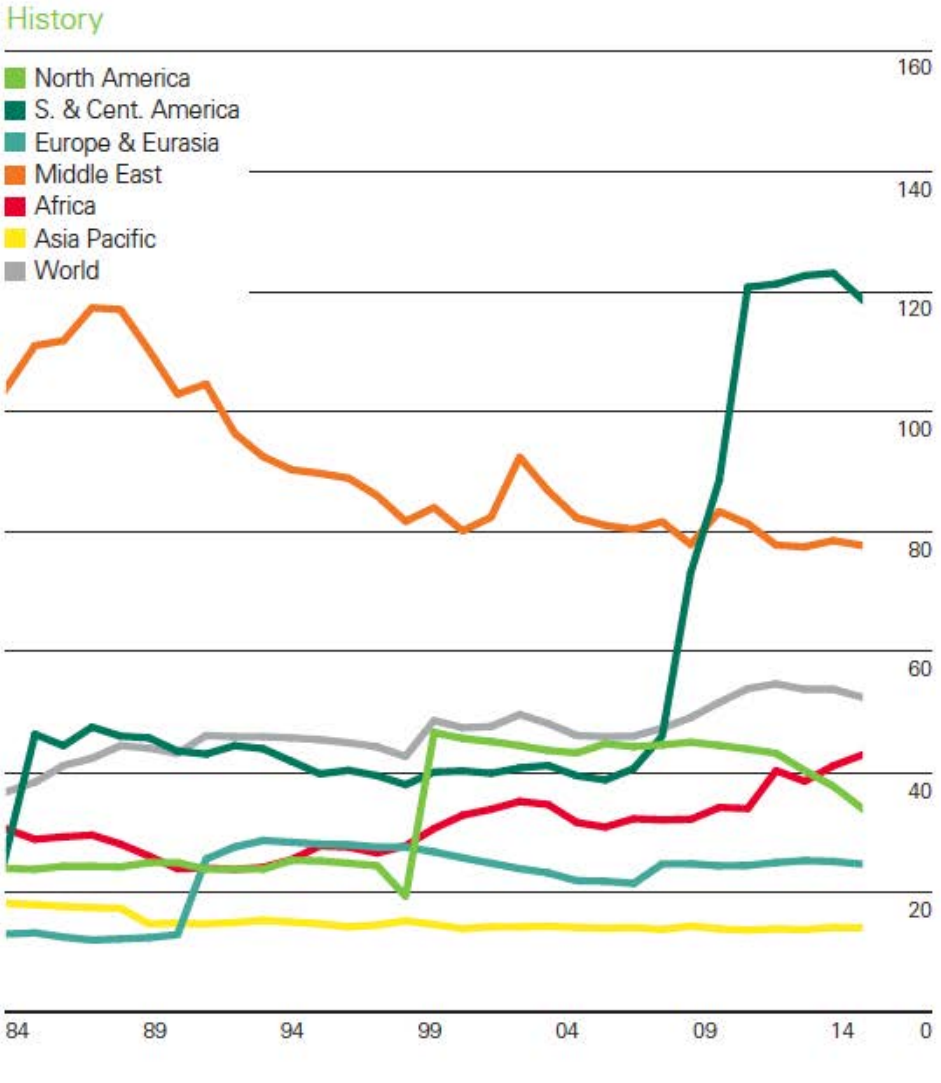




World oil production significantly outpaced consumption in 2014, rising by 2.1 million b/d; all of the growth was in non-OPEC countries, which recorded a record increase. US output grew by 1.6 million b/d, its largest increase on record. OPEC production was essentially flat, with declines among African OPEC producers offset by rising Middle East output. Global consumption increased by 840,000 b/d, with emerging economies accounting for all of the growth; China saw a below-average increase but still accounted for the largest increment to consumption.

Oil





Total world proved oil reserves reached 1700.1 billion barrels at the end of 2014, sufficient to meet 52.5 years of global production. The largest addition to reserves came from Saudi Arabia, adding 1.1 billion barrels. The largest decline came from Russia, where reserves fell by 1.9 billion barrels. OPEC countries continue to hold the majority of the world's reserves, accounting for 71.6% of the global total. South & Central America continues to hold the highest R/P ratio, more than 100 years. Over the past decade, global proved reserves have increased by 24%, or more than 330 billion barrels.