“Classic” energy resources and geology: the present situation

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Fossil fuel (~88%)

oil (~35%)

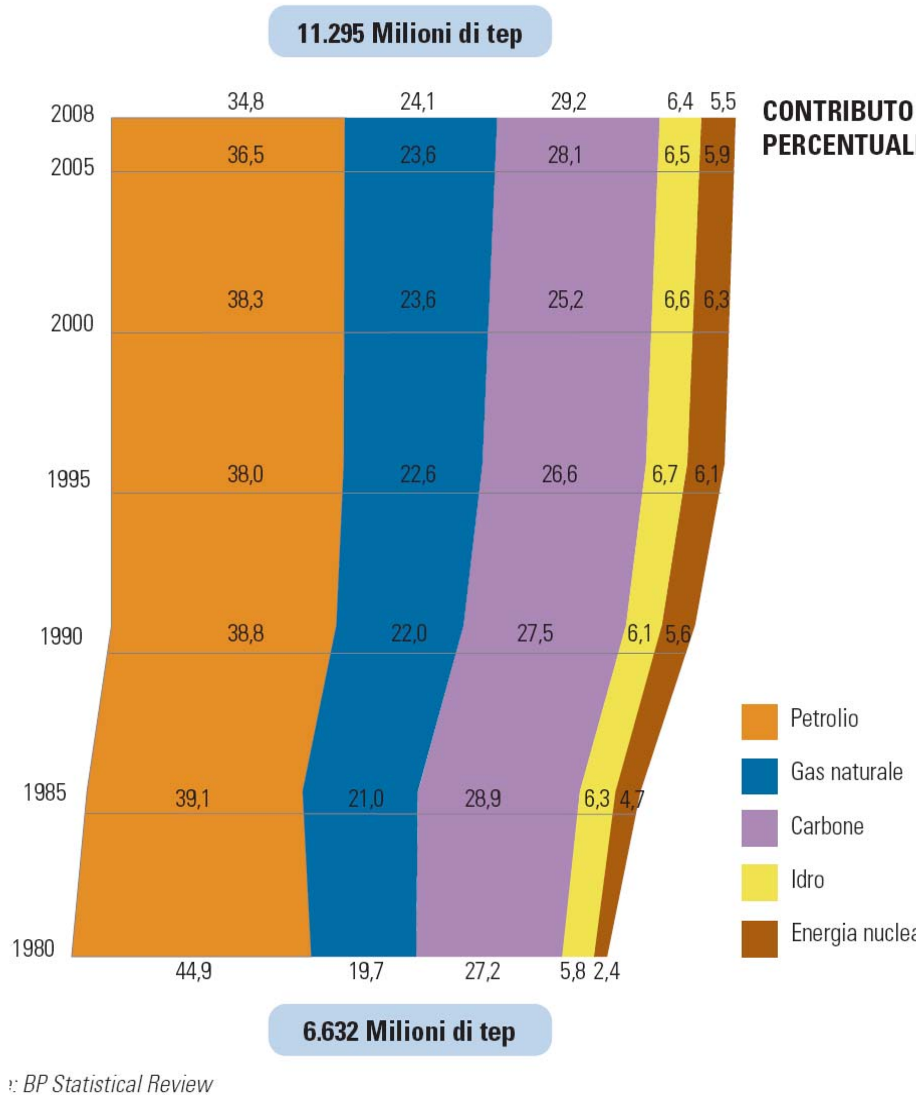
natural gas (~24%)

coal (~29%)

Hydropower, wind/solar power ~6.4%

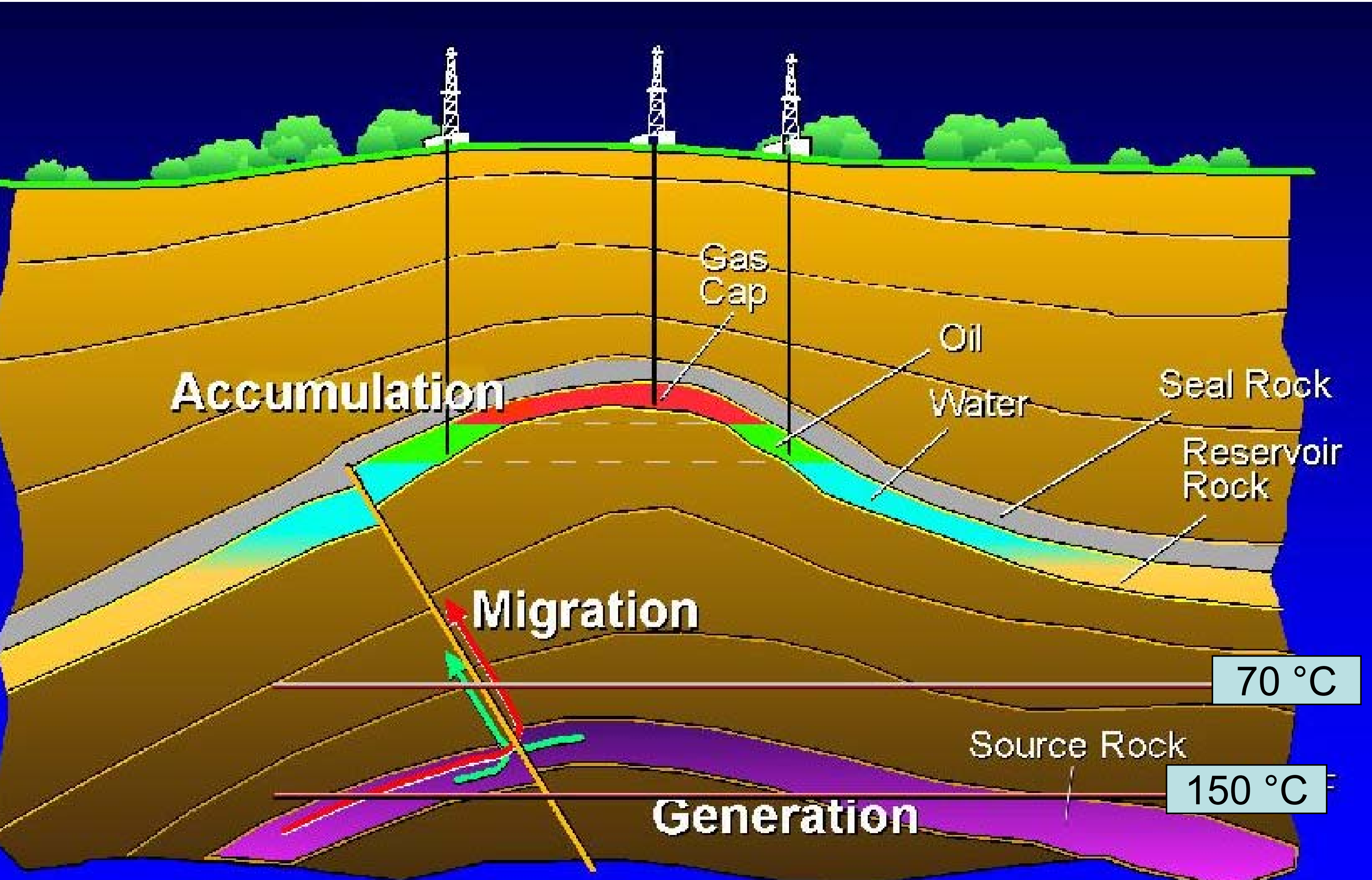
Nuclear power 5-6%

Total ~11 billions Toe/year



UP – Data Book 20

Oil + gas: the main source, related to the "Petroleum System"



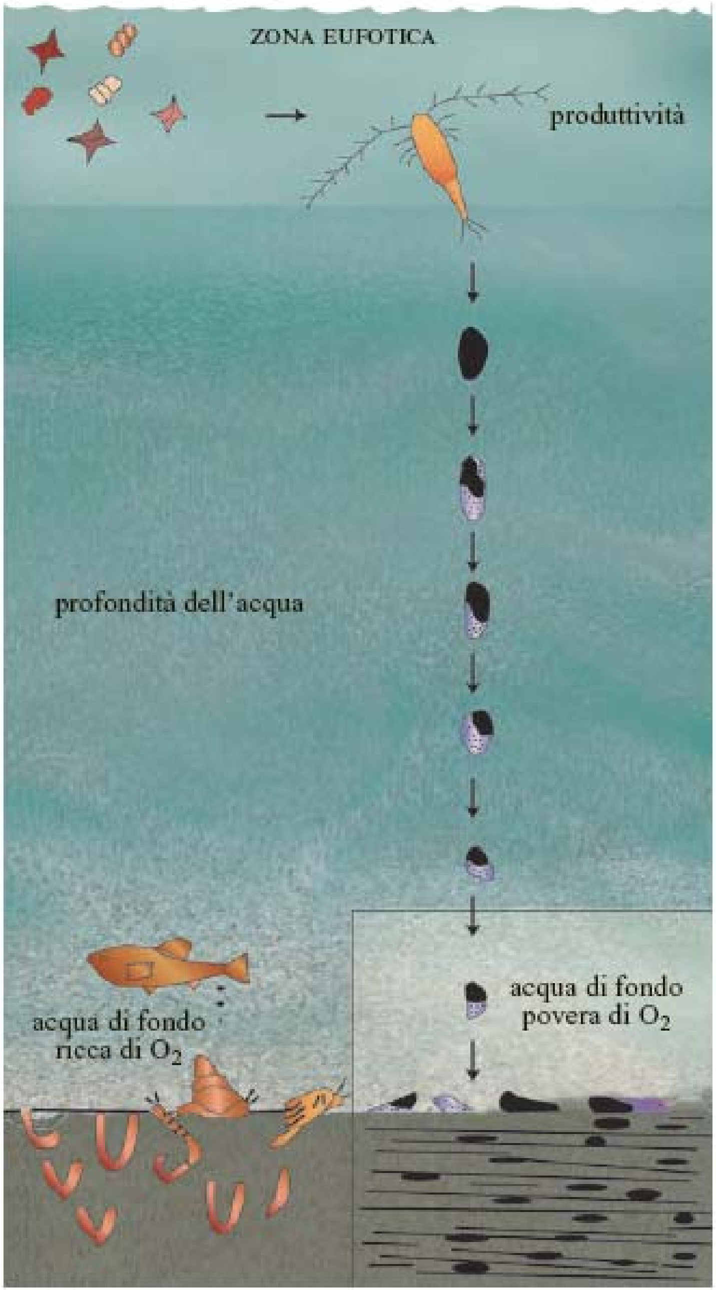
West 2009
www.soton.ac.uk/~imw/kimblack.ht

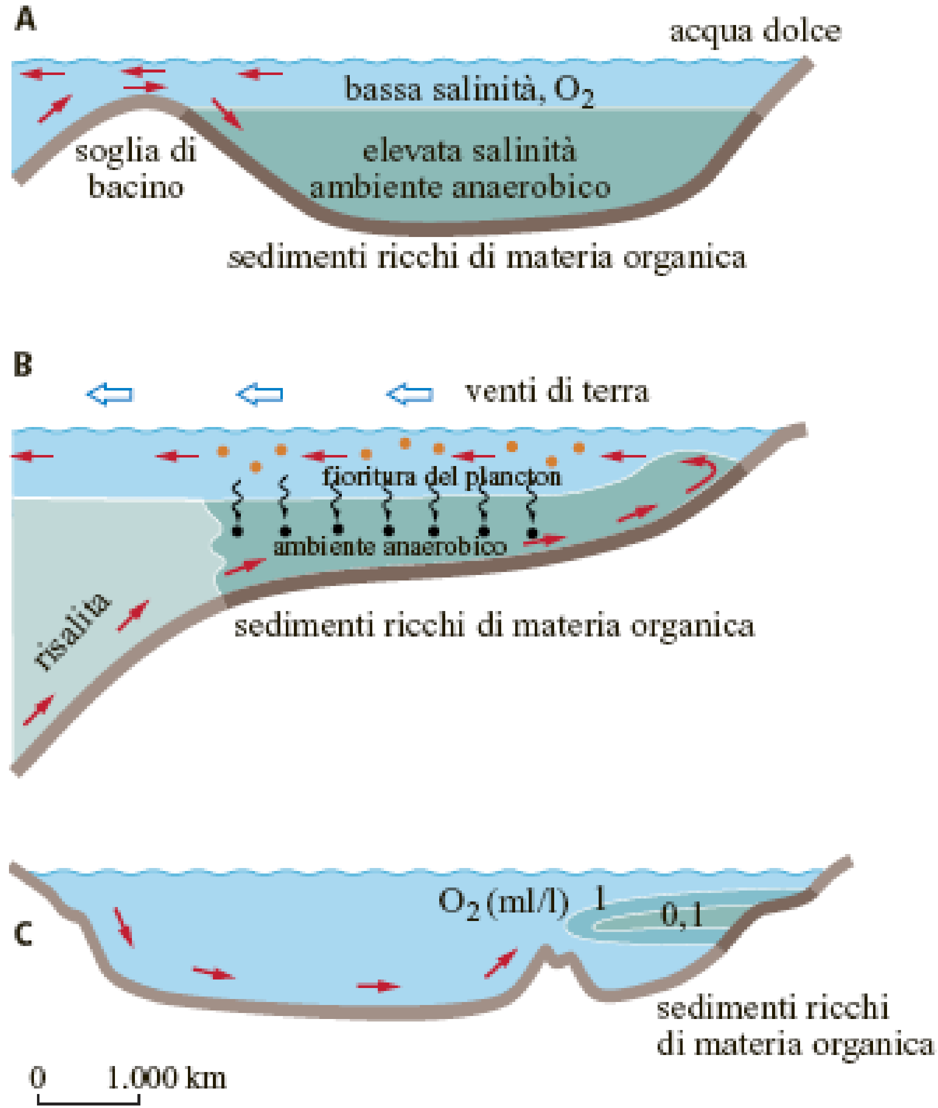
Generation

1. source rock

Kimmeridge clay 20 % organic matter

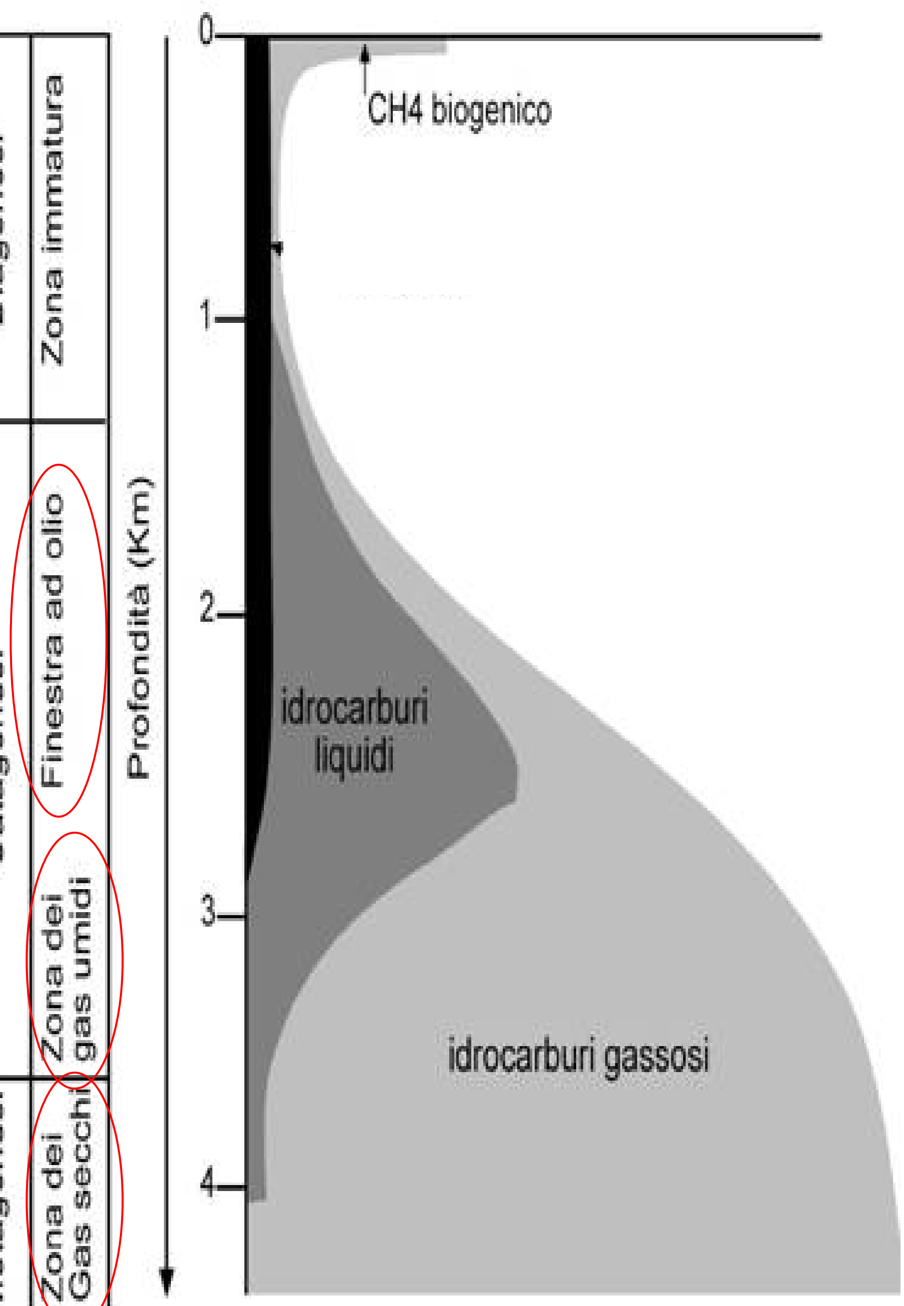
Blackstone 70 % organic matter





deposition of organic matter in anoxic environment

Huc, 2005



2. Trasformations related to burial (increase of P, T)

*Diagenesis: proteins and carbohydrates break down to form new structures that comprise a waxy material known as “**kerogen***” and a black tar like substance called “bitumen”*

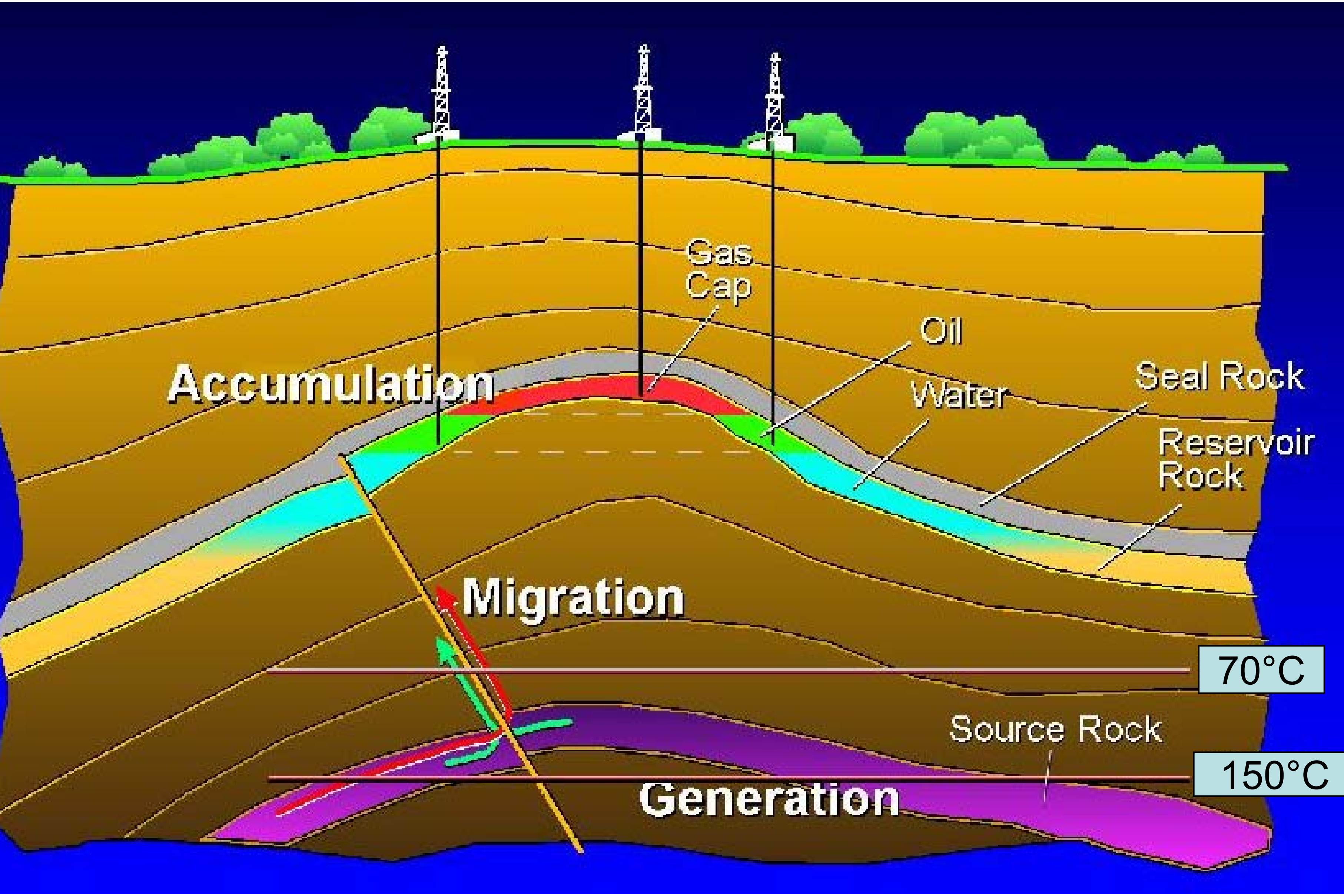
*Catagenesis: as temperatures and pressures increase (deeper burial) the process of catagenesis begins, which is the thermal degradation of kerogen to form **hydrocarbon chains***

“oil window”

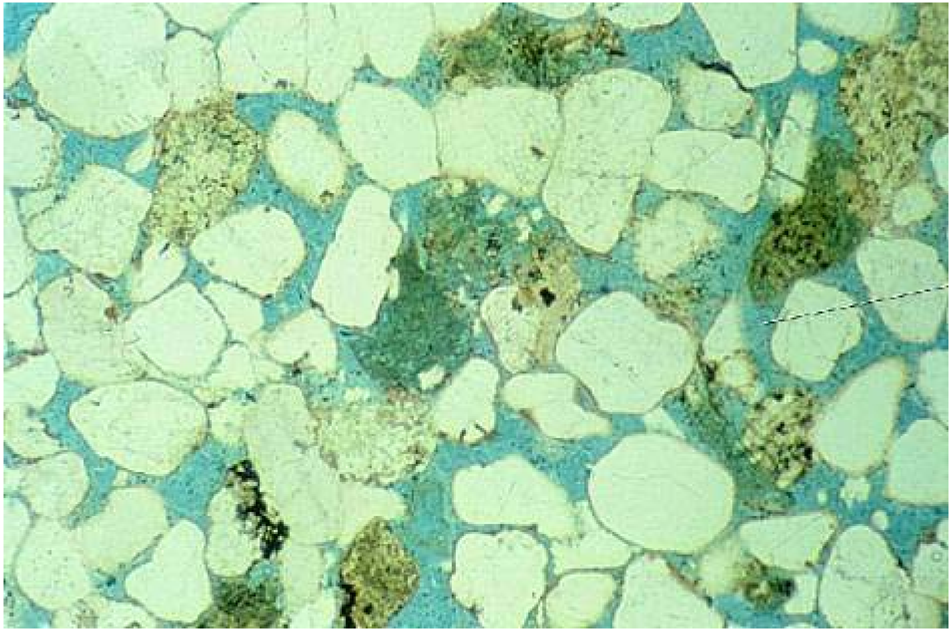
Metagenesis: “dry gas” (metano)

** Complex mixture of substances with high molecula weight*

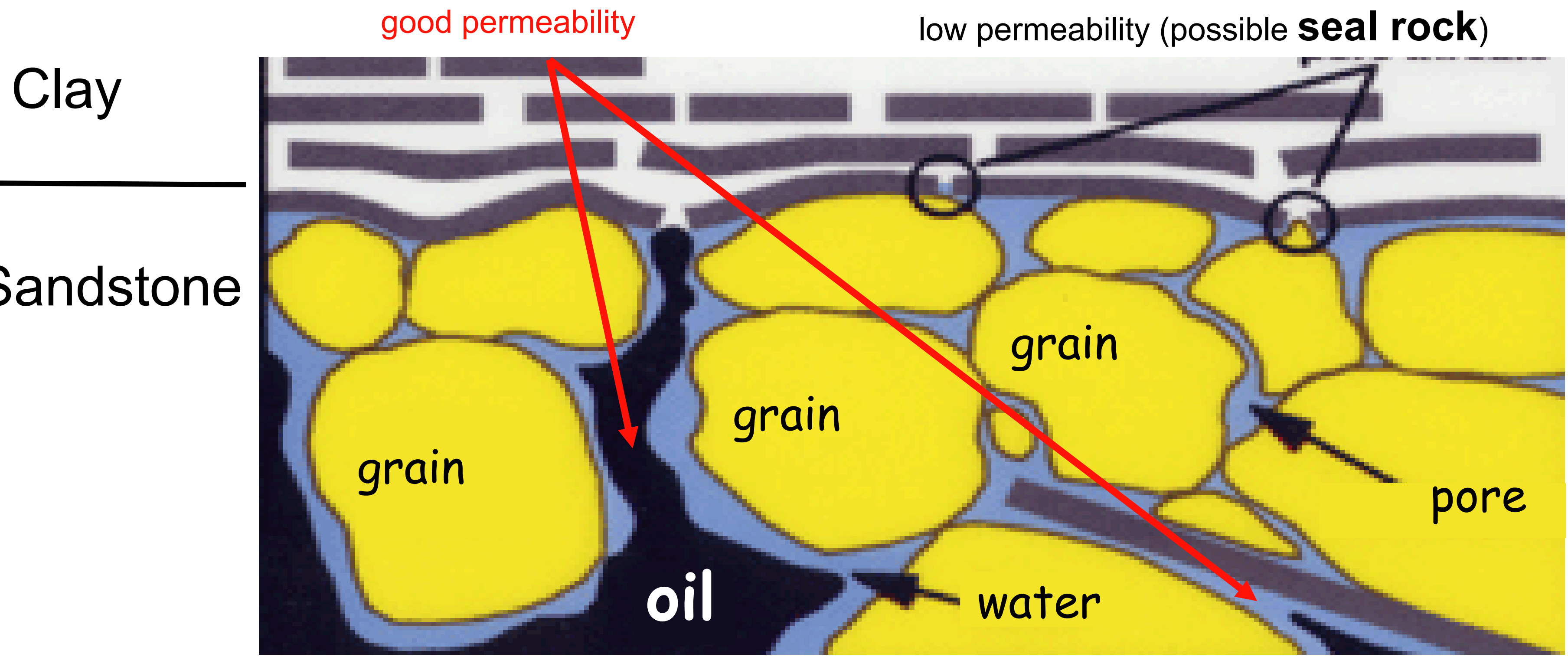
Migration and Accumulation



in the reservoir



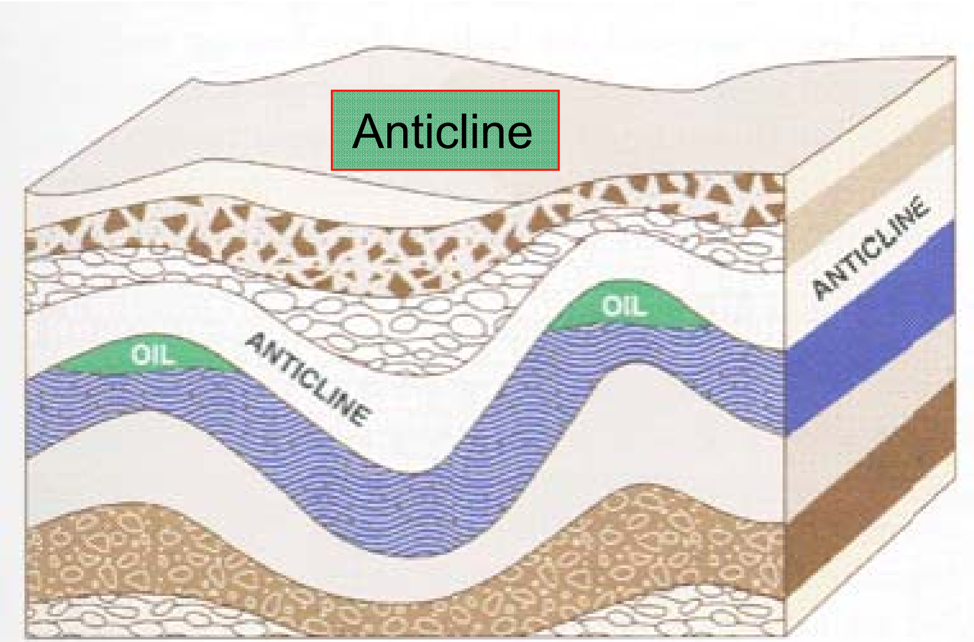
"Clean" sandstone, well sorted and not cemented: a perfect reservoir rock

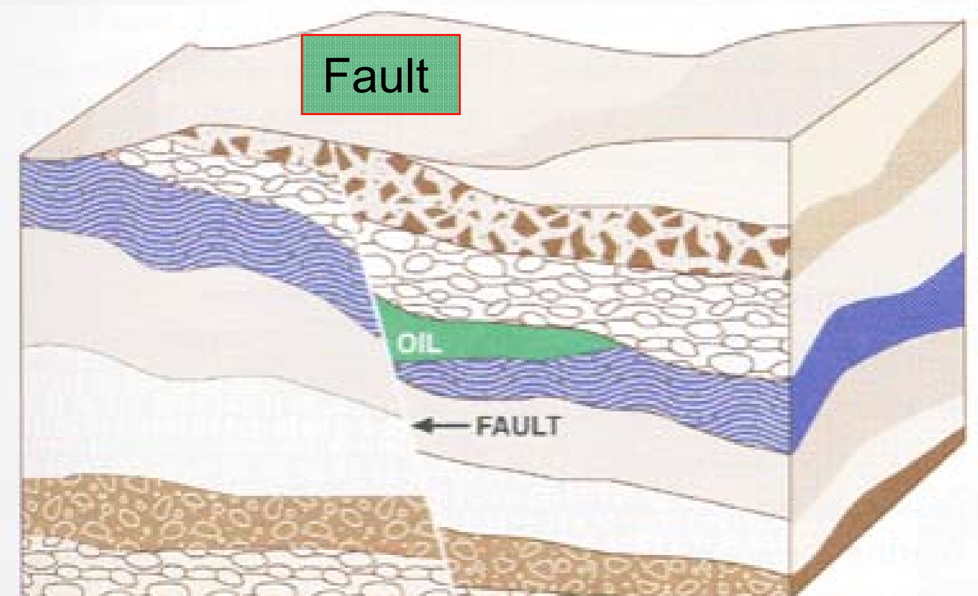

good permeability
low permeability (possible **seal rock**)
Clay
Sandstone
grain
grain
grain
pore
oil
water

Petroleum seep in California

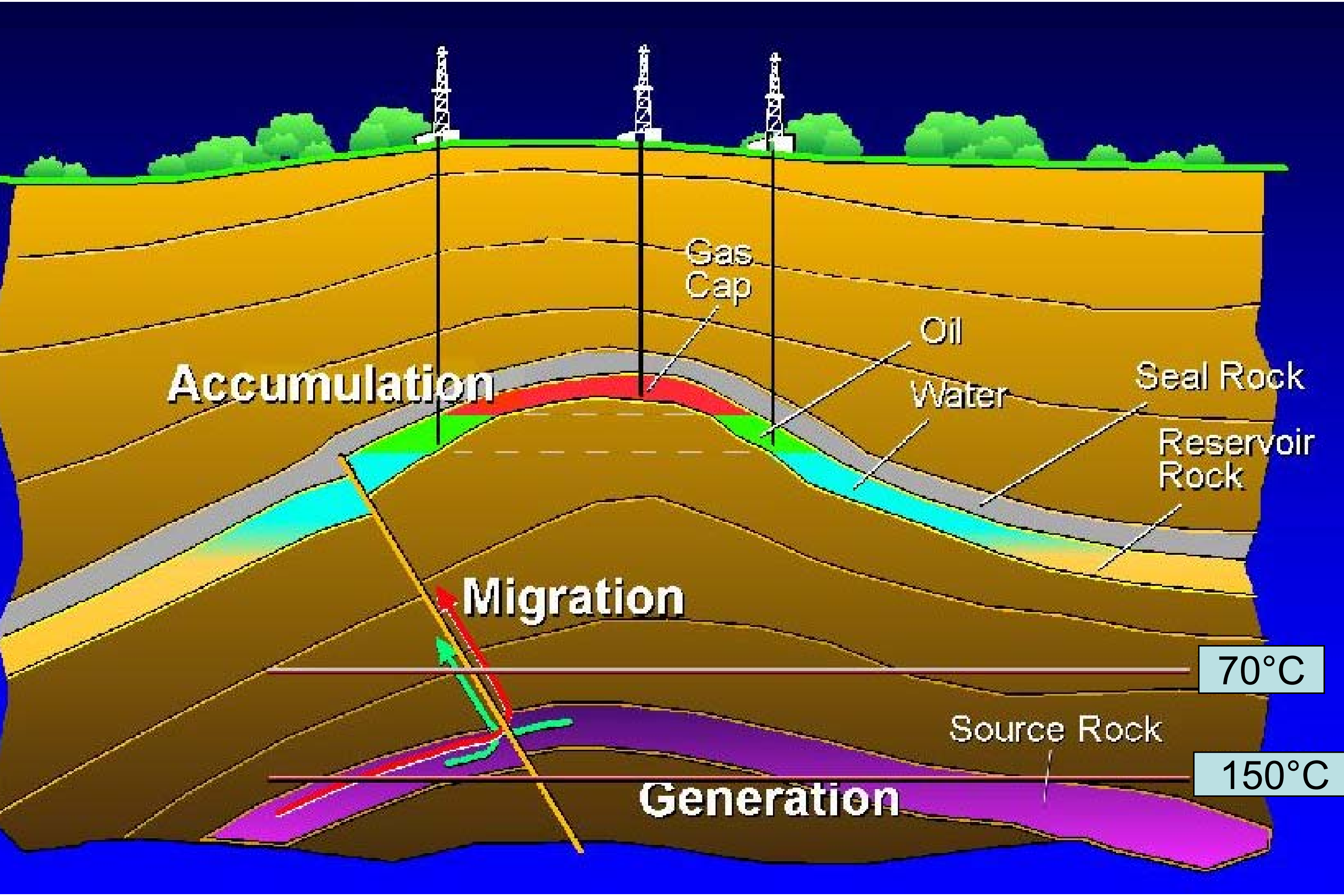
Hydrocarbons pool at Trinidad

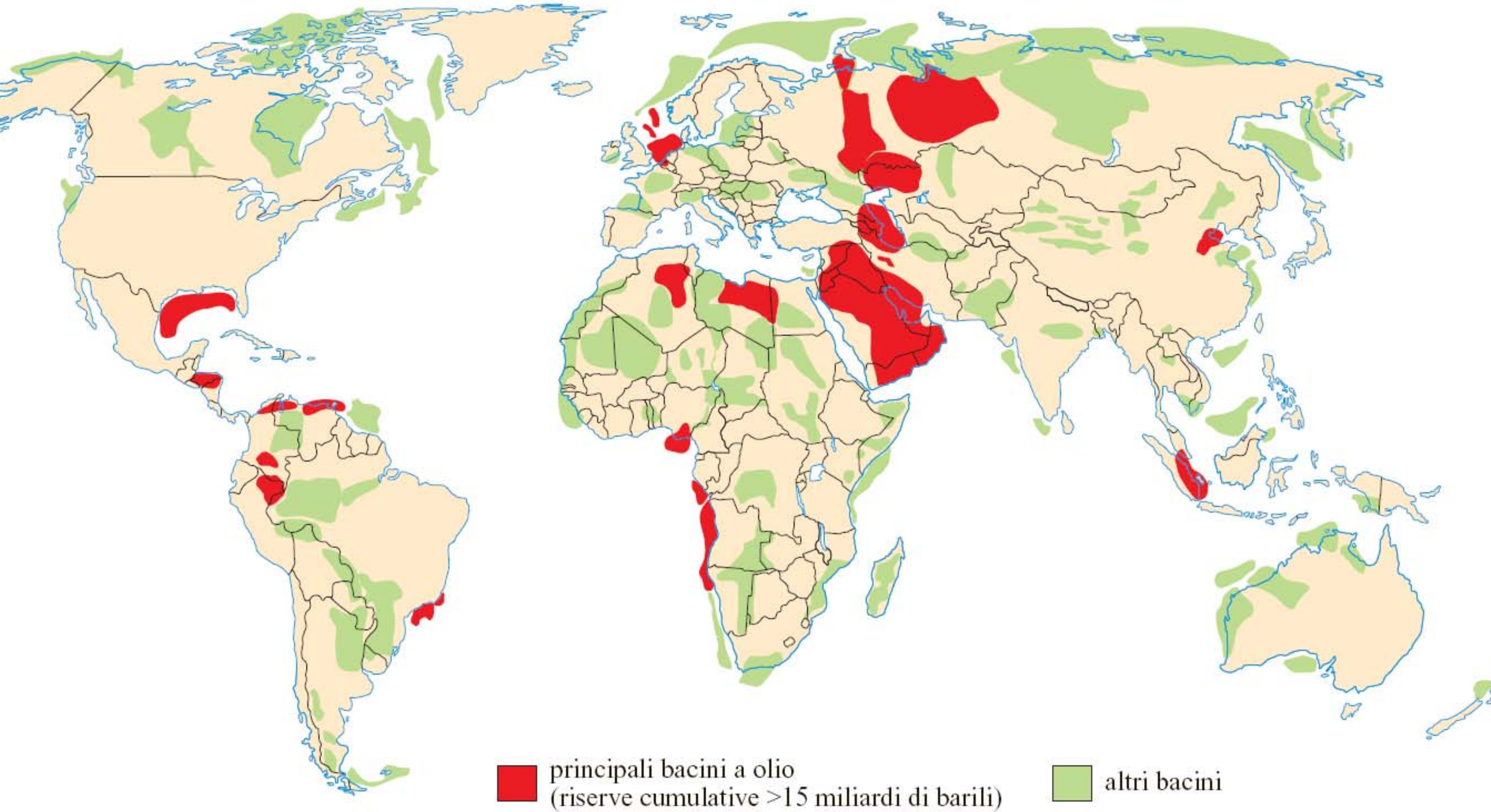
Hydrocarbons Traps





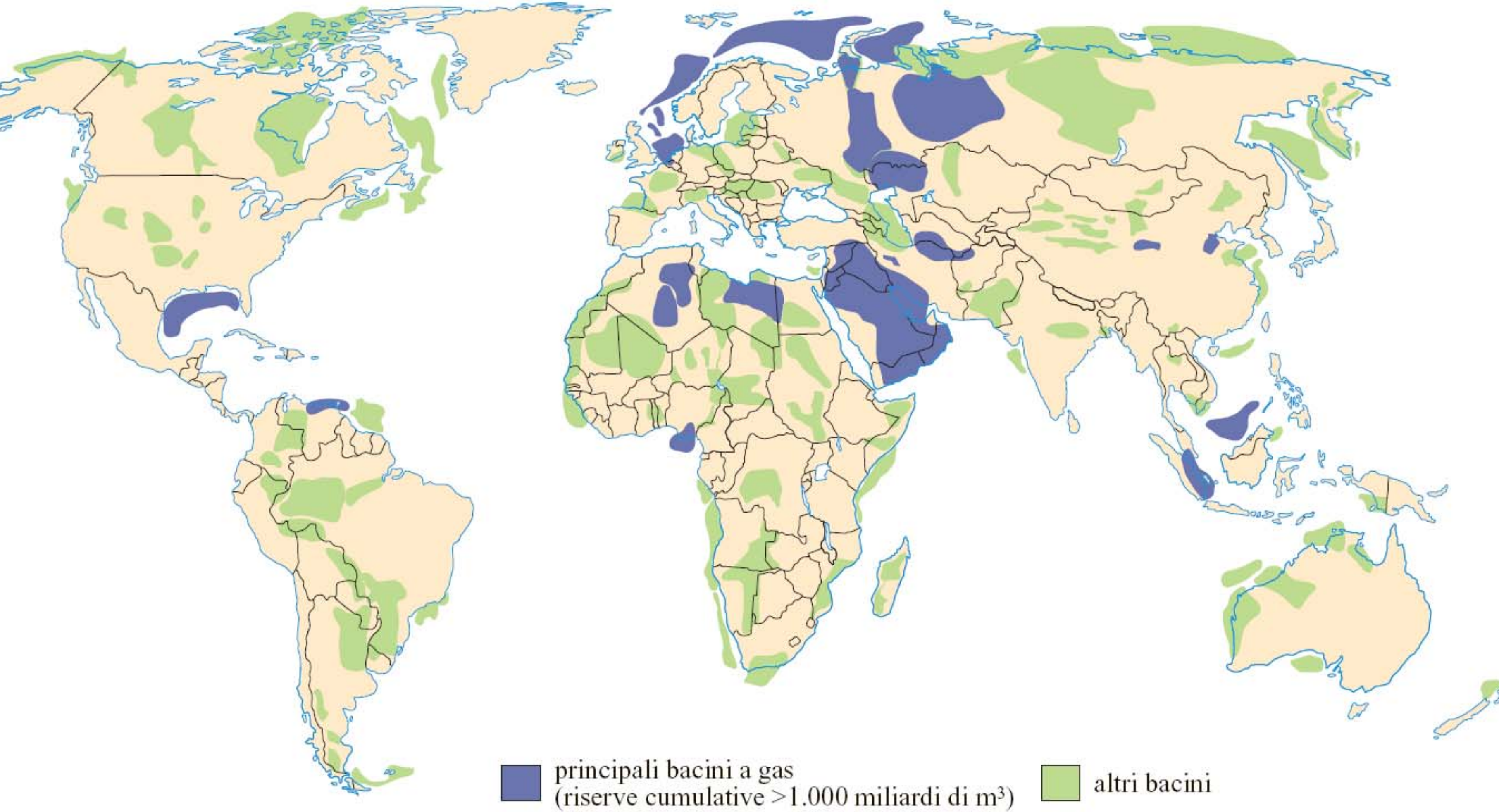
Anticline structures cropping out in Iran


Gas
Cap
Oil
Accumulation
Seal Rock
Water
Reservoir
Rock
Migration
70°C
Source Rock
150°C
Generation



egagiant: > 50 billion barrels (= 6,8 billion t)
upergiant: 5-50 billion barrels
ant: da 0.5-5 billion barrels

Prato, 2005

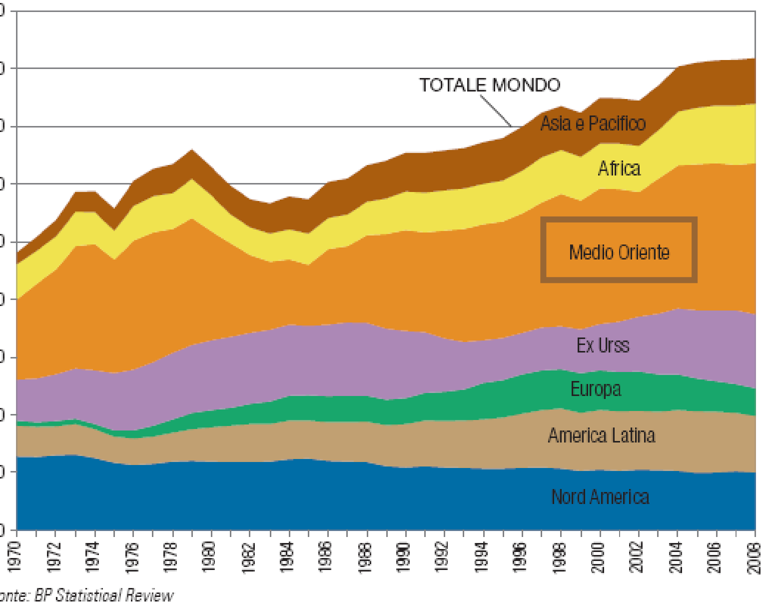


upergiant: > 850 billion m^3
iant: 85-850 billion m^3
ajor: 17-85 billion m^3

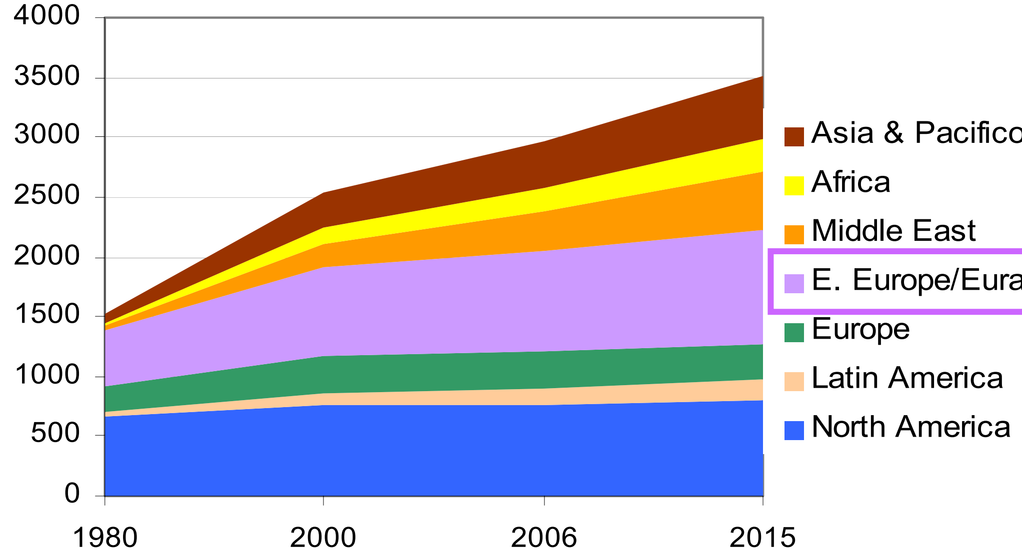
Prato, 2005

World production

oil



gas



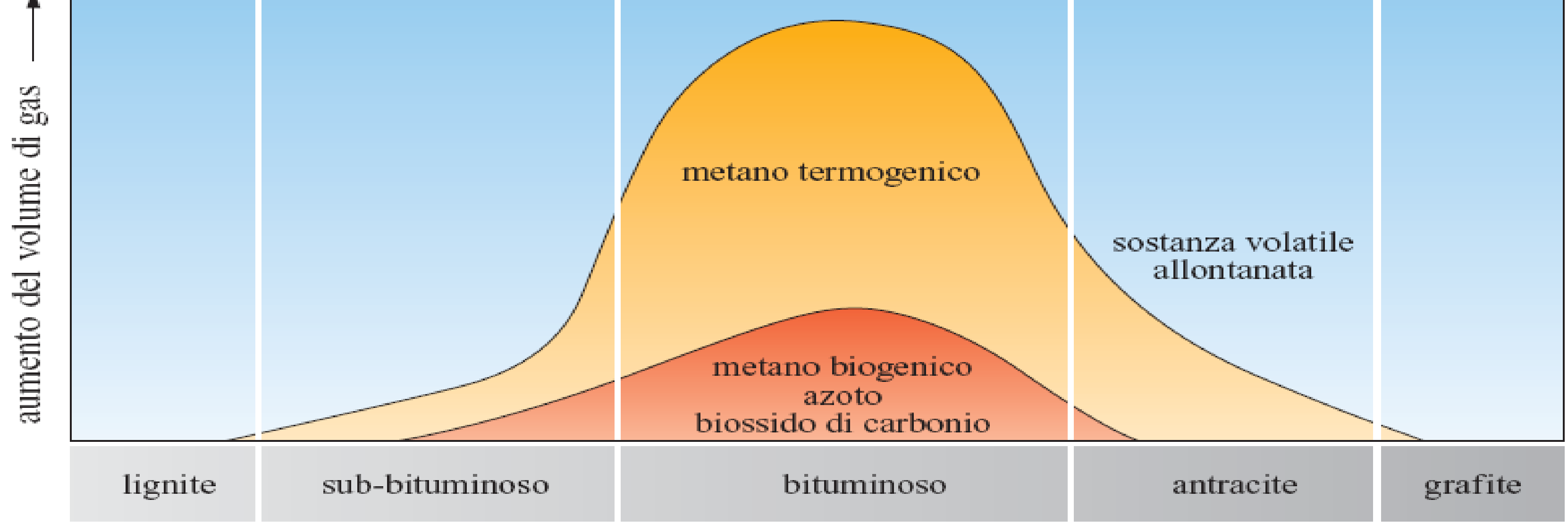
Million barrels/day

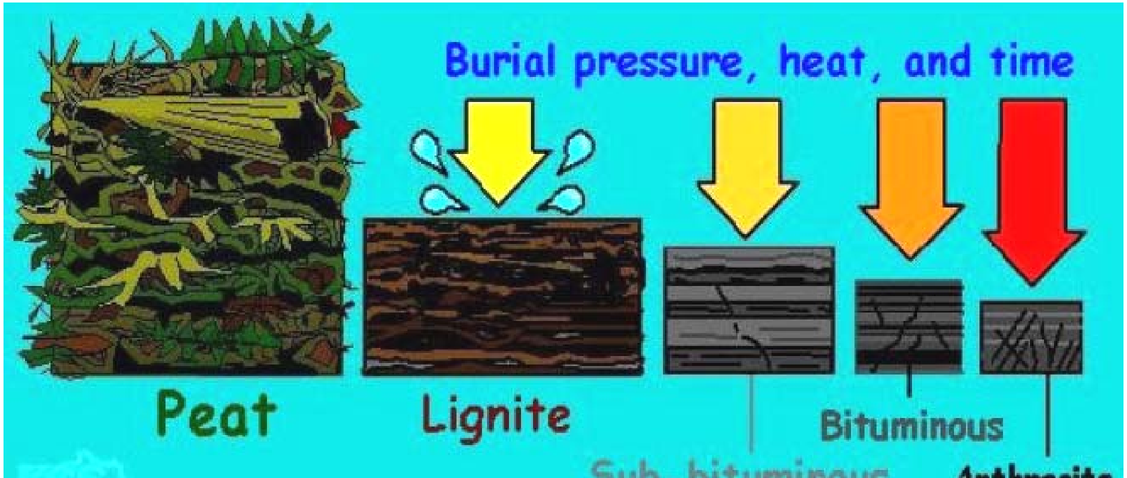
UP data book 2010

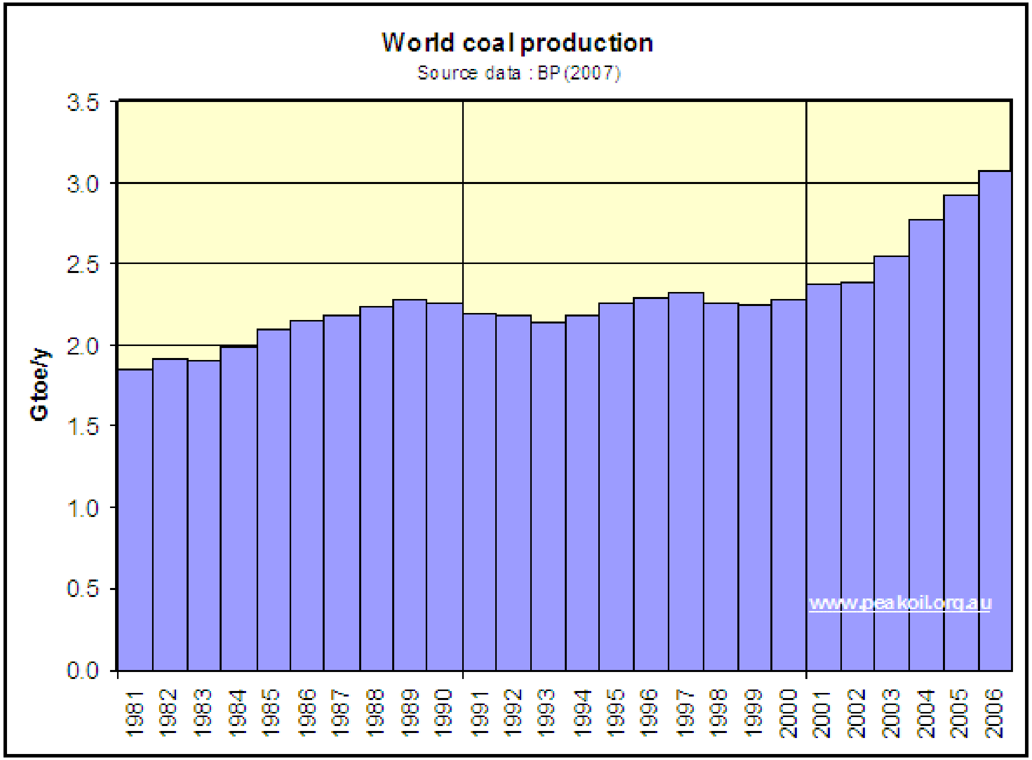
Billion cubic metres

drawn from World Energy Outlook 2008

Absaloko coal mine, Montana

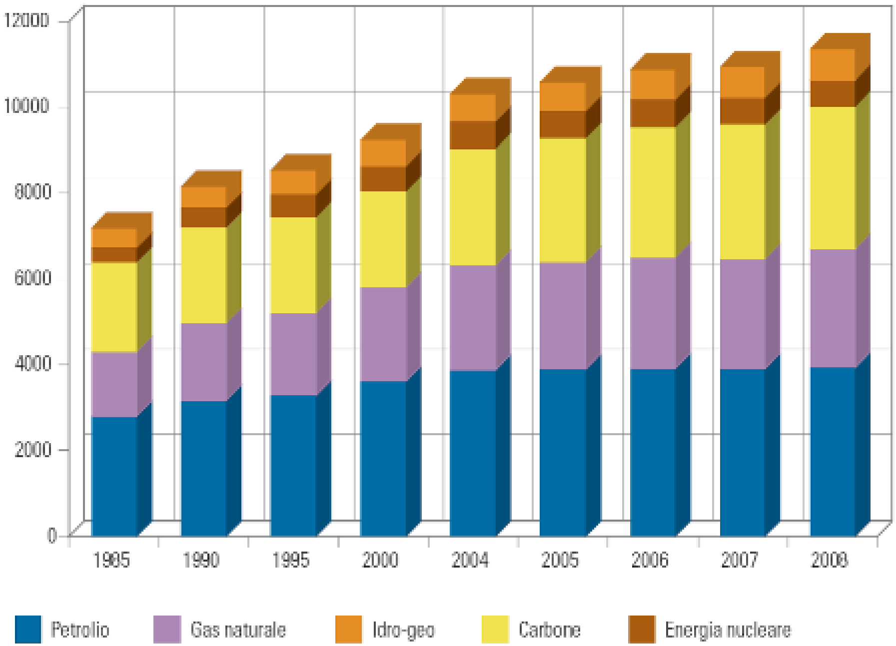

aumento del volume di gas
metano termogenico
sostanza volatile
allontanata
metano biogenico
azoto
biossido di carbonio
lignite
sub-bituminoso
bituminoso
antracite
grafite


Burial pressure, heat, and time
Peat
Lignite
Bituminous



Anderson et al., 200

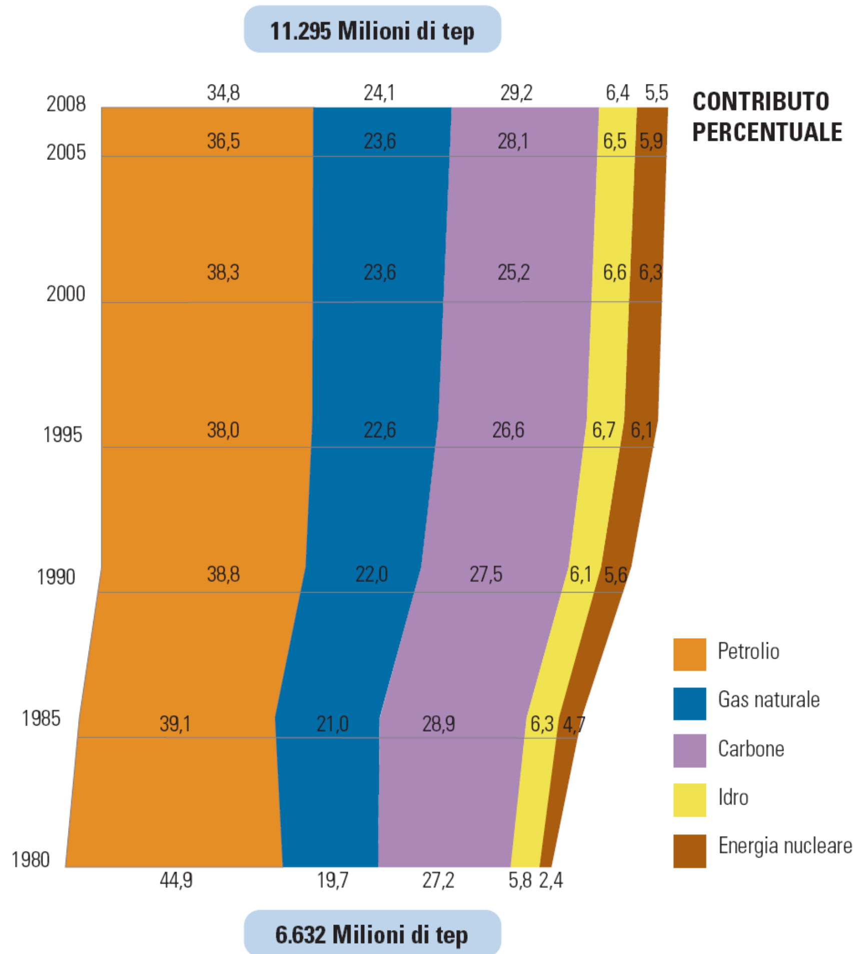
The overall consumption



Fonte: BP Statistical Review

2008: ~11.3 milions toe

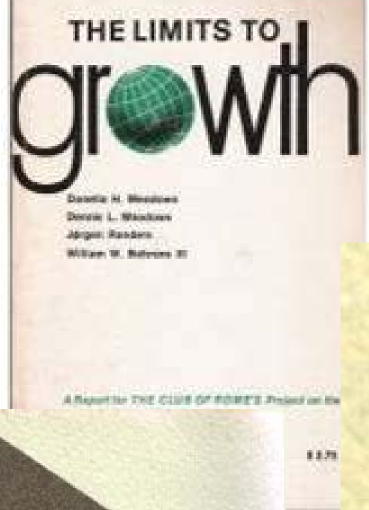
CONTRIBUTO DELLE VARIE FONTI AL CONSUMO ENERGETICO MONDIALE

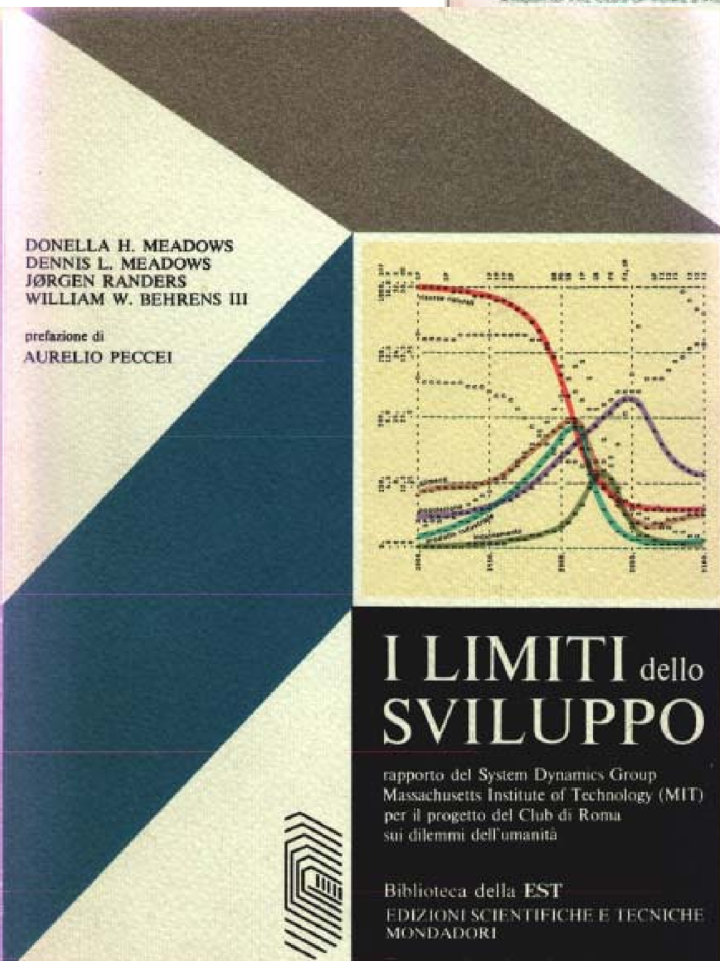


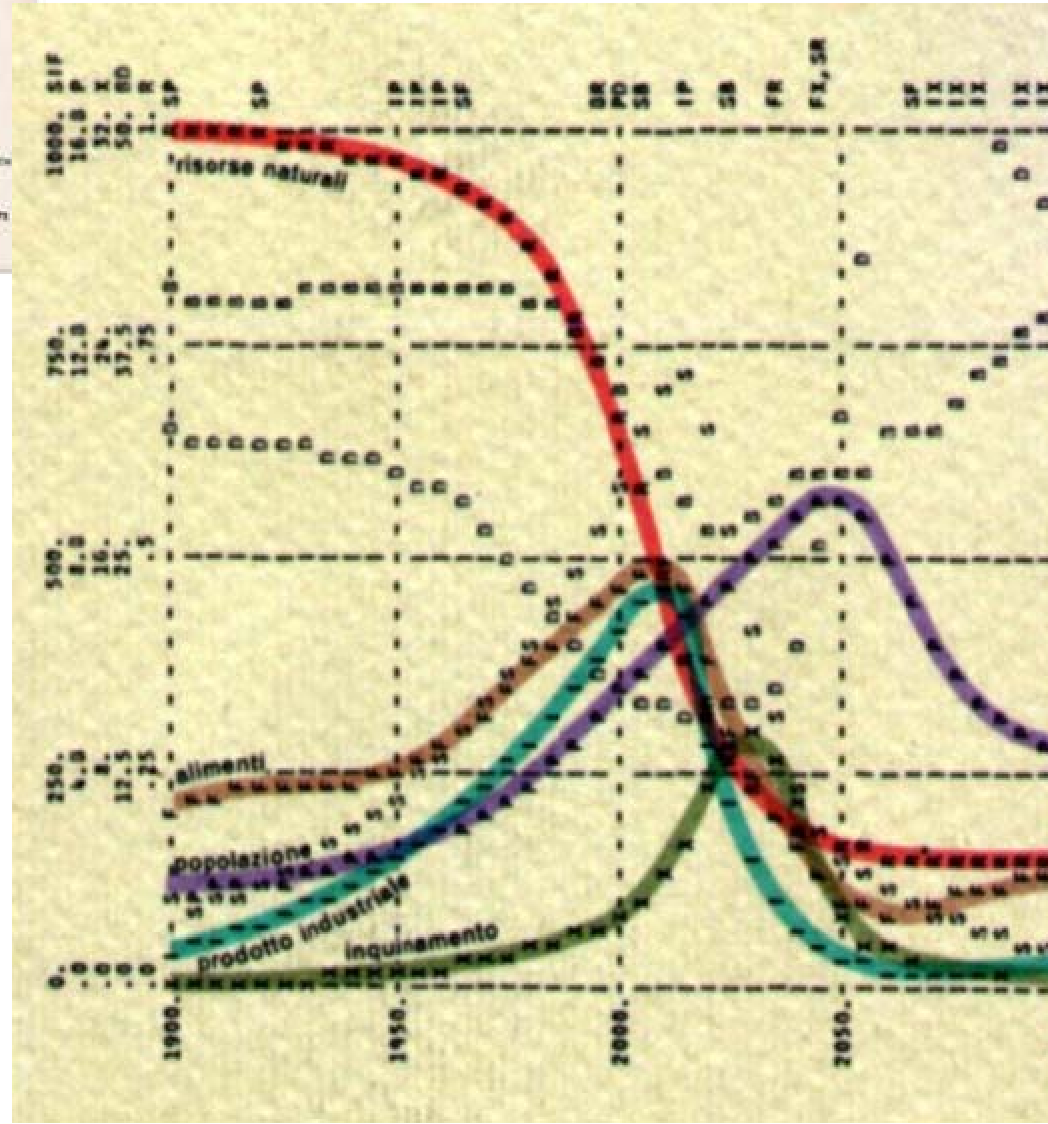
…: BP Statistical Review

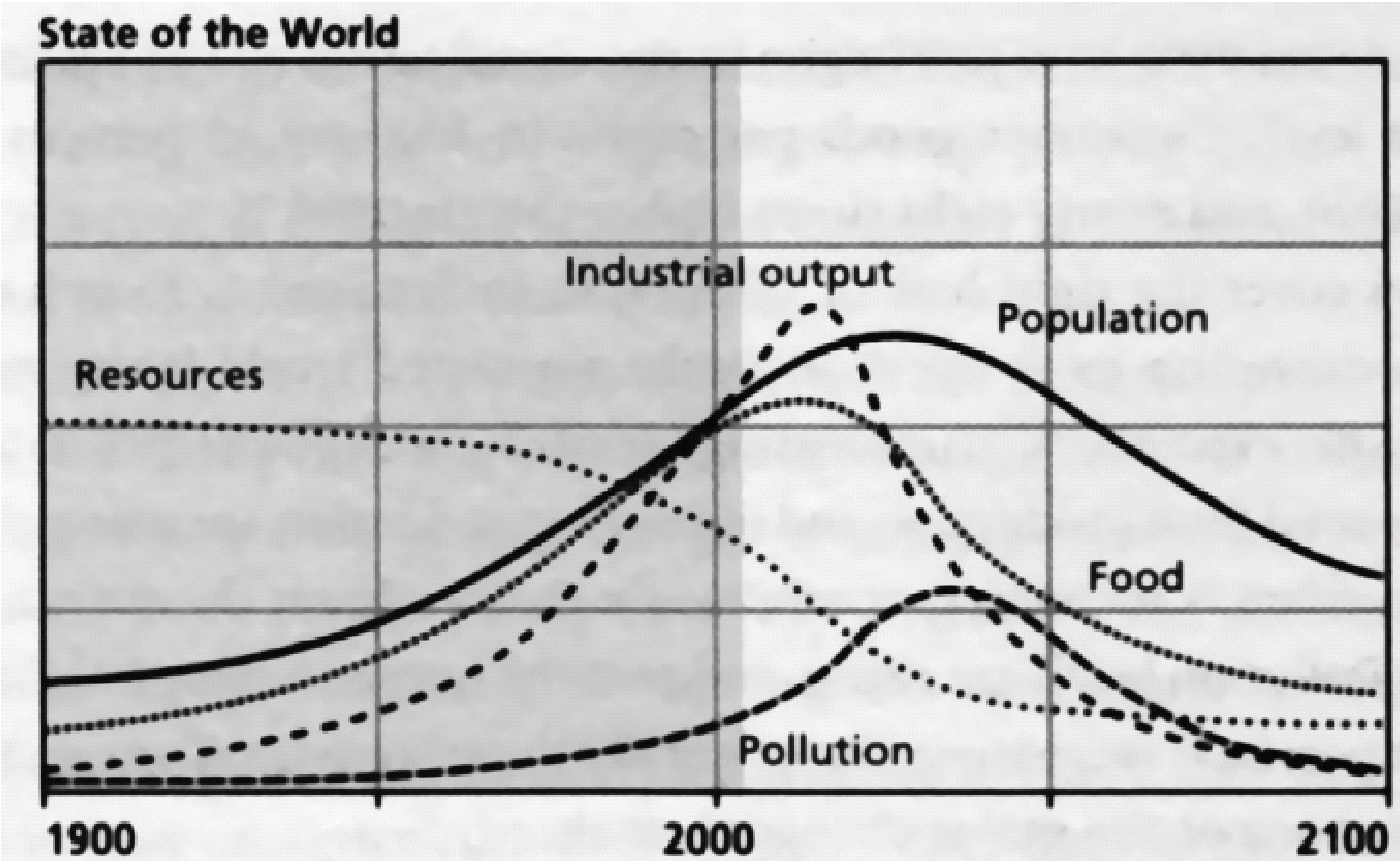
What are the **reserves**?

1972: Club di Roma: "The limits to growth"

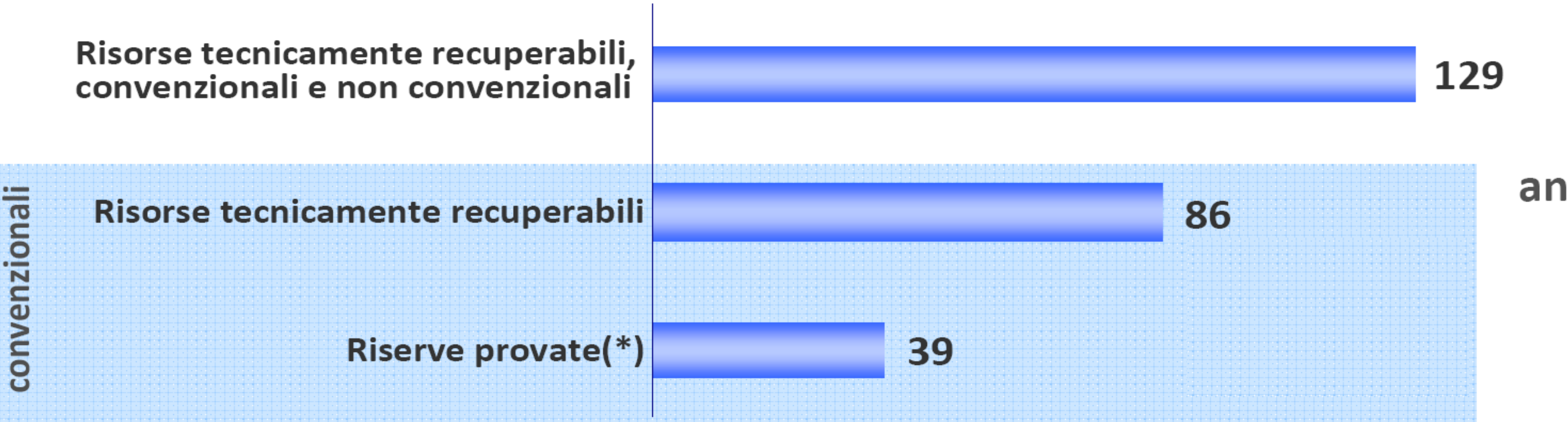


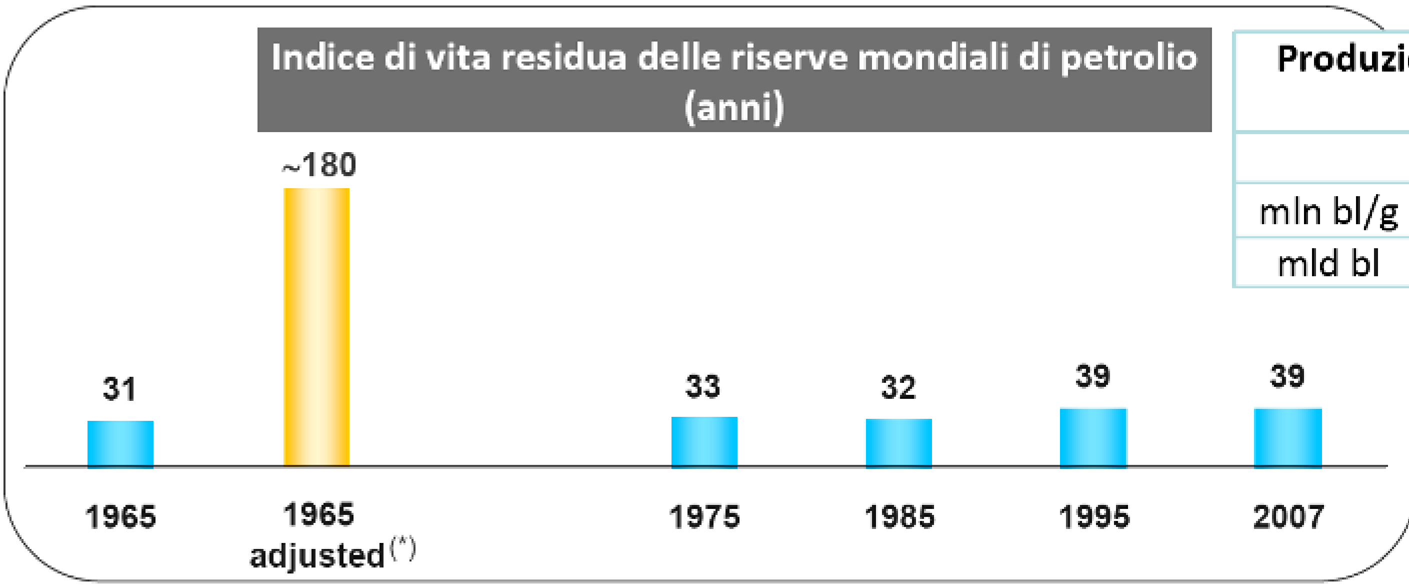





State of the World
Industrial output
Population
Resources
Food
Pollution
1900
2000
2100

Reserves estimates: Oil





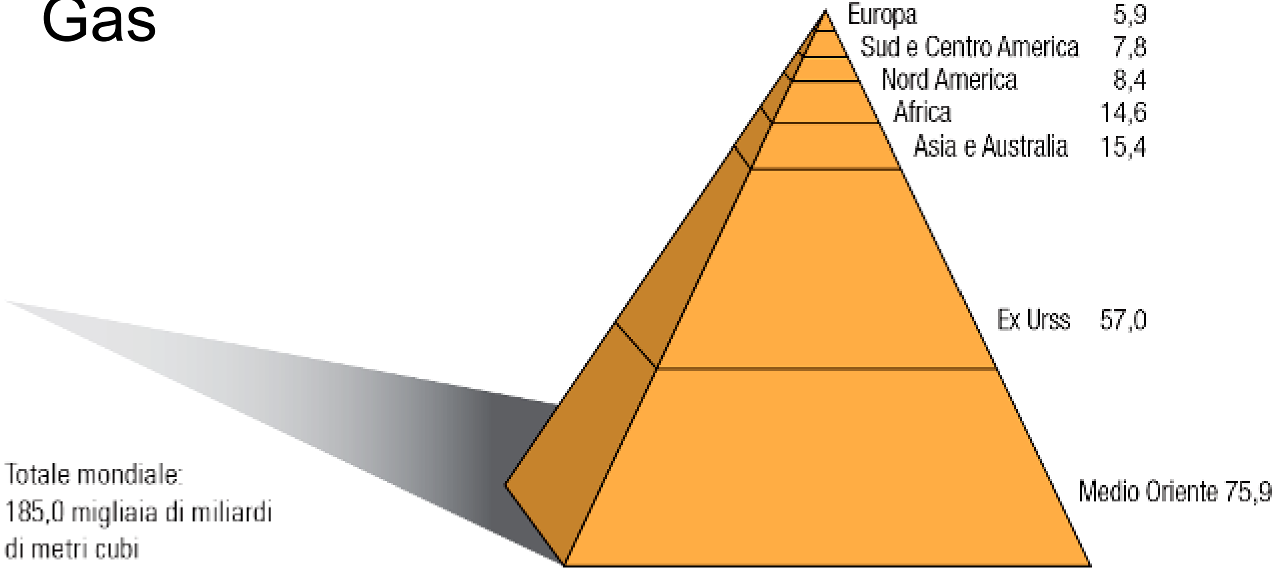
Produzione mondiale di petrolio		
	1965	2007
mln bl/g	32	83
mld bl	12	31

(*) Calcolato sommando alle riserve di fine 2007 la produzione cumulata dal 1966 a oggi

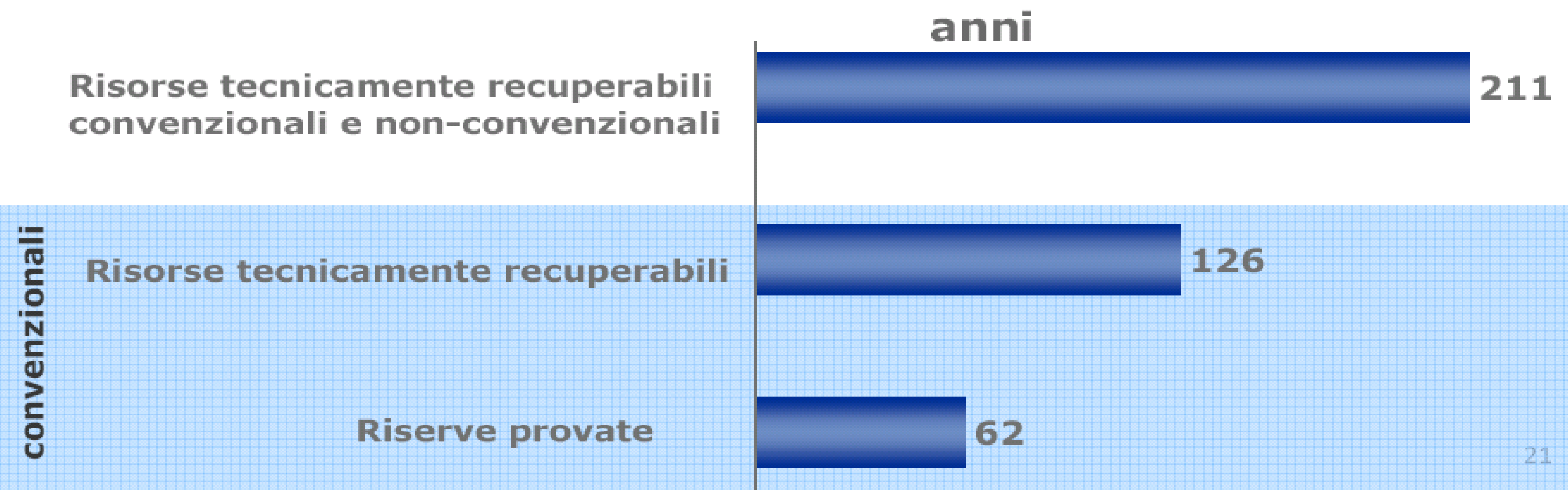
mod. da Pino 2010

Gas

da UP data book 2010



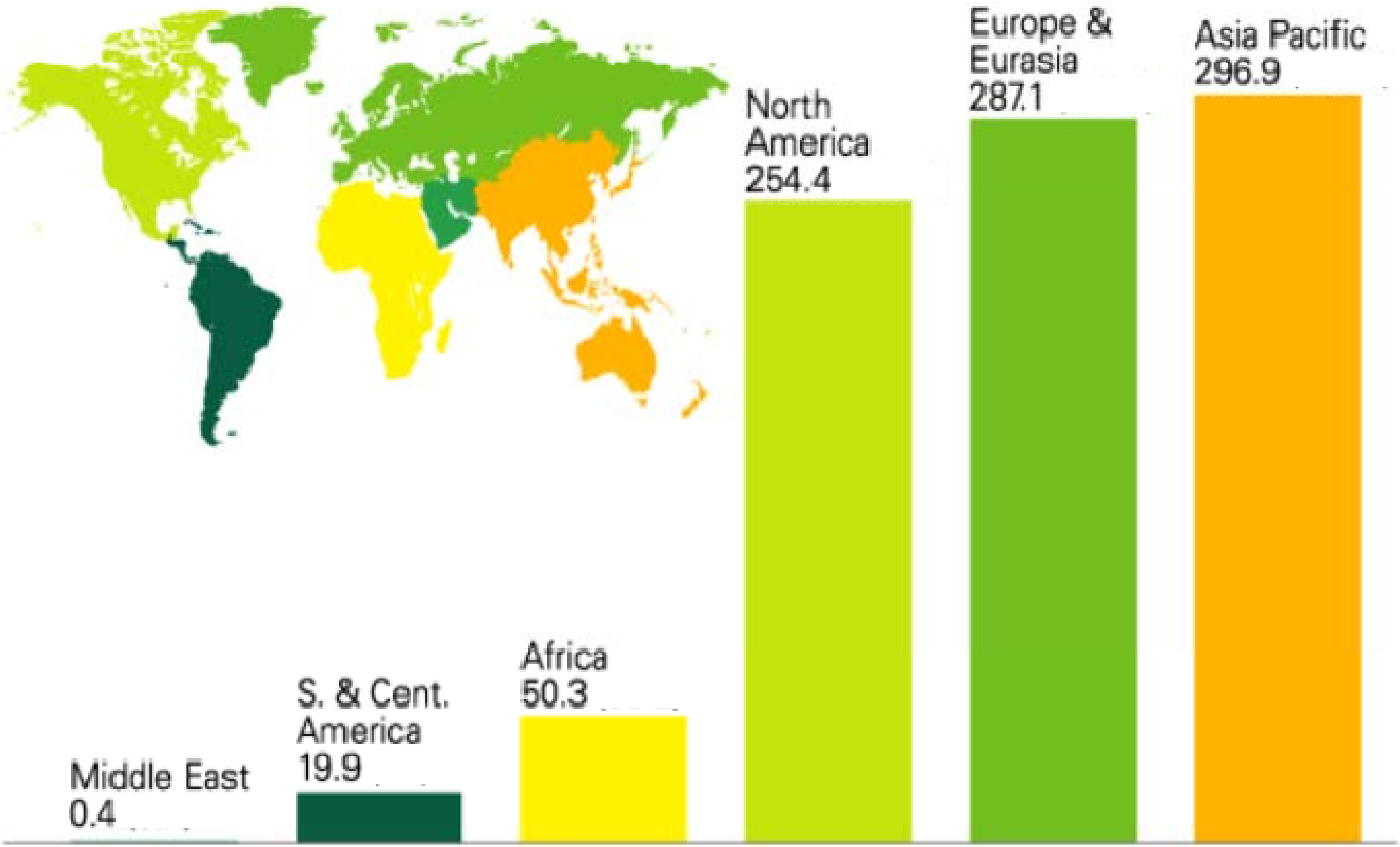
Fonte: BP Statistical Review



Proven reserves ~180 trillion cubic metres. Three countries – Russia, Iran, Qatar - hold 56%

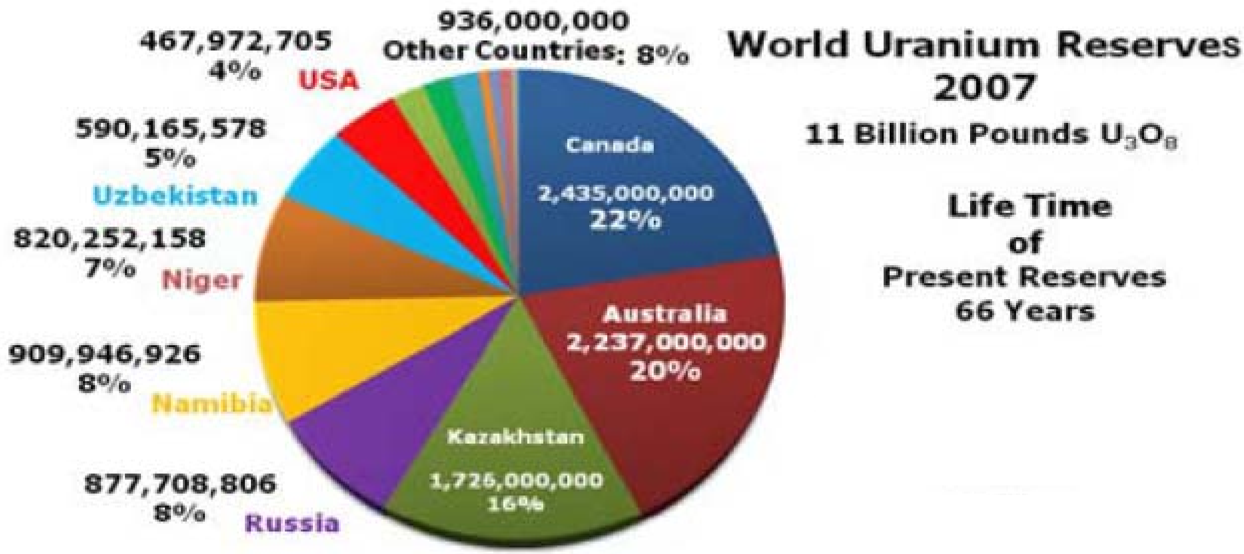
Coal

Reserves ~ 220 years



$t \cdot 10^9$

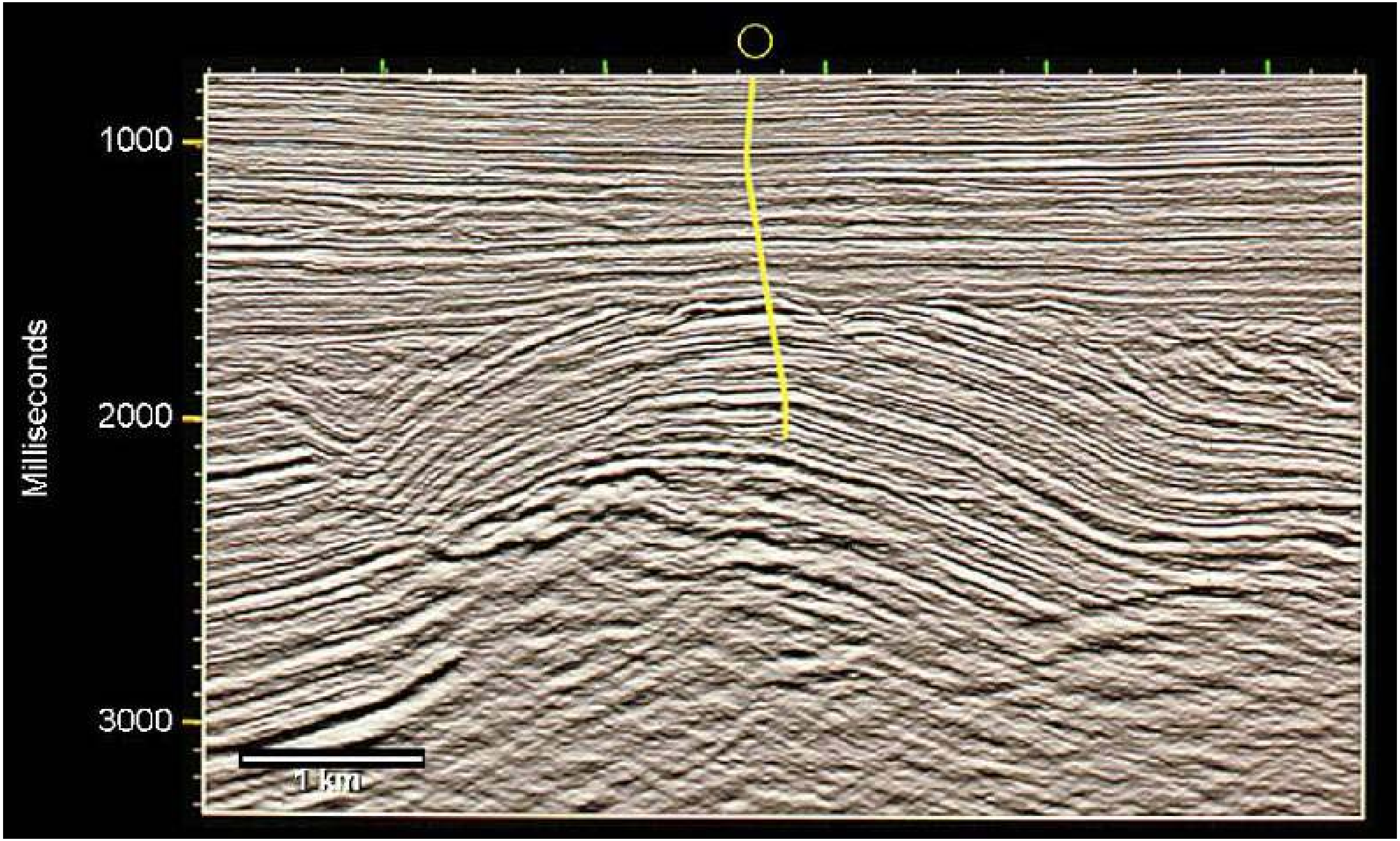
data 2009 mod. from Energy & Resourse Institu



IAEA, www. iaea.org

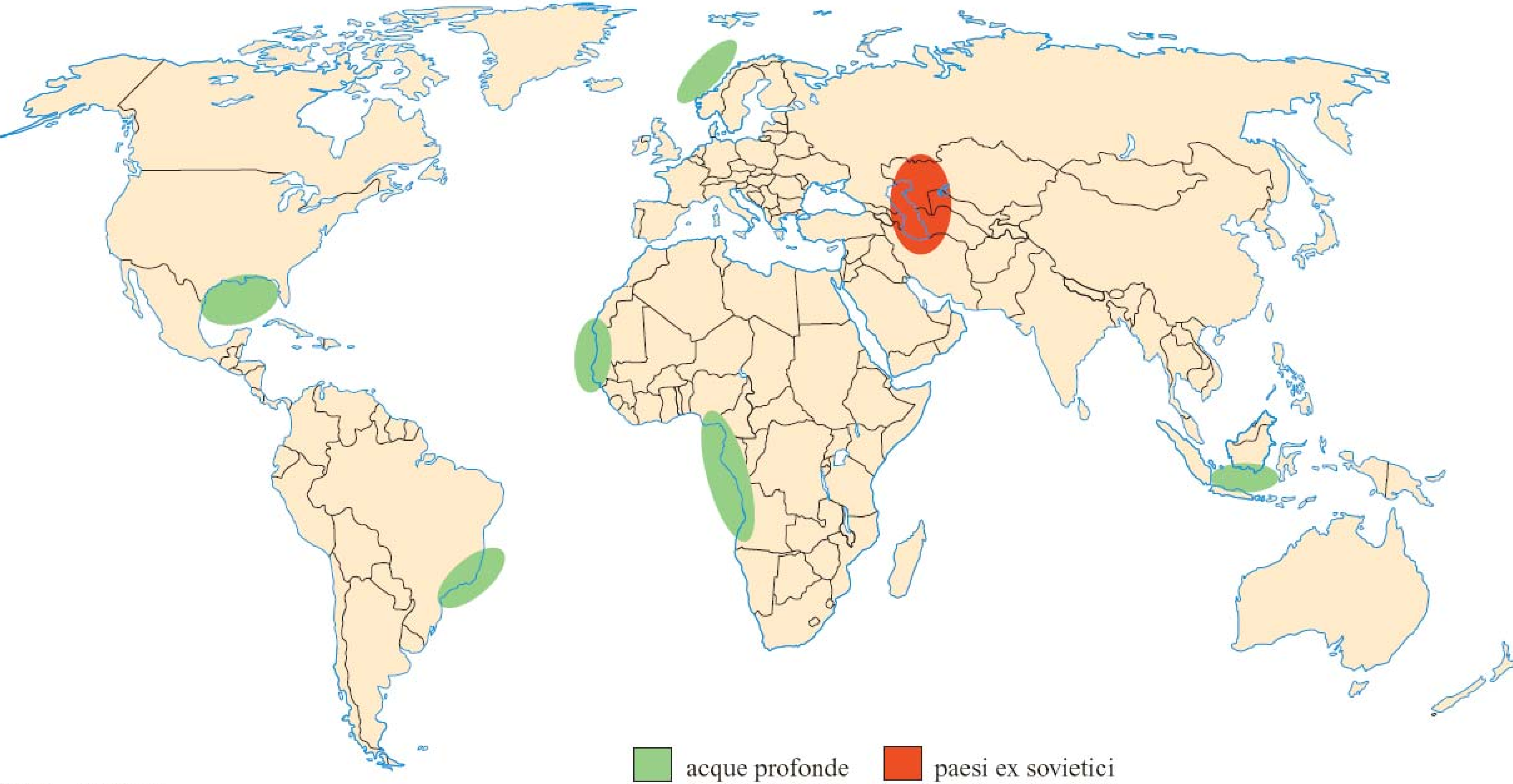
What has changed?

Strong improvements in resource sciences and technology



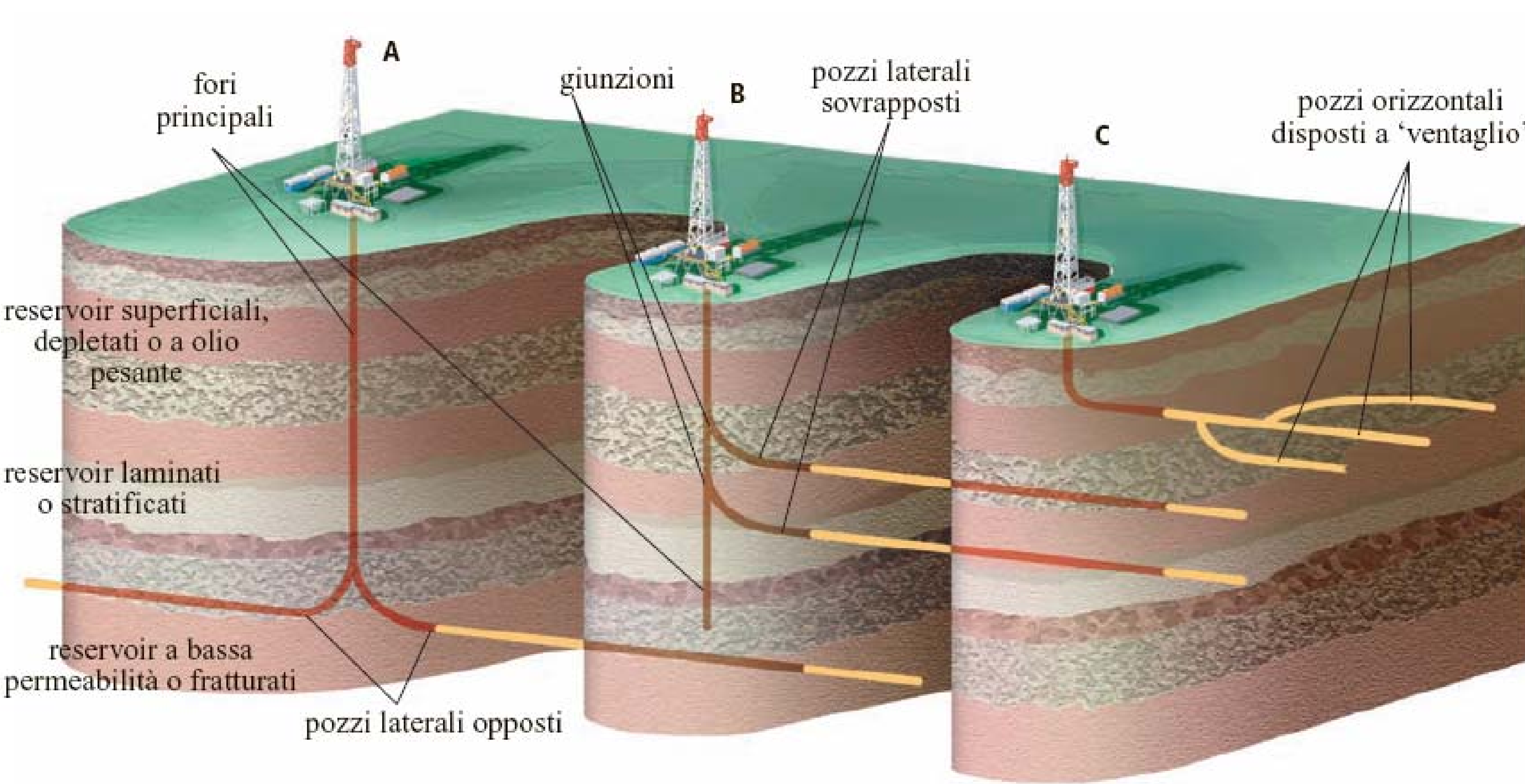
Buried anticline in a seismic reflection image

New AREAS



Prato, 2005

Improvements in drilling techniques
(e.g., directional drilling techniques)



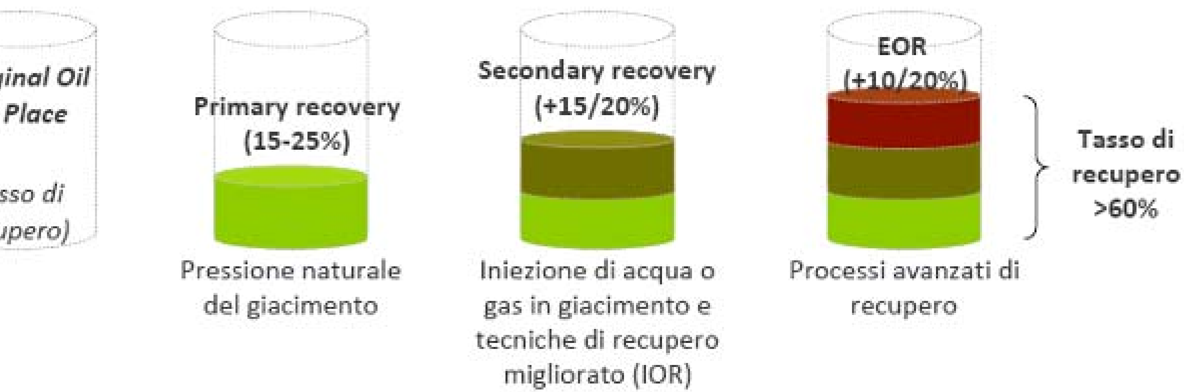
da Fraija et al., 2002

Techniques of

Improved Oil Recovery

and

Enhanced Oil Recovery



now avg. recovery 30-35%

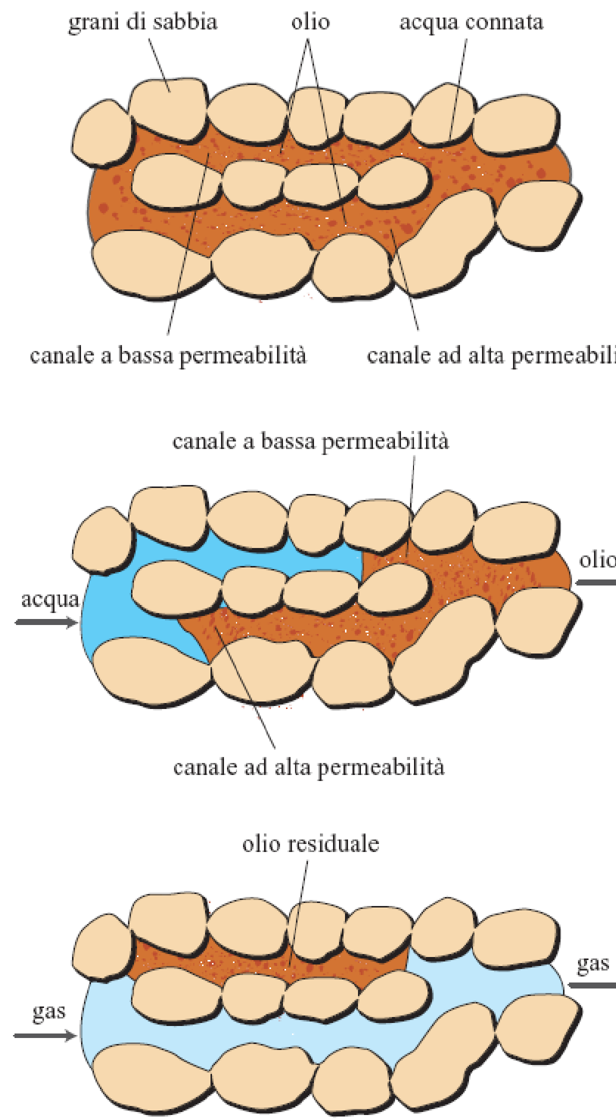
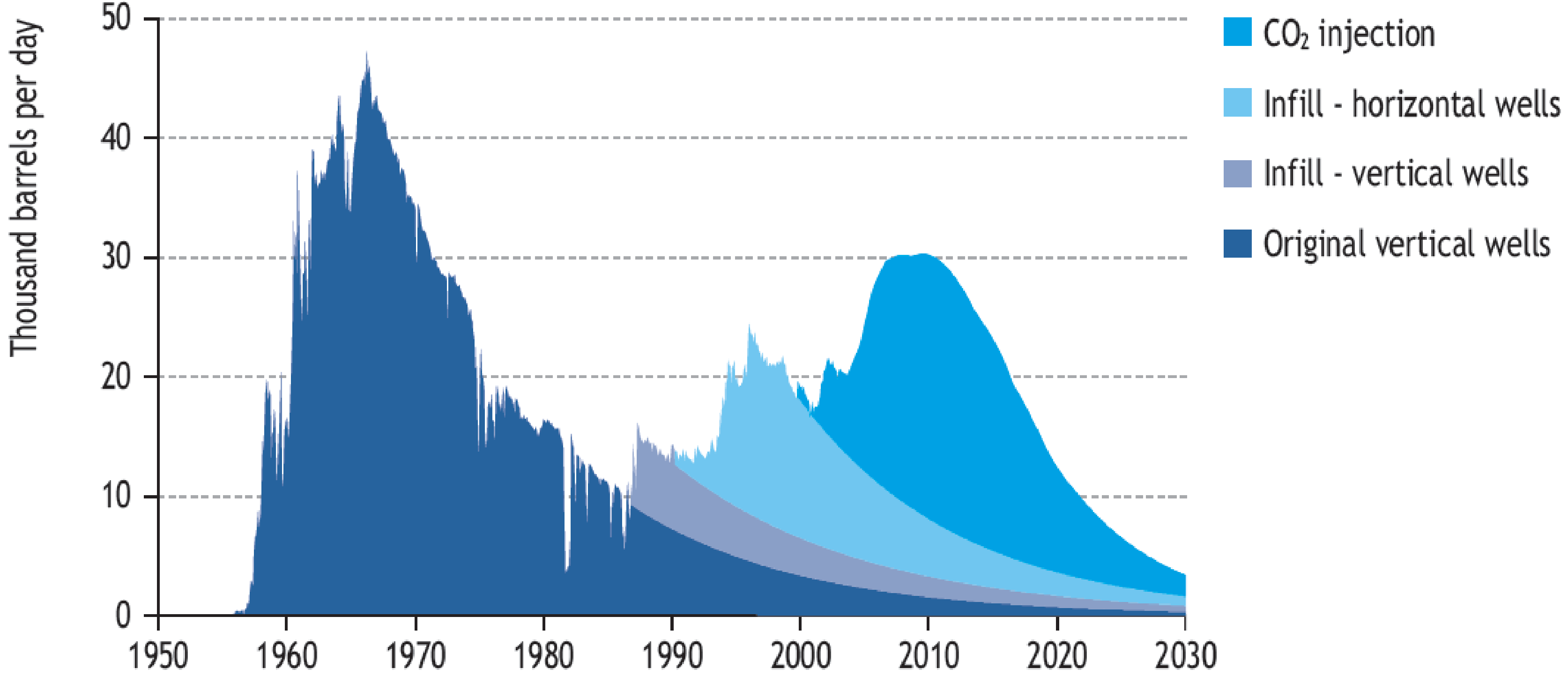


fig. 11. Spiazzamento degli idrocarburi alla scala dei pori della roccia serbatoio.

A case study of oil reserves growth: the impact of technology on oil production from the Weyburn field in Canada



Source: PTRC Weyburn-Midale website (www.ptrc.ca).

World Energy Outlook 2008

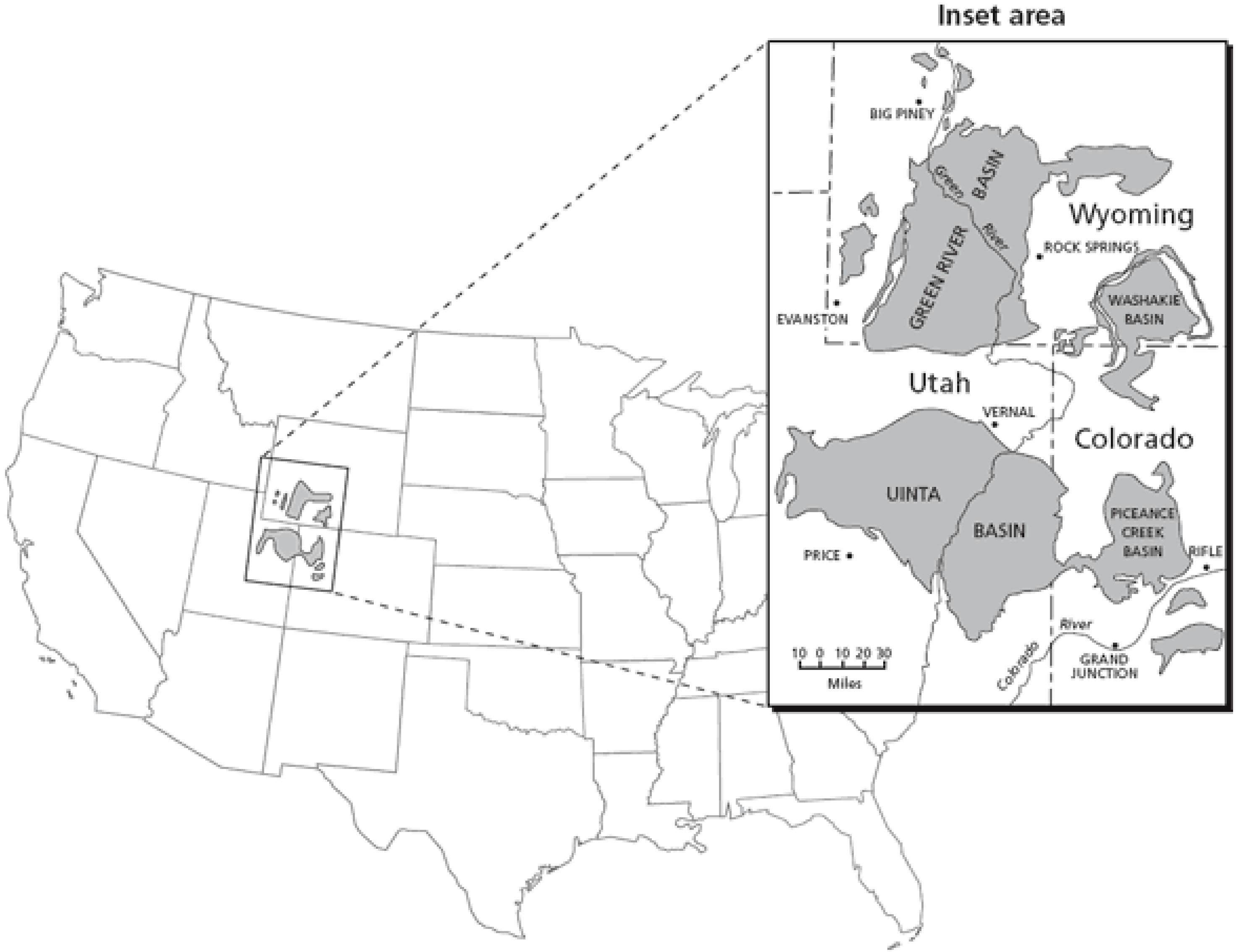
non conventional resources


Oil shales

Oil shale immature source rock

Oil Shale = fine-grained sedimentary rock (slate) strongly enriched in kerogen, which can produce hydrocarbons when heated

Location of the Green River Formation Oil Shale and Its Main Basins

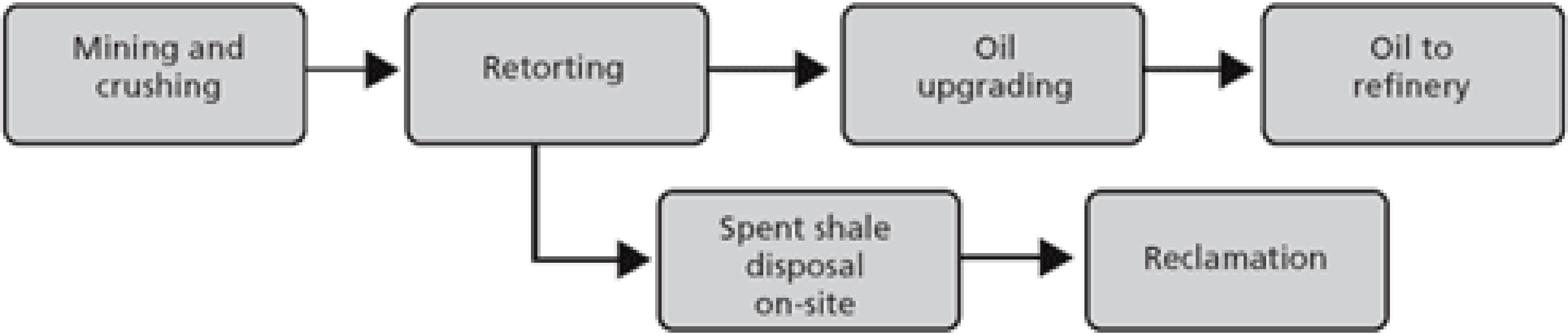


SOURCE: Adapted from Smith, 1980.

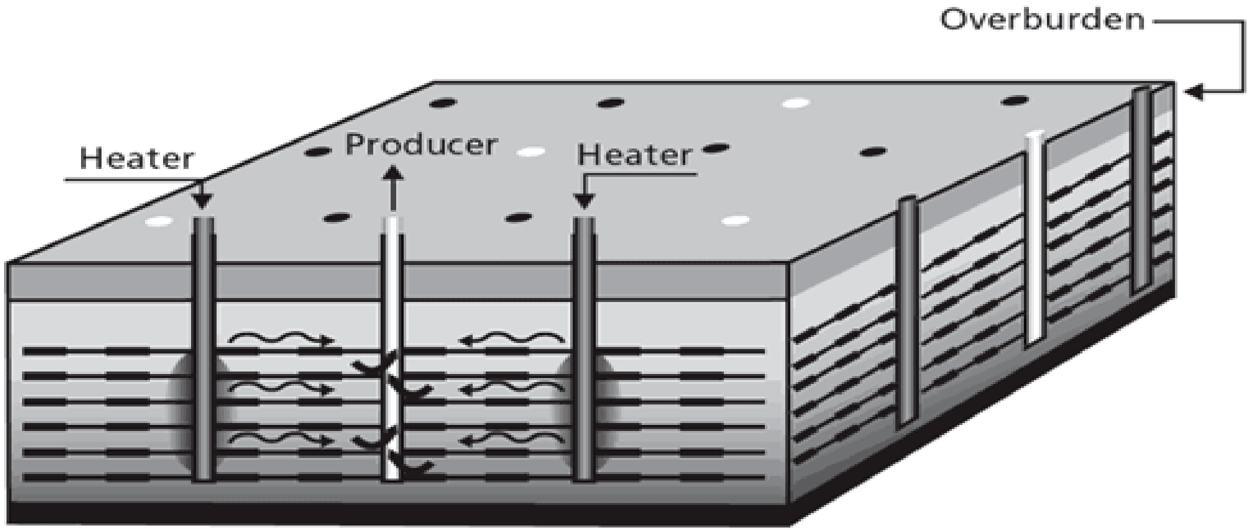
RAND *MG414-2.1*

Oil shale crushed for the retorting process

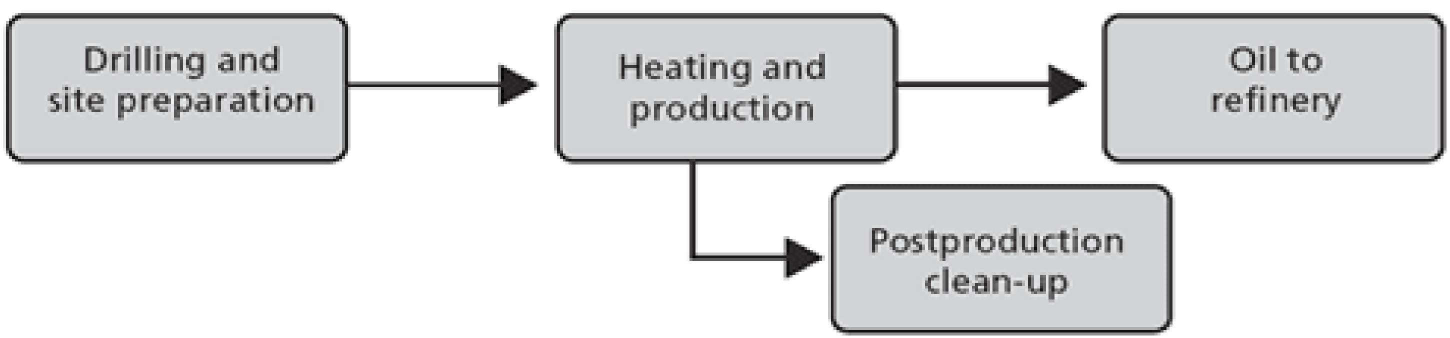
Major Process Steps in Mining and Surface Retorting

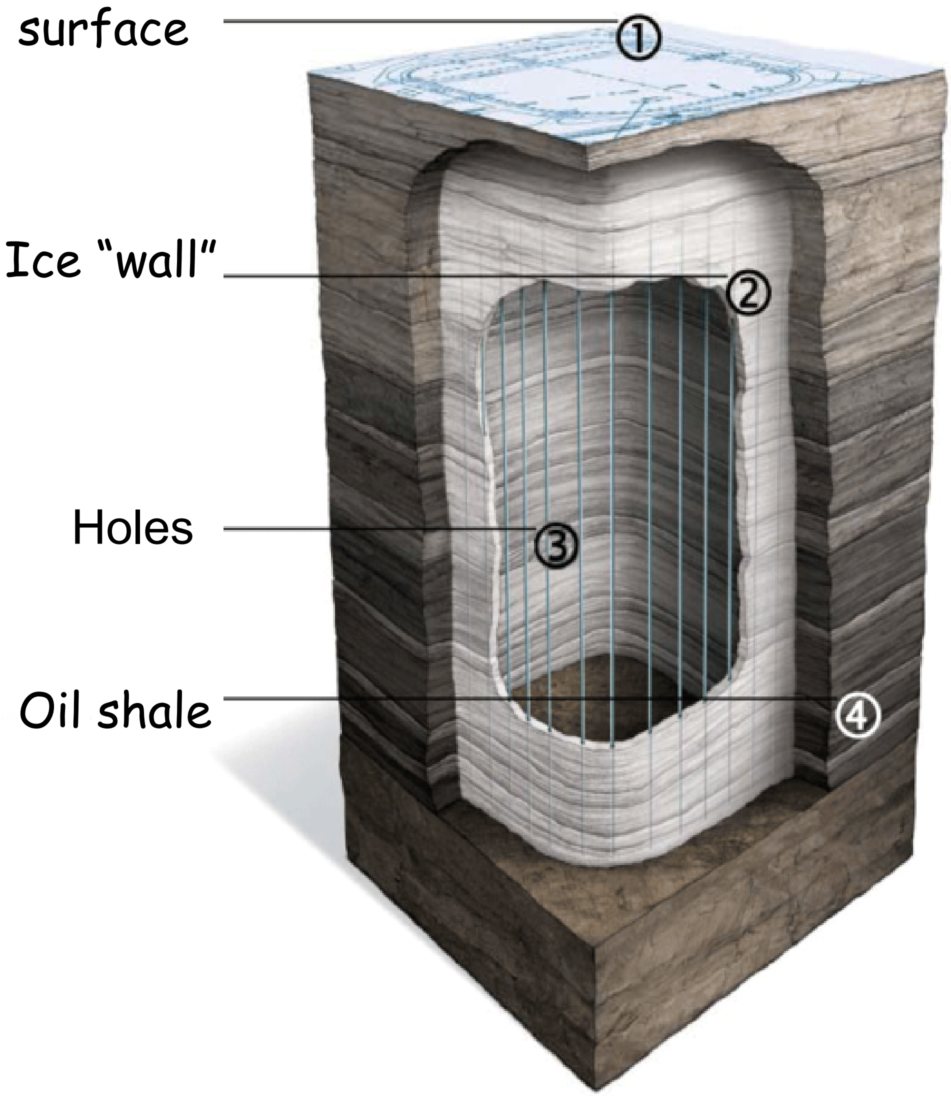


The Shell In-Situ Conversion Process



Major Process Steps in Thermally Conductive In-Situ Conversion

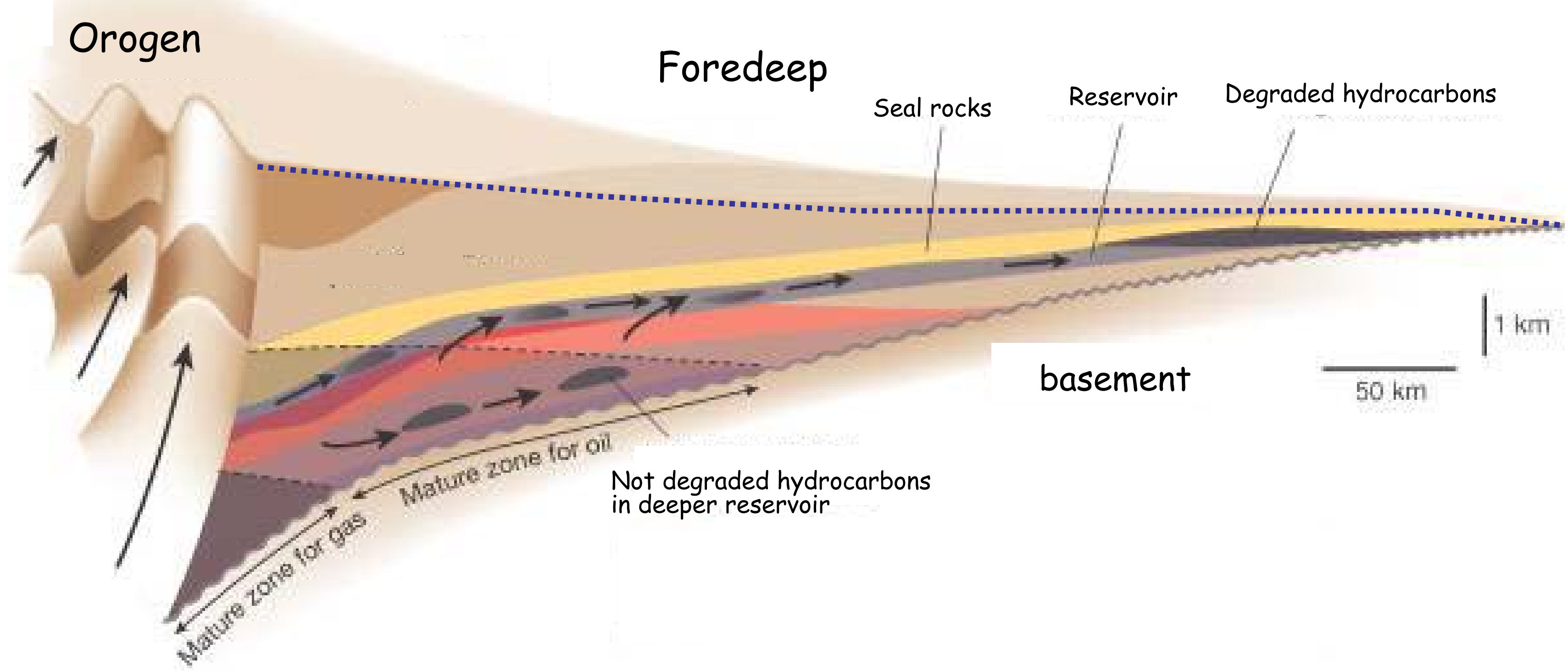




Before heating and exploitation groundwater is eliminated by creating an “ice wall”

oil:	extra heavy oil / bitumen high viscosity high sulphur content
Main problem:	low permeability of the shale

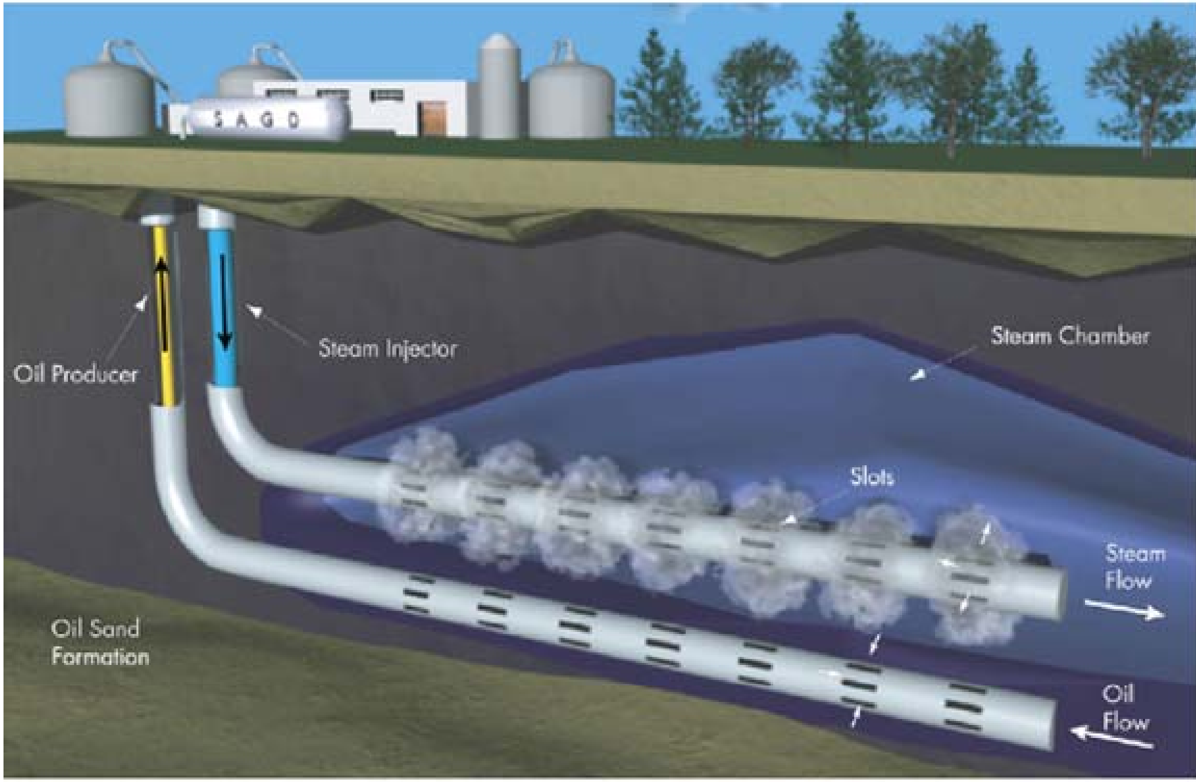

Tar sands: reservoir rocks close to surface


Orogen
Foredeep
Seal rocks
Reservoir
Degraded hydrocarbons
1 km
basement
50 km
Mature zone for oil
Not degraded hydrocarbons
in deeper reservoir
Mature zone for gas

oil: extra heavy oil / bitumen
high viscosity
high sulphur content

Tar sands: >3 $\cdot 10^{12}$ barrels

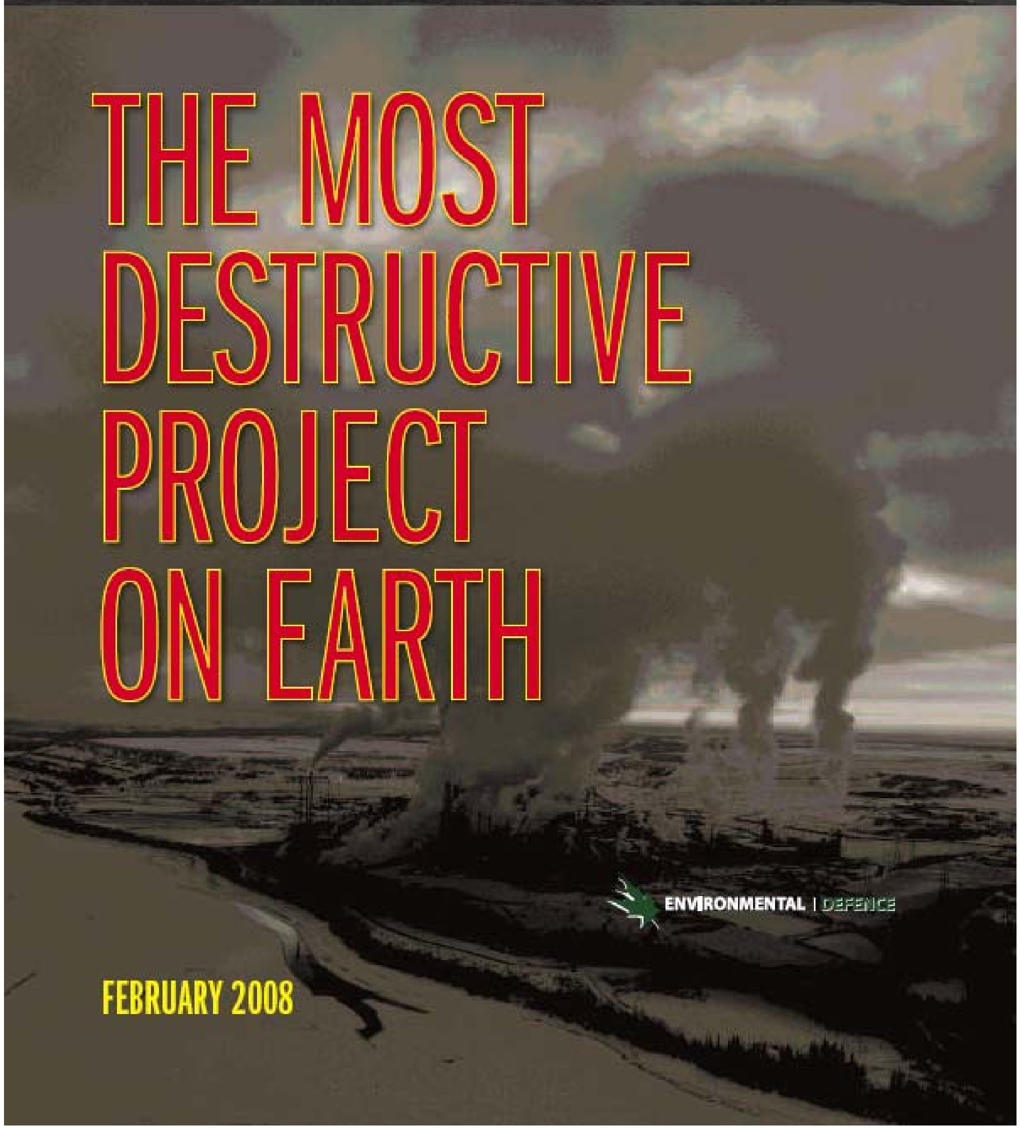
Strip mining



In situ exploitation:
- vapour injection
- solvents injection
- injection of oxygen and in situ combustion with production of heat

CANADA'S TOXIC TAR SANDS

THE MOST DESTRUCTIVE PROJECT ON EARTH



FEBRUARY 2008

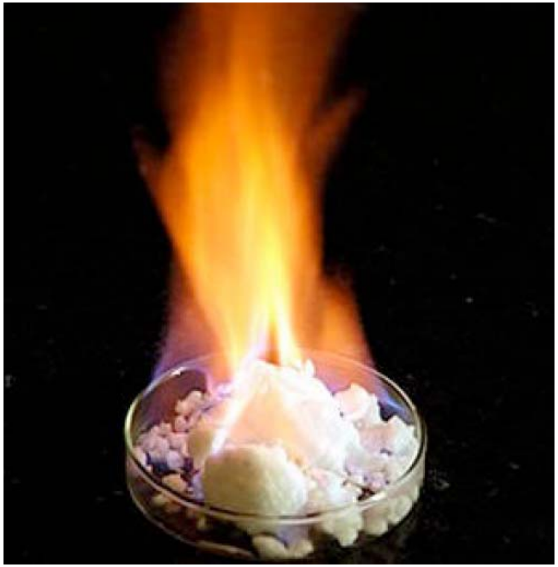
non conventional gas

- gas hydrates

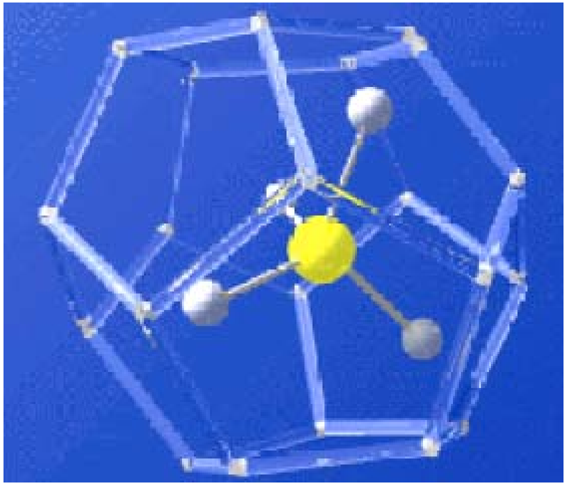
- coalbed methane

- gas from shales

- gas from low permeability sand/sandstone (tight gas)



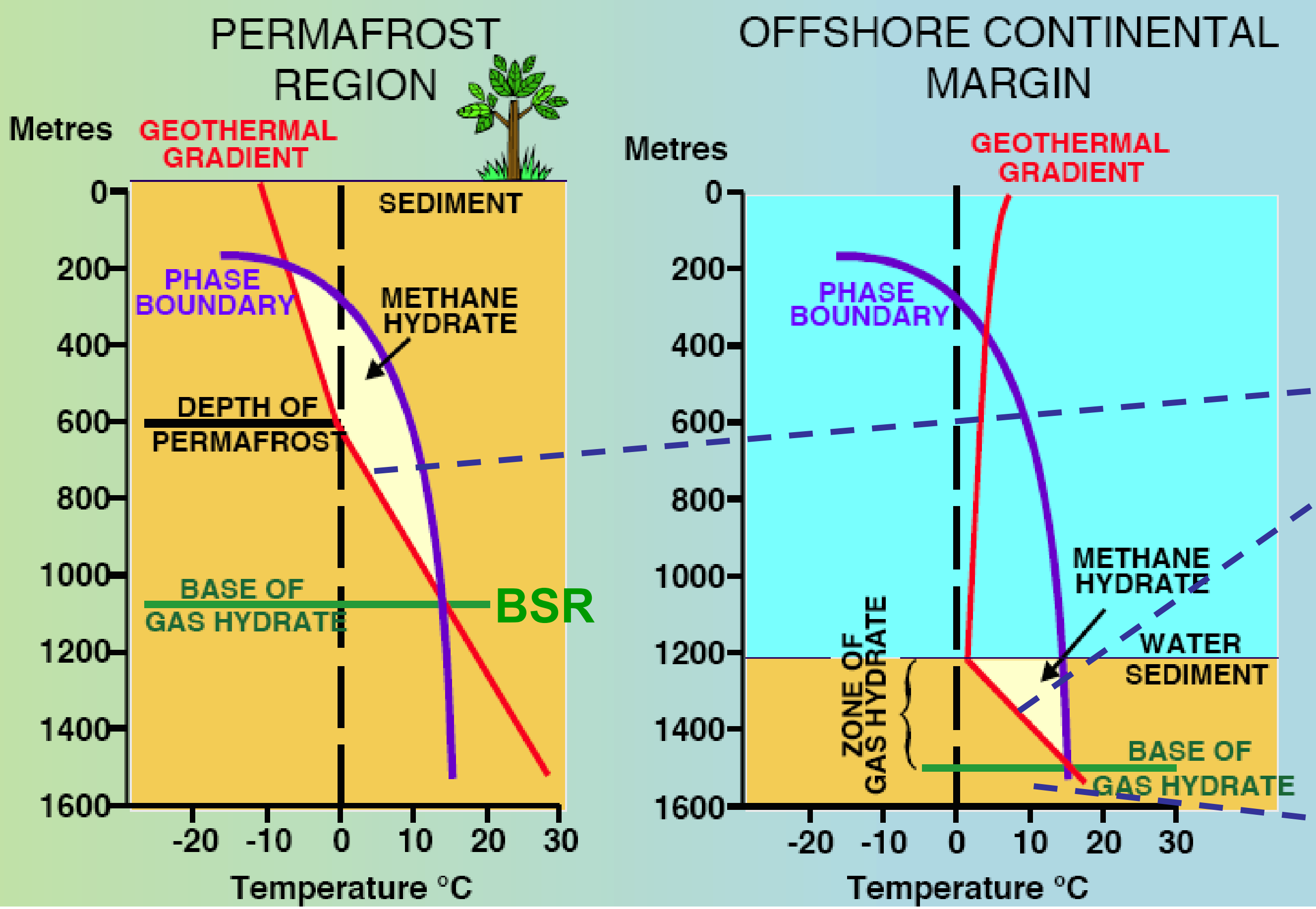
Gas hydrates, clathrates

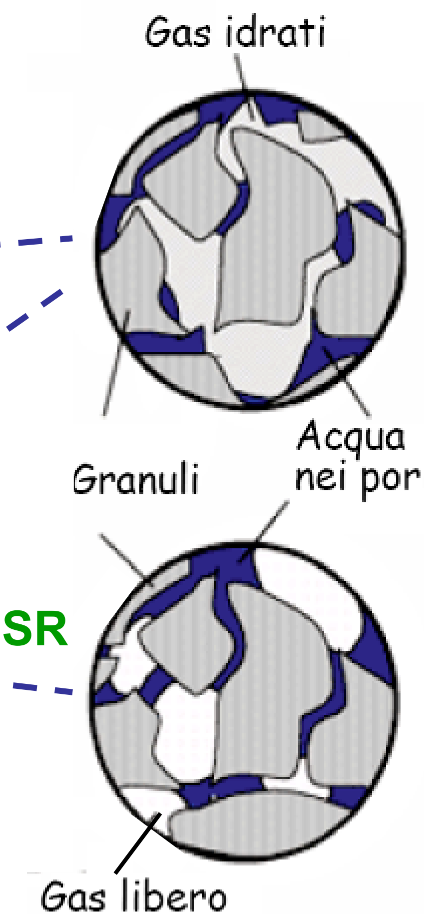


Crystalline water-based solids in which small non polar molecules (typically gases: methane, CO_2…) are trapped inside “cages” of hydrogen bonded water molecules

The most common are methane clathrates

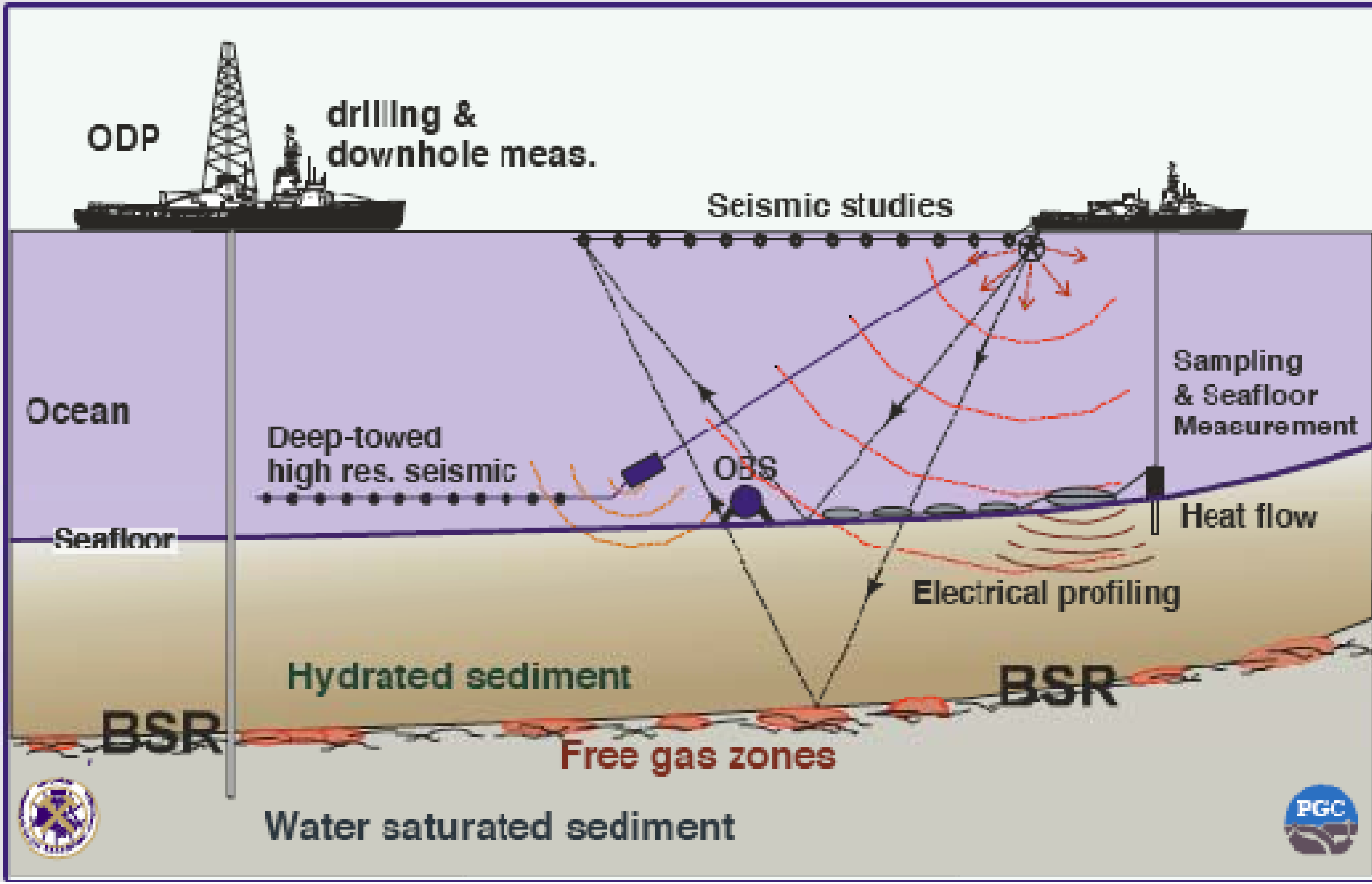
Depths & Temperatures where Gas Hydrates are Stable





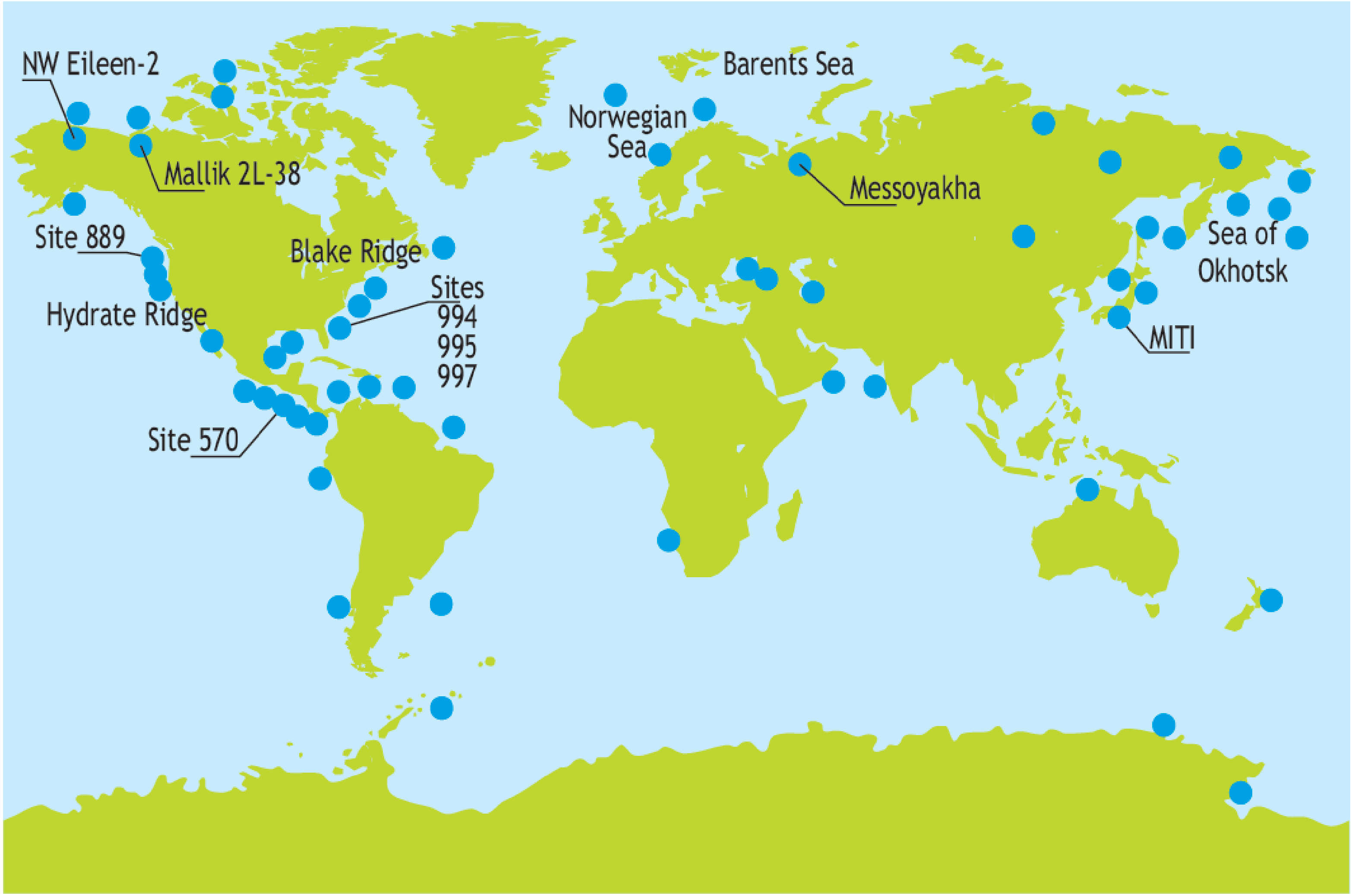
BSR: Bottom Simulating Reflector

Marine Gas Hydrate Studies




b
c

Location of gas-hydrate resources



World Energy Outlook 2008

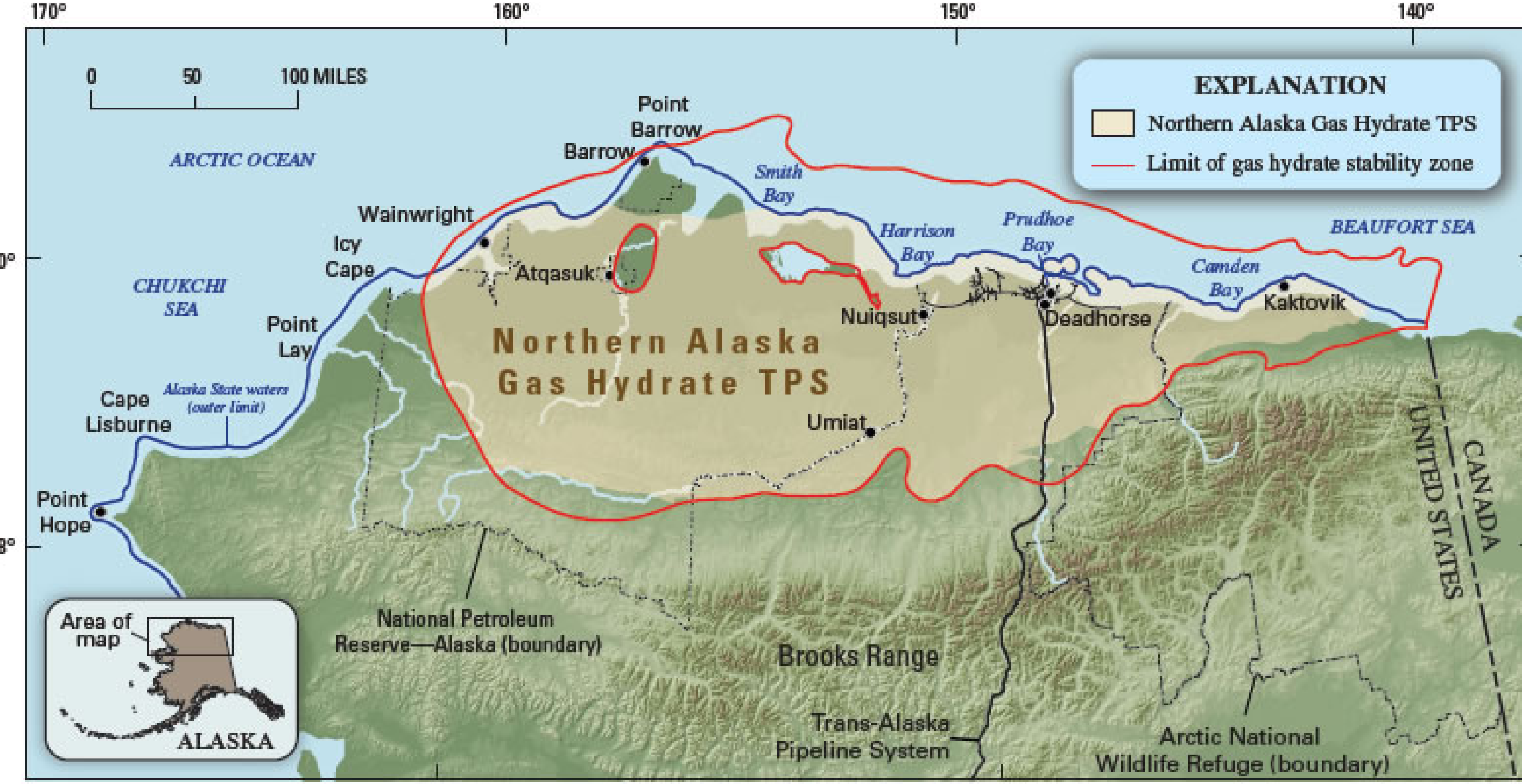


Figure 1. The Northern Alaska Gas Hydrate Total Petroleum System (TPS) (shaded in tan), and the limit of gas hydrate stability zone in northern Alaska (red outline).

Japan's Commitment to Production Leads International Gas Hydrate Research

- Japan: USDOE estimates $50 Million USD each year of research.
- United States: H.R. 1753, authorizes $165 Million USD over five years for new research.
- India: $16 Million USD/year in a total budget of $56 Million USD over five years.
- Canada: $2.02 Million USD over the next four years.
- Korea – expected annual expenditure in near term up to $6 Million USD/year
- Primarily government and research

Canada

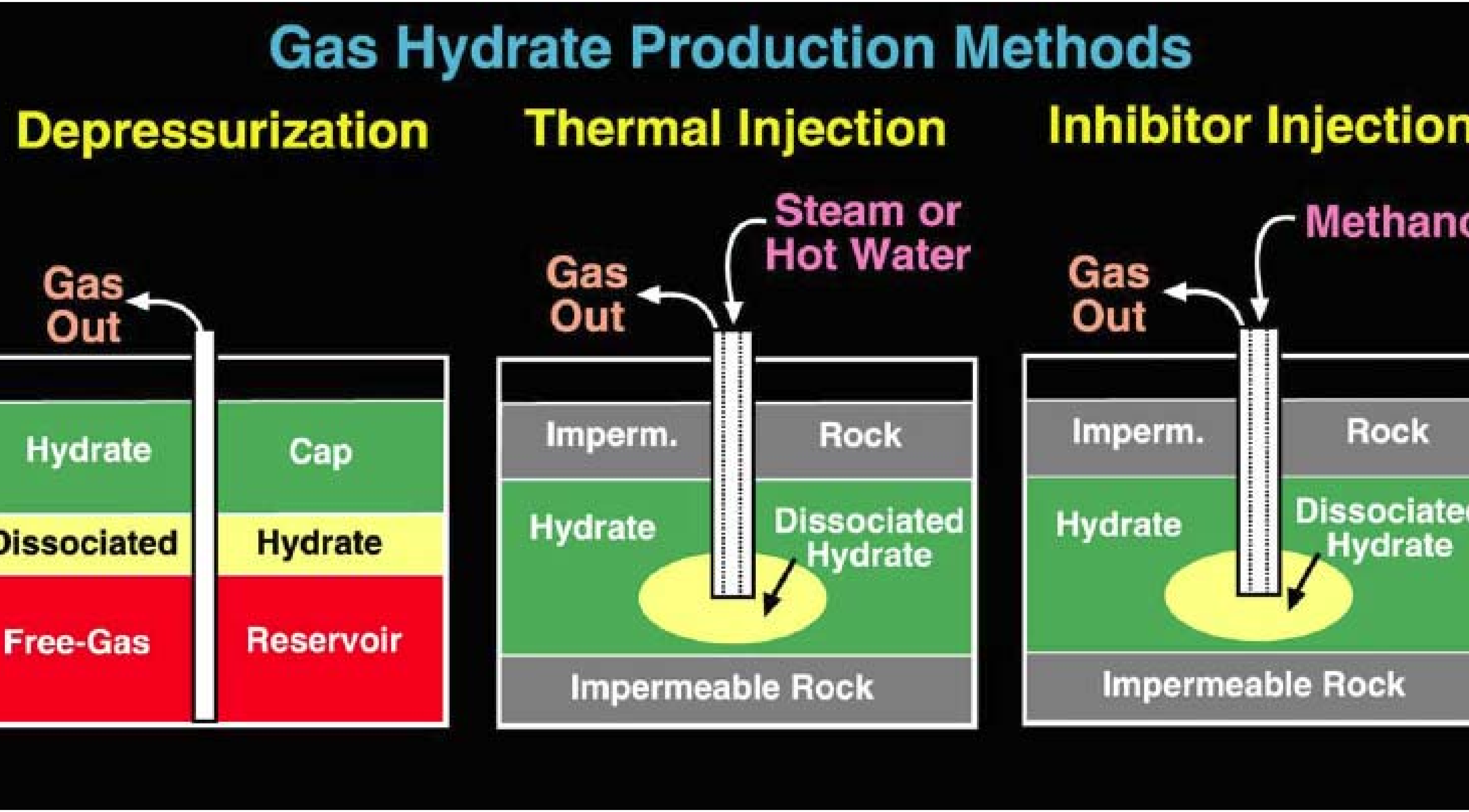
Summer 2009 Methane Hydrate Newsletter

NETL

- Joint Industry Project Leg II Discovers Rich Gas Hydrate Accumulations in Sand

Energy

Gas Hydrate Resource
Smaller But Sooner



Possible methods for exploitation of gas hydrates

- Depressurization
- Heating : hot water, vapour, microwaves…
- Injection of chemical inhibitors in order to dissociate ("melt") the gas hydrates

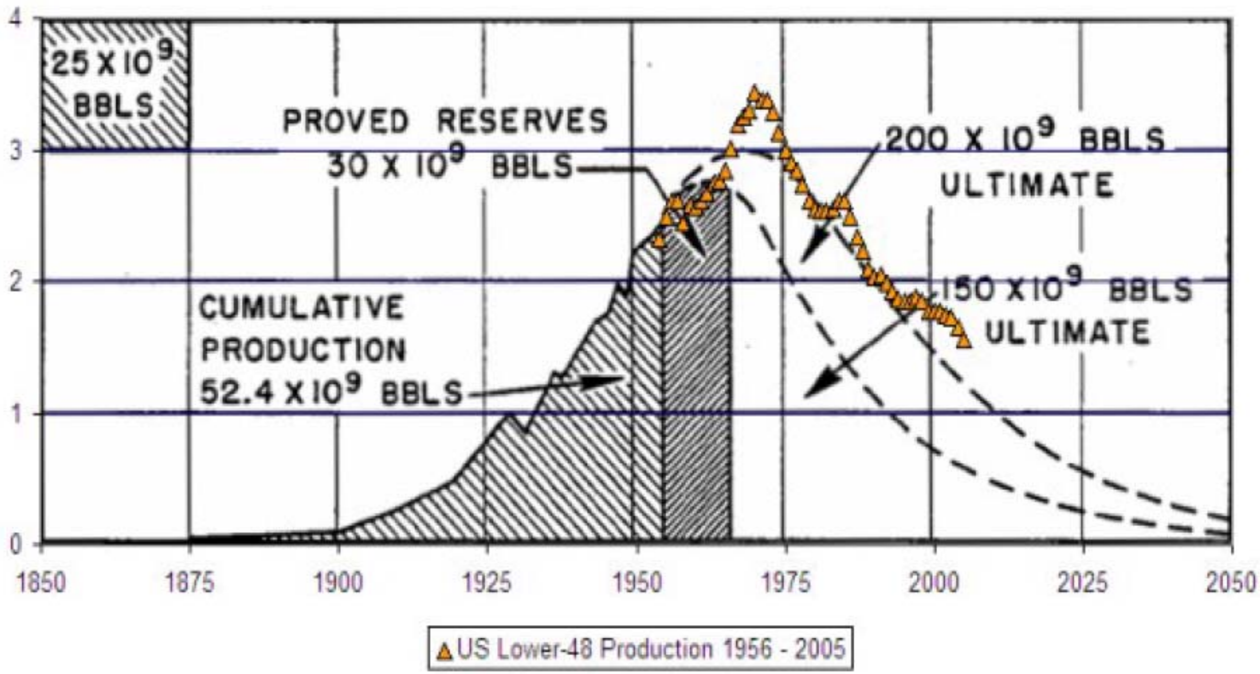
…but the situation is not that simple

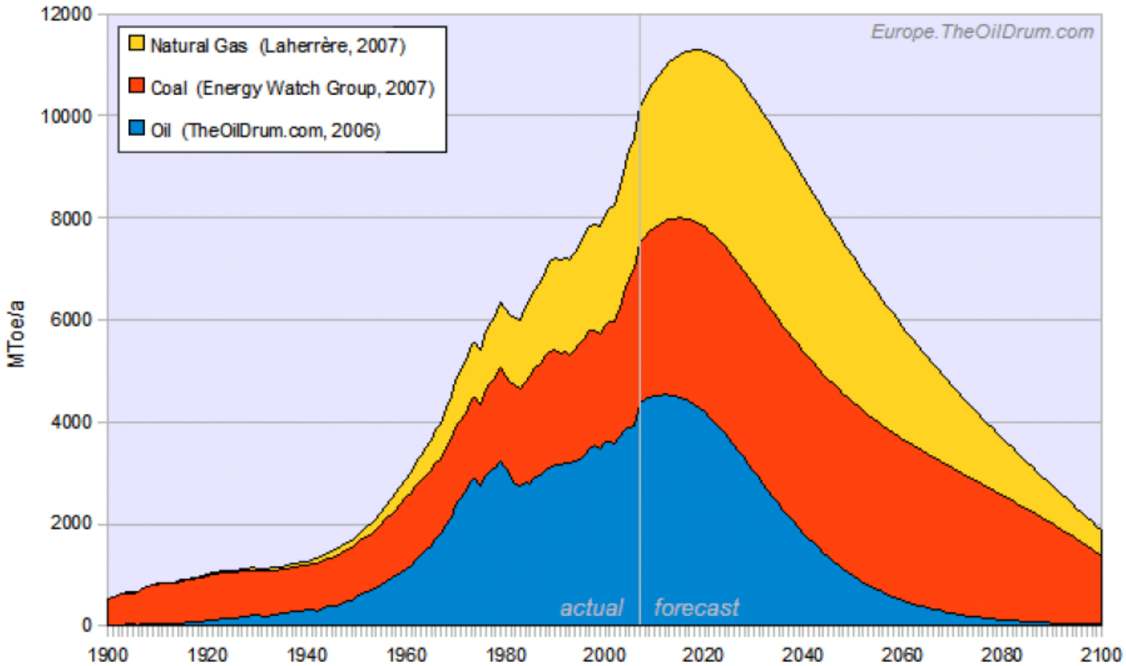
“Hubbert’s theory” (1956):

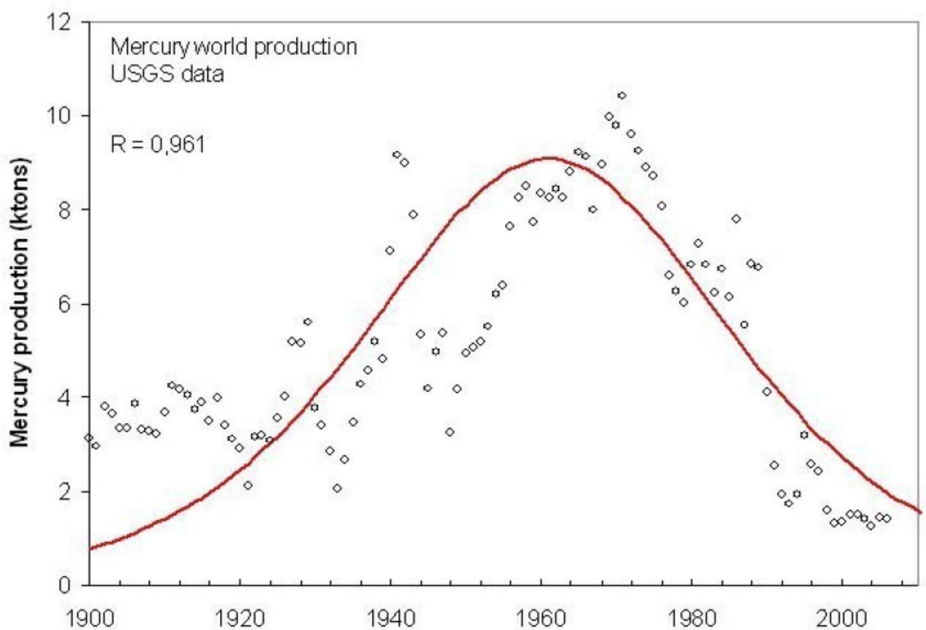
Fossil fuel production in a given region over time follows a roughly bell-shaped curve (*Hubbert curve*).

After fossil fuel reserves are discovered, production at first increases approximately exponentially, as more extraction commences and more efficient facilities are installed

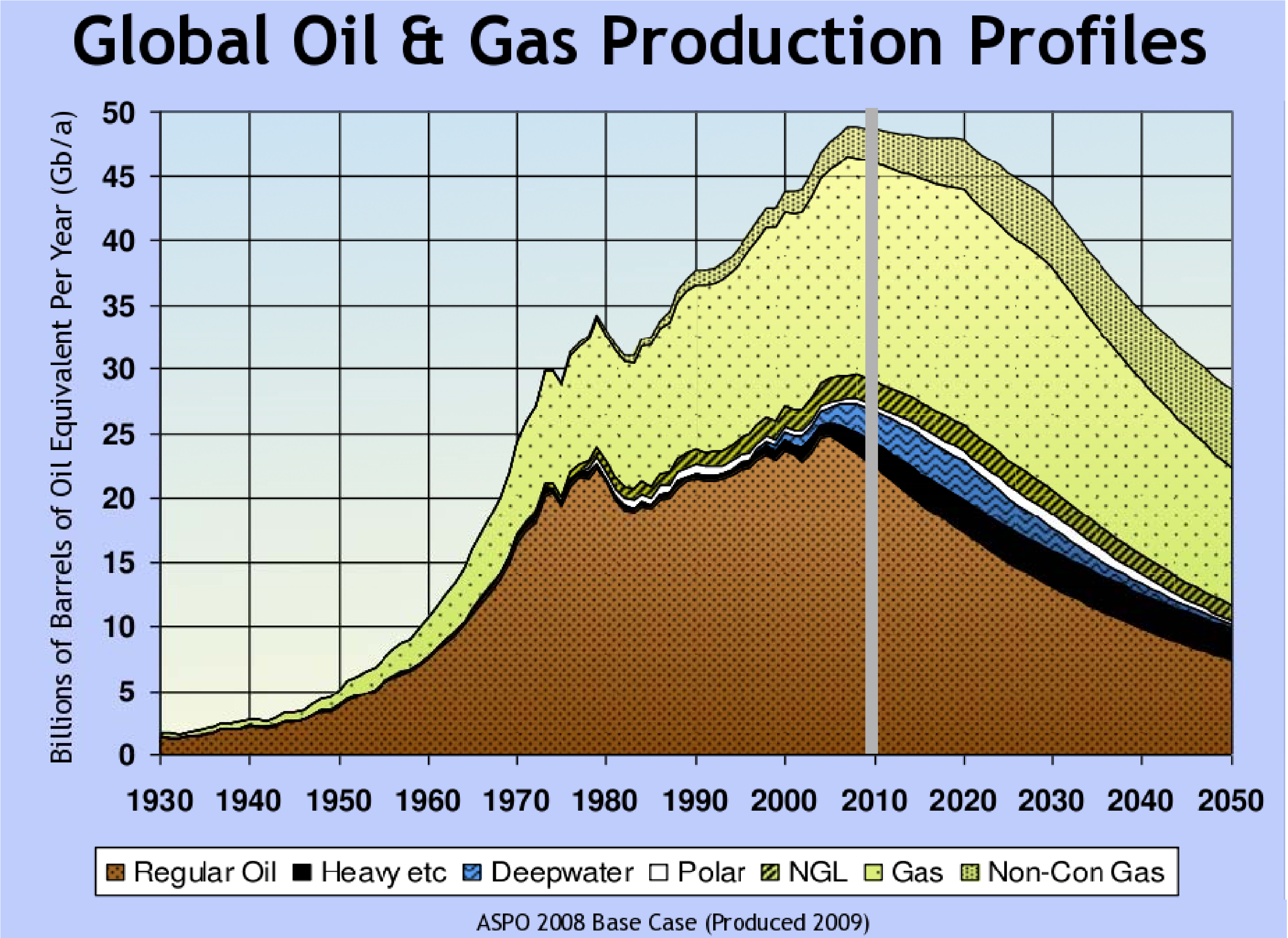
At some point, a peak output is reached, and production begins declining until it approximates an exponential decline.



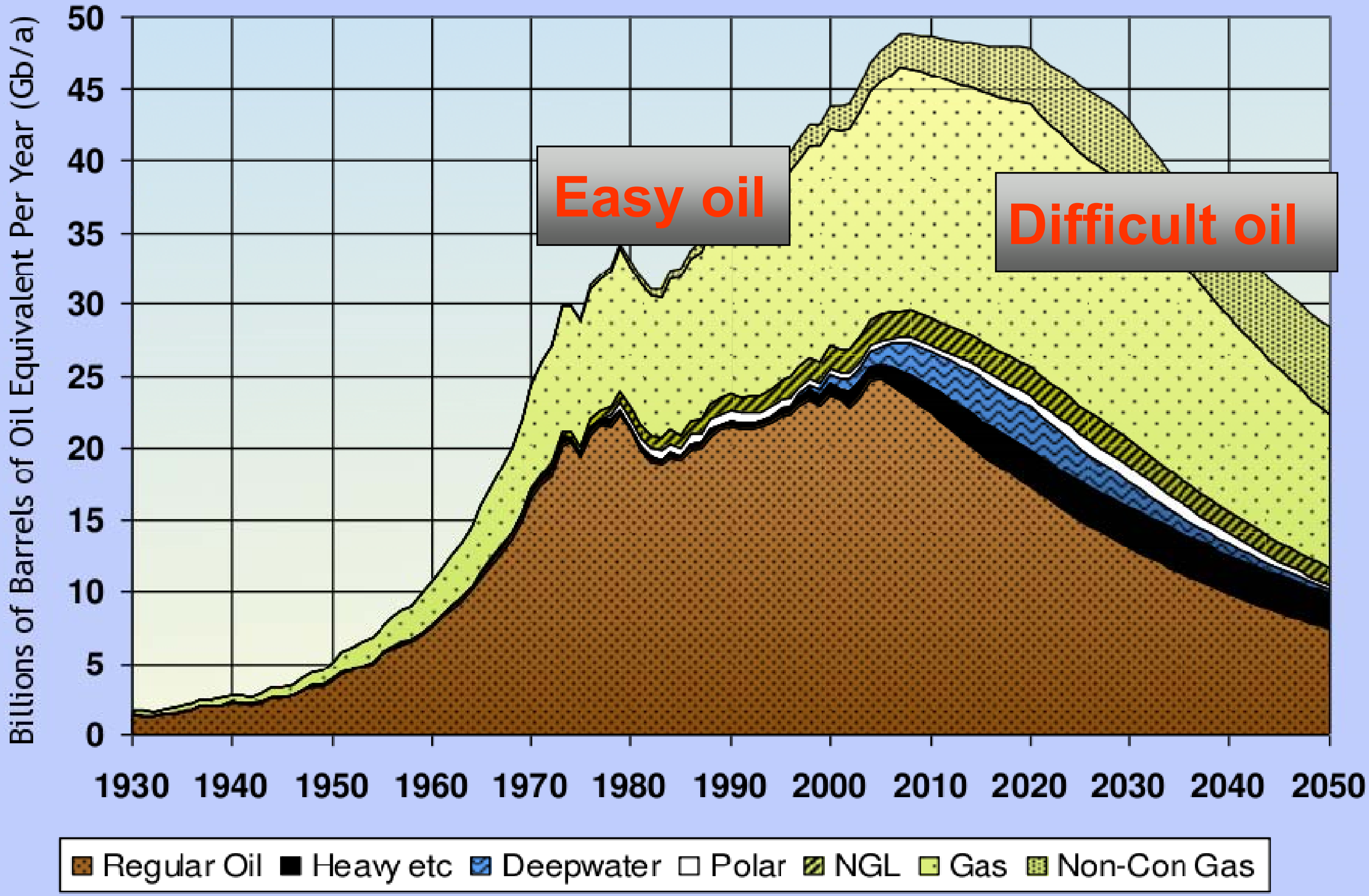

Natural Gas (Laherrère, 2007)
Coal (Energy Watch Group, 2007)
Oil (TheOilDrum.com, 2006)
Europe.TheOilDrum.com
MToe/a
actual
forecast
12000
10000
8000
6000
4000
2000
0
1900
1920
1940
1960
1980
2000
2020
2040
2060
2080
2100


Mercury world production
USGS data
R = 0,961
Mercury production (ktons)
12
10
8
6
4
2
0
1900
1920
1940
1960
1980
2000

Are we at the "petrol peak"?



Global Oil & Gas Production Profiles



ASPO 2008 Base Case (Produced 2009)

- **deeper and deeper deposits, in remote areas**

-IOR/EOR techniques

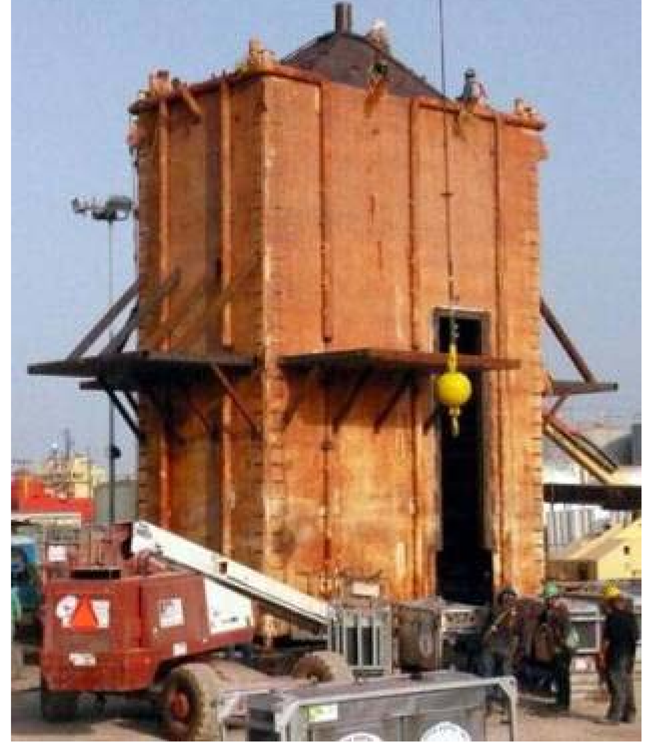
- exploitation of non conventional often poor-quality deposits; hydrocarbons recovery with complex, expensive methods, which often imply a strong impact on the environment

→ increasing costs; environmental concern

- climate change: greenhouse effect, CO_2 emissions

- nuclear: other types of problems

21 april 2010 – The Deepwater Horizon rig



the “dome”

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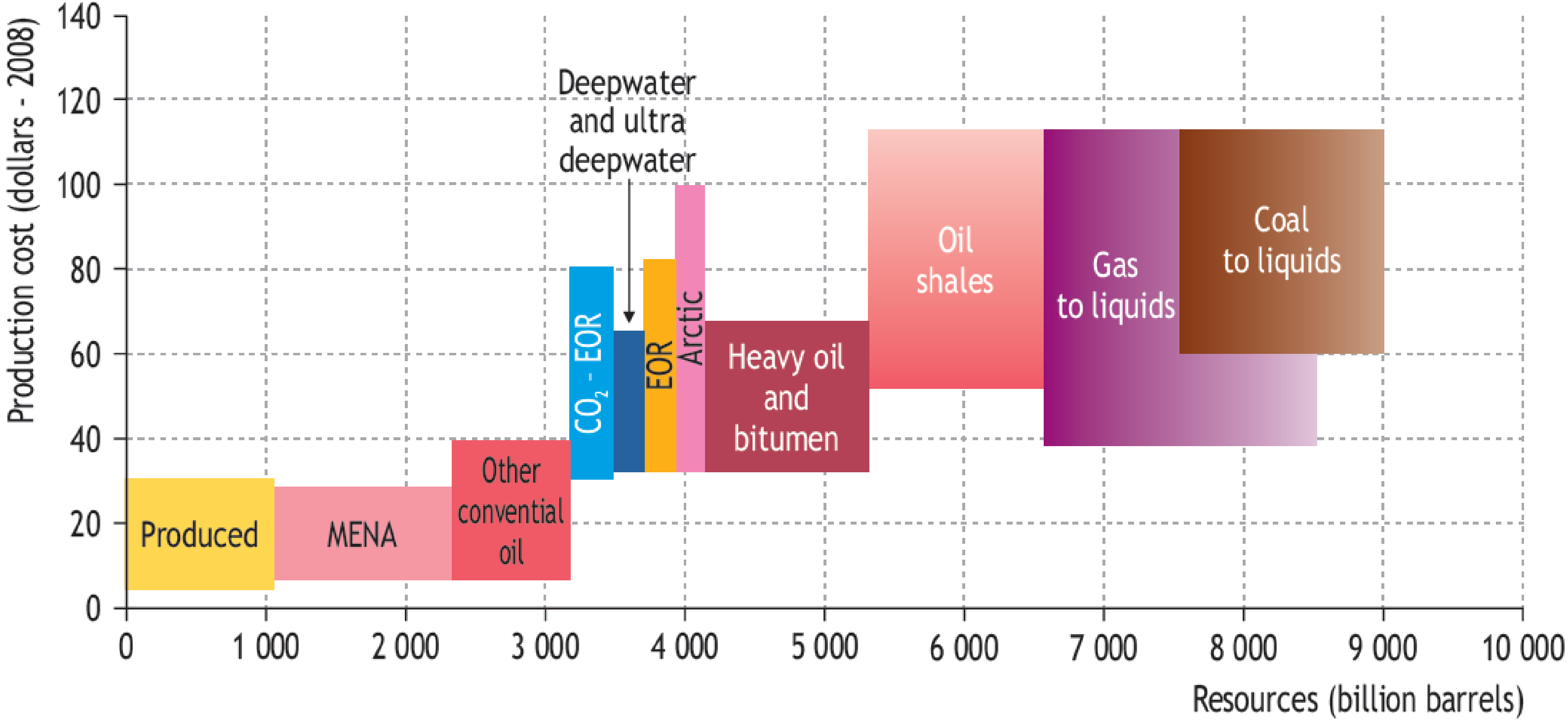
Long-term oil-supply cost curve



Note: The curve shows the [redacted]. Cost [redacted] There is also a significant uncertainty on [redacted] cost as the technology is not yet commercial. MENA is the Middle East and North Africa. The shading and overlapping of the gas-to-liquids and coal-to-liquids segments indicates the range of uncertainty surrounding the size of these resources, with 2.4 trillion shown as a best estimate of the likely total potential for the two combined.

NGL: Natural gas liquids, obtained during the natural gas processing: ethane, propane, butanes, pentanes…

World Energy Outlook 2008

Coal to liquid: Coal transformed to liquid, generally by adding hydrogen

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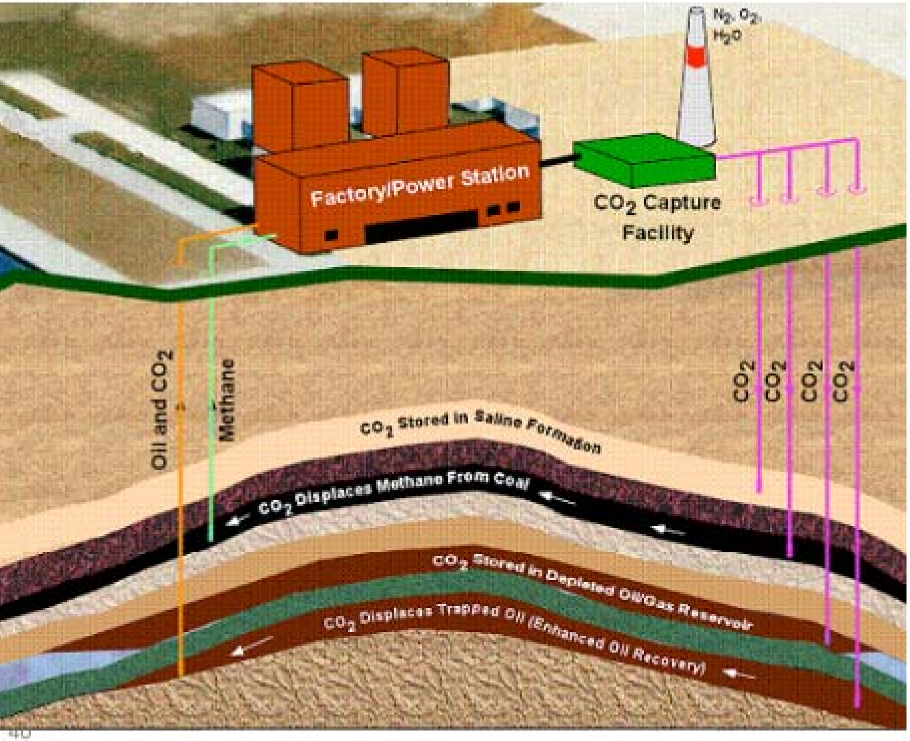
s an example coal: the cheapest energy source

is surely incompatible with the environment (global warming), unless CCS (Carbon Capture and Storage) technologies are adopted…

but in this case probably it is not anymore a cheap source



Sleipner, attivo dal 199