UNCONVENTIONAL PETROLEUM

New energy resources for the 21st century and thereafter

Unconventional petroleum resources include:

1. Coalbed Methane
2. Shale-gas
3. Shale-oil
4. Oil from shales
5. Gas from tight, ultra-deep reservoirs
6. Oil from Tar Sands
7. Hydrothermal petroleum
8. Gas Hydrates
9. Biogenic gas

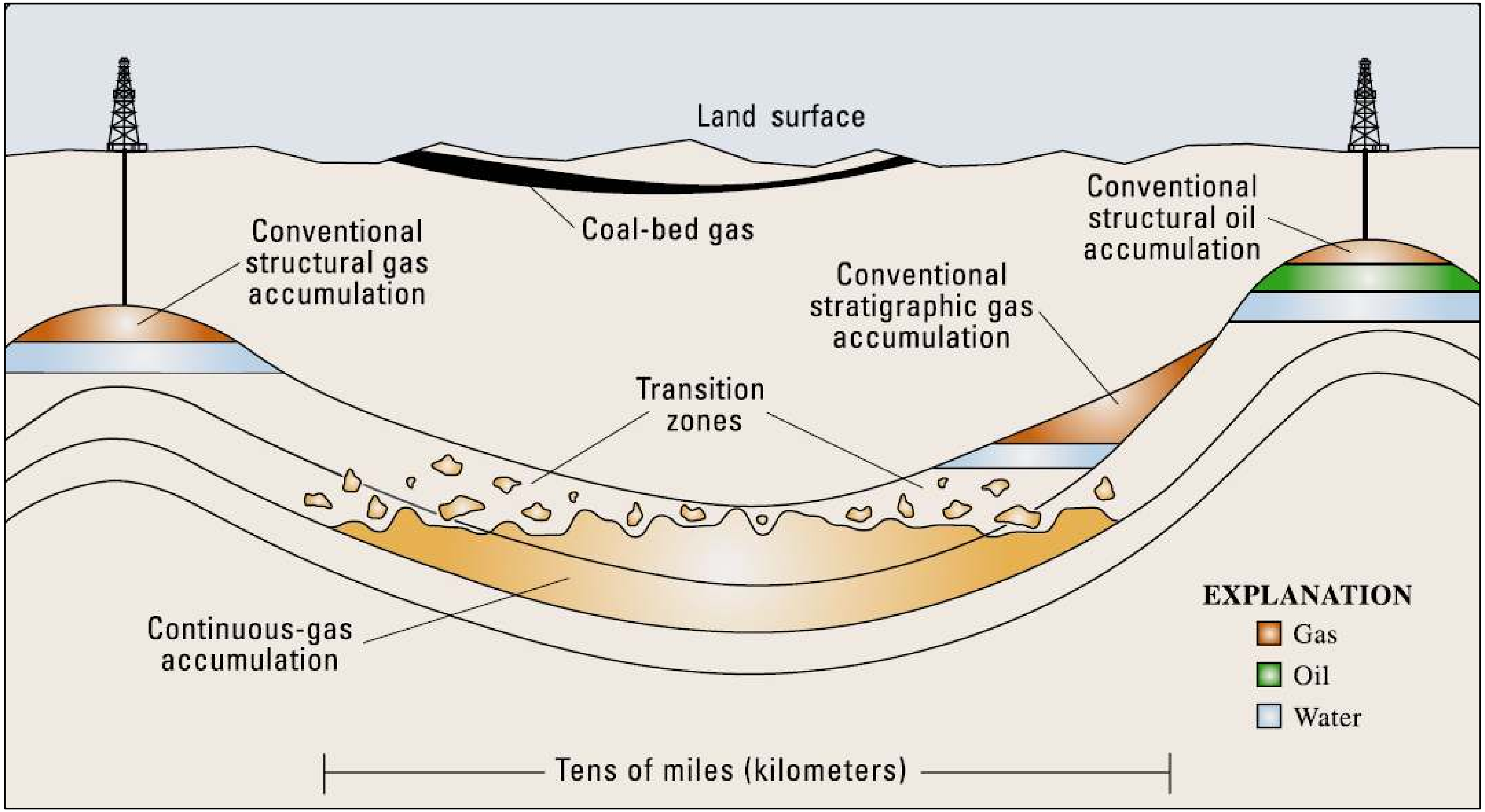
Items 2–4: SHALE-EXTRACTED unconventional petroleum or "shale resources"

Items 7–8: Future energy quantities

Coalbed methane, gas shales, and tight gas reservoirs are commonly referred to as continuous gas accumulations. They are regionally extensive and not buoyancy-driven accumulations, mostly independent of structural and stratigraphic traps.

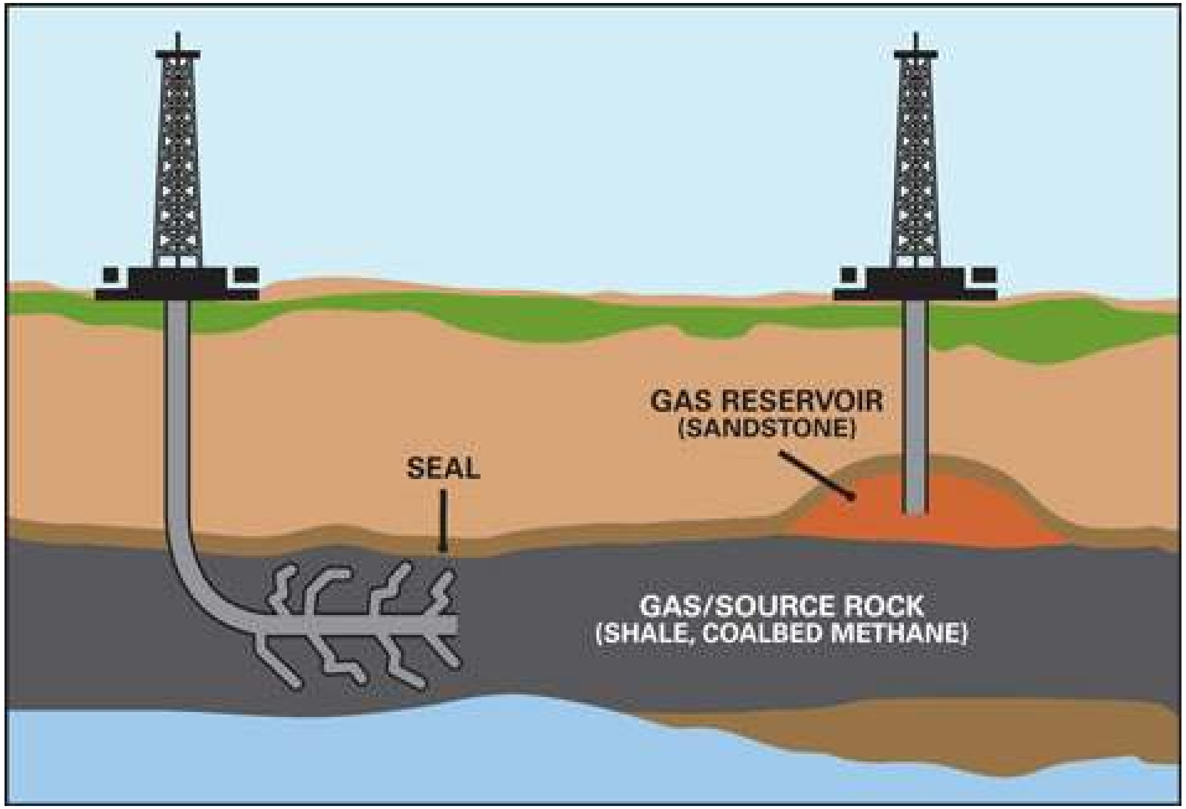
TYPES OF CONVENTIONAL AND UNCONVENTIONAL PETROLEUM ACCUMULATIONS

Continuous (or unconventional) gas occurs as basin-centred gas, coalbed gas, shale-gas, fractured-reservoir gas, and tight-reservoir gas (from USGS, *Natural Gas Production in the US,* 2002), The current name for unconventional petroleum used by SEC is "***Non-Traditional Petroleum***".



1) Gas Shales

Gas shales are organic-rich, fine-grained sedimentary rocks (shale to siltstone) containing a minimum of 2% TOC. Gas shales are, or have been within the gas window (1.0-2.0% Ro) and contain thermogenic methane. While all liquid petroleum and most of the gas could have migrated from the source rock, some gas has been retained in the shale, both as adsorbed on organic matter and as free gas in fractures and pores. Due to their extremely low permeability, gas shales require extensive natural or artificial fracturing to produce commercial quantities of gas.

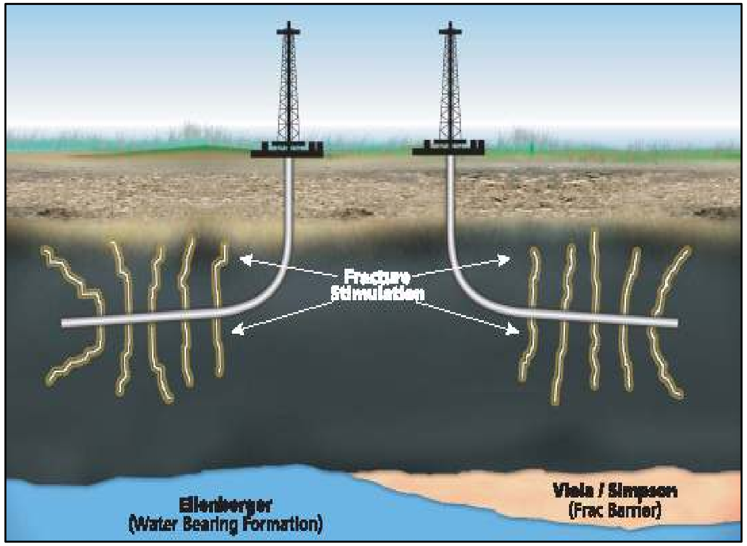


Source: European Student Think Tank website

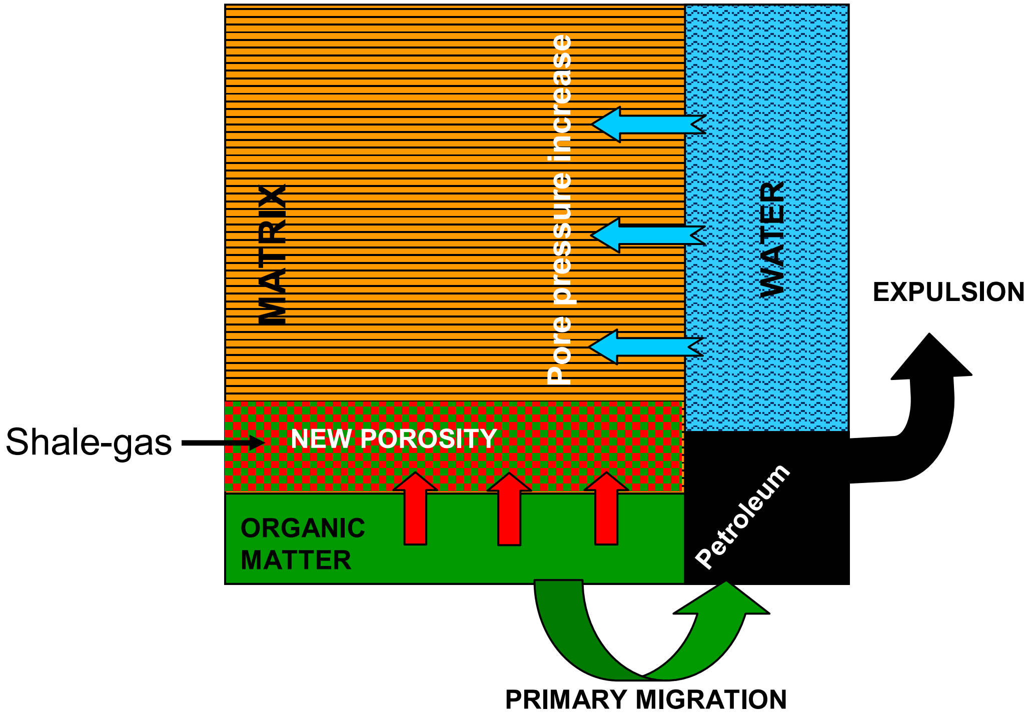
The pore spaces in black shales are not large enough for gas molecules to flow through easily. Organic-rich shales commonly have only *micro-porosity*. Additional micro-porosity is created: (i) when the organic matter matures and expels petroleum; when the black shales are in the gas window, approx 4.3% extra porosity is created by OM decomposition. (ii) The rock may, in addition, contain natural fractures due to stress or overpressure, which are often concentrated in *fracture swarms*.

Shale-gas wells are not difficult to drill, but they are difficult to complete, as the rock around the wellbore must be hydraulically fractured before the well can produce significant amounts of gas. Fracturing involves isolating sections of the well in the producing zone, then pumping fluids and proppant (grains of sand or other material used to hold the cracks open) down the wellbore through perforations in the casing and out into the shale. The pumped fluid (often water) is enough to crack shale as much as 1000 metres in each direction from the wellbore.

(from Schlumberger's "white paper" on Shale Gas)

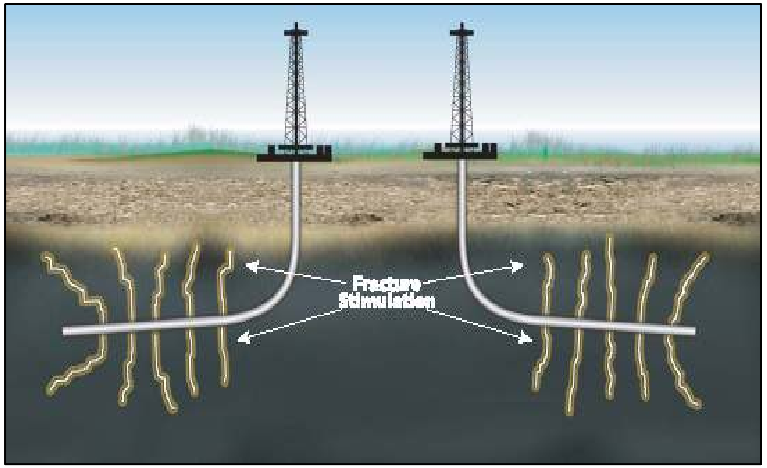


(from Oil & Gas Investor, Shale Gas, 2006)



The issue of vertical scale in public perception

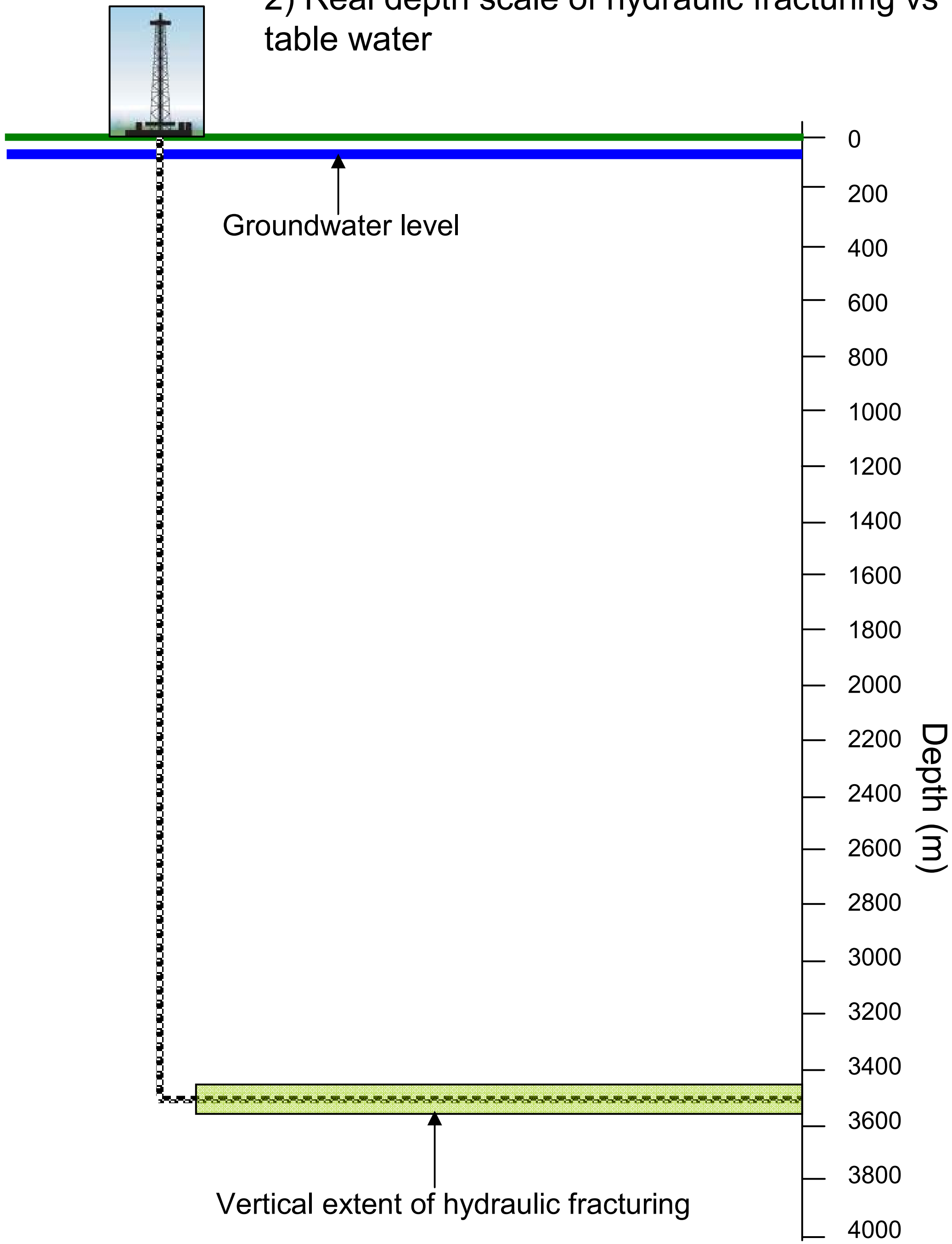
1) Misleading image of hydraulic fracturing



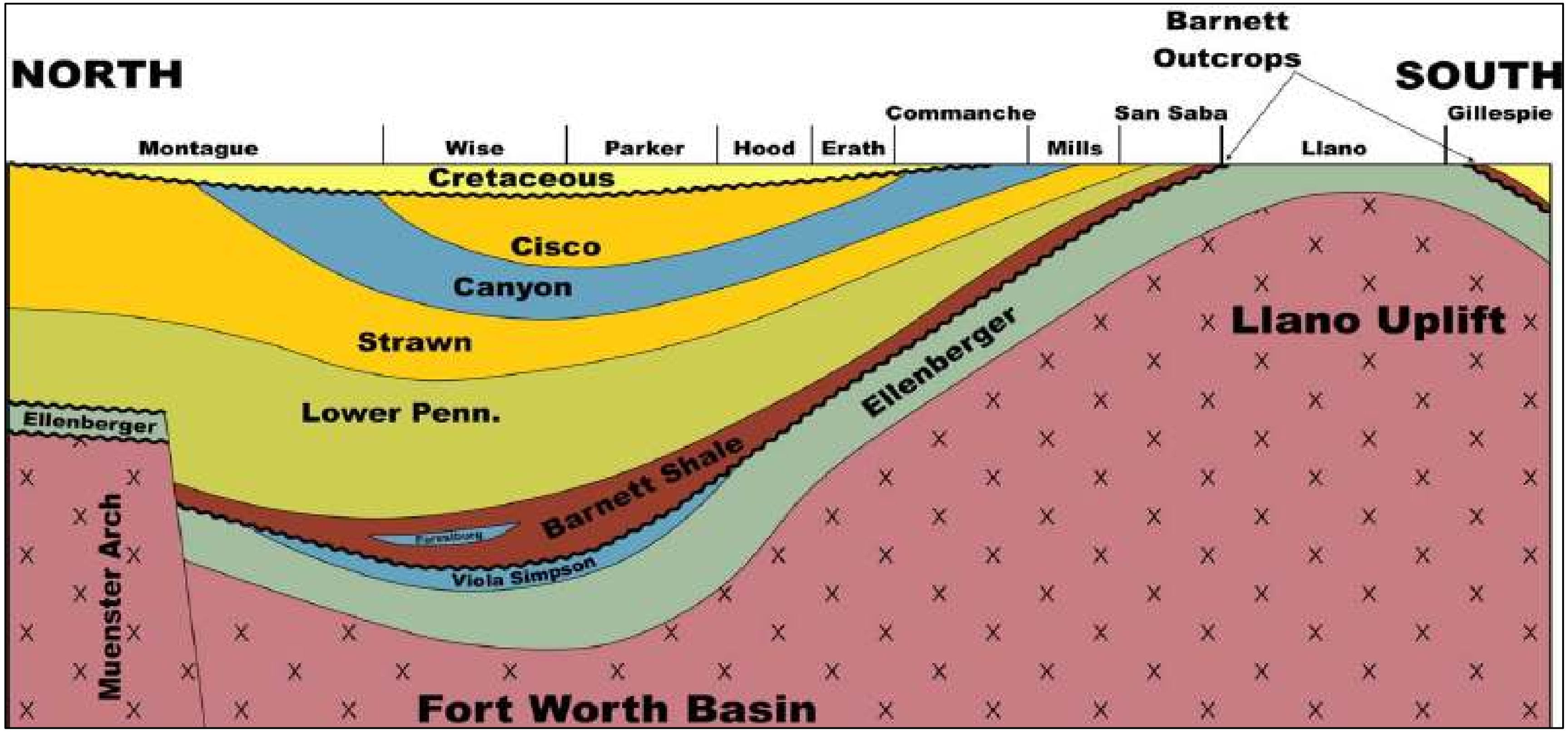
Oil & Gas Investor, Shale Gas, 2006

The fractures reach the water table. No depth scale is shown.

2) Real depth scale of hydraulic fracturing vs table water



North-South section of the Fort Worth Basin, showing the development of the Barnett Shale play (Pollastro, 2004; Montgomery *et al.,* 2005)



The Mississipian **Barnett Shale** play in Fort Worth Basin, Texas, is the largest producer of natural gas in this state. It contains proven reserves of more than 2.7 TCF of gas. The shale contains a Type II, low sulphur kerogen that has been through the gas window. The gas is stored: (i) **ad**sorbed on the solid material and, (ii) as compressed free gas in pores & fractures. The present-day average TOC is about 3.2% (3-13%) and the Hydrogen Index is 165. The average porosity of the shale is 5-6% and the permeabilities less than 0.01 mD.

2) Oil Shales

Any shallow rock yielding oil in commercial amount upon pyrolysis is considered to be an oil shale.

Oil shales can be thermally immature or mature mudstones, siltstones, marlstones, or carbonates.They range in age from Cambrian to Tertiary. They are very organic-rich, with minimum 5% TOC and Type I and II kerogens.

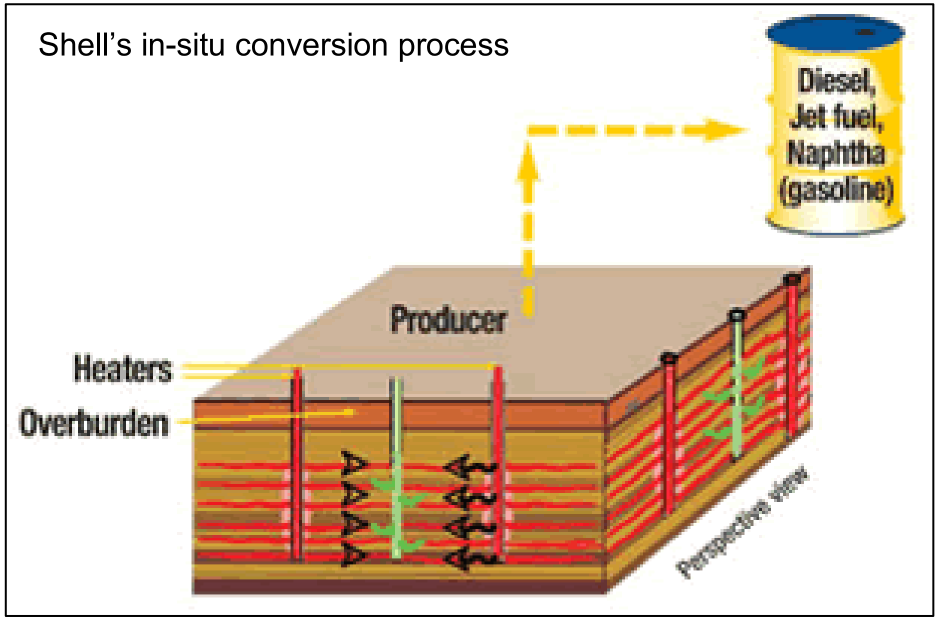
For some US oil shales yields range between 0.2 barrels of oil per ton of rock to 1.10 barrels of oil per ton of rock.

Mining of Posidonia oil shales, southern Germany

Oil shale is defined as a fine-grained sedimentary rock containing organic matter that yields substantial amounts of oil and combustible gas upon destructive distillation. Most of the organic matter is insoluble in organic solvents (kerogen) hence, it must be decomposed by heating ("*retorting*") to release such materials. A deposit of oil shale with economic potential is generally one that is at or near enough to the surface to be developed by open-pit or conventional underground mining. Oil shales range widely in organic content and oil yield. Commercial grades of oil shale, as determined by their yield of shale oil, ranges from about 100 to 200 litres per metric ton (l/t) of rock. The U.S. Geological Survey has used a lower limit of about 40 l/t for classification of Federal oil-shale lands. Others have suggested a limit as low as 25 l/t.

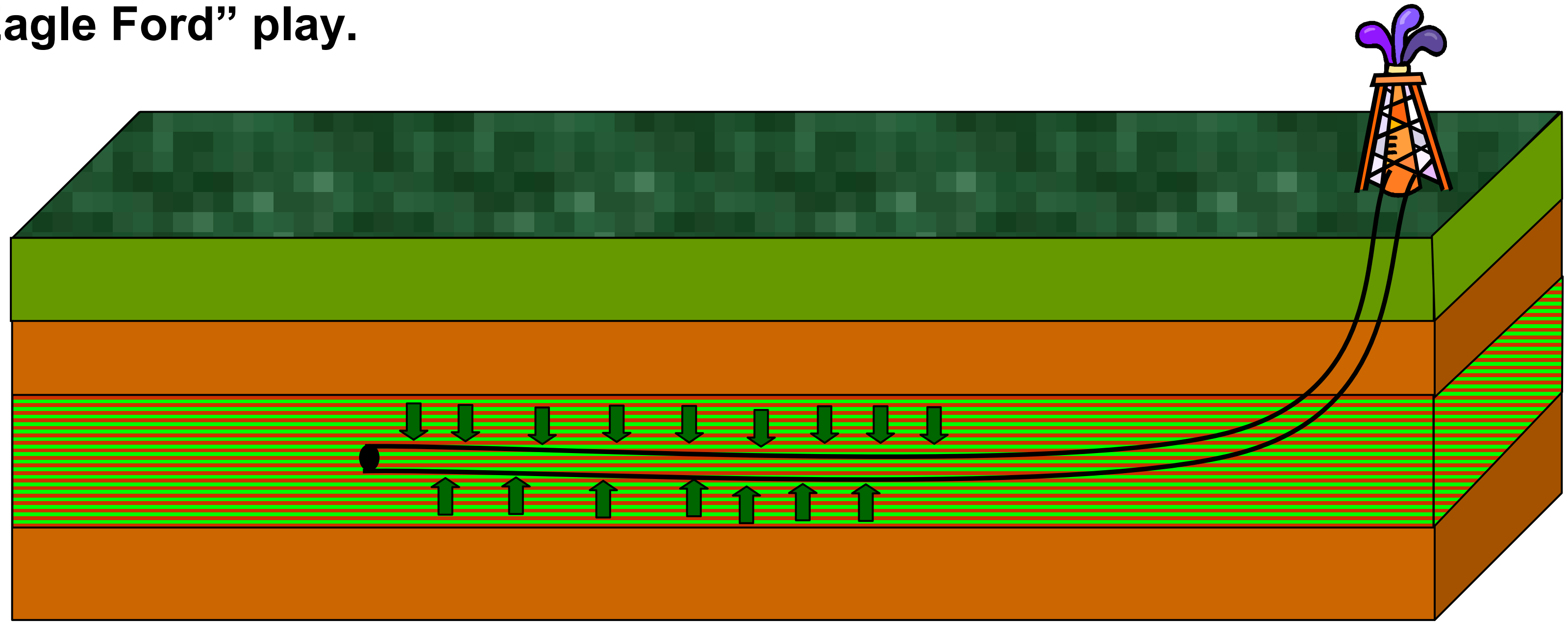
Deposits of oil shales exist in many parts of the world. They range from Cambrian to Tertiary age and may occur as minor accumulations of little or no economic value, or as giant deposits that occupy thousands of square kilometres and reach thicknesses of 700 m or more.

Oil shale can be mined using one of two methods: (i) underground mining using the *room-and-pillar* method; or, (ii) surface mining. After mining, the oil shale goes through "*retorting*", a heating process that separates the oil fractions from the mineral fraction. After retorting, the oil must be upgraded by further processing before it can be sent to a refinery,



Oil Shales in Scotland

“Shale-oil” against “Oil from Shale”: drilling directly into oil-mature *fractured* black shales to pump the residual oil. The “Eagle Ford” play.



The efficiency of this method depends heavily on the amount of natural fractures in the oil shales. Exploration strategies include: (i) mapping areas of thick black shale; (ii) mapping kitchen areas of peak hydrocarbon generation; (iii) mapping fracture intensity and, (iv) drilling long horizontal wells. Several wells have been drilled in the US since the early 1960s, but no commercial success has been achieved, although artificial fracturing has been carried out.

Natural fractures in shales may occur during *isostatic rebound after melting of an ice cap*. Black shale horizons in areas that were subjected to glaciation and post-glaciation periods are particularly sought after by shale-oil explorers.

3) Tight Gas and Ultra-Deep Reservoirs

Tight gas sands are low-permeability, gas-bearing reservoirs (in a variety of rock types) that have matrix permeability to gas of **less than 0.1 mD**. The reservoirs are extensive, usually overpressured and often found in basin-centre settings. The terms used more often are “Basin-Centred Gas Accumulations” (BCGA) or, “Basin-Centred Gas Systems”.

Estimates of Recoverable Gas in Basin-Centered Accumulations in the United States*

Basin	USGS, 1996	NPC, 1992
Greater Green River	119.3	–
Uinta-Piceance	16.74	–
San Juan	21.15	–
Denver	3.16	–
Appalachian	44.97	–
East Texas	6.03	–
Columbia River	12.2	–
TOTAL	**223.55**	**232**

*USGS = U.S. Geological Survey (Johnson et al., 1996); NPC = National Petroleum Council (1992). All values in tcf gas.

"**Natural gas from tight sands** is conventional natural gas extracted from unconventional reservoirs" (Canadian Centre for Energy Information)

Conventional reservoirs are clastic or carbonate rocks that possess a network of connected pore spaces between the grains. Gas production from such reservoirs can be established without the need for large-scale stimulation or sophisticated production tools.

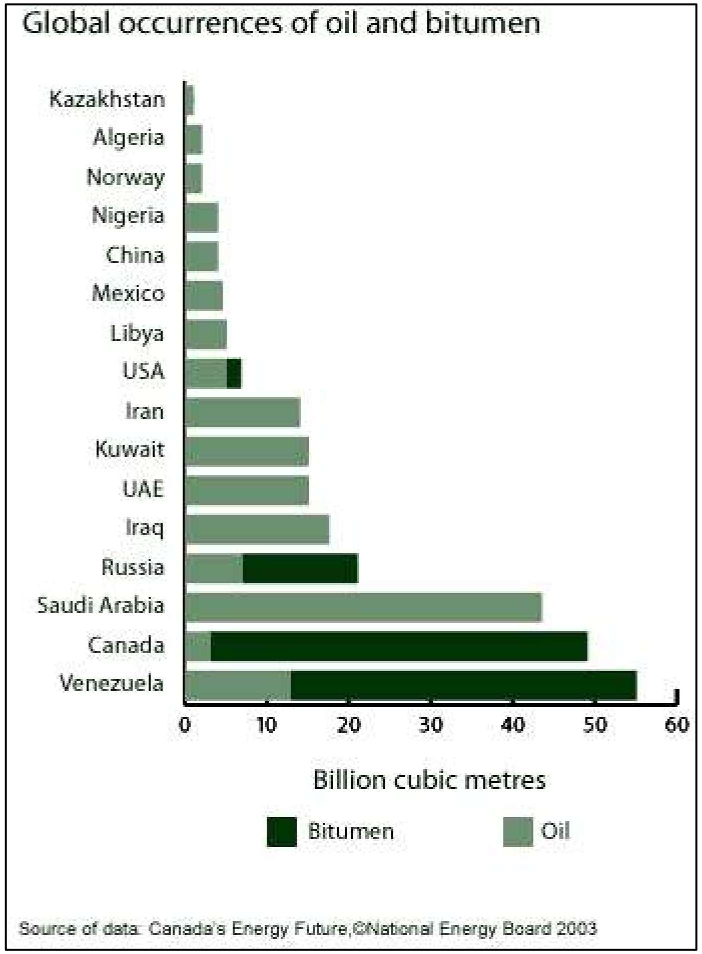
Unconventional, "tight" reservoirs have very low permeability, less than 0.1 mD. They are reservoirs that cannot produce gas at economic flow rates, without assistance from significant stimulation methods. Tight gas sands are frequently found in the proximity of conventional reservoirs.

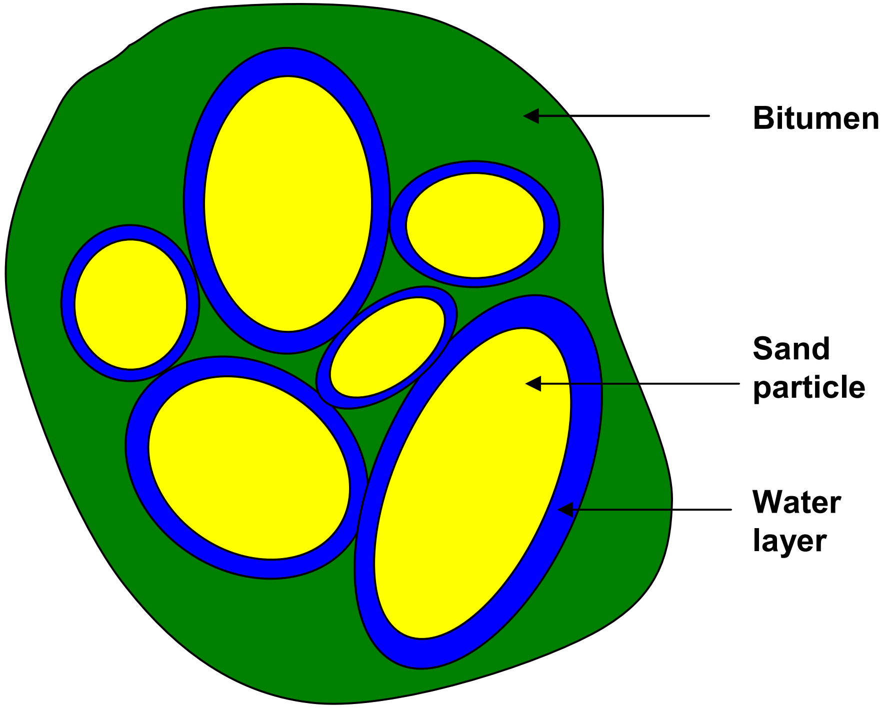
Potential gas-bearing tight sands can be seen on wireline logs. Normally, only those with extensive fracture systems are produced.

Tight sandstone units located at basin centres have been recently explored, due to the potential of porosity preservation by overpressure. Wells are drilled directionally at high angles to the fracture sets to optimise production. Currently, natural gas from tight sandstones is being produced in Canada, USA, Australia and Argentina.

4) Oil (Tar) Sands

Oil sands (also called *tar sands*) are sandstones containing a bitumen-like, extra heavy oil in relatively large quantities. The high viscosity bitumen is immobile under normal reservoir temperatures. In order to be produced, the hydrocarbons must be mined or extracted *in situ* from the rock by the use of heat or solvents.





Each grain is surrounded by a layer of water and a film of bitumen

(Canadian Centre for Energy Information)

Industry classification of crude oils, based on their gravity

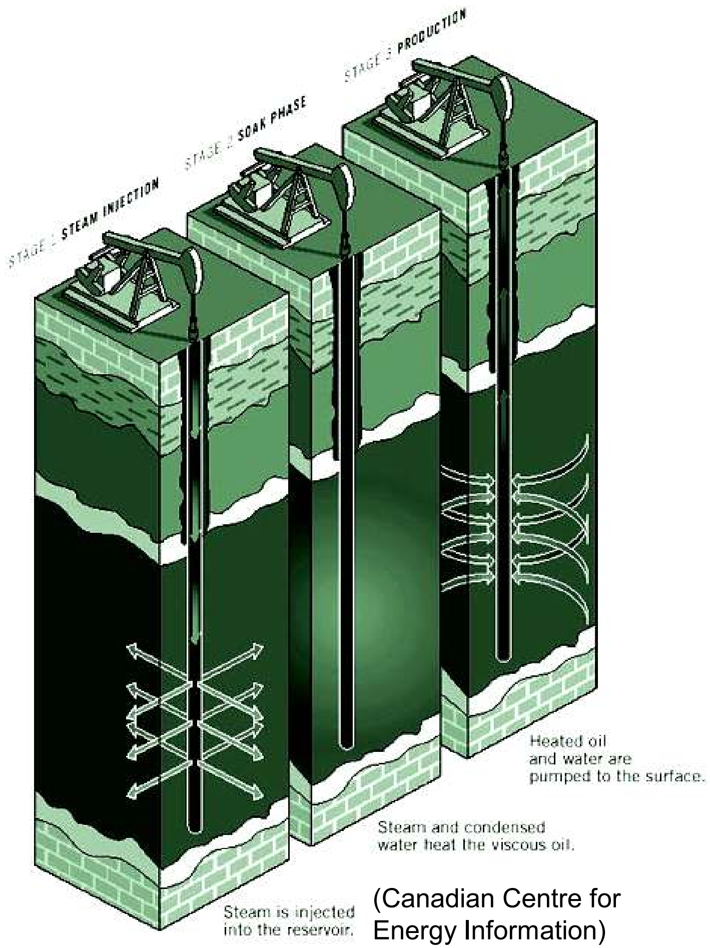
API° GRAVITY	SPECIFIC GRAVITY (kg/m3)	CLASSIFICATION
45.4	**800**	
40.0	**825**	**LIGHT OIL**
35.0	**850**	
31.1	**870**	
30.2	**875**	
25.7	**900**	**MEDIUM OIL**
22.3	**920**	
21.5	**925**	
17.4	**950**	**HEAVY OIL**
13.6	**975**	
10.0	**1000**	
6.5	**1025**	**EXTRA HEAVY OIL**
3.3	**1050**	**(BITUMEN)**
0.1	**1075**	

(Canadian Centre for Energy Information)

Heavy oils and Tar Sands characteristics (from Tissot & Welte, 1978)

- There is a major difference between “Heavy Oil” and “Tar Sands”. The former are a petroleum product that can be found in any reservoir rock. The latter defines a sandstone that contains a bitumen-rich, extra-heavy oil in large quantities. Both cases, however, are the result of petroleum degradation in reservoirs.
- Classification:
  - **Heavy oils** have viscosity between 100-10,000 centipoise at reservoir conditions and specific gravity between 0.93-1.00 gr/cm^3 (10º-12 º API).
  - **Tar sands (extra heavy oils)** have viscosity larger than 10,000 centipoise at reservoir conditions and specific gravity over 1.00 gr/cm^3 (less than 12 º API).
- A very puzzling feature is the abnormally high quantity of in-place oil in these deposits. The volume of in-place oil in the Athabasca accumulation is three times larger that in Ghawar Field.
- Factors conducive to the generation and accumulation of such huge quantities of oil include:
  - A very rich source rock with unusually large expulsion properties
  - A very efficient top seal
  - A very large drainage area
- Foreland basins are regions where the above factors can co-exist. Their wide homoclinal slope, upwards from a source rock, favours a long-distance migration. At outcrop, entry of meteoric water and the degradation of the oil may occur. Shallow degradation creates an “asphalt plug”, which acts as a very efficient seal and stops the loss of petroleum to the surface.

Geographically, oil sands and heavy oil are found throughout the world with the greatest potential resources identified in Canada, Venezuela and the former Soviet Union. Globally, oil sands are estimated to contain approximately 20 trillion barrels of oil; however the true resource base could be much larger because heavy oil resources have not traditionally been documented unless they are economically viable in current market conditions.



(Canadian Centre for Energy Information)

Production methods of heavy oil sands

- **Vertical wells and pumps**
- **Horizontal wells with coiled tubing**
- **Cold heavy oil production with sand: sand, usually in concentrations of one to eight per cent by volume, is allowed to enter the wellbore along with the oil**
- **Vapour extraction: vapourized solvents (ethane or propane) are injected into the sands and create a vapour-chamber through which the oil flows due to gravity drainage.**
- **Fireflooding: air or oxygen is injected into the producing formation and, along with some of the bitumen, is ignited to increase the temperature and enable the oil to flow more easily to a production well.**
- **Cyclic steam stimulation: Steam - which saturates the oil sands, softening and diluting the bitumen - is injected into the formation and after several weeks of "soaking," the oil is produced by the same wells in which the steam was injected.**
- **Steam-assisted gravity drainage: involves drilling two horizontal wells one above the other. Steam is continuously injected through the upper wellbore, softening bitumen that drains into the lower wellbore and is pumped to the surface.**

Oil sands mining

Overburden is firstly removed to expose the oilsands. Oilsands are mined with draglines to excavate the face of the formation. Trucks, power shovels, bucket-wheels and long conveyor belts move the raw bitumen to processing facilities. The oil sands are put into crushers that break up lumps and remove rocks. During *hydrotransport*, the oil sands are mixed with hot water (35°C or 50°C) and are piped to the processing plant. During hydrotransport, the bitumen begins to separate from the sand, water and minerals. In the processing plant, the oil sands are dumped into rotating tumblers, slurried by steam, hot water and caustic soda and then discharged onto vibrating screens to remove rocks and lumps of clay. During further separation, the bitumen forms a thick froth at the top of the separation vessel and the sand settles on the bottom.

Hydrotransport

Processing plant

In-place reserves of heavy oils in the world (Tissot & Welte, 1978)

COUNTRY	AREA	AGE OF RESERVOIR	VOLUME IN PLACE billions of barrels
Venezuela	Orinoco Heavy Oil Belt	Cretaceous & Oligocene-Miocene	940-3150
Canada	Athabasca	Early Cretaceous	1400
	Cold Lake	Early Cretaceous	
	Wabasca	Early Cretaceous	
	Peace River	Early Cretaceous	
	Carbonate Triangle (Alberta)	Paleozoic	0-1260
Russia	Melekess (Volga-Ural)	Permian	125
	Other Paleozoic	Paleozoic	21
U.S.A.	Tar Triangle	Permian	16
	Uinta Basin	Eocene	11
	Others		35
		TOTAL	2600-6000 Bbl

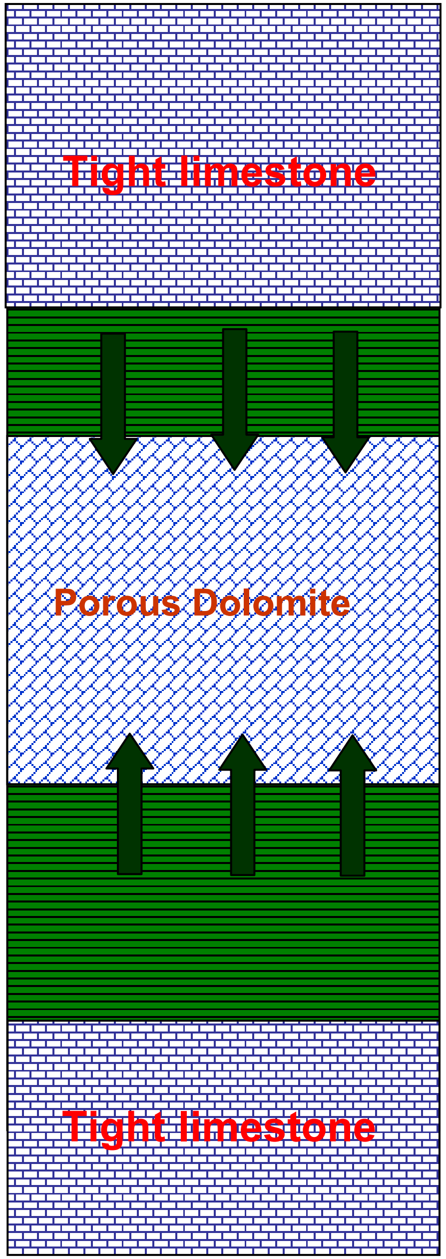
Bakken petroleum system in the Williston Basin, US & Canada: a particular "unconventional petroleum" play.

• **The Bakken formation** (Upper Devonian-Lower Mississippian) **consists of three members: lower organic-rich shale, middle dolomite, and upper organic-rich shale. The shales were deposited in relatively deep marine conditions and the dolomite was deposited as a coastal carbonate bank during a sea level fall. The middle dolomite member is the principal oil reservoir (at ~3.2 km depth).**

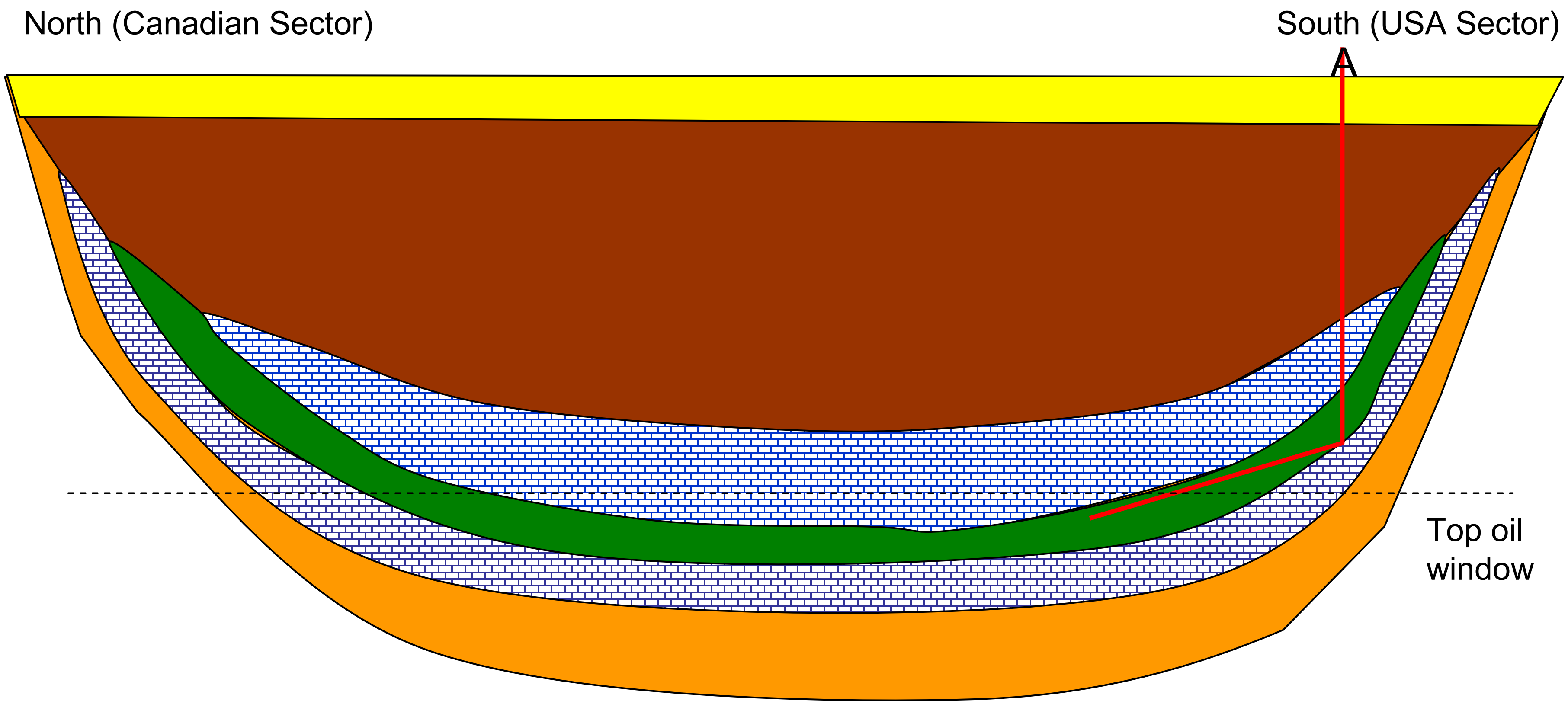
• **Porosities in the Bakken dolomites average about 5%, and permeabilities are very low, averaging 0.04 millidarcies. However, the presence of horizontal fractures makes the dolomites an excellent candidate for horizontal drilling.**

• **Once the Bakken organic-rich shales are in the oil window, they try to expel oil to all directions. As they are sealed from above and below by tight limestones, they expel the oil towards the more porous dolomite. Overpressure generated by the oil, may play an additional role in micro-fracturing the dolomites, thereby enhancing their permeability.**

• **The greatest Bakken oil production comes from *Elm Coulee Oil Field*, Montana, where production began in 2000 and is expected to ultimately total 270 MMBbl. The USGS estimates that the Williston Basin contains 3.0-4.3 billion barrels of technically recoverable oil.**

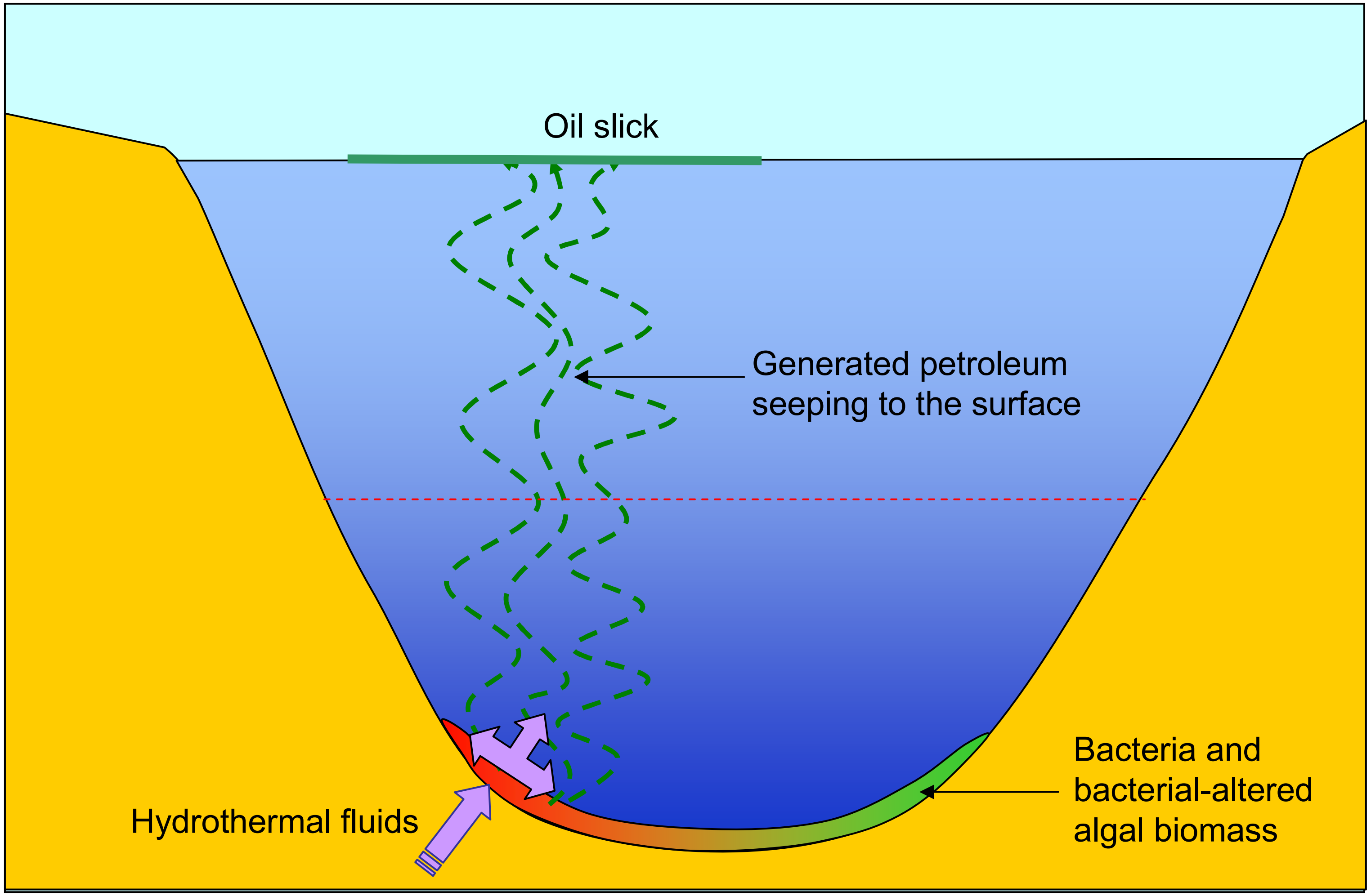


The generated oil from the Bakken black shales (41°API) fills totally the dolomite section, which is sealed from all directions. Hence, the oil accumulation is stratigraphically trapped and extends throughout the dolomite formation in the basin. The play is both “conventional” (a classic stratigraphic trap) and “continuous” (the oil is not trapped by hydrodynamic processes in discrete traps but it extends regionally)



5) Hydrothermally-matured petroleum source rocks

a. from bacterial mass “cooked” by hot water emanating at the seabed.

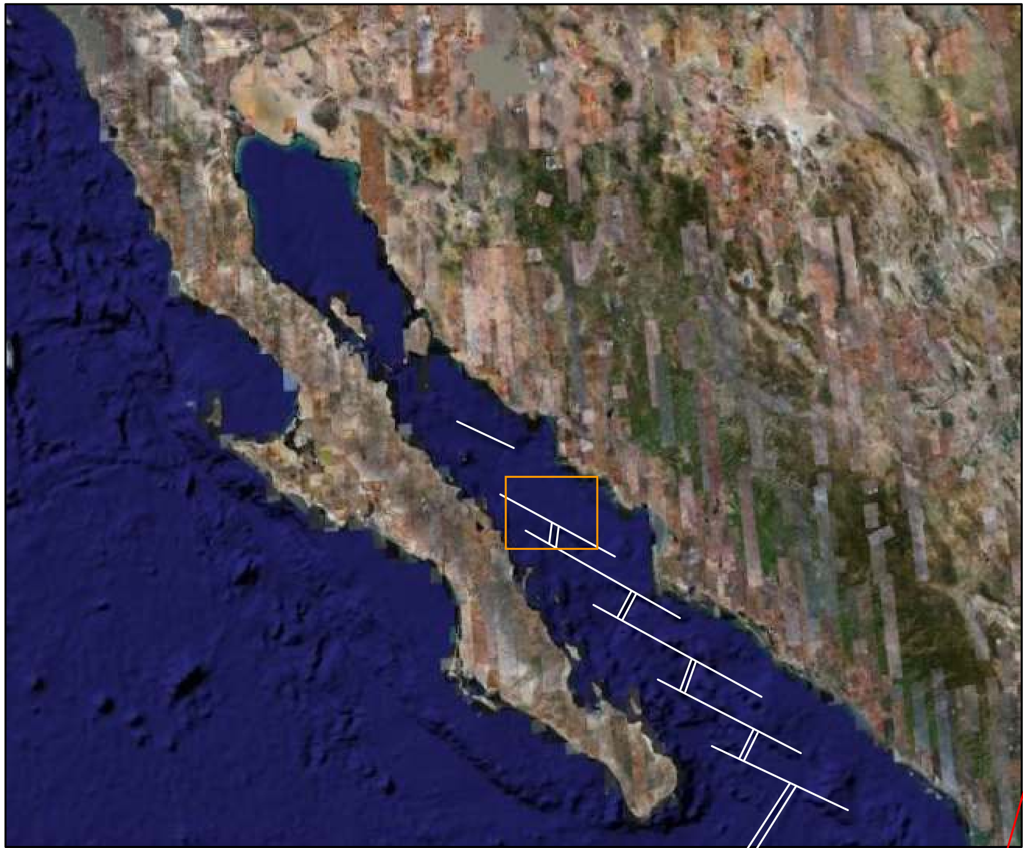


Petroleum generation in hydrothermal systems: the mechanism

(Simoneit, 1988; Simoneit et al., 2000)

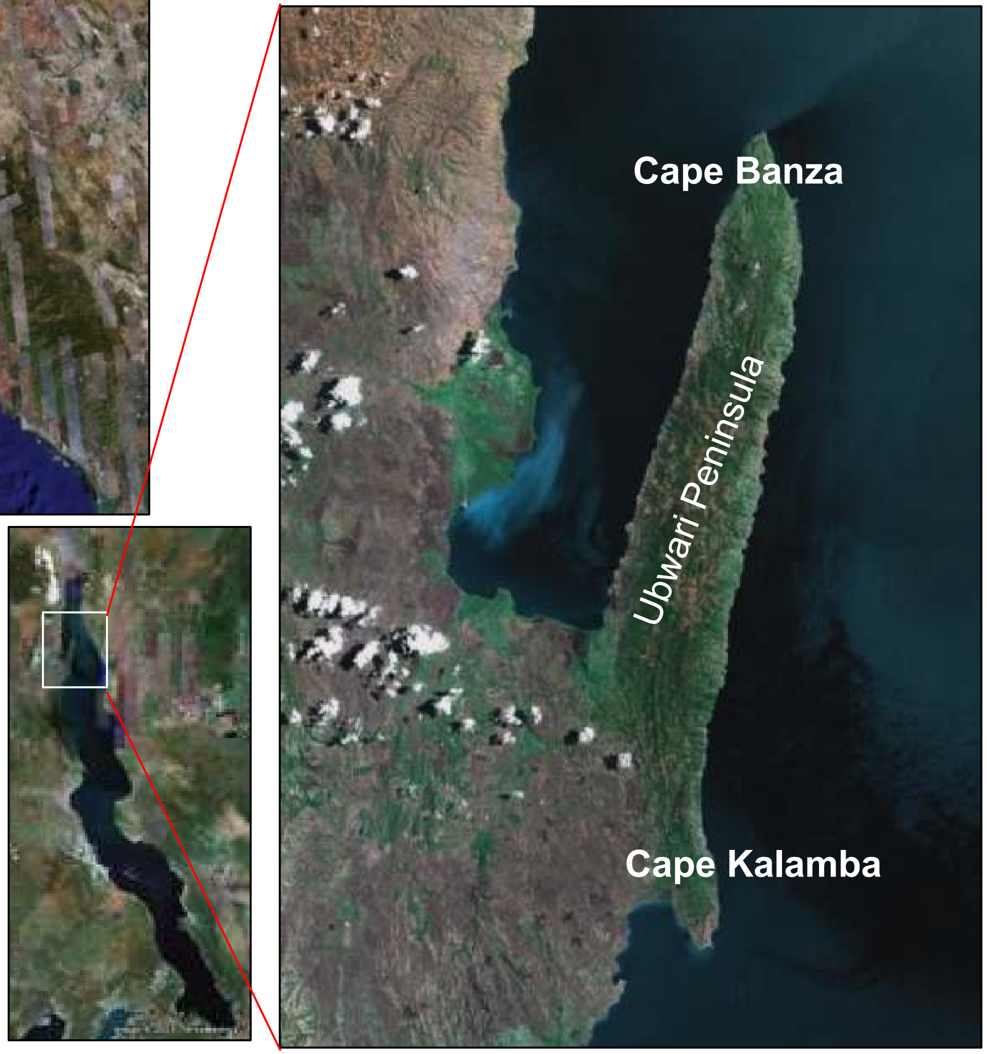
- The source of petroleum is bacterial and bacterially-degraded algal biomass, found at the bottom of the sea or lake. The organic material comprises lipids (terrigenous & marine), fulvic & humic acids, cell membranes, terrestrial carbonaceous material and some biogenic gas.
- A hydrothermal vent can provide high temperature fluids that "cook" the organic material "instantaneously" (within 1000-30 000 years) in a single step (instead of three), producing liquid petroleum.
- In the case of Lake Tanganyika, the source rock is Pleistocene lake sediments, 25,600 years old. The temperature of the hydrothermal fluids is less than 200º C. The generated petroleum floats to the lake surface, where it forms an extensive oil slick.
- The petroleum products are very similar to the ones produced by the thermogenic method, apart from the larger amount of polyaromatic compounds and of sulphur. They migrate away from the heat source mainly in solution in the hydrothermal water.
- The combination of a *methane* source (to provide the nutrition for bacteria) and a *hydrothermal spring* (to provide the maturation) is the ideal situation for hydrothermal petroleum. Active continental rifts are environments that satisfy these conditions.
- Sites in the world where hydrothermal petroleum has been found include the East African Rift lakes, Gulf of California, as well as active spreading centres on the East Pacific Rise and Mid-Atlantic Ridge.

Hydrothermal petroleum generation



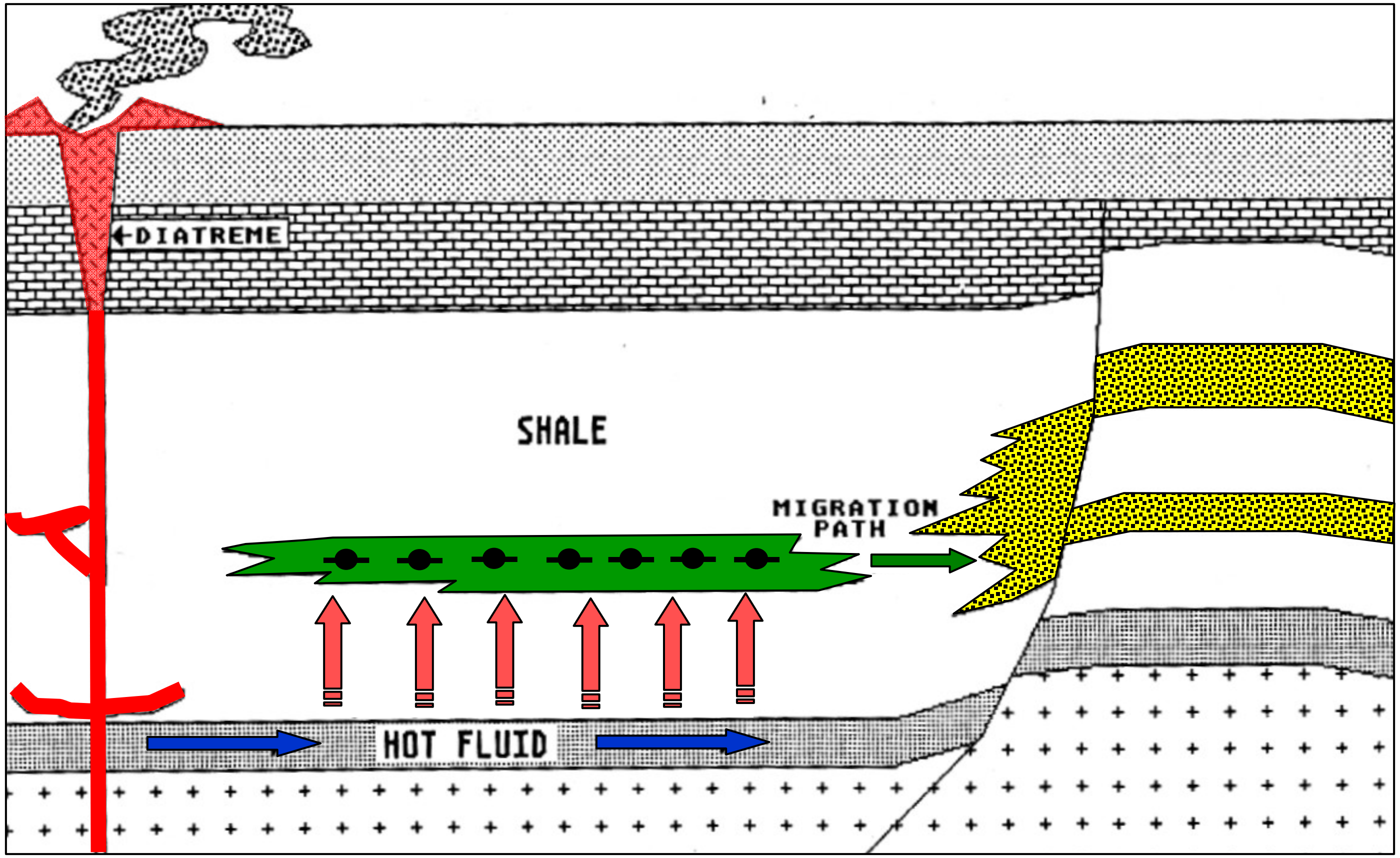
Guaymas Basin (a spreading ridge in the Gulf of California)

Northern Tanganyika Lake, Cape Kalamba oil seeps



b. Hydrocarbon generation from a source rock heated by hot fluids in a hydrothermally-affected basin

(Bruce *et al.*, 1999)

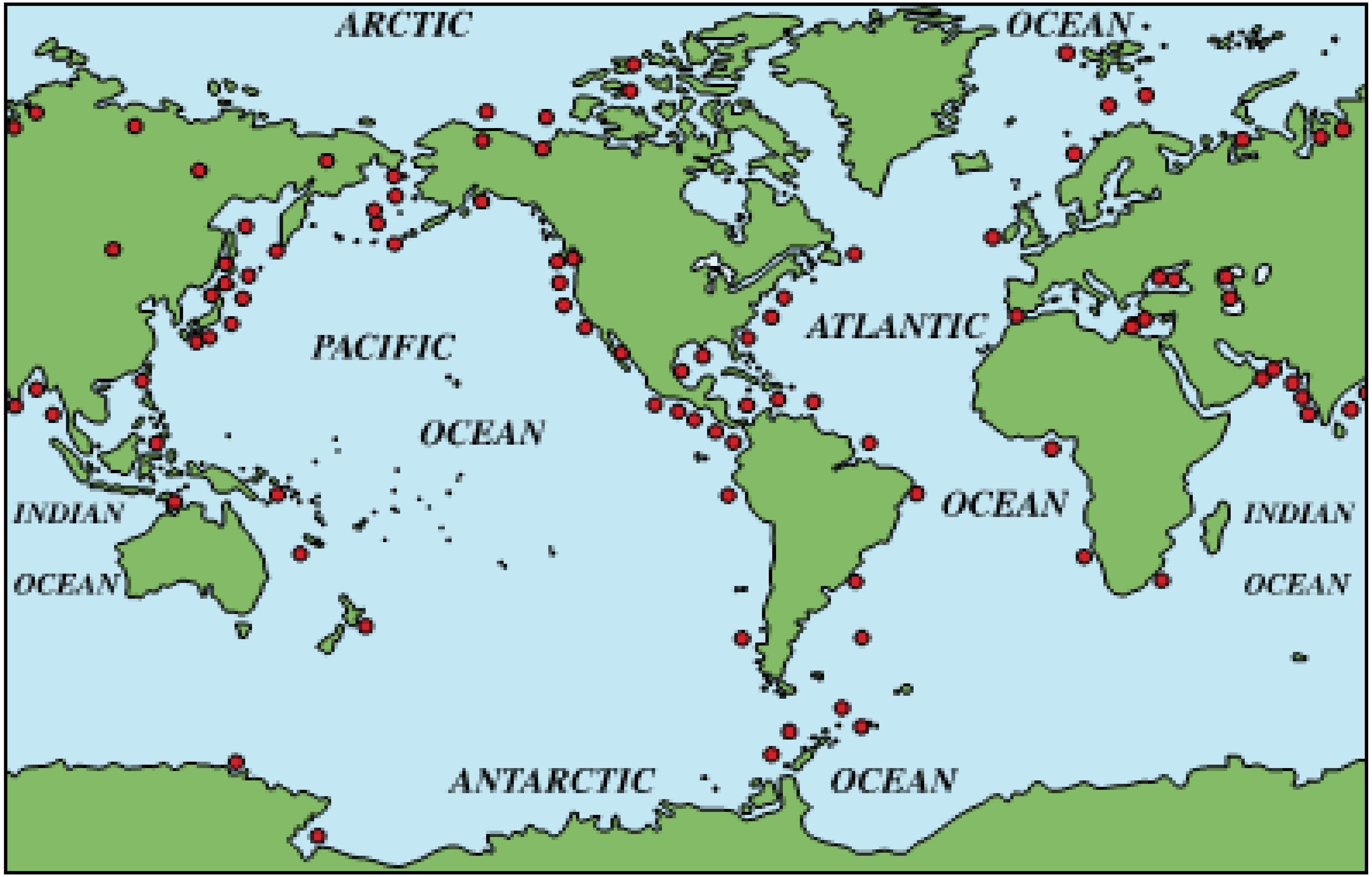


Hydrothermal modelling indicates that **organic-rich rocks up to 200 m away from hot fluids flowing in a porous layer, can be heated enough (200º C) to promote hydrocarbon generation in times of the order of thousands of years.**

Example: a 20 m-thick source rock is buried at 3 km depth in a basin with 30º C geothermal gradient and lies 200 metres above a hot porous bed. After 1000 years, the temperature of the source rock will be approximately 200º C.

6) Gas (methane) hydrates

LOCATION OF POSSIBLE GAS HYDRATES FIELDS



Source: the Global Warming Policy Foundation website

- **Gas hydrate (*clathrate* or *methane ice*) is a crystalline solid consisting of gas molecules, usually methane. Each molecule is surrounded by a cage of water molecules. It looks very much like water ice. Methane hydrate is stable in ocean floor sediments at water depths greater than 300 meters.**

- **Extremely large deposits of methane hydrate have been found in sediments under the ocean floors of the Earth. Gas hydrates give a very characteristic seismic reflection, which mimics the reflection from the ocean floor (*Bottom Simulating Reflector*, BSR)**

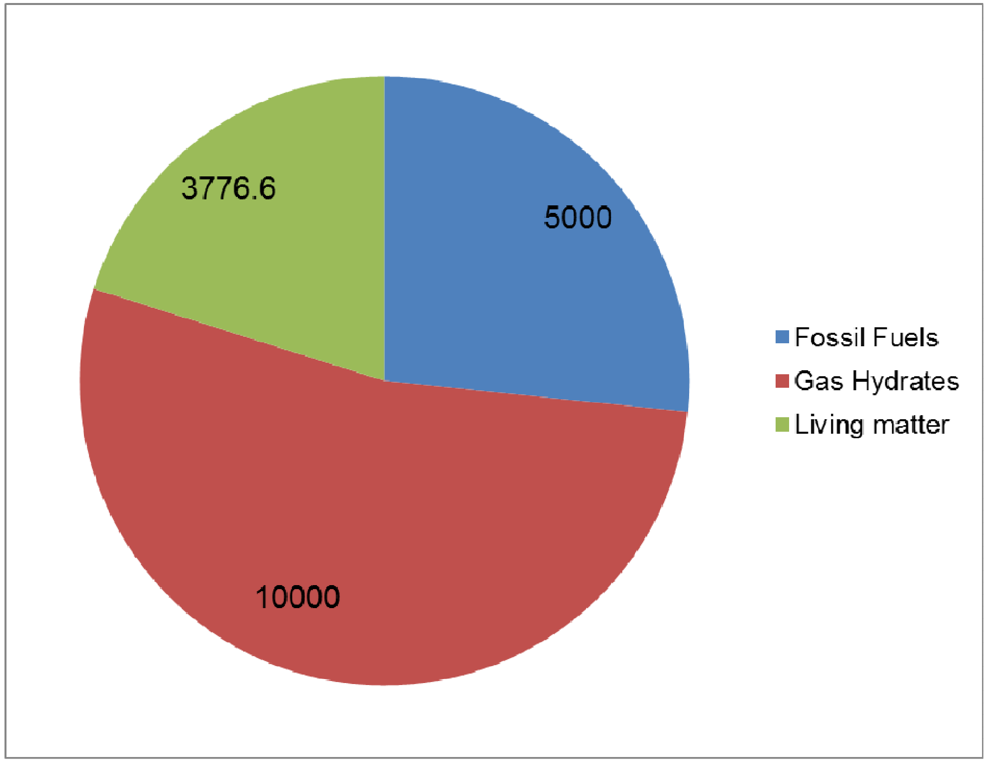
- **Gas hydrates are commonly found in the shallow marine sedimentary succession. They occur both in deep marine locations and as outcrops on the ocean floor. Methane hydrates form (i) by microbial action in the shallow sedimentary section; and, (ii) by migration of thermogenic gas along faults, followed by crystallization of the rising gas molecules by cold sea water. In oceanic gas deposits, only ~1% of the total volume of the unit is gas hydrates. The remainder is composed of sediment.**

- **Necessary conditions for the formation of gas hydrates are found in polar continental regions where surface temperatures are less than 0 °C (permafrost), as well as in the oceans at water depths greater than 300 m, where the bottom water temperature is around 2 °C. Continental deposits have been located in Siberia and Alaska, both in sandstones and siltstones at depths less than 800 m. Oceanic deposits seem to be widespread on the continental shelves**

Types and reserves of oceanic gas hydrate deposits

1) The first type consists mostly (> 99%) of methane, derived from bacterial reduction of CO_2. These deposits are located within a depth zone around 300-500 m (the *Gas Hydrate Stability Zone*).
2) The second type contains a higher proportion of wet gas. Methane has been generated both by bacterial decomposition of organic matter, as well as from katagenesis. Examples of this type of deposits have been found in the Gulf of Mexico and the Caspian Sea.

Global estimates range between 1770 TCF - 3530 TCF. In the majority of regions, however, deposits are considered too dispersed for economic extraction. Development of a specialised technology for extracting methane from the gas hydrate deposits is still under research.



Distribution of organic carbon in Earth reservoirs (not including carbon in rocks and sediments). Numbers in *gigatons of carbon*

7) Bacterial gas

• Bacterial gas is formed at shallow depths and low temperatures by anaerobic bacterial decomposition of sedimentary organic matter. The maximum temperature of bacterial life is about 60°-80°C and the size of the pores they need to survive ranges between 0.2-2 microns.

• Bacterial gas is very “dry” (i.e., it consists almost entirely of methane). In contrast, thermogenic gas can contain significant concentrations of "wet gas" components (ethane, propane, butanes) and condensate (C5+ hydrocarbons).

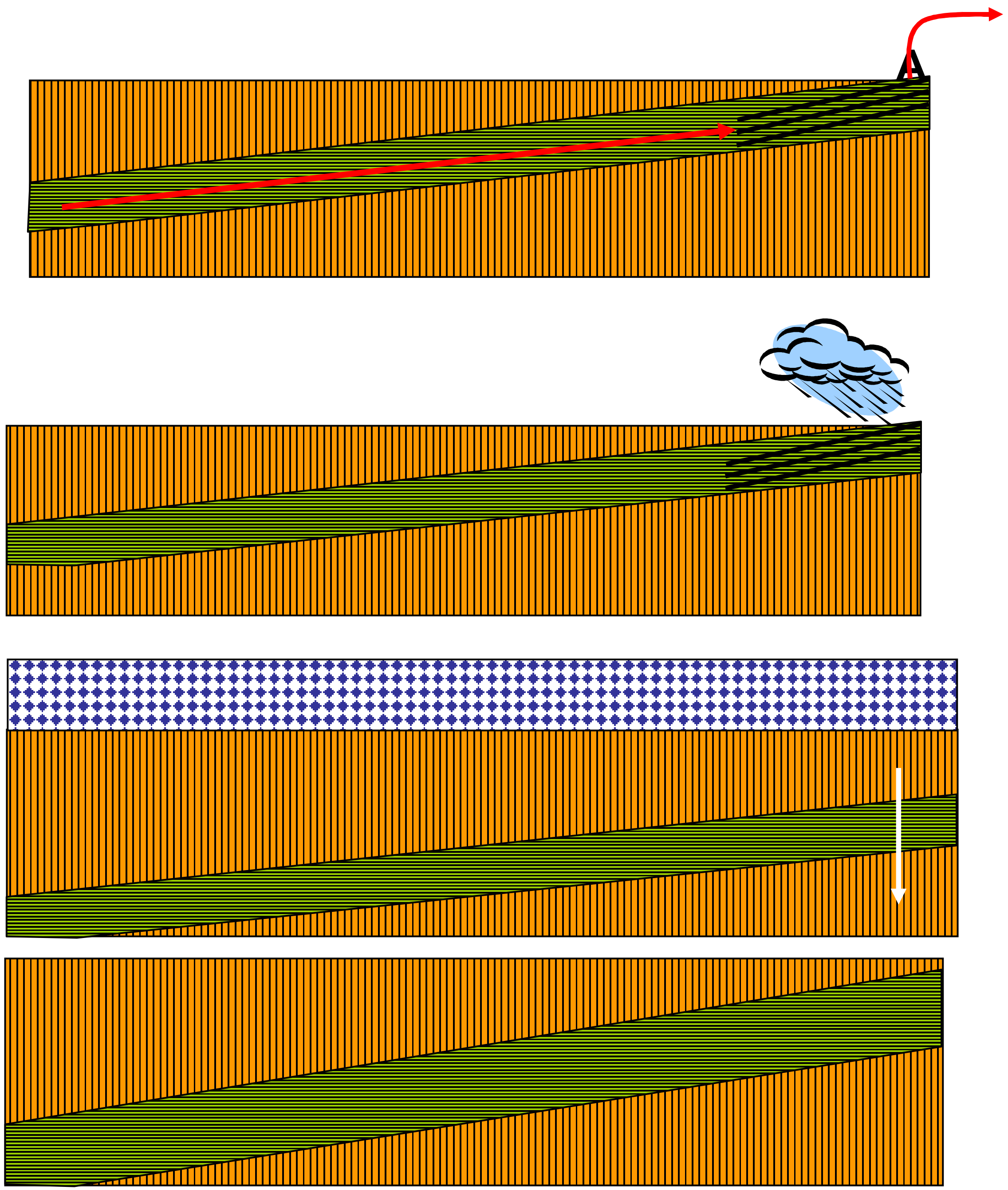
• In numerous cases, bacterial gas occurs in sufficient quantities to be economically produced solely for the gas value. In fact, bacterial (“biogenic”) gas accounts for as much as 20% of the world's natural gas resource

• Bacterial gas can only accumulate as a free-gas phase. A free-gas state results when bacterial gas generation exceeds the gas solubility in the pore waters, or when gas exsolution from pore water is caused by reduction of the hydrostatic pressure. Exsolution of gas can be a consequence of falling sea level or uplift and erosion. Gas saturation of formation waters can only occur at shallow depths (<1200-2000 m).

• Shallow bacterial gas falls into two different categories: (i) Early-generation gas accumulates soon after deposition of reservoir and source rocks. The bacteria may exist in either sandstones or claystones. Early biogenic gas traps have a blanket geometry, following the shape of the rock unit it belongs; (ii) Late-generation gas accumulations have ring-like geometries, often at the edges of the basin. Long time intervals separate deposition of reservoir and source rocks from gas generation.

• The small sizes of the bacteria result in high production of bacterial gas in most clastic sediments, even with very small pores.

THE ANTRIM & NEW ALBANY BIOGENIC SHALE-GAS FORMATION



5. SHALLOW BIOGENIC AND THERMOGENIC GAS PRODUCTION FROM THE BLACK SHALES.

4. METEORIC WATER INTRODUCES BACTERIA INTO THE FRACTURES OF THE BLACK SHALE

3. POST-GLACIAL REBOUND OF THE BLACK SHALE, FORMATION OF FRACTURES IN THE SHALES

2. DEEP BURIAL OF BLACK SHALE HORIZON DUE TO ICE CAP

1. TILTING OF BLACK SHALE HORIZON