ENERGY SUPPLY: OIL

An Introduction to the Oil and Gas Industry

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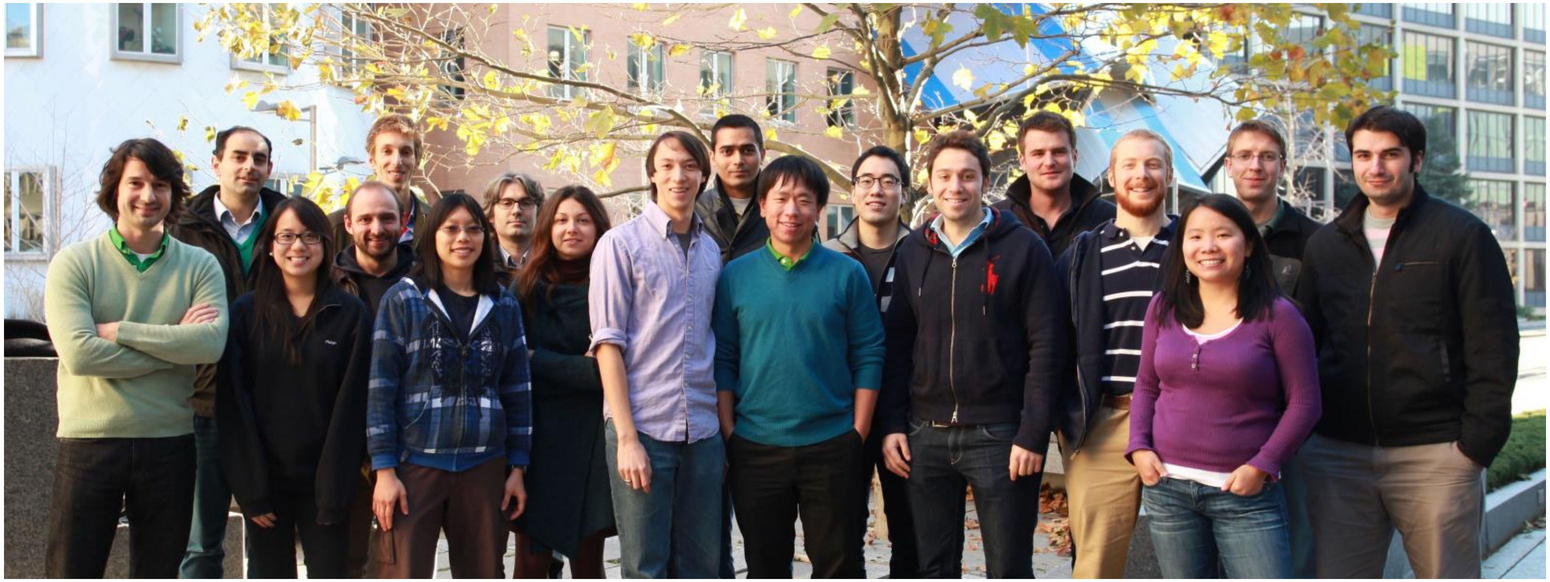
Photo by Sean Paroski

Lab4Energy

MIT, Cambridge, January 15, 2014



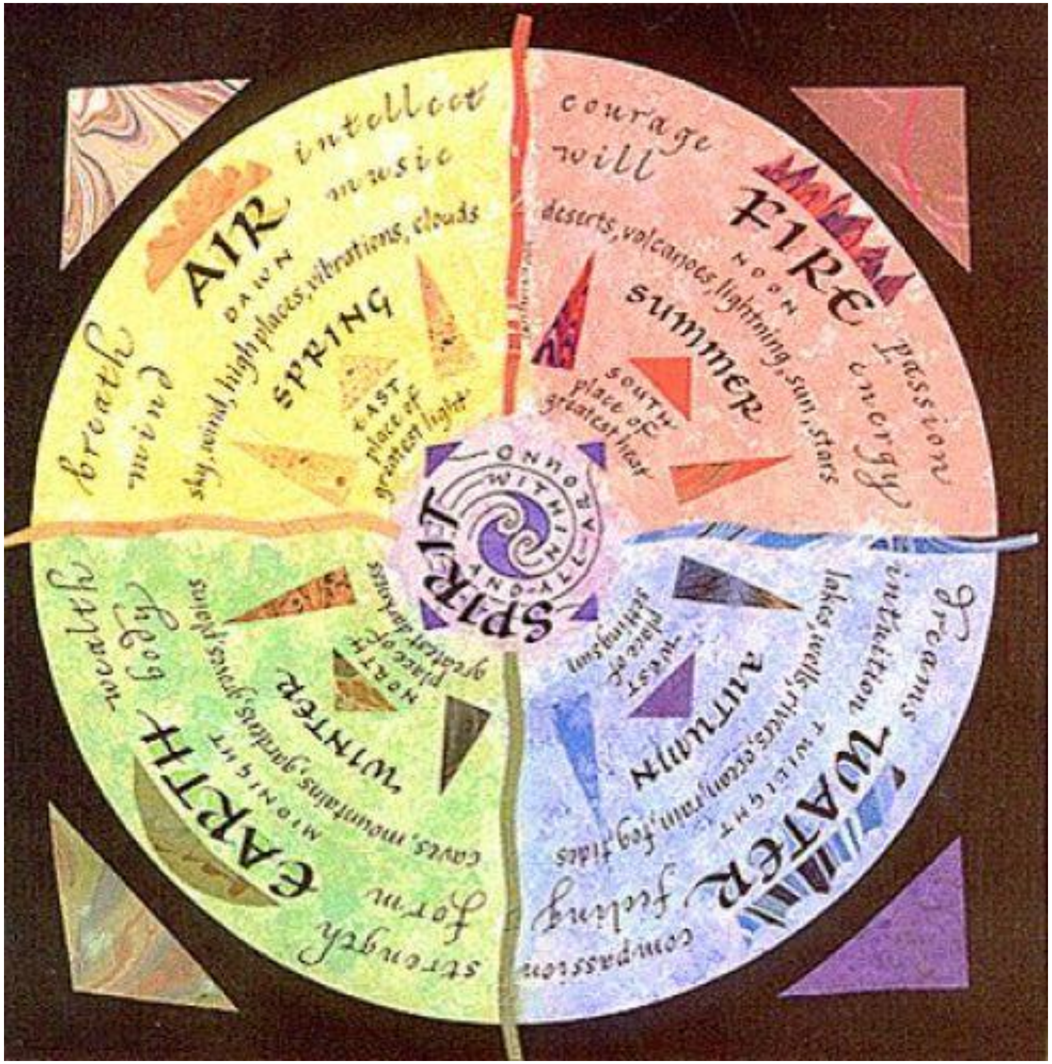
Juanes Research Group @ MIT

http://juanesgroup.mit.edu

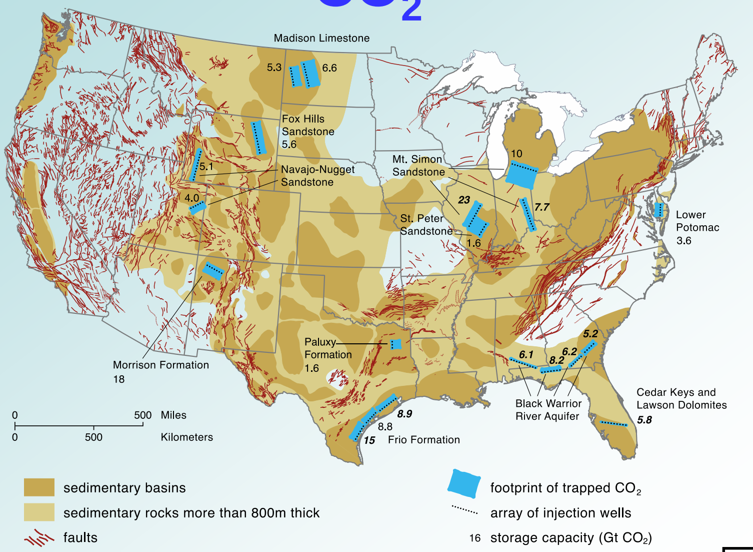
We study the physics of multiphase flow in porous media.

We apply our theoretical, computational and experimental research to geophysical problems in the area of energy and the environment

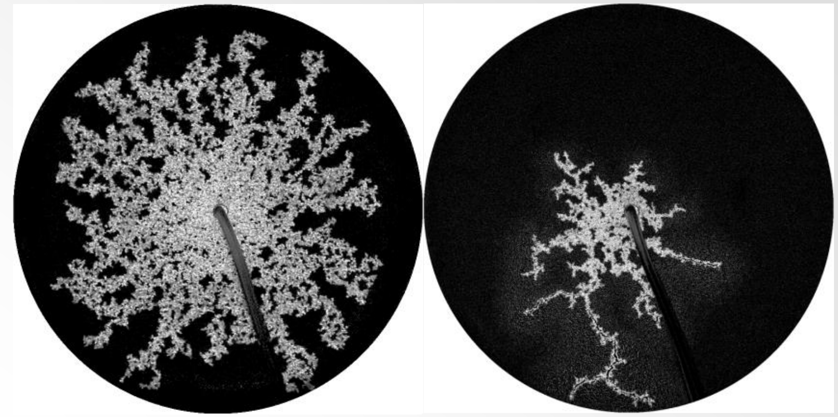
The four classical elements



CO_2

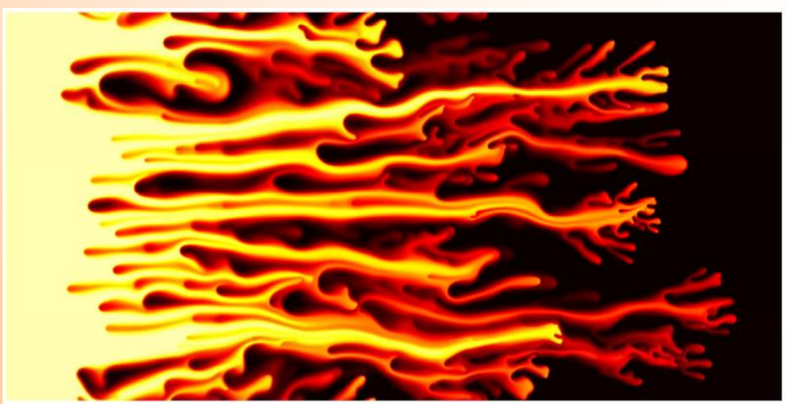


Methane

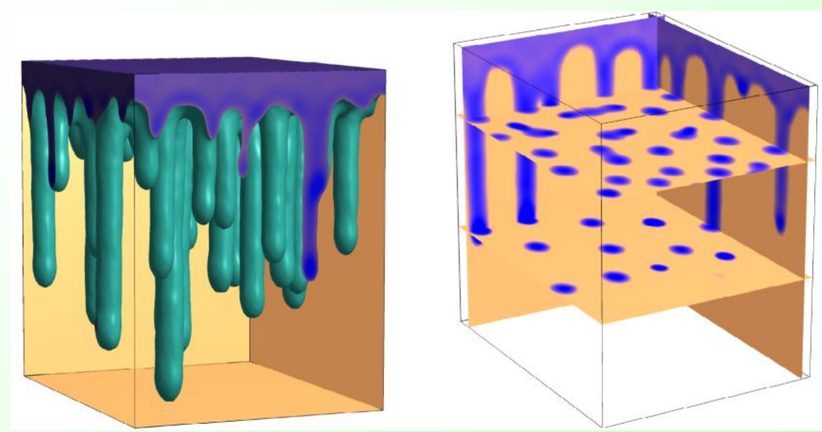


JRG

Oil



Water



Outline of the lecture

Hydrocarbons at a glance

What is petroleum?

Physical structure of rocks

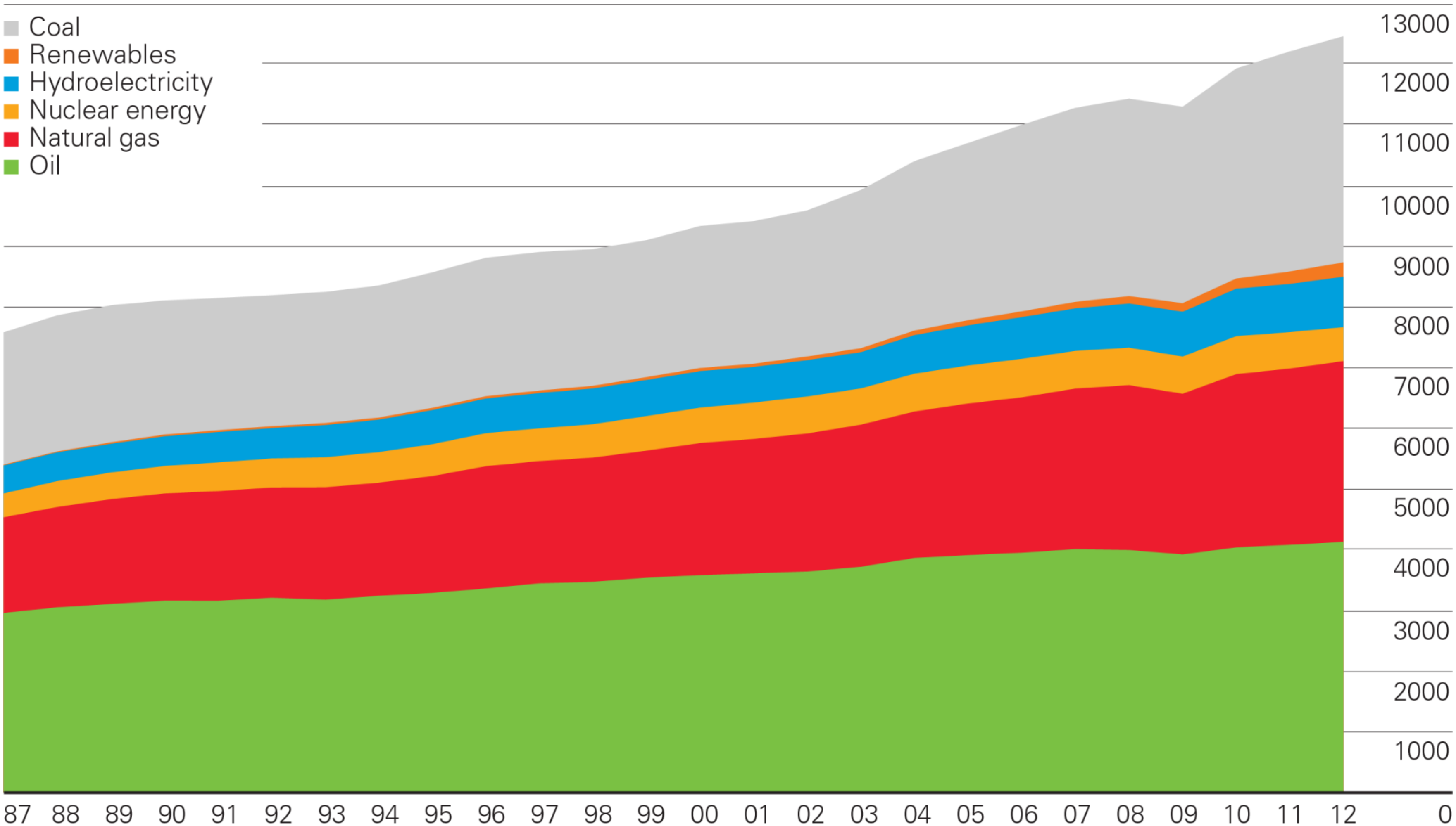
The oil and gas industry

From conventional to unconventional oil and gas

Challenges ahead

Hydrocarbons at a glance

Primary energy world consumption
Million tonnes oil equivalent



BP Statistical Review of World Energy 2012

World energy

Fossil fuels provide ~85% of the primary energy of the planet, and have done so for decades

Fossil fuels cannot be replaced overnight

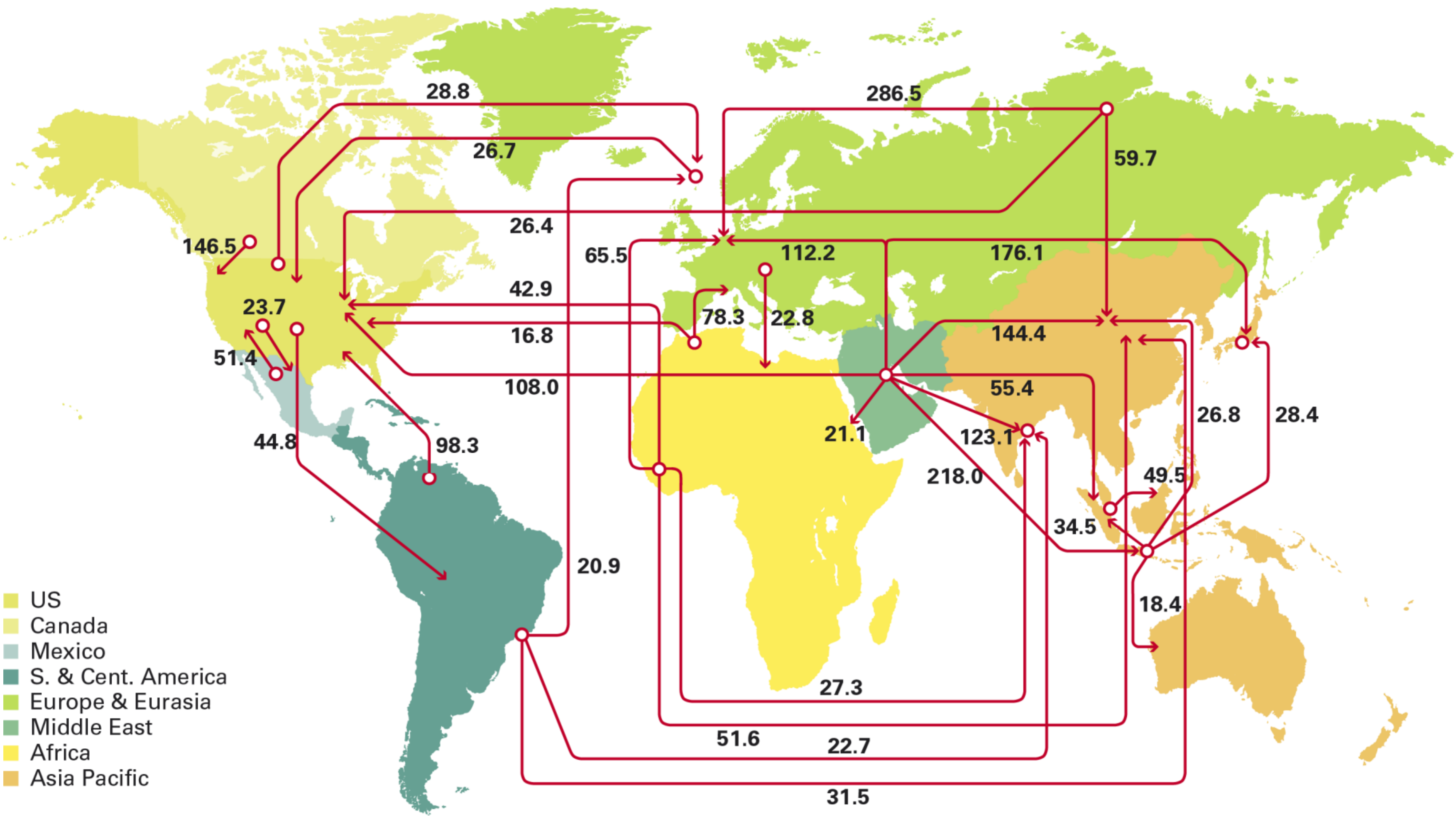
Oil is the most “efficient” form of energy storage

- **very high energy density**
- **easy to store and transport**

Oil dominates the energy markets

Major oil trade movements 2012

Trade flows worldwide (million tonnes)



Petroleum

What is petroleum?

mixture of hydrocarbons

natural states :	**gas**	**natural gas**
	liquid	**crude oil**
	solid	**wax, tar, asphalt, coal**

State determined by

composition
pressure
temperature

Petroleum composition

Petroleum is composed of organic chemicals

At normal pressure and temperatures

- gas if molecules small
- liquid if predominantly larger molecules

Average composition of crude oils (liquid)

11-13 wt% hydrogen
84-87 wt% carbon
Traces of oxygen, sulfur, nitrogen, helium (impurities)

Why are the ranges of composition so narrow?

Organic chemicals built primarily of CH_2 groups
$2/(2+12) = 14\%$ $12/(2+12) = 86\%$

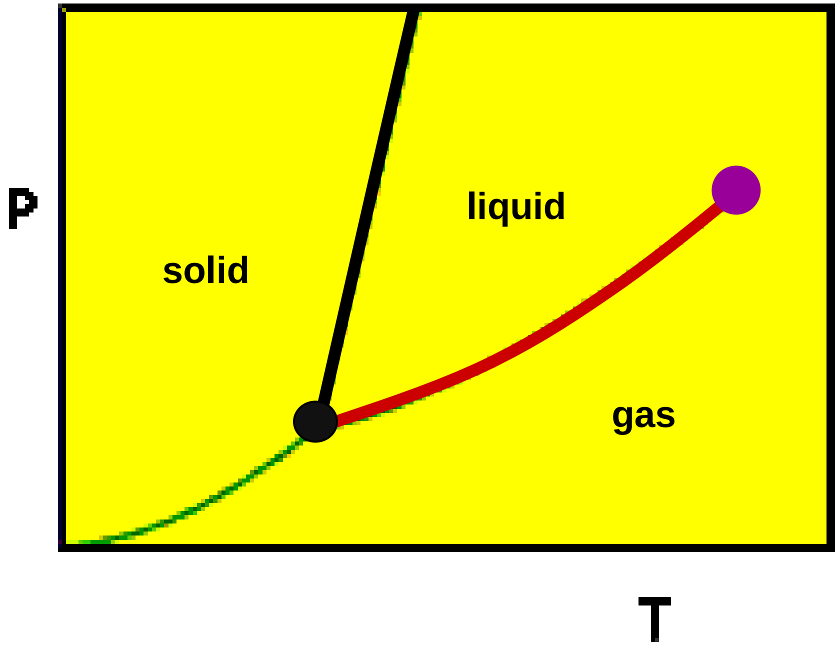
Typical fractions of crude oil

Crude fraction	Boiling point degF	Chem. Comp.	Uses
Hydrocarbon gas	to 100	C1-C2 C3-C4	Fuel gas Bottled fuel gas, solvent
Gasoline	100-350	C5-C10	Motor fuel, solvent
Kerosene	350-450	C11-C12	Jet fuel, cracking stock
Light gas oil	450-580	C13-C17	Diesel fuel, furnace fuel
Heavy gas oil	480-750	C18-C25	Lubricating oil, bunker foil
Lubricants/waxes	750-950 (100)	C26-C38	Lubricating oil, paraffin wax, petroleum jelly
Residuum	950+ (200+)	C38+	Tars, roofing compounds, paving asphalts, coke

Phase behavior: PT diagram

Recall Gibbs phase rule: F = N - M + 2 , where

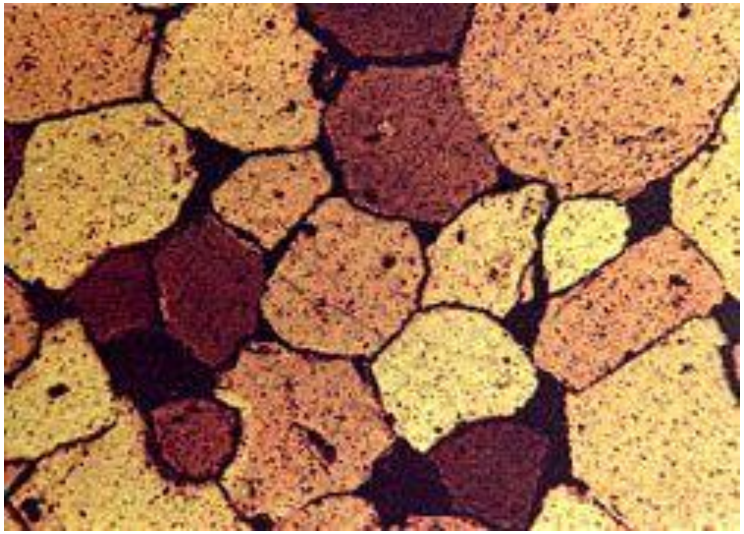
F = number of degrees of freedom
N = number of components (one for a pure substance)
M = number of phases



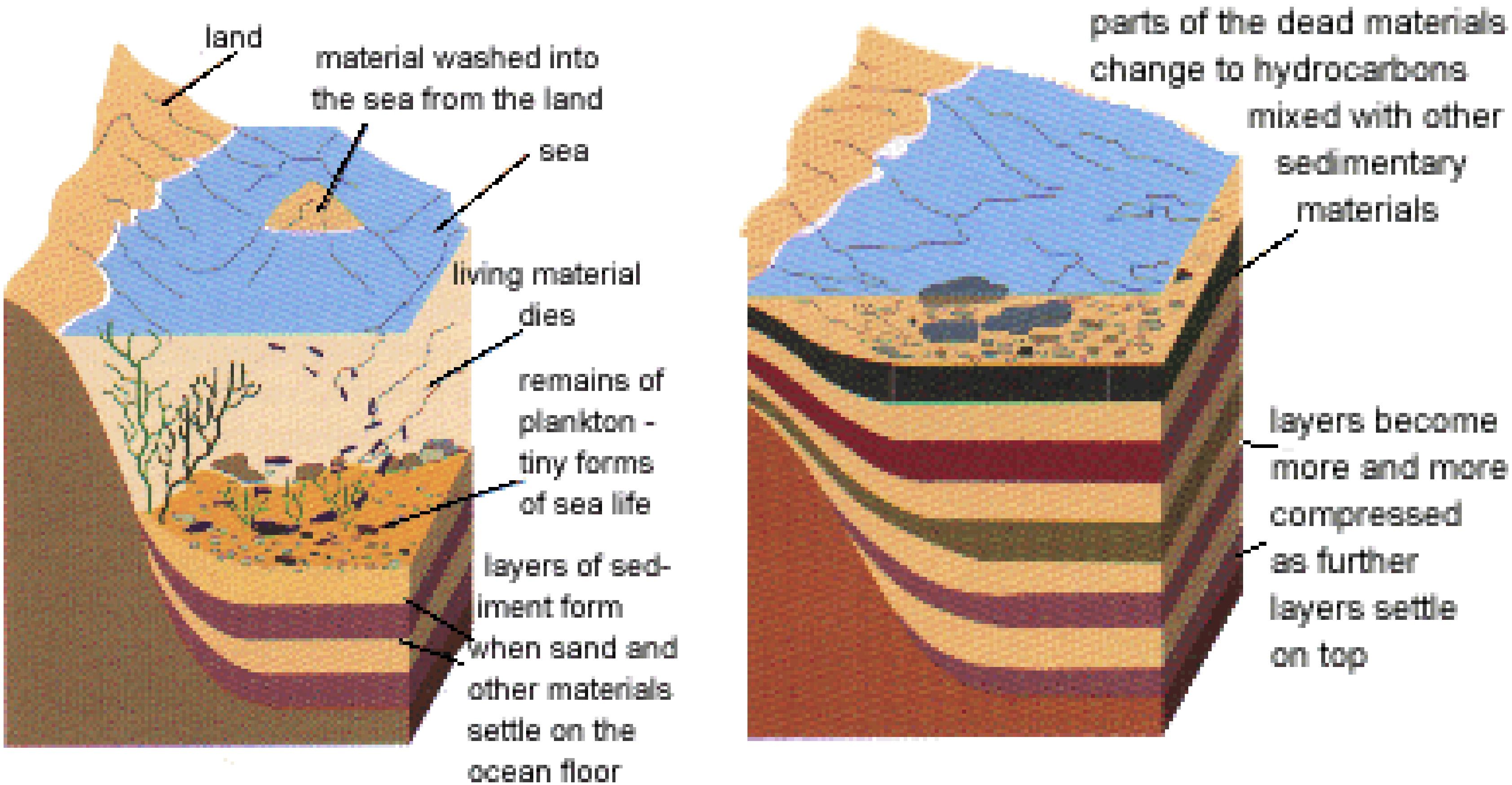
Reservoir rocks

Petroleum is contained in the pore space or interstices of rock materials (the reservoir rocks)

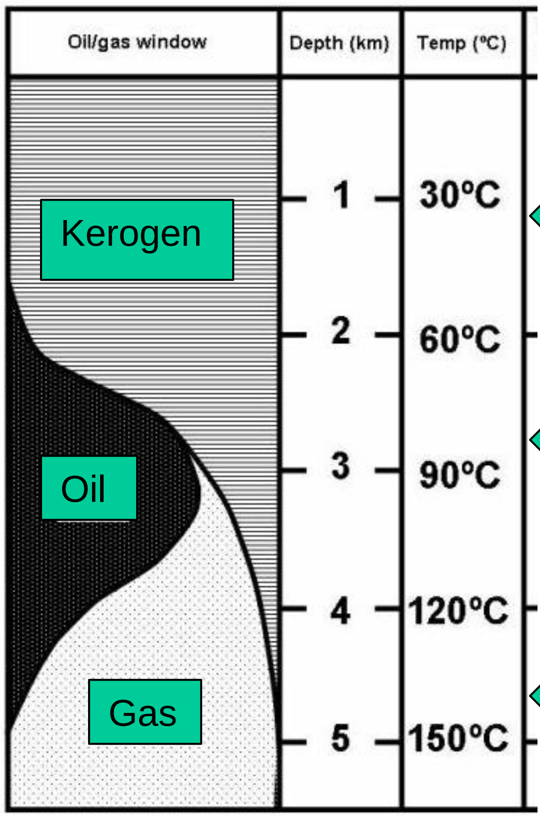
Reservoir rocks are sedimentary materials (sandstones, shales, limestones)



Origin: sedimentation and compaction



Origin: cooking



www.oilandgasgeology.com/oil_gas_window.jpg

As Black Shale (sediment+organic matter) is buried, it is heated.

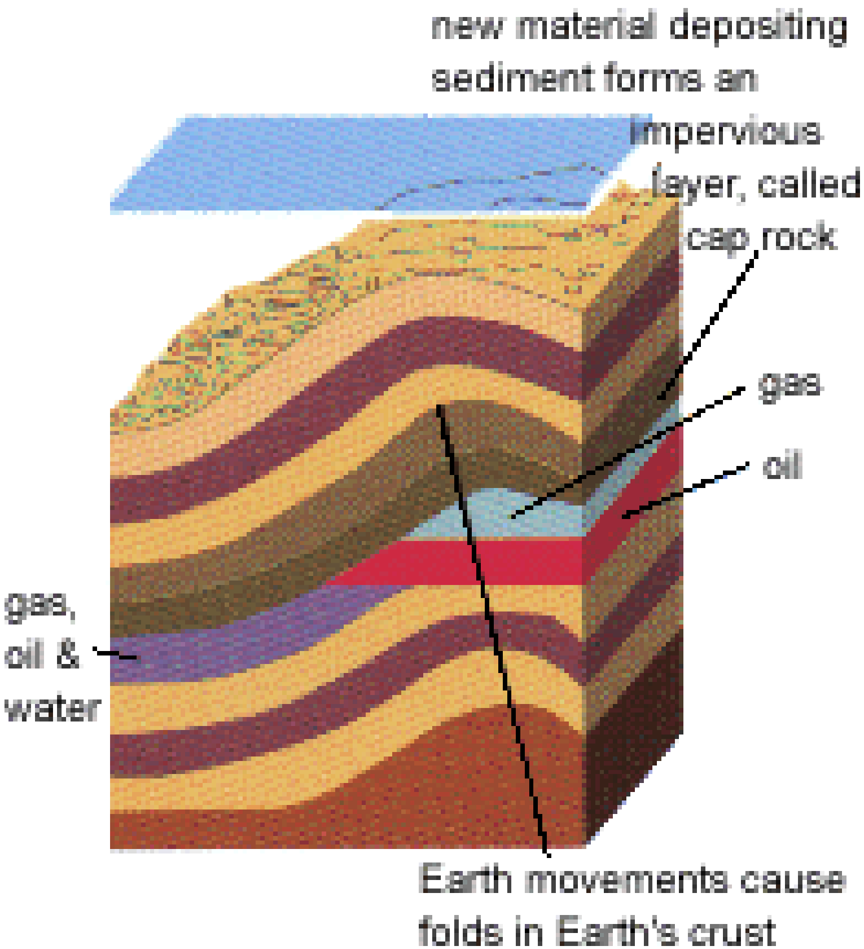
Organic matter is first changed by the increase in temperature into kerogen, which is a solid form of hydrocarbon

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

Around 150° C, it is changed into a gas

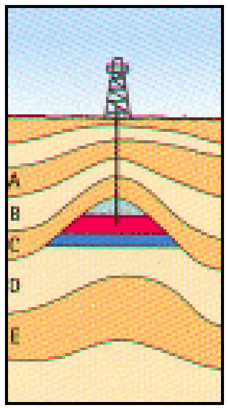
A rock that has produced oil and gas in this way is known as a Source Rock

Origin: migration

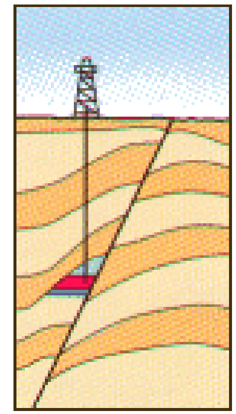


Oil originates in source beds and is transported due to buoyancy through a carrier bed (migration layers) to accumulate in traps

Different kinds of traps

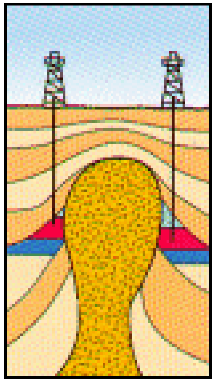


a. ANTICLINE TRAP. An anticline is fomed when the crust folds to form a dome-shaped layer like an upside-down bowl. The dome can be a rock which will not let the oil or gas pass upwards or sideways (impervious). This is called the 'cap rock'. It can also be a layer of clay. Notice the order of the layers in the trap. Gas is the least dense, so it rises above the oil.



b. FAULT TRAP. When rocks move, they may slide past each other. This changes the layers next to each other. The oil trapped in the sedimentary rock can be forced next to a layer which will not let the oil and gas move any further.

Traps



c. COMBINATION TRAP. An example of this type of trap is the 'salt dome'. When a sea dried up a layer of salt was formed. Eventually, this layer became rock salt which is impervious. Through a combination of rock movements, the salt can be forced through the layers around it to form a plug. This trapped oil, gas and water.

Fluid distributions

In general, reservoir fluids are not distributed evenly in the reservoir.

Nonuniform fluid distributions are caused by

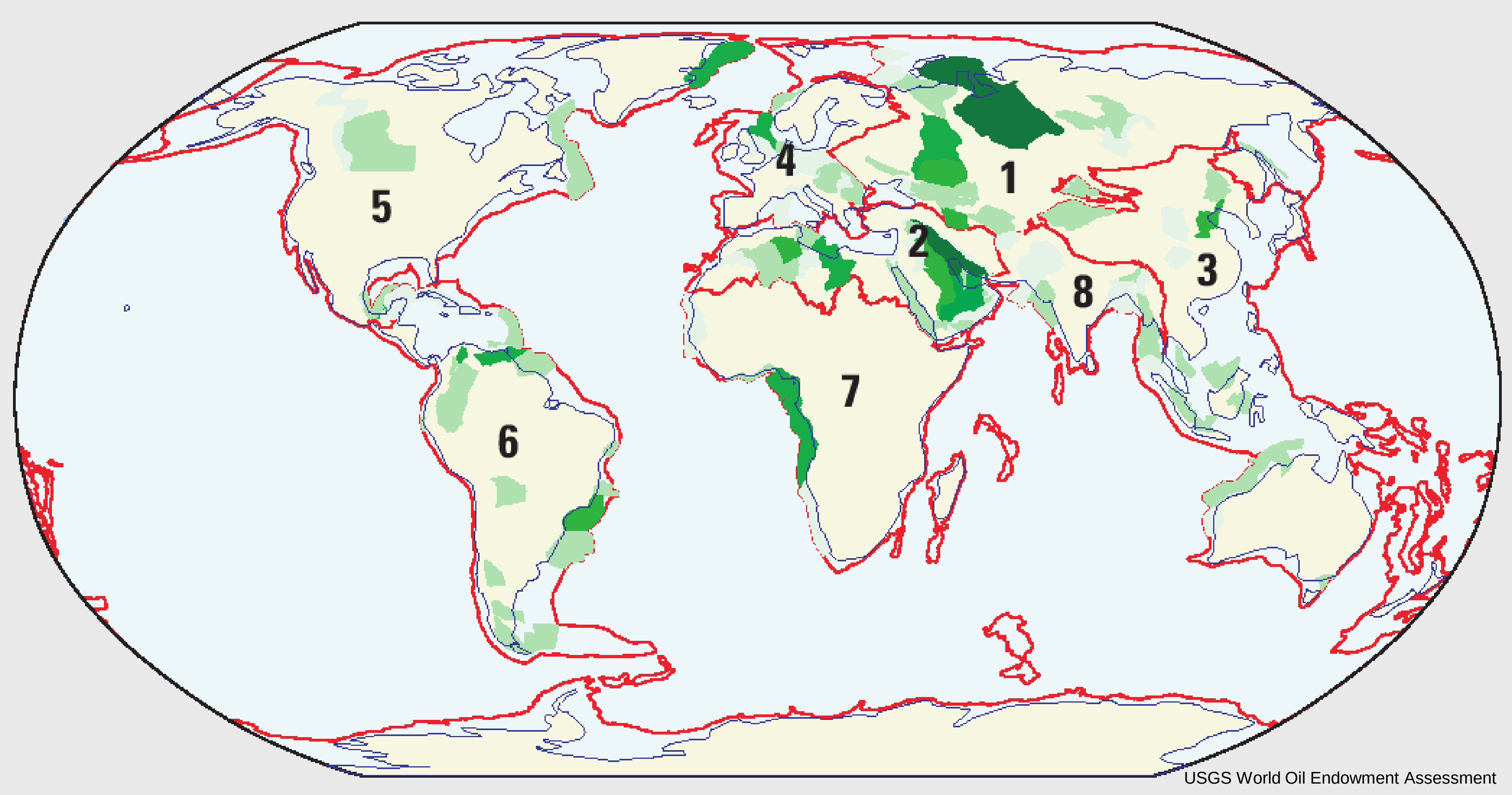
gravitational forces

capillary forces

Assuming we have oil, gas and water in the reservoir, what distribution do you expect?

World petroleum provinces

Petroleum is not distributed evenly throughout the world



USGS World Oil Endowment Assessment

Why is the Arabian plate so rich and prolific?

FACTORS:

- **Long history of almost uninterrupted sedimentation**
- **Repeated and extensive source beds over geological time**

- **Excellent carbonate (and some sandstone) reservoirs**
- **Excellent regional seals**
- **Huge anticline traps**

- **Areal extent of the NE margin shelf (3000 km long, 2000 km wide) for which there is no analogue**

Ref: Ziad R. Beydoun, a leading figure in petroleum geology

Physical structure of rocks

Types of rocks

Three basic types of rocks according to the pressure/temp conditions in which they formed:

- **sedimentary: formed at "low" pressure/temp**
- **metamorphic: changes in composition and texture due to high pressure/temp**
- **igneous: formed from cooling of molten rock (magma)**

Types of sedimentary rocks according to their origin:

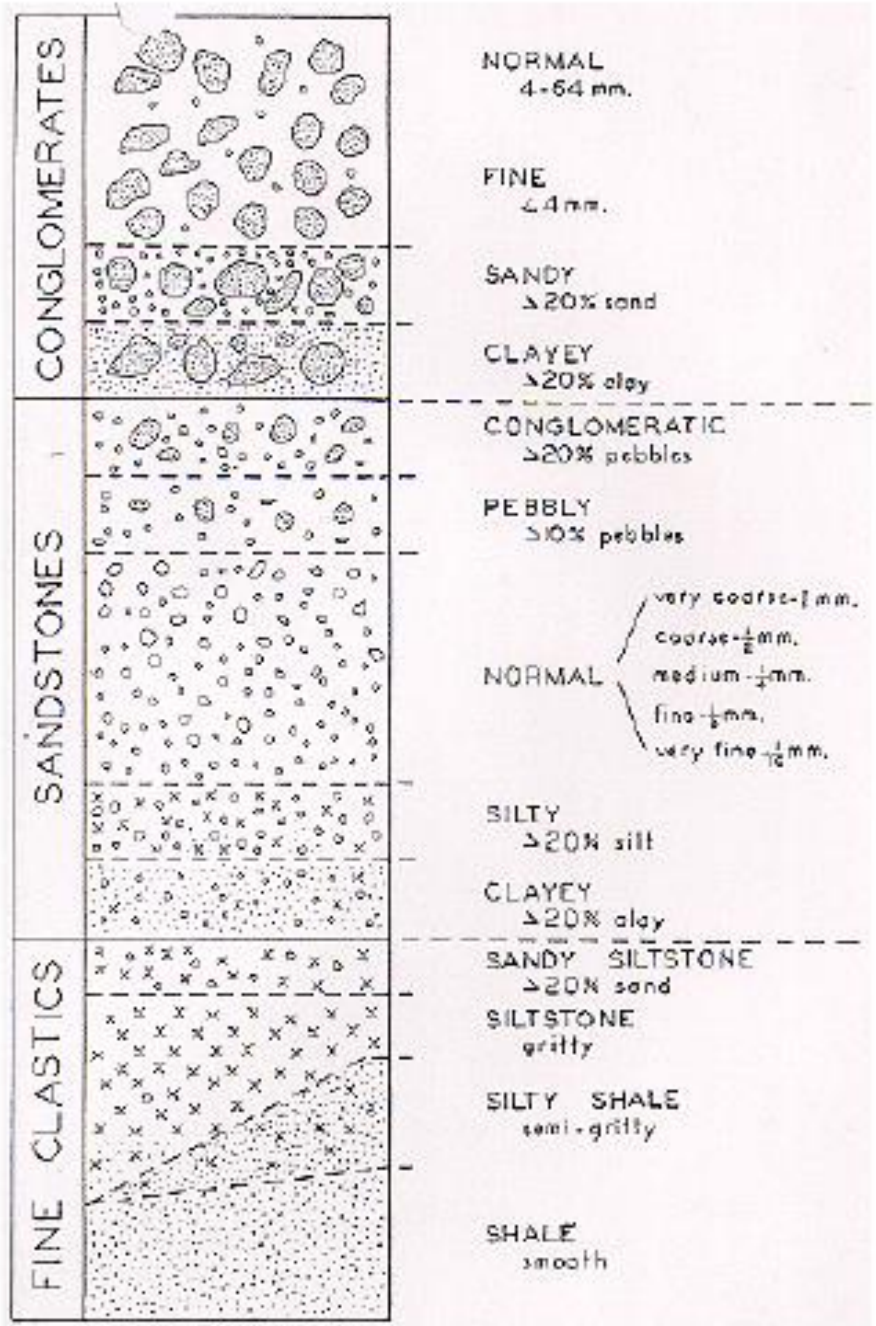
- **clastic: formed from fragments of other rocks (sediments)**
- **chemical: formed from precipitation of ions in solution**
- **organic: formed from dead organisms**

Formation of clastic sedimentary rocks:

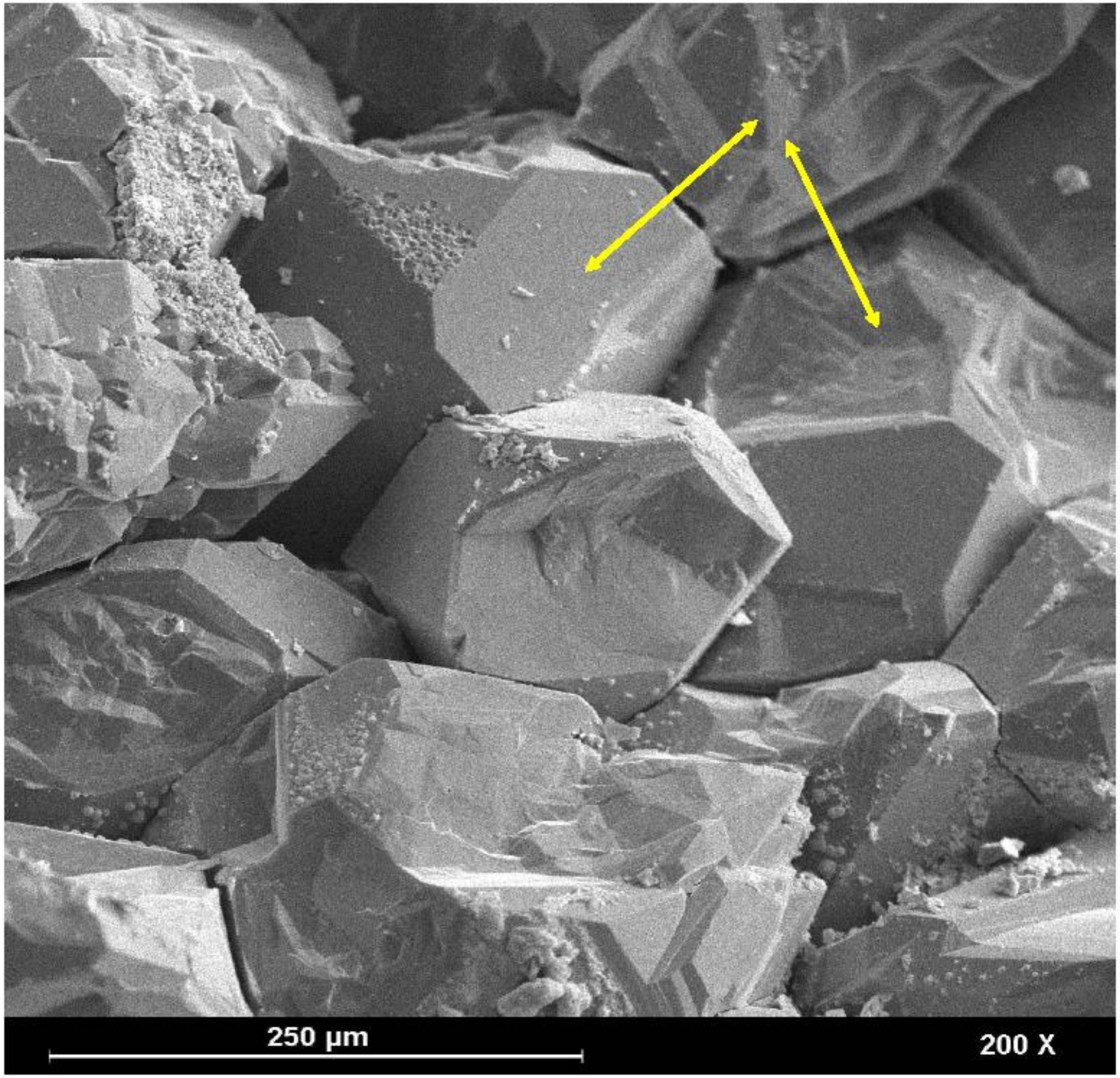
- **weathering**
- **sediment transport**
- **deposition and compaction**

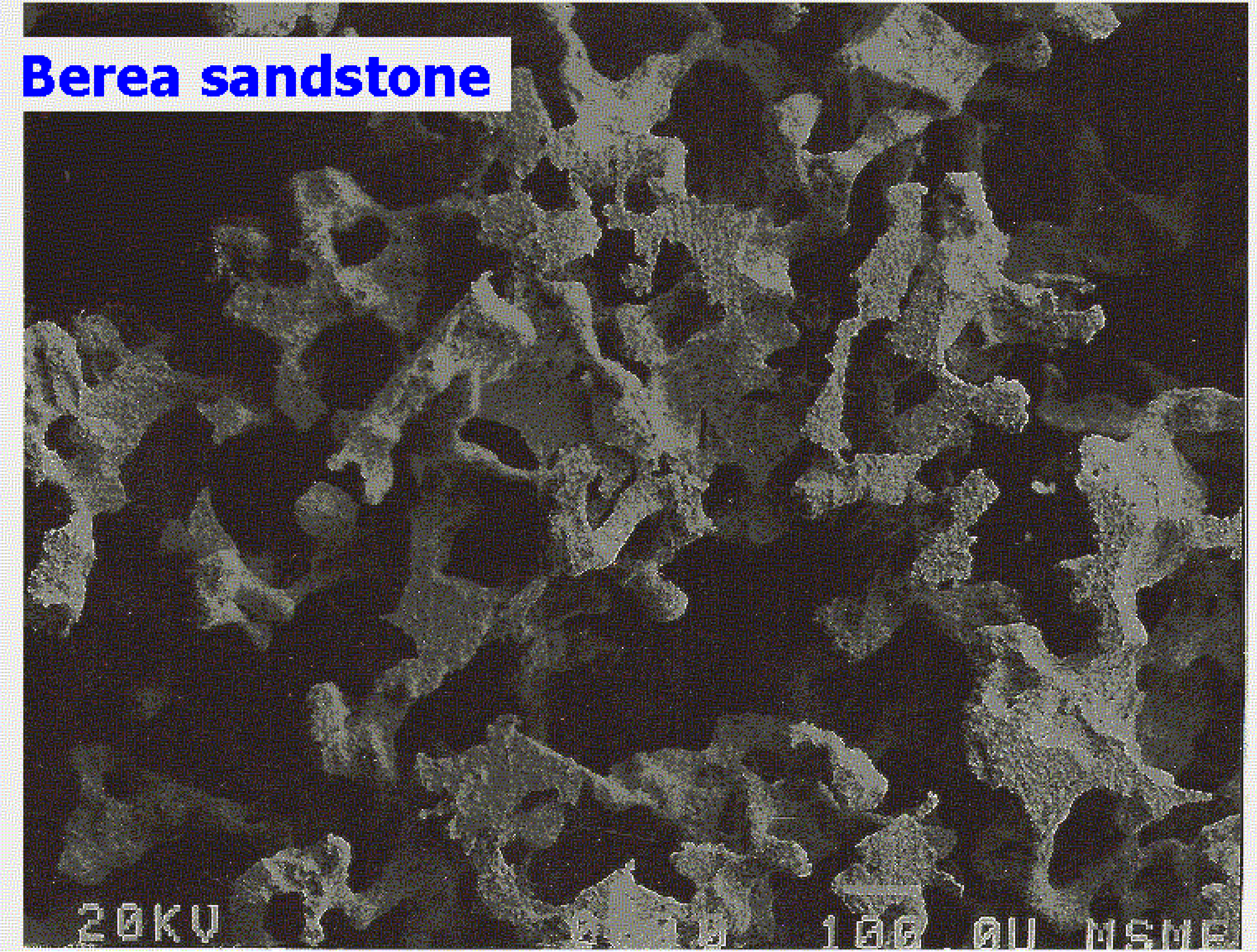

COARSE GRAVEL
FINE GRAVEL
SAND
SILT
CLAY

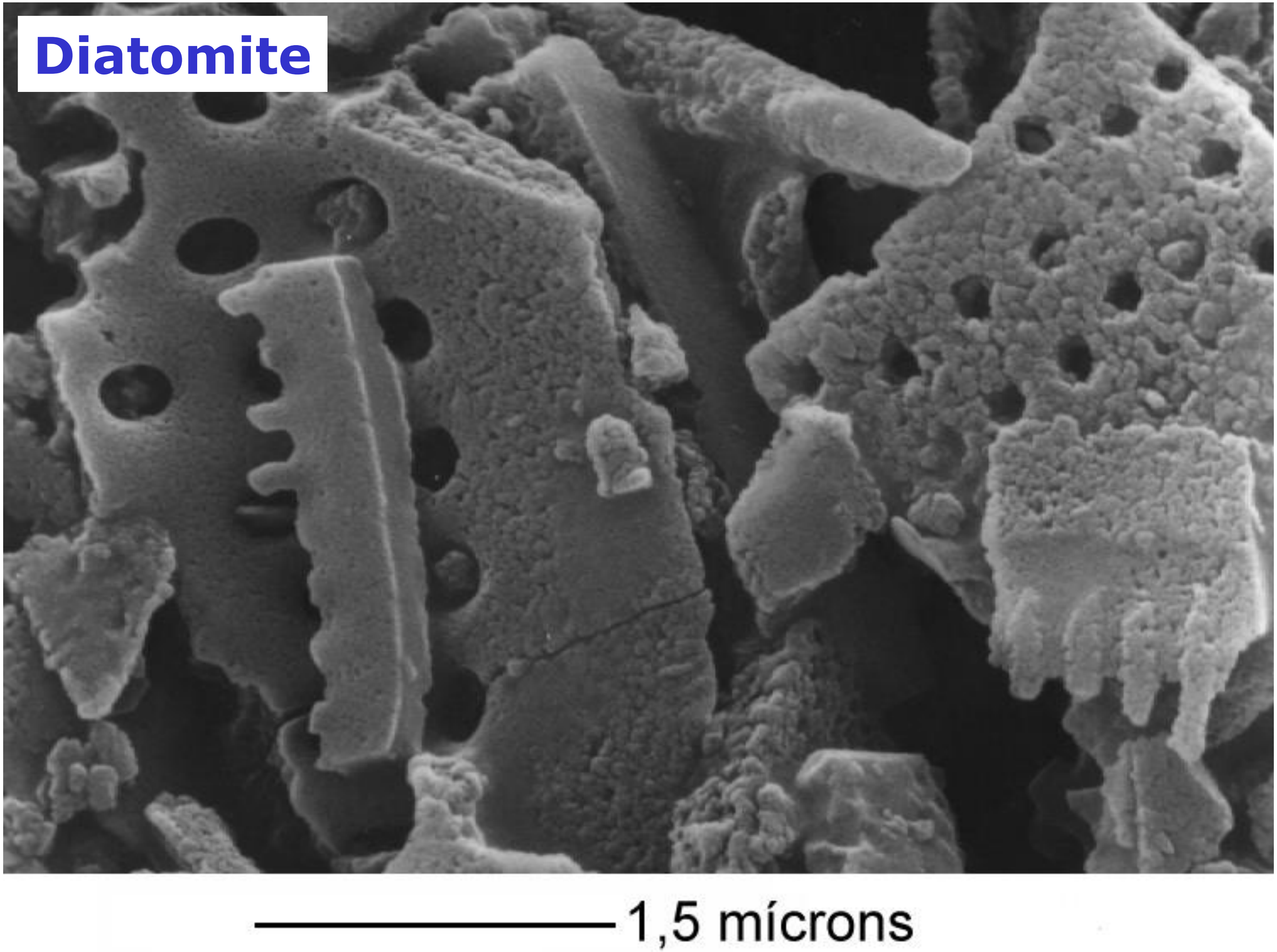

plus 2"
1 1/4"–2"
3/4"–1 1/4"
3/8"–3/4"
3/8"–#4
#4–#10
#10–#20
#20–#40


CONGLOMERATES
NORMAL
4-64 mm.
FINE
≤4 mm.
SANDY
≥20% sand
CLAYEY
≥20% clay
SANDSTONES
CONGLOMERATIC
≥20% pebbles
PEBBLY
≥10% pebbles
NORMAL
very coarse-1 mm.
coarse-½ mm.
medium-¼ mm.
fine-⅛ mm.
very fine-1/16 mm.
SILTY
≥20% silt
CLAYEY
≥20% clay
FINE CLASTICS
SANDY SILTSTONE
≥20% sand
SILTSTONE
gritty
SILTY SHALE
semi-gritty
SHALE
smooth

Fontainebleau Sandstone




Berea sandstone
20KV
100.0U


Diatomite
1,5 mícrons

Physical properties of rocks

We are interested in

- **how much fluid is contained in a rock**

    measured by percentage of void space or porosity

- **how easy it is for the fluid to flow**

    determined by fluid properties and permeability

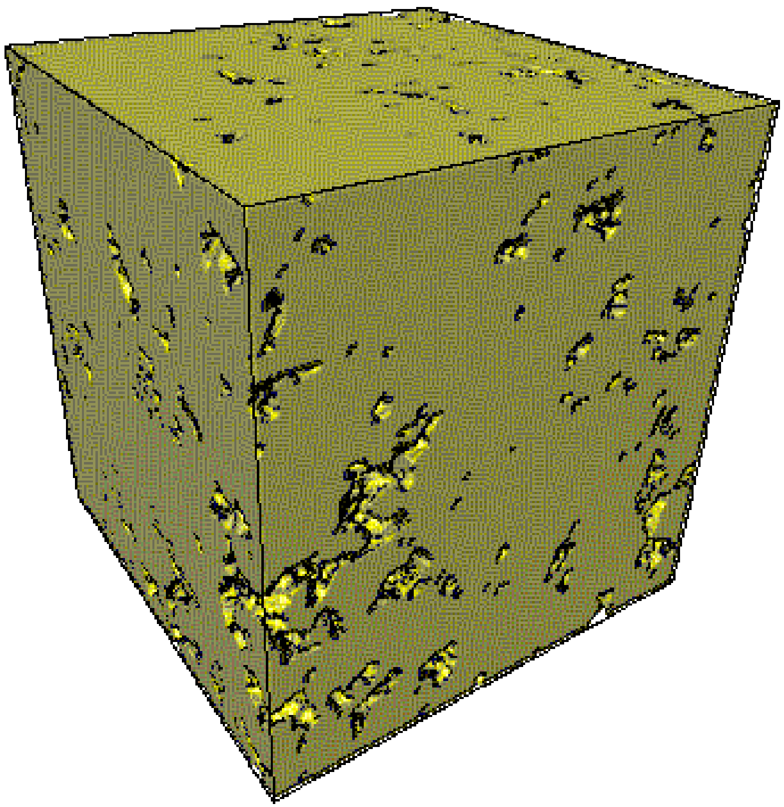
Porosity

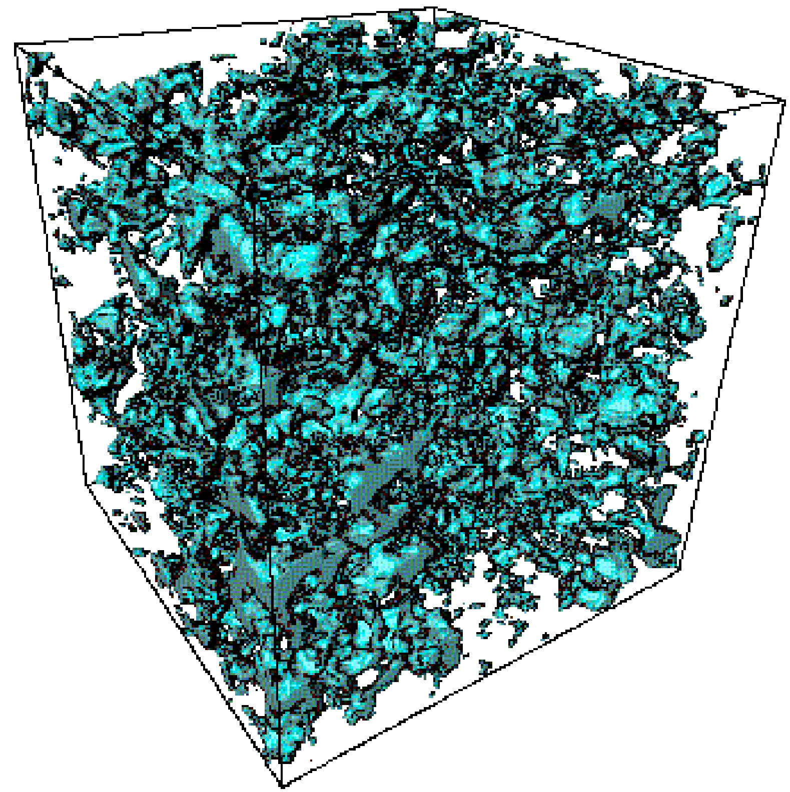
Porosity measures space available in rock for storage

Denoted by ϕ and defined by

$$\phi = \frac{\text{pore volume}}{\text{bulk volume}}$$

North Sea Sandstone



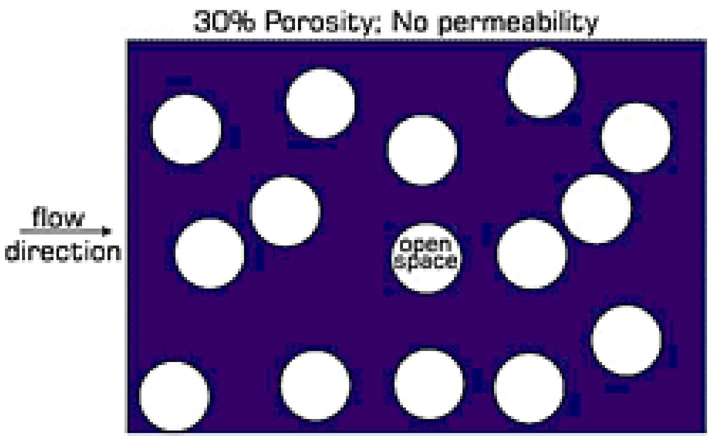


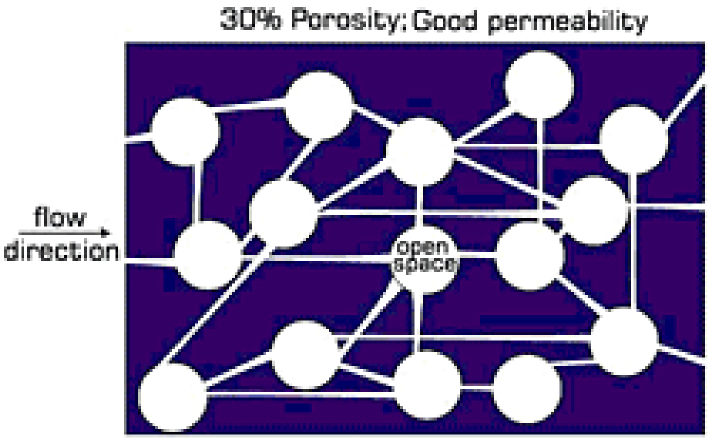
size: 200x200x200

resolution: 10 µm

Micro CT Image

Courtesy of Statoil





Non-connected pores

Connected pores

Level of connection determines to great extent permeability

Not all pore space contributes to fluid flow or permeability

Effective porosity measures the interconnected pore space

Unconsolidated	**Porosity**
Spherical packing, well shaken	36-43 %
Sand	37-50 %
Crusted rock	44-45 %
Soil	43-54 %
Consolidated	
Sandstone	8-38 %
Limestone, dolomite	4-10 %
Coal	2-12 %
Concrete	2- 7 %

Laboratory determination of porosity:

see Amyx, Bass & Whiting, pp 43-57.

Permeability k

Measures the ability of a rock formation to conduct fluids

It is the most important parameter in petroleum geology

It has units of area [sq cm]. Usually reported in darcys:

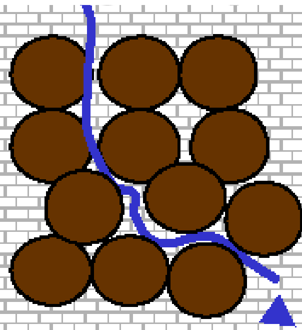
1 darcy = 10^{-8} cm^2

It varies many orders of magnitude depending on rock type:

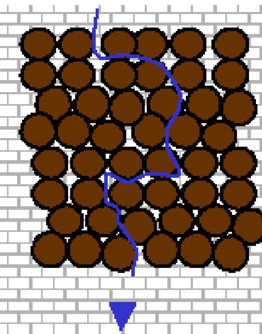
shale: 0.001 md or less
diatomite: 0.1-10 md
sandstone: 1-1000 md or more

Factors affecting permeability

- Permeability is proportional to grain size squared

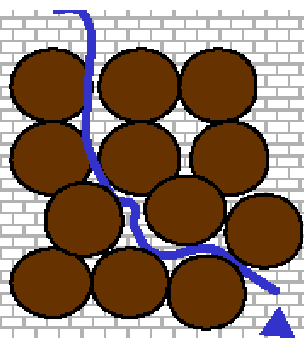


Well-sorted; permeable

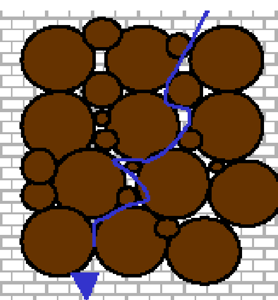


Well-sorted; less permeable

- Permeability is lower in poorly-sorted granular materials



Well-sorted; permeable



Poorly sorted,
less permeable

The oil and gas industry

Early history of the petroleum industry

1846 **Abraham Gesner develops kerosene, a liquid fuel distilled from oil shale**

1859 **Edwin Drake drills first producing oil well in Titusville, Pennsylvania**

1870 **Rockefeller forms Standard Oil**

Early history of the petroleum industry

1903 Petroleum boom in California

Oil wells in Long Beach, California (ca. 1923)

1908 Petroleum boom in Persia

PLATE 3.1 A CABLE-TOOL GUSHER
This photograph, taken in 1911, shows one of the very early company wells drilled on the "maidan" at Masjid-i-Sulaiman after penetrating the reservoir.

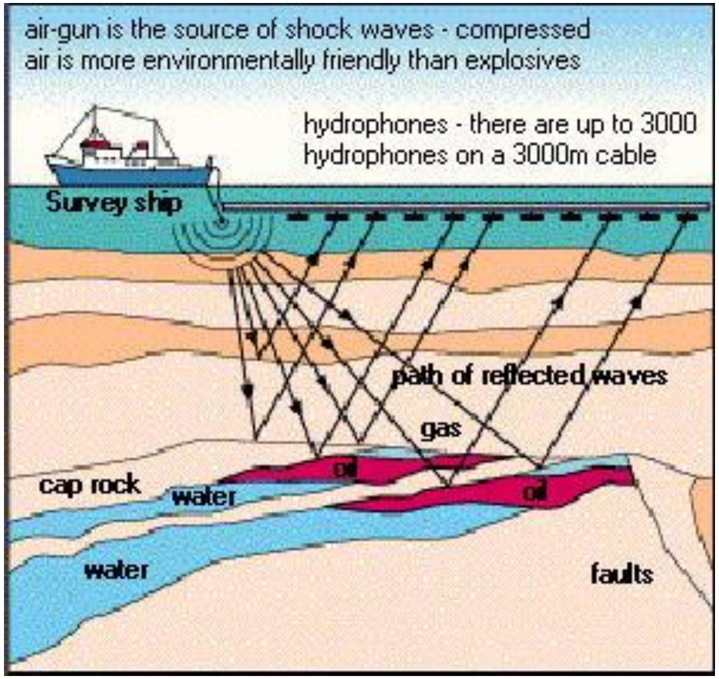
Locating oil reservoirs

geological features (satellite pictures)

magnetometers

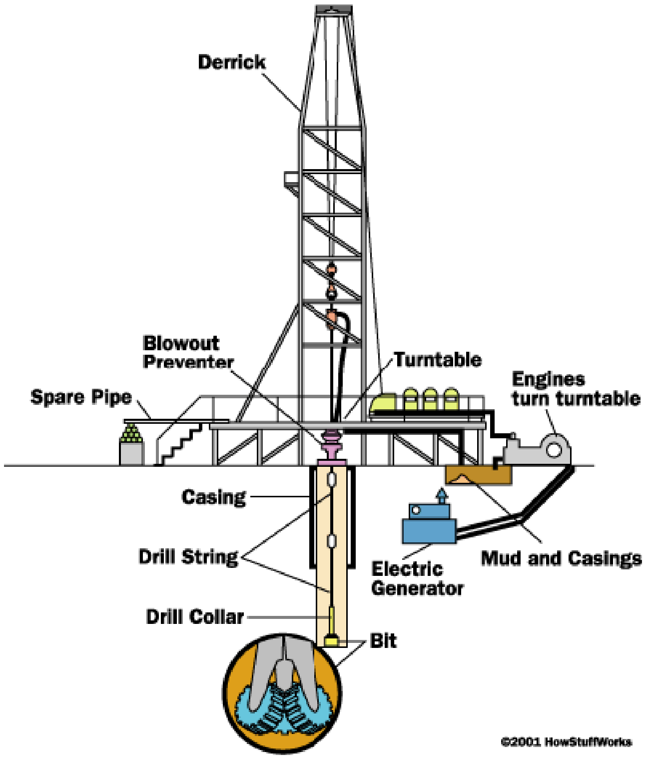
gravitometers

seismic surveys



Drilling

Schematic of an oil rig



Casing prevents collapse and allows drilling mud to circulate

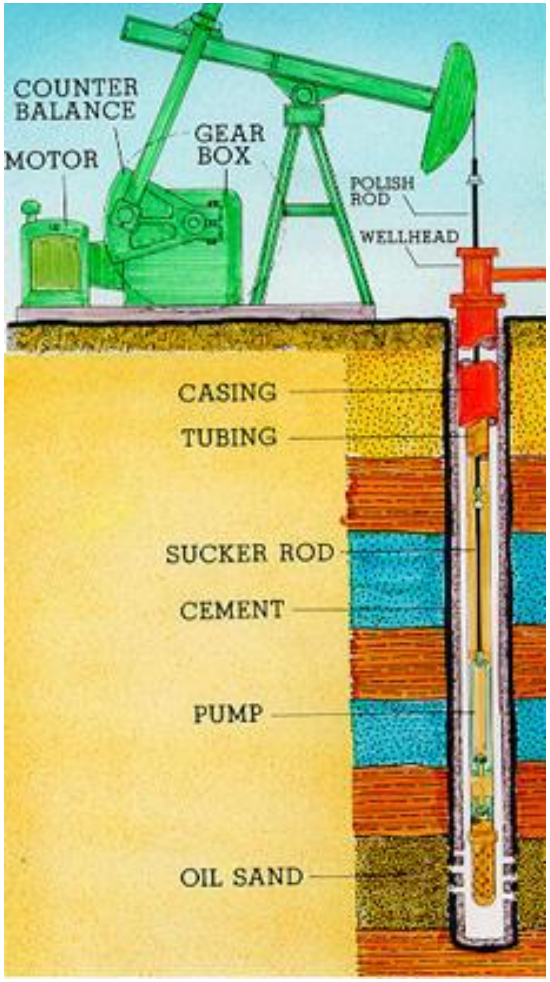
Drilling mud mixture of water, clay and chemicals used to lift cuttings to surface

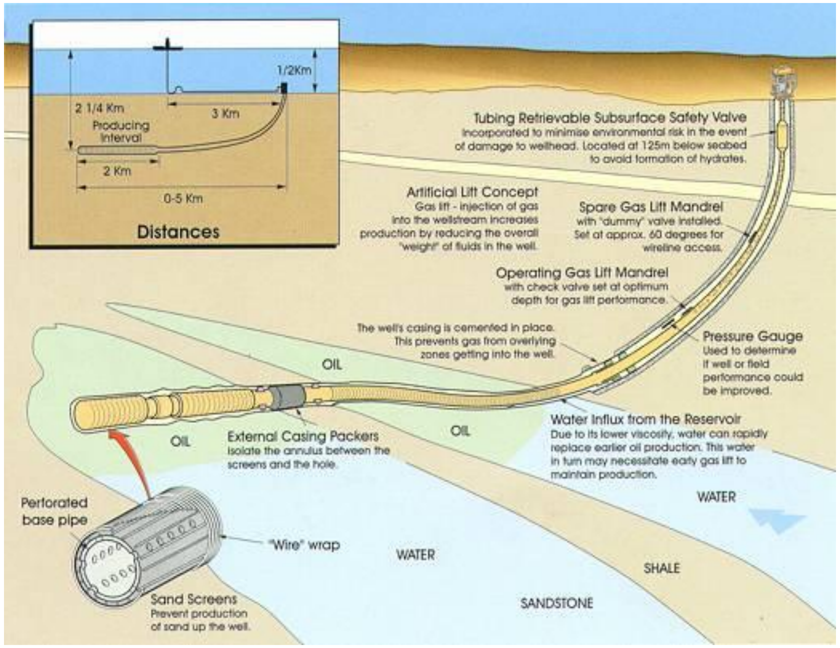
Upon reaching final depth, casing is perforated and oil flow starts:

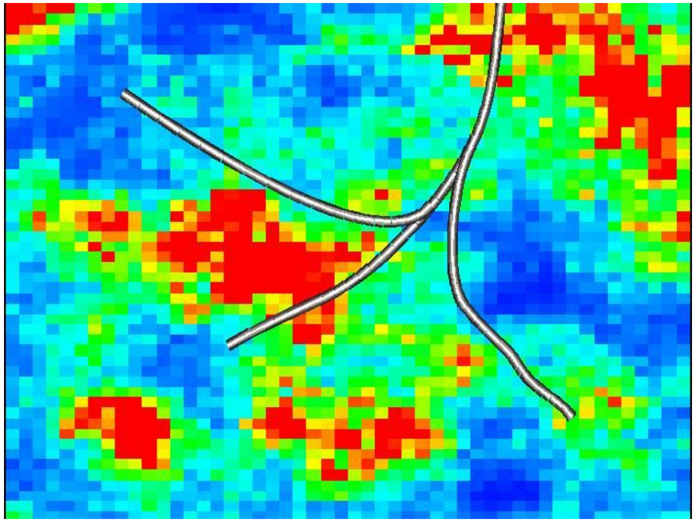
- Acid stimulation
- Hydraulic fracturing

Primary production:
Result of pressure difference between reservoir and surface

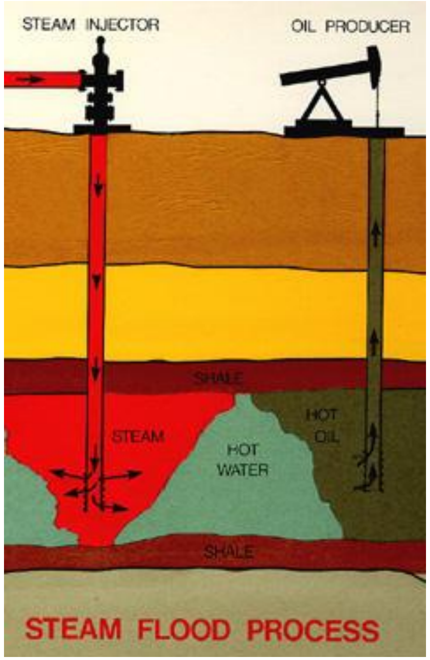
Wells


COUNTER BALANCE
MOTOR
GEAR BOX
POLISH ROD
WELLHEAD
CASING
TUBING
SUCKER ROD
CEMENT
PUMP
OIL SAND


1/2Km
2 1/4 Km
3 Km
Producing Interval
2 Km
0-5 Km
Distances
Tubing Retrievable Subsurface Safety Valve
Incorporated to minimise environmental risk in the event of damage to wellhead. Located at 125m below seabed to avoid formation of hydrates.
Artificial Lift Concept
Gas lift - injection of gas into the wellstream increases production by reducing the overall "weight" of fluids in the well.
Spare Gas Lift Mandrel
with "dummy" valve installed. Set at approx. 60 degrees for wireline access.
Operating Gas Lift Mandrel
with check valve set at optimum depth for gas lift performance.
The well's casing is cemented in place. This prevents gas from overlying zones getting into the well.
Pressure Gauge
Used to determine if well or field performance could be improved.
OIL
OIL
OIL
External Casing Packers
Isolate the annulus between the screens and the hole.
Water Influx from the Reservoir
Due to its lower viscosity, water can rapidly replace earlier oil production. This water in turn may necessitate early gas lift to maintain production.
WATER
Perforated base pipe
"Wire" wrap
WATER
SHALE
Sand Screens
Prevent production of sand up the well.
SANDSTONE



Enhanced Oil Recovery (EOR)



Water flooding

Polymer flooding

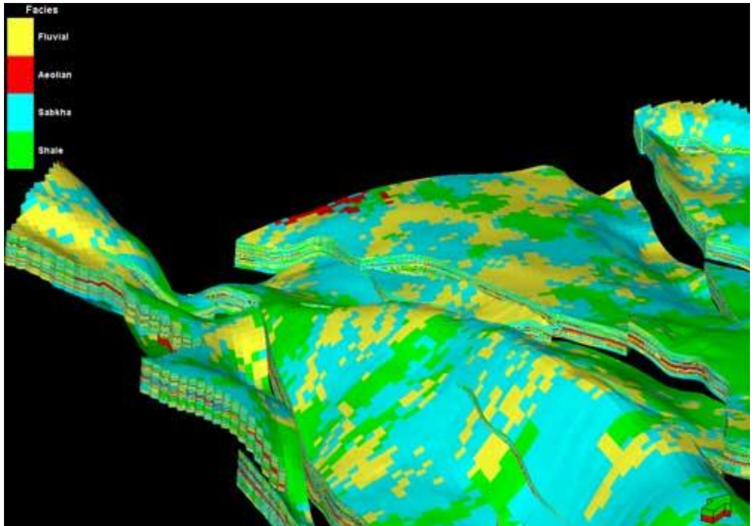
Gas injection (CO_2)

Steam injection

In-situ combustion

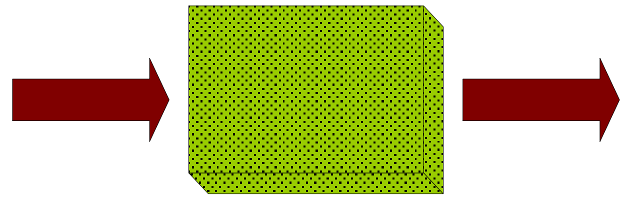
Other heating techniques

Reservoir Simulation



British Geological Survey

Reservoir Divided into Blocks

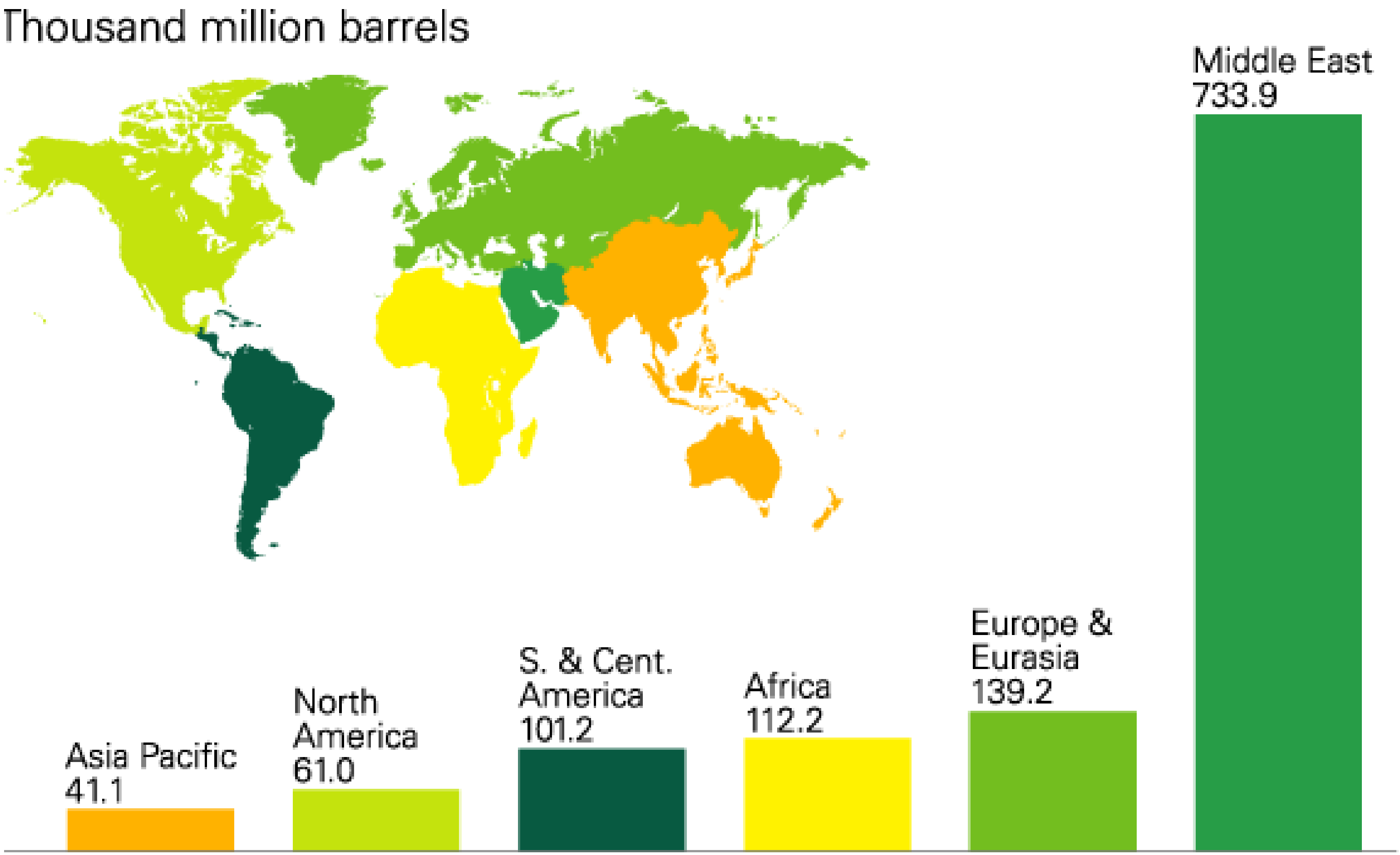


Inflow - Outflow = Accumulation

Flow Rate=Transmissibility (Driving Force)

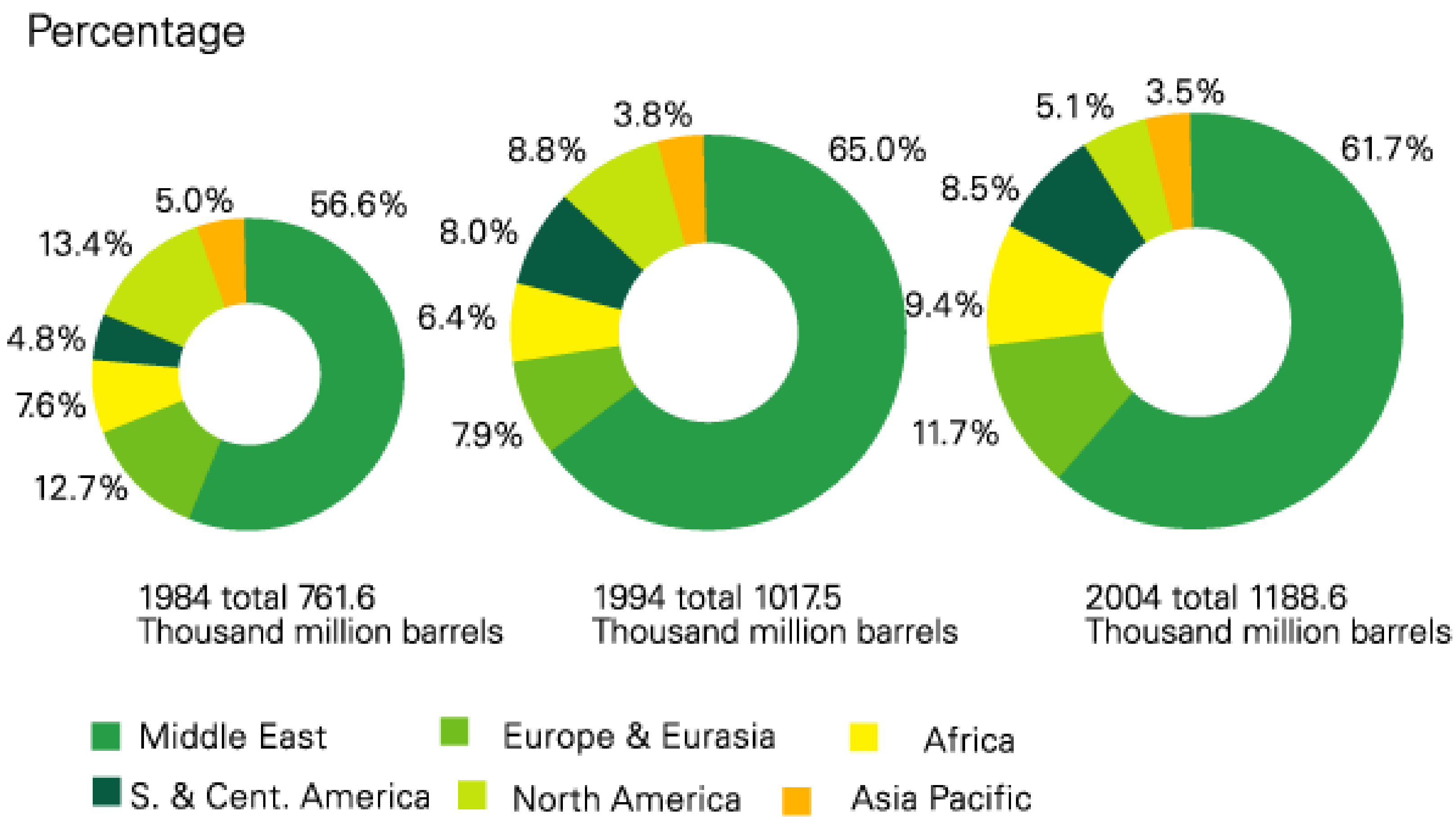
From conventional to unconventional oil

The conventional view:
Proved oil reserves at end 2004



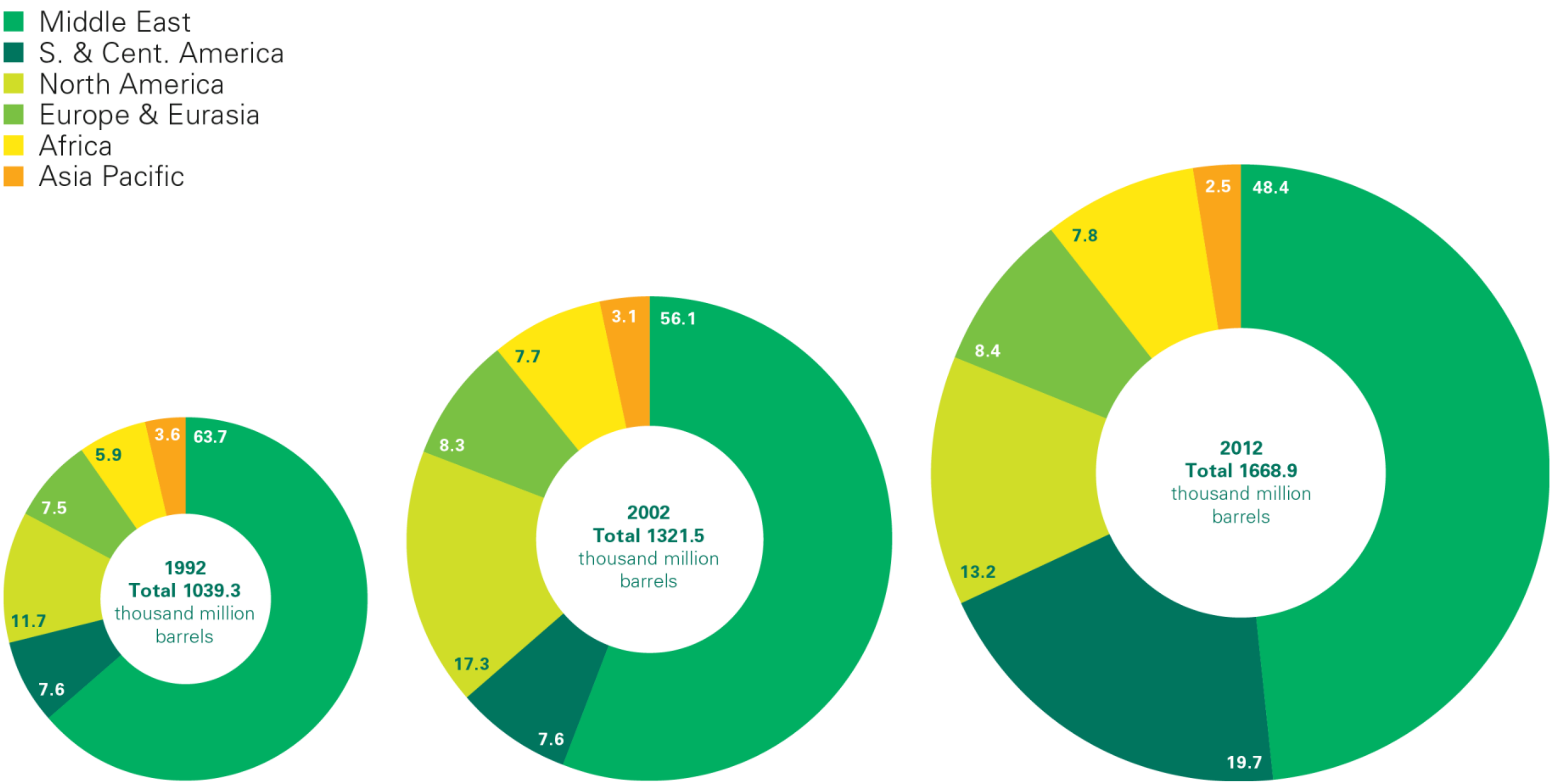
From BP Statistical Review of World Energy 2005

The conventional view:
Distribution of proved (oil) reserves 1984,1994, 2004



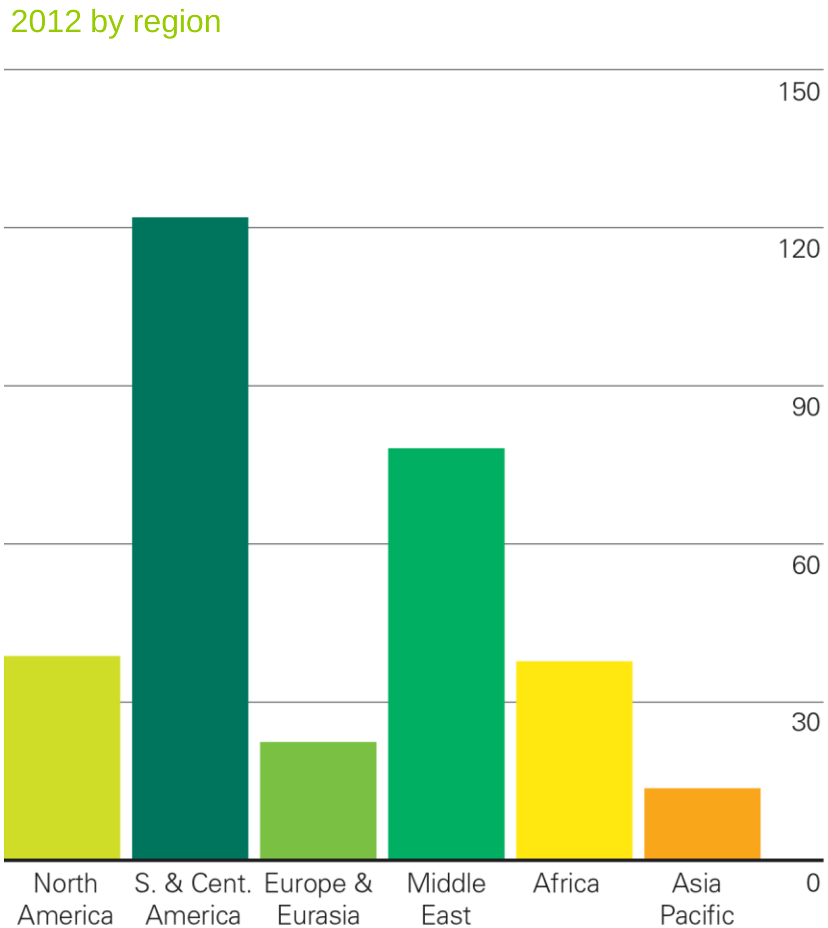
From BP Statistical Review of World Energy 2005

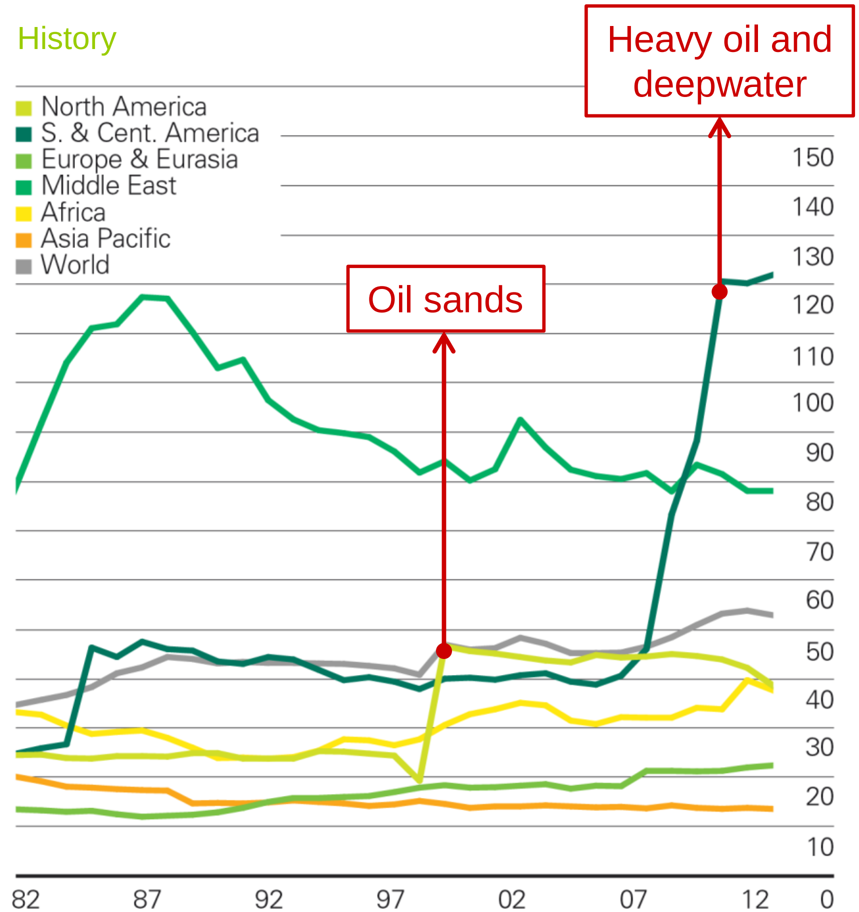
Distribution of proved oil reserves in 1992, 2002 and 2012
Percentage



Oil reserves-to-production (R/P) ratios

Years



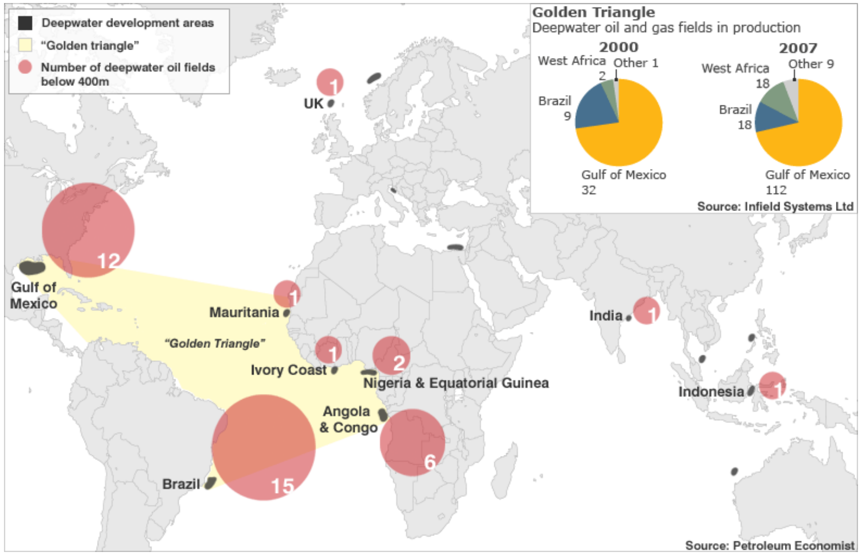


Unconventional hydrocarbon resources

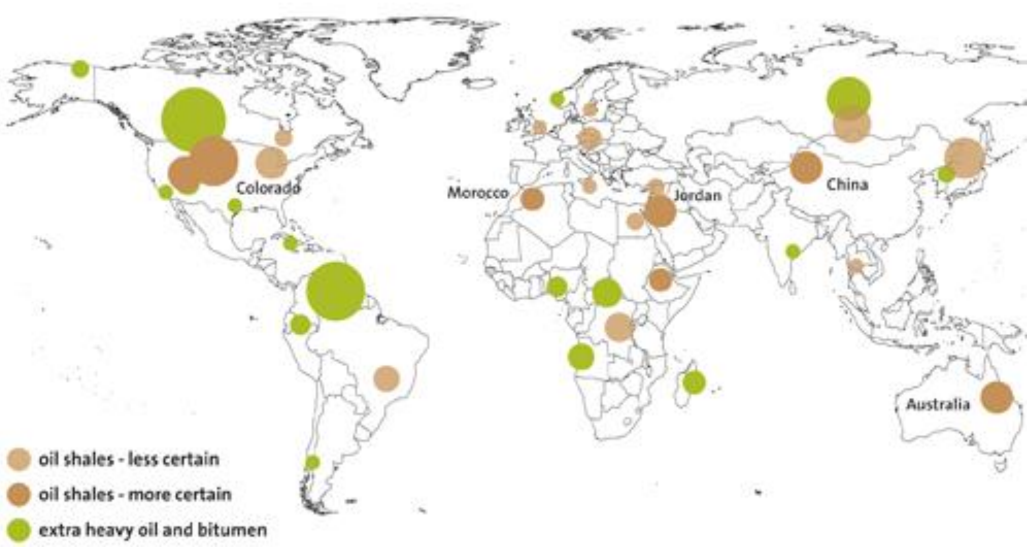
"Beyond conventional" resources

A shift in geographical distribution

Ultra deepwater



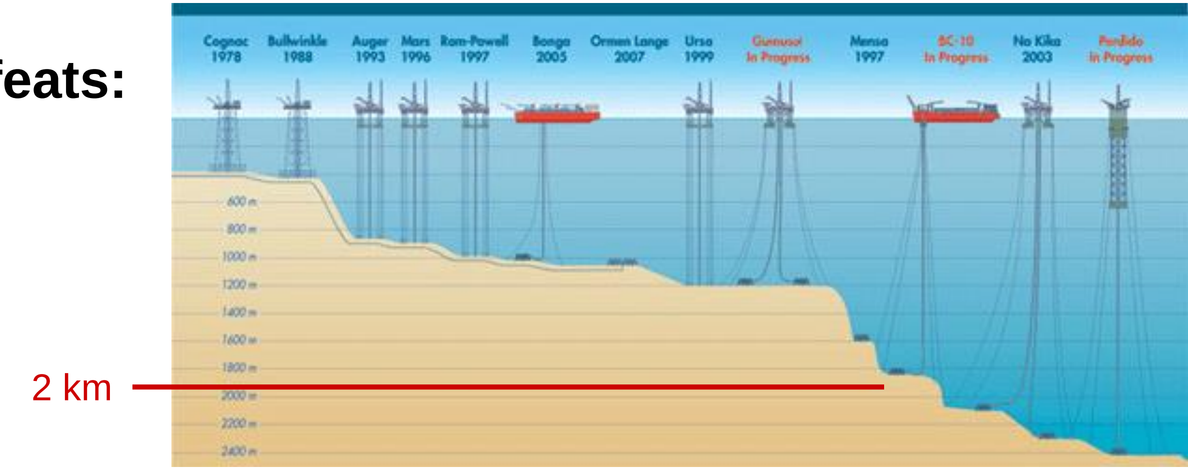
Oil shales and oil sands



Ultra deepwater: drilling

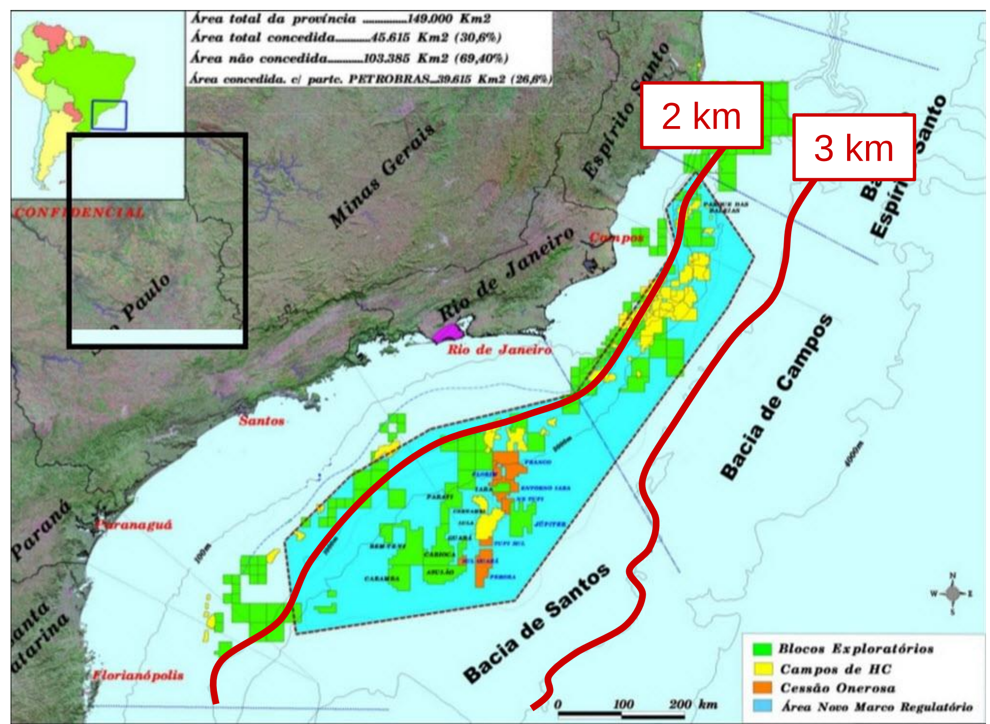
Amazing technological feats:

~ 3km of water column
~ 7km reservoir depth



Examples:

Santos and Campos basins, offshore Brazil



Oil and gas shales: Fracking

Old technology: has been used to enhance production since 1950s

What has changed is the scale at which it is implemented

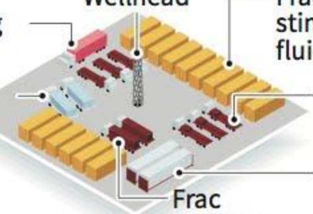
- **in combination with horizontal drilling**
- **multiple (10 to 100) stages per well**

Hydraulic fracturing - how it works

THE PROCESS

Hydraulic fracturing, commonly known as fracking, is the creation of fractures in rock formations in the earth using pressurised fluid, generally for the purpose of extracting natural gas

Common Fracturing Equipment

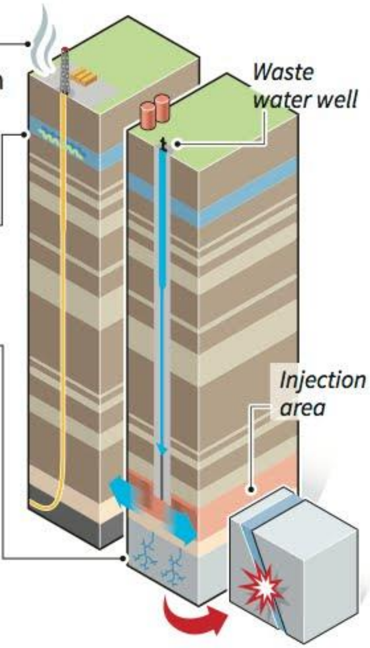


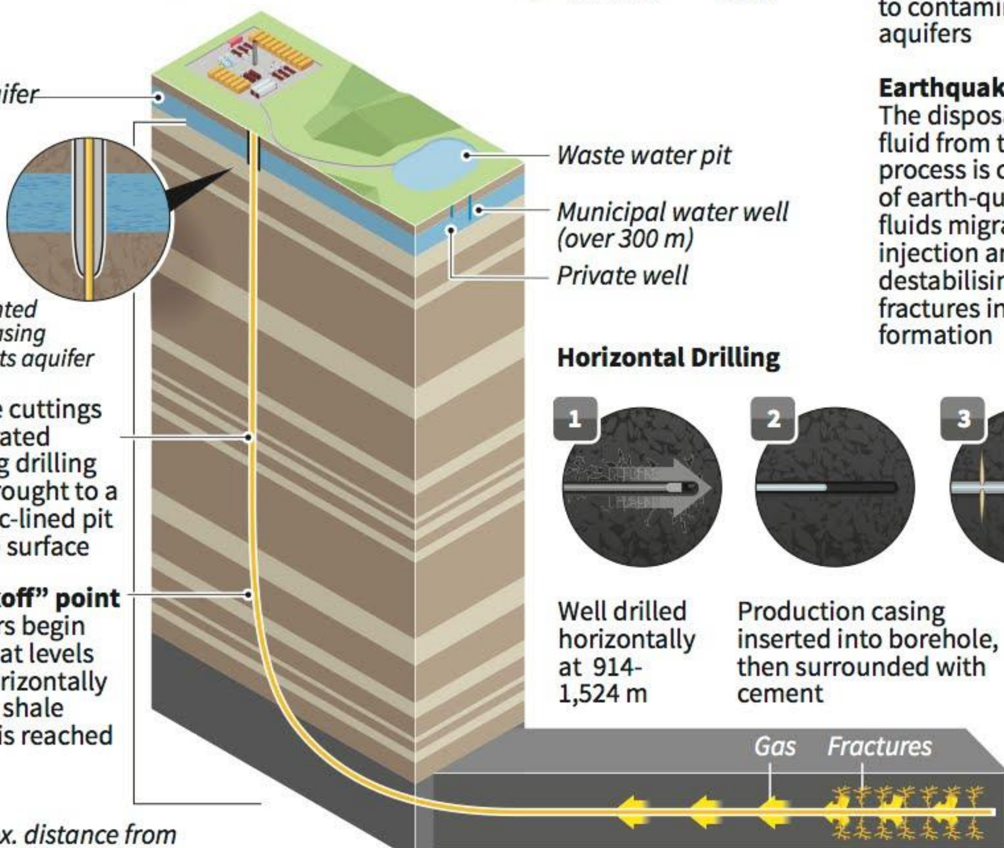
RISKS

Air emissions
Methane gas associated with natural gas extraction can leak into air

Drinking water
Chemicals used in fracking process have the potential to contaminate aquifers

Earthquakes
The disposal of waste fluid from the fracking process is cited as a cause of earth-quakes. Disposed fluids migrate below the injection area, destabilising the natural fractures in the rock formation





Horizontal Drilling

1. Well drilled horizontally at 914-1,524 m
2. Production casing inserted into borehole, then surrounded with cement
3. Charges then detonated inside a perforating gun, blasting small holes into the shale
4. Pressurised mixture of water, sand and chemi-cals then pumped into the well at 15,900 litres a minute
5. The fluid generates numerous small fissures in the shale, freeing trapped gas that flows to the surface

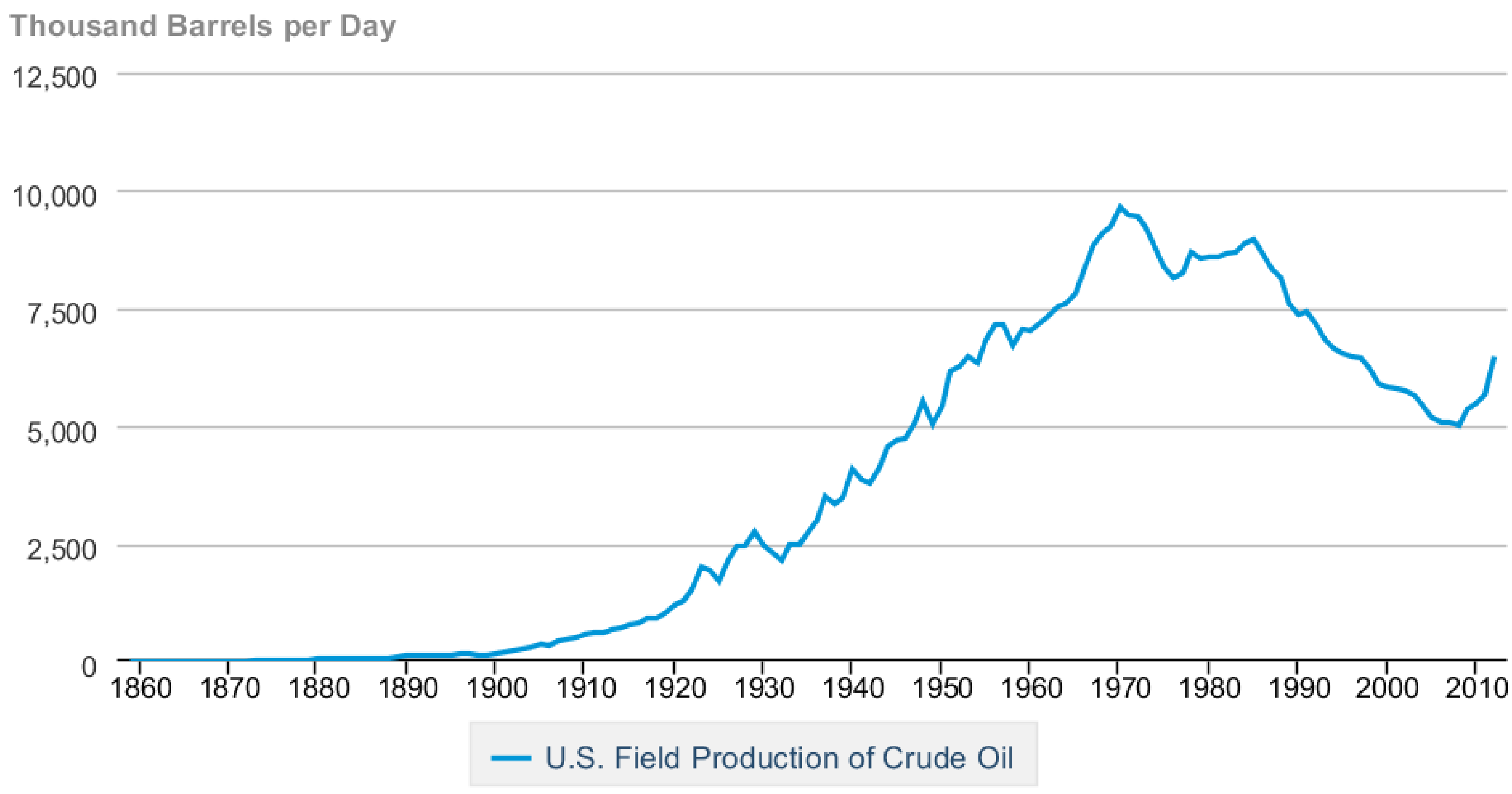
Sources: National Geographic, Chesapeake Energy, EIA., USGS

Staff, 24/12/2012

REUTERS

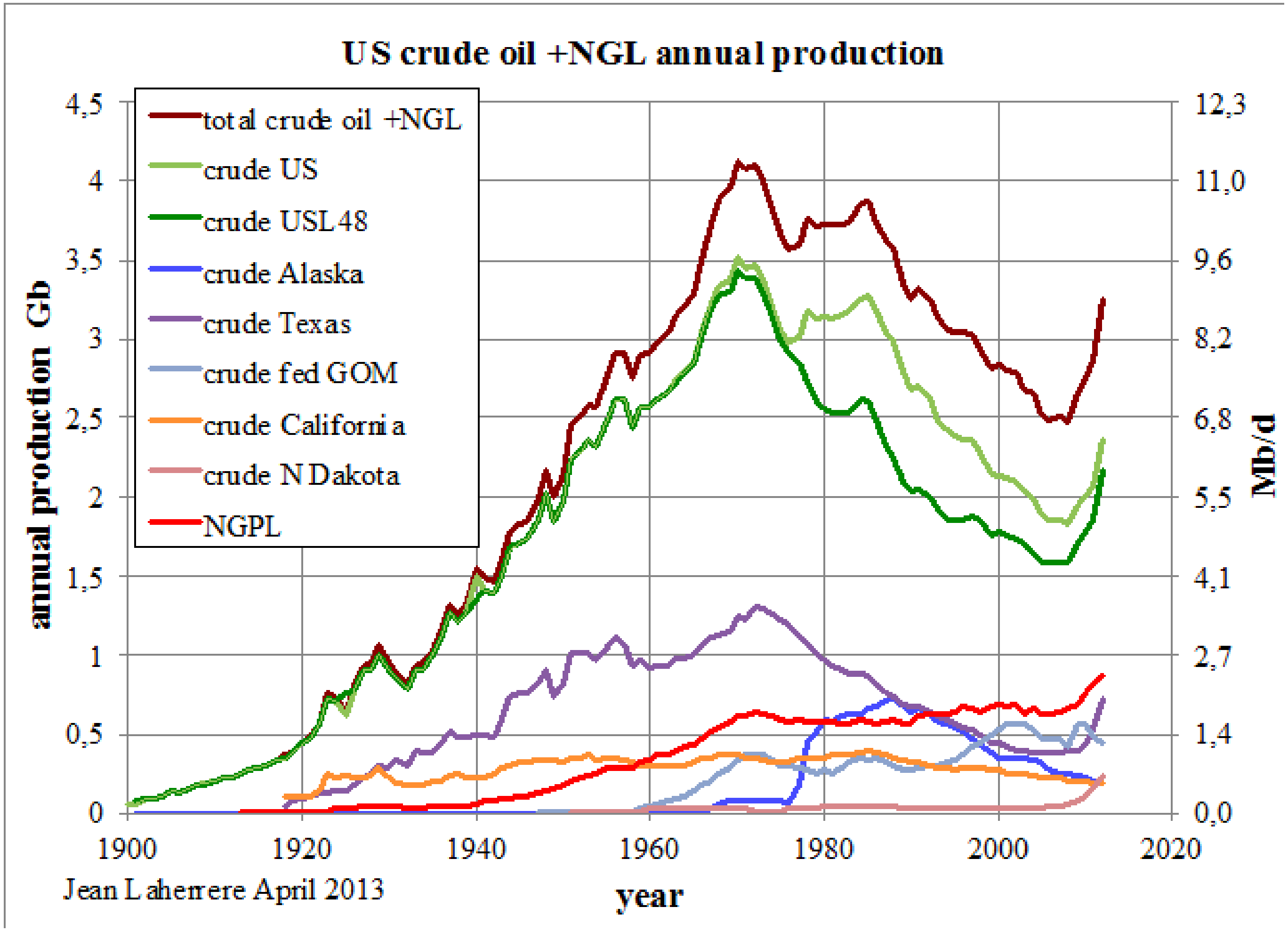
US oil production

Production of shale oil and shale gas have revolutionized the energy landscape in the US



Source: U.S. Energy Information Administration

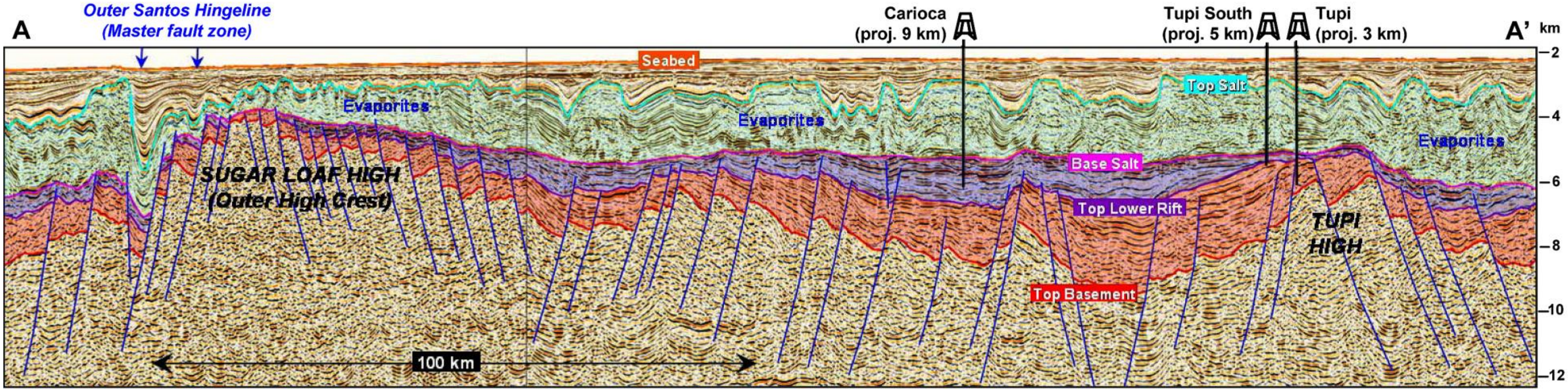
US oil production by region



Challenges

Exploration

Deeper, higher-resolution <u>seismic imaging</u>
in more complex environments (deep water, "pre-salt")



Production of conventional oil and gas

60% of the remaining conventional oil is in fractured carbonates

Fast flow through fractures, slow flow through matrix

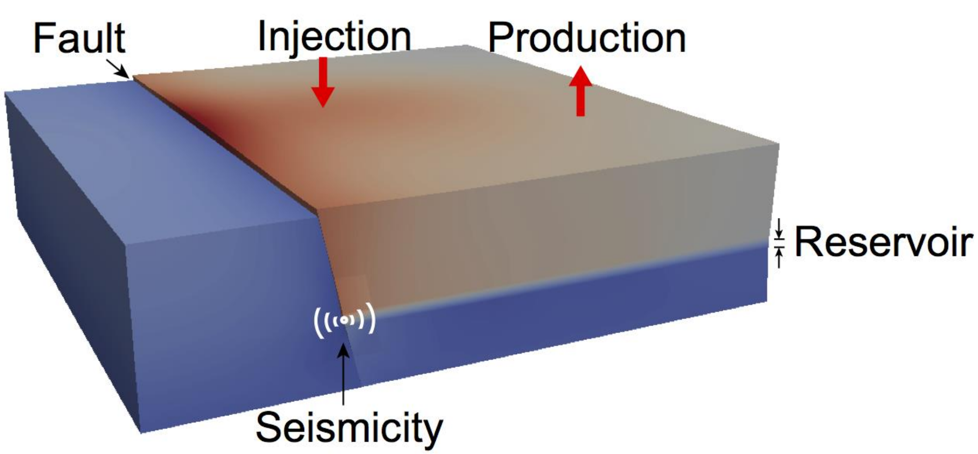
Mixed wettability (from water-wet to oil-wet)

(www.see.leeds.ac.uk)

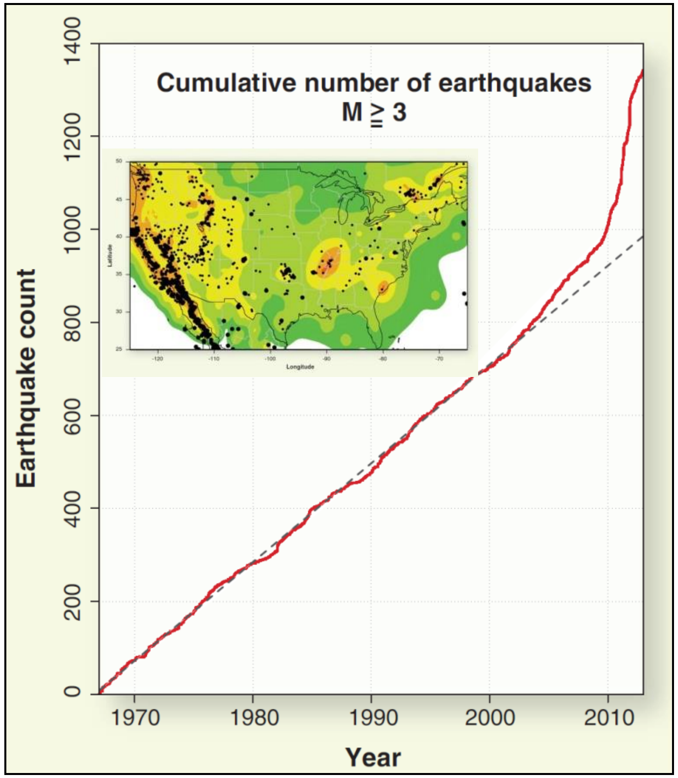
Production of unconventionals

Risk of leakage of fracking fluids

Risk of induced seismicity by produced-water disposal



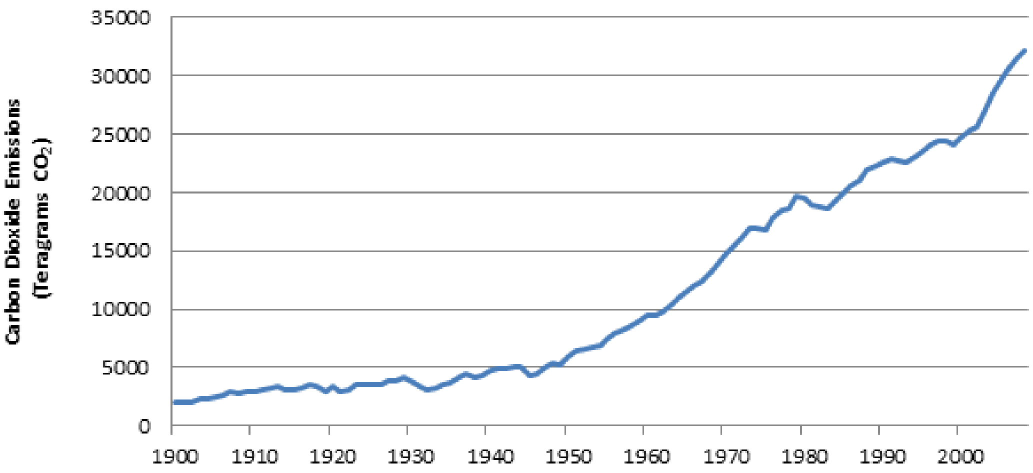
(Birendra Jha, PhD 2013)



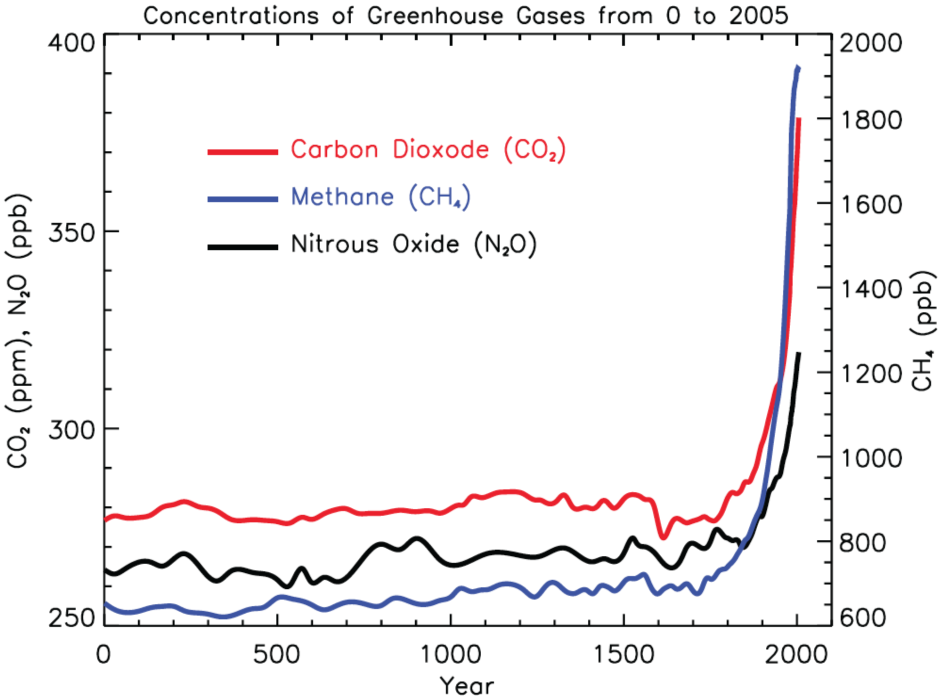
(Ellsworth, *Science* 2013)

Environmental impact of fossil fuels

Global carbon emissions from burning fossil fuels continue to grow



Unprecedented rate of increase of atmospheric greenhouse gases (GHG)



(IPCC 2007)

Energy-climate challenge

Reductions in emissions are needed to stabilize atmospheric CO2 concentrations at *some* level (e.g., double the pre-industrial level)

Energy needs will likely increase over the next decades

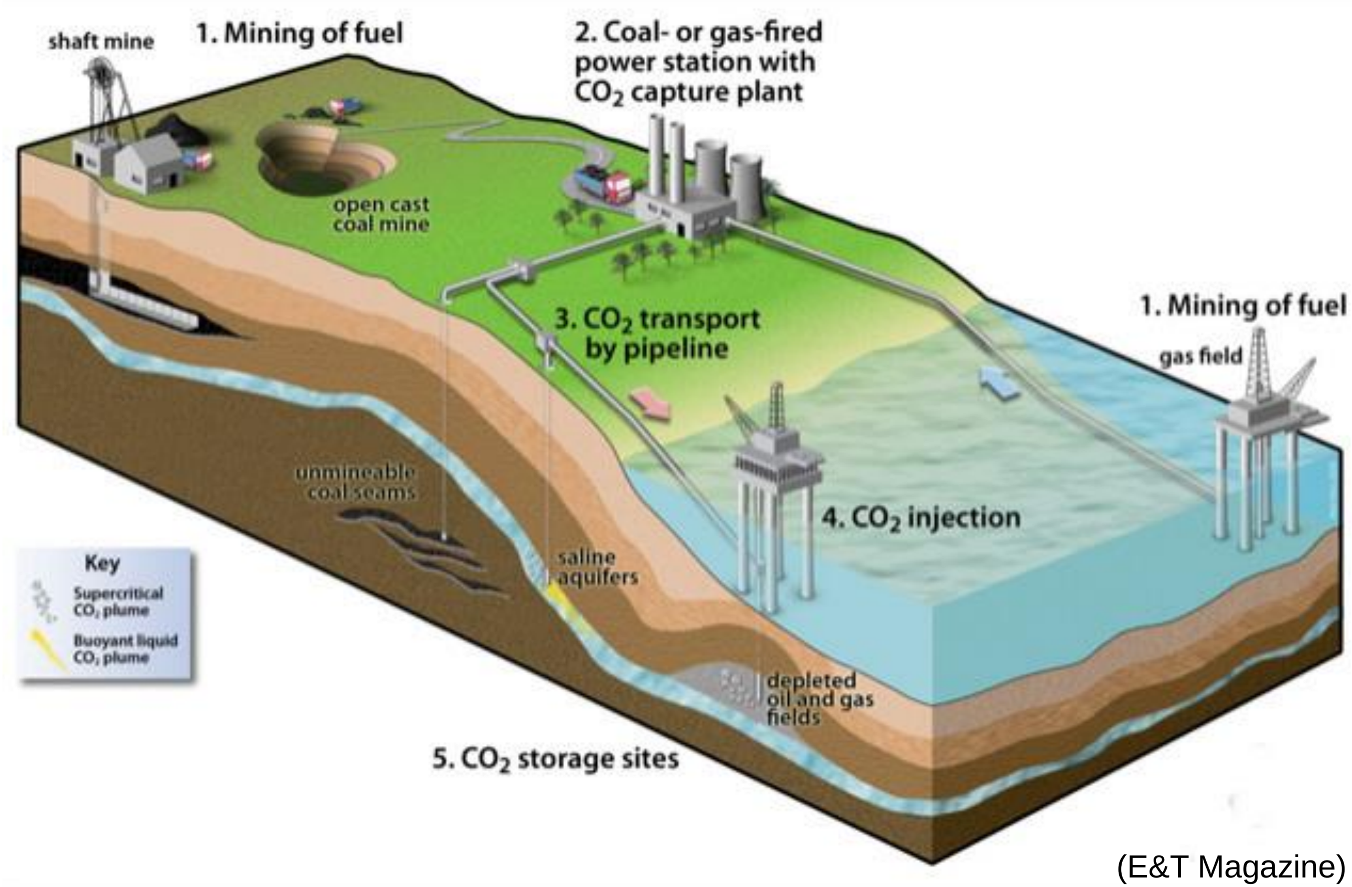
<u>Challenge:</u> balancing emissions and meeting energy demands

A portfolio of GHG mitigation technologies should be deployed:

- **improved efficiency**
- **nuclear energy**
- **"renewable" energy (wind, solar, …)**
- **forestation**
- **geoengineering interventions**
- **…**
- **Carbon capture and storage (CCS)**

Carbon capture and storage

<u>Capture</u> anthropogenic CO2 from large stationary sources (coal-fired and gas-fired power plants), <u>compress</u> it, and <u>inject</u> it in deep geologic formations for long-term <u>storage</u>



(E&T Magazine)

How big is the problem, really?

In the United States alone …

- **Current emissions ~ 7 billion metric tons per year (7 $GtCO_2/yr$)**
- **Coal- and gas-fired power plants ~ 30% ~ 2 $GtCO_2/yr$**

Take 1 GtCO2/yr ("1 unit") …

- **That's 1 billion tons per year, 10^{12} kg/yr**
- **At a reservoir density ~ 500 kg/m^3, that's 2×10^9 m^3/yr**
- **1 m^3 = 6.25 bbl, 1 year = 365 days, gives …**
- **35 million barrels of compressed CO2 per day**

1000 times the injection rate at Sleipner

~ 1 Sleipner every two weeks for the next 50 years

And this is just to tackle 3% of our current worldwide emissions