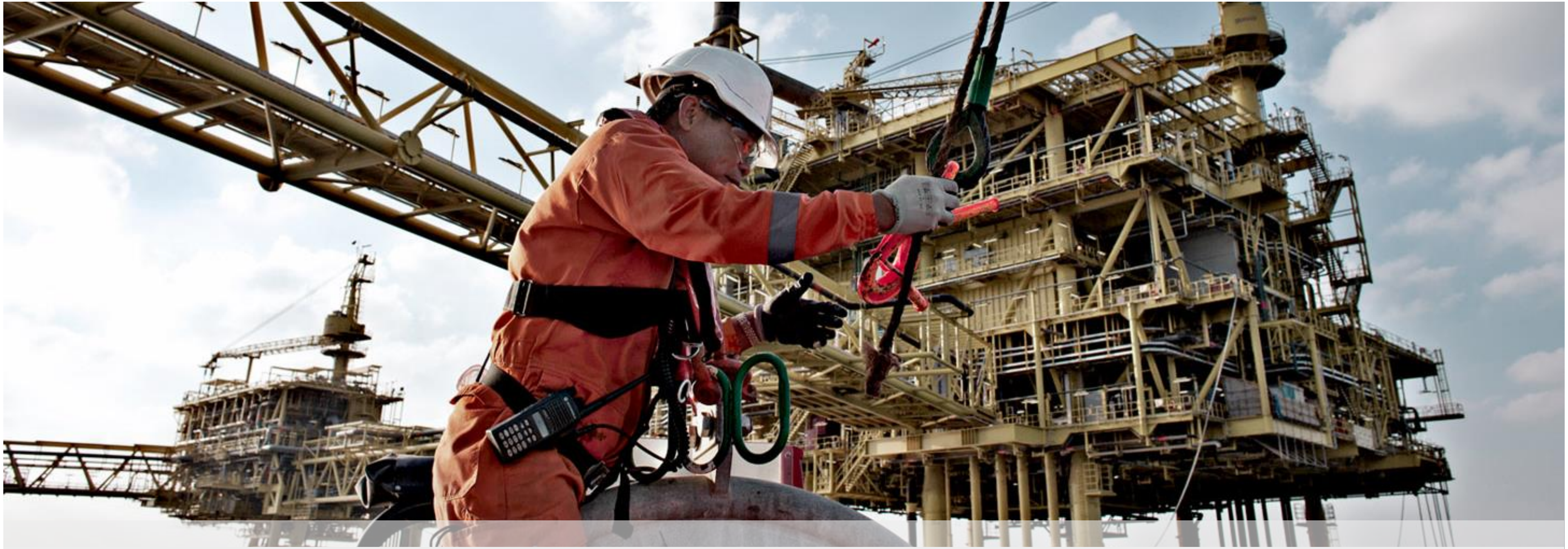


Where is the oil coming from

18.06.2013

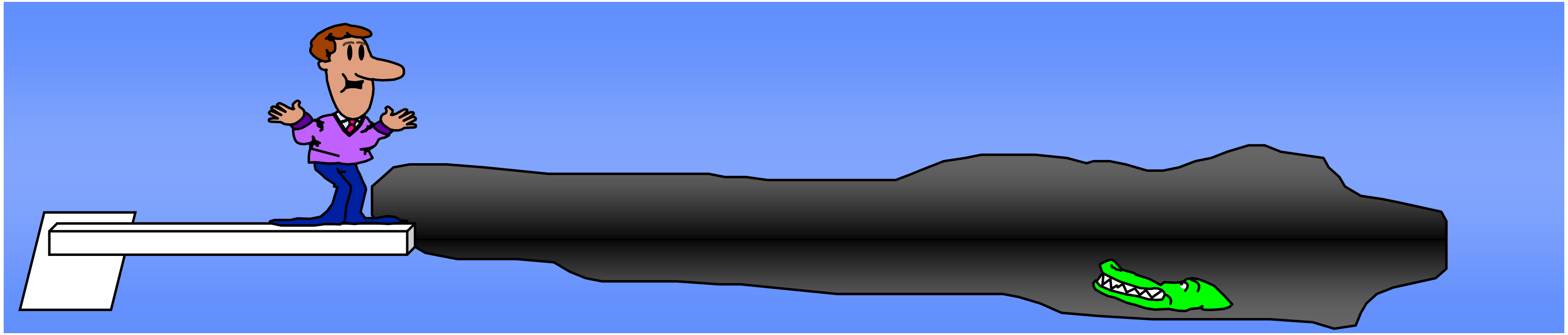
MINSC Workshop

Finn Engstrøm / Global Production Development

MAERSK OIL

Where does the oil come from?

Or does oil come from big underground oil pools ?

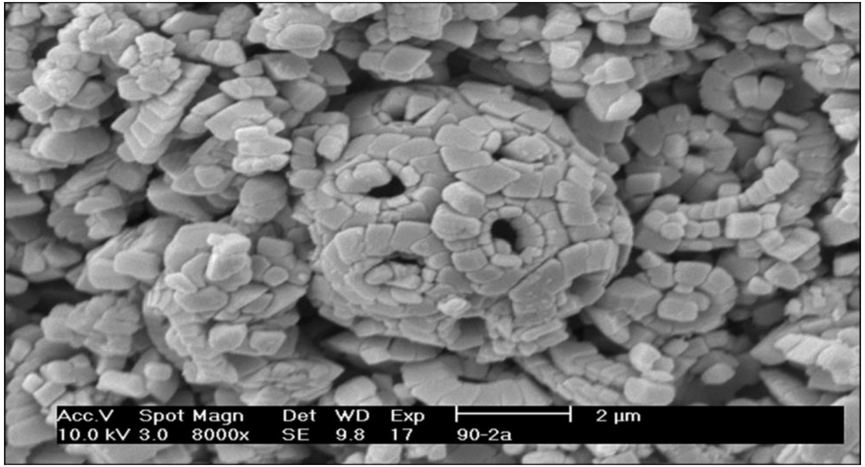


Actually …

Most oil is comes from tiny pore spaces in rocks deep below the surface of the earth

But

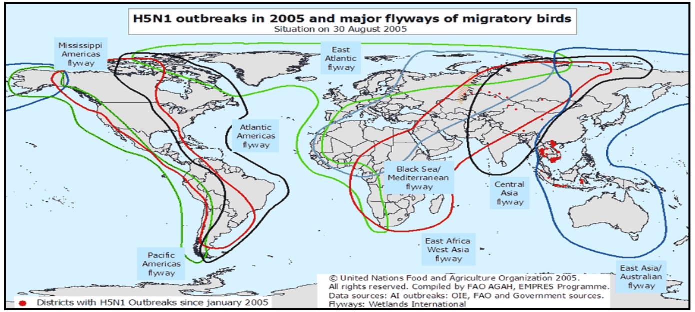
- How did the oil got trapped in the tiny pore spaces,
- How do we find where the oil is deep below the surface of the earth
- How do we get it up

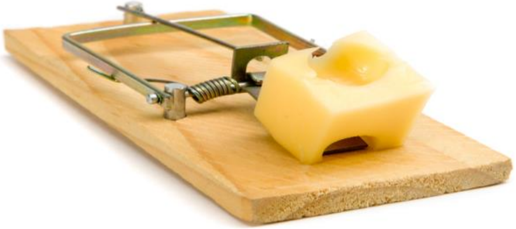


Petroleum System Components

Sourcerock
/Kitchen

Migration
Route

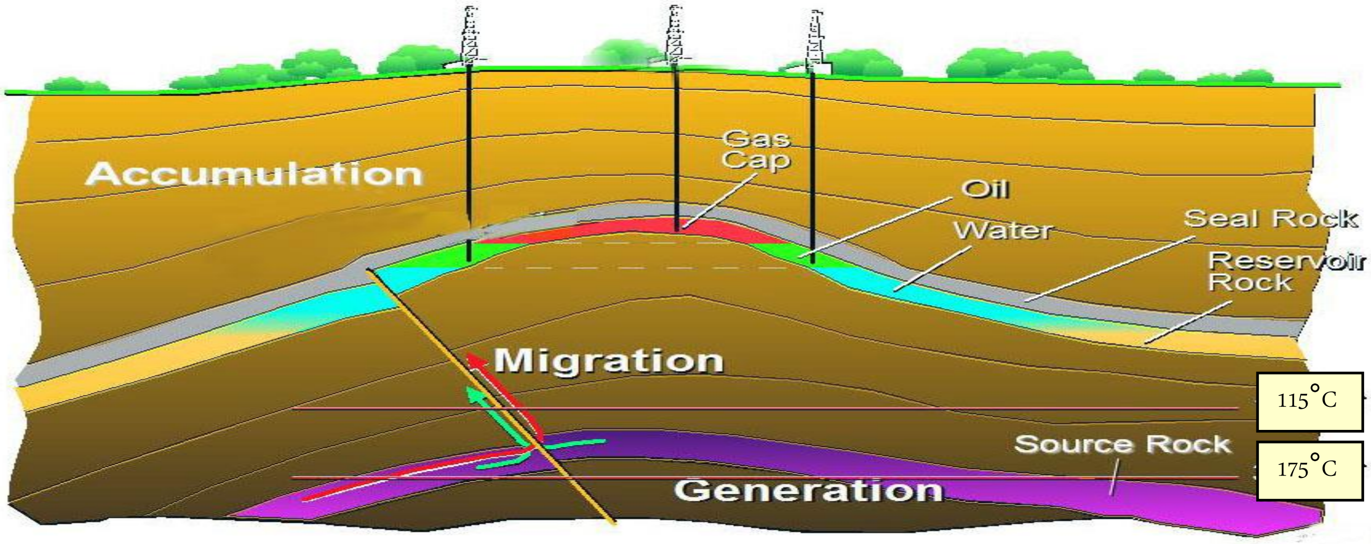




Trap

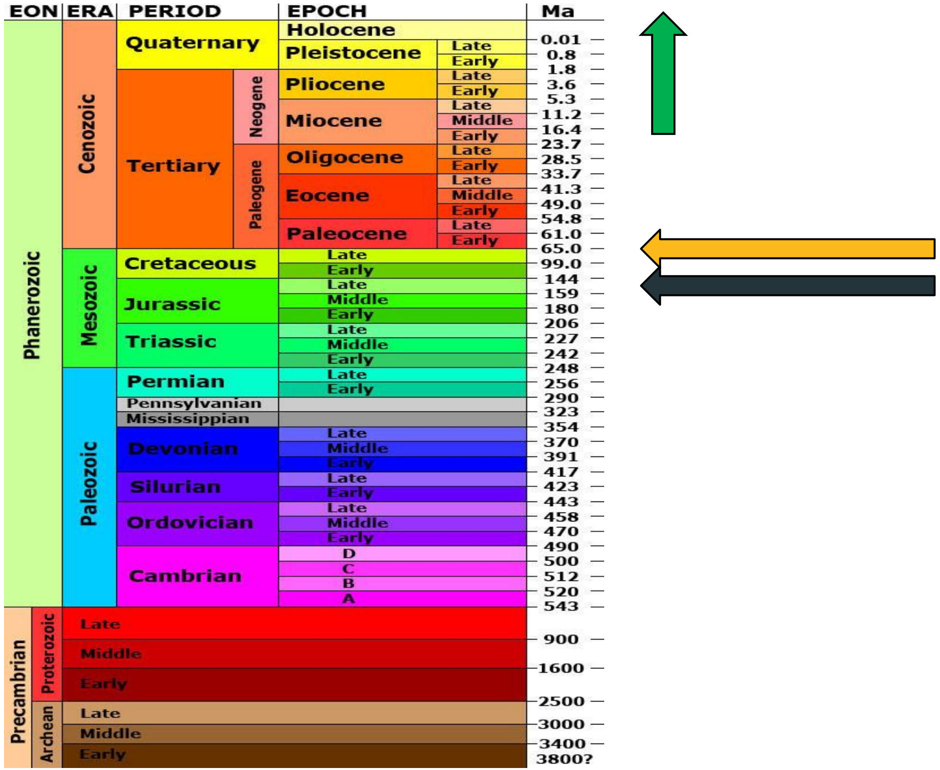
Reservoir

Simple Petroleum System



Source Rock :	Generates Hydrocarbons which migrate through a
Migration Route:	until stopped in a
Trap:	that includes
Reservoir Rock:	of sufficient porosity and permeability to store significant volumes and allow production at a reasonable rate.

But things take time – long time



EON	ERA	PERIOD		EPOCH		Ma
Phanerozoic	Cenozoic	Quaternary		Holocene		0.01
				Pleistocene	Late	0.8
					Early	1.8
		Tertiary	Neogene	Pliocene	Late	3.6
					Early	5.3
				Miocene	Late	11.2
					Middle	16.4
					Early	23.7
			Paleogene	Oligocene	Late	28.5
					Early	33.7
				Eocene	Late	41.3
					Middle	49.0
					Early	54.8
				Paleocene	Late	61.0
					Early	65.0
	Mesozoic	Cretaceous		Late		99.0
				Early		144
		Jurassic		Late		159
				Middle		180
				Early		206
		Triassic		Late		227
				Middle		242
				Early		248
	Paleozoic	Permian		Late		256
				Early		290
		Pennsylvanian				323
		Mississippian				354
		Devonian		Late		370
				Middle		391
				Early		417
		Silurian		Late		423
				Early		443
		Ordovician		Late		458
				Middle		470
				Early		490
		Cambrian		D		500
				C		512
				B		520
				A		543
Precambrian	Proterozoic	Late				900
		Middle				1600
		Early				2500
	Archean	Late				3000
		Middle				3400
		Early				3800?

Oil Migration

Chalk Reservoirs

Jurassic Source Rocks

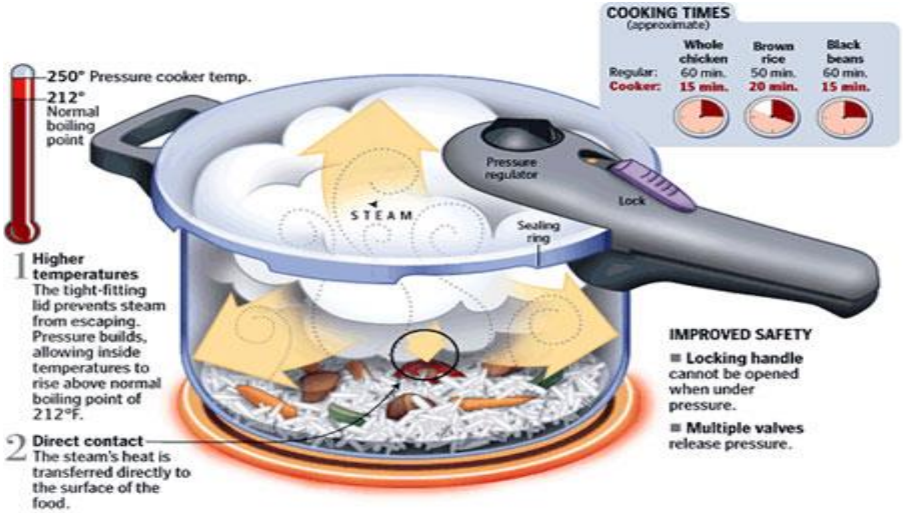
Types of Petroleum

Oil and gas are formed by the thermal cracking of organic compounds buried in fine-grained rocks.

Algae = Hydrogen rich = Oil-prone

Wood = Hydrogen poor = Gas-prone

Pressure Cooker



COOKING TIMES
(approximate)

	Whole chicken	Brown rice	Black beans
Regular:	60 min.	50 min.	60 min.
Cooker:	**15 min.**	**20 min.**	**15 min.**

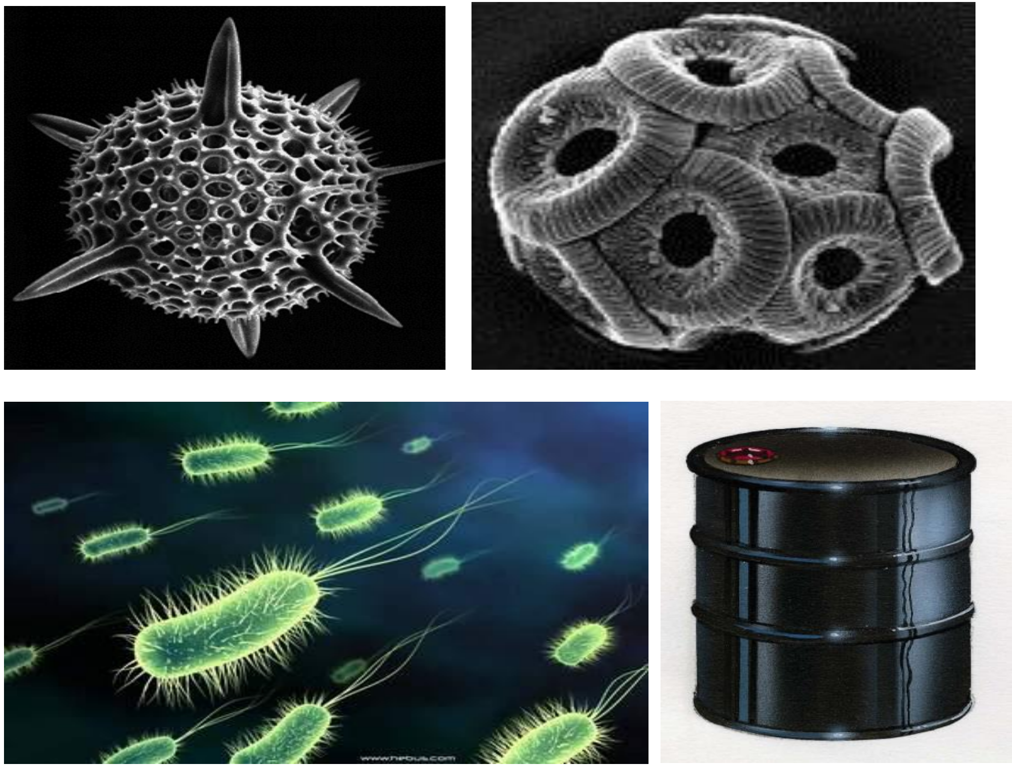
1 **Higher temperatures** The tight-fitting lid prevents steam from escaping. Pressure builds, allowing inside temperatures to rise above normal boiling point of 212°F.

2 **Direct contact** The steam's heat is transferred directly to the surface of the food.

IMPROVED SAFETY

- **Locking handle** cannot be opened when under pressure.
- **Multiple valves** release pressure.

Marine Source Rocks



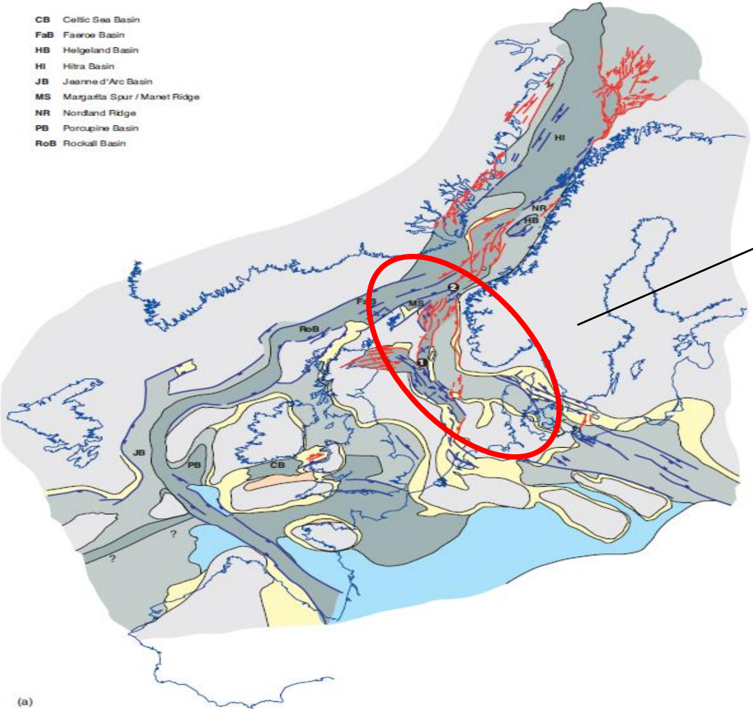
Huge numbers of microscopic organisms accumulate on the ocean floor and if the conditions are right (essentially low oxygen availability) they are preserved and increase the carbon content of the rocks.

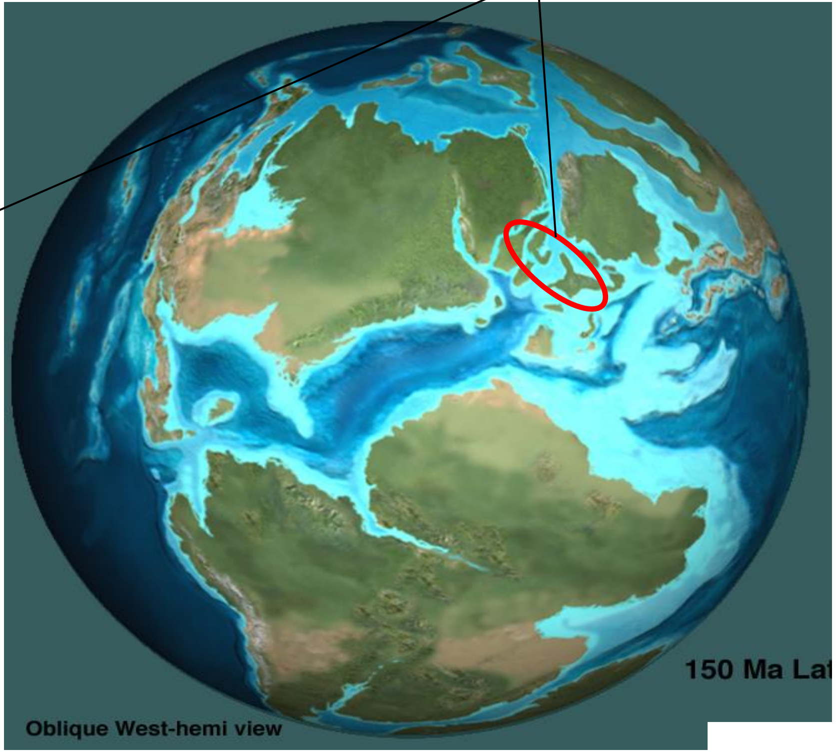
On burial and heating this carbon can be expelled as hydrocarbon.

Marine source rocks are predominantly oil prone.

Late Jurassic

Restricted basin into which the Kimmeridge Clay source rock is deposited



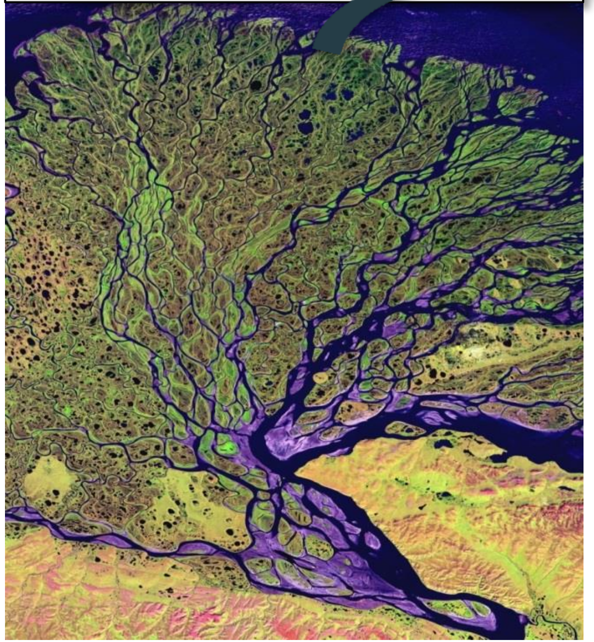


Kimmeridge Shale

The Kimmeridge Shale contain so much kerogene that it may burn

Terrestrial source rocks – responsible for many gas fields

Lena Delta, Siberia



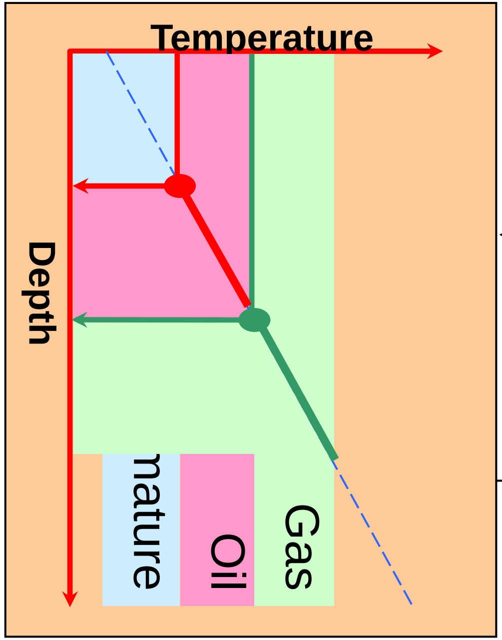
Organic material preserved in swamp areas due to low oxygen content

Produces a predominantly gas prone source rock

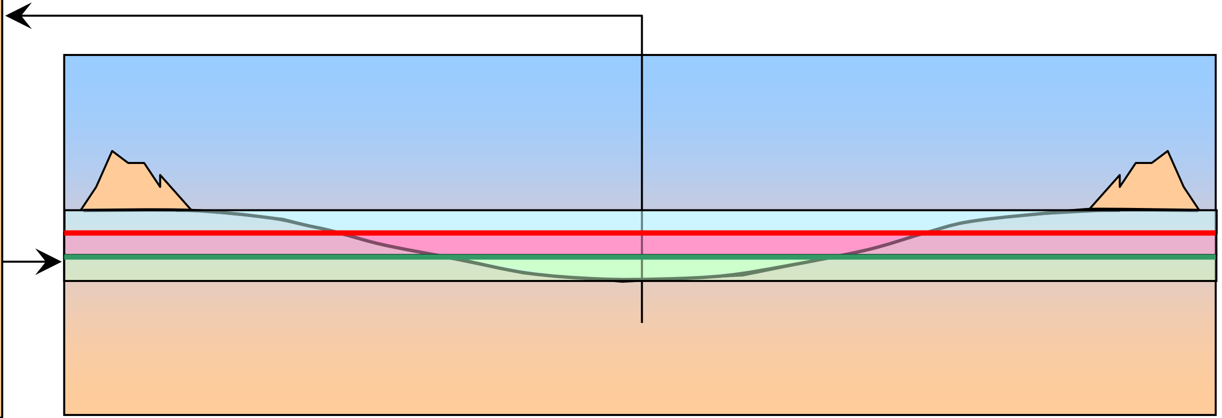
The same setting in the Carboniferous produced much of the worlds abundant coal deposits

Source systems: Generation and Expulsion

With burial over time, increasing temperature and pressure causes source rocks to *generate* and *expel* hydrocarbons



This is often referred to as a source "kitchen" or a "charge system"



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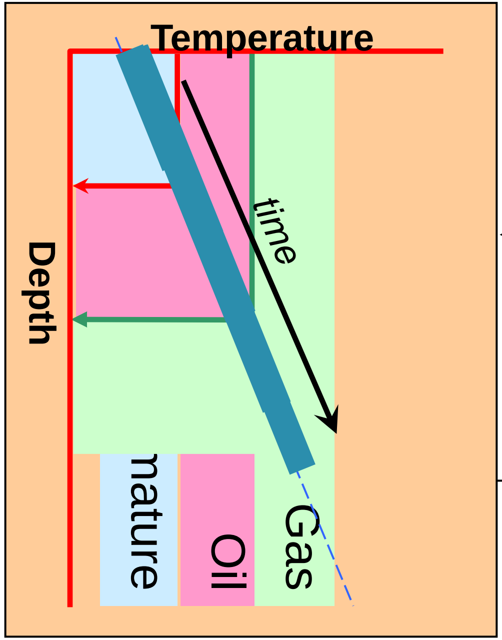
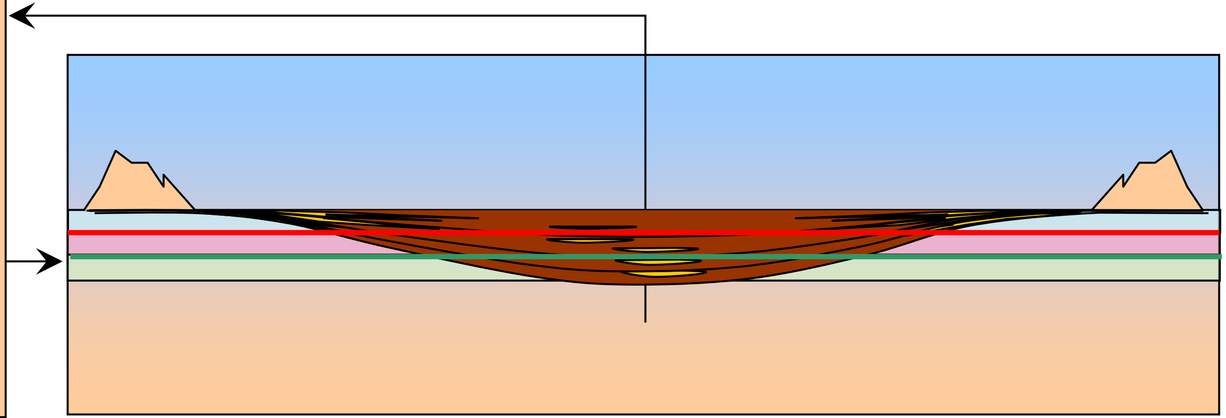
OIL

Source systems: Generation and Expulsion

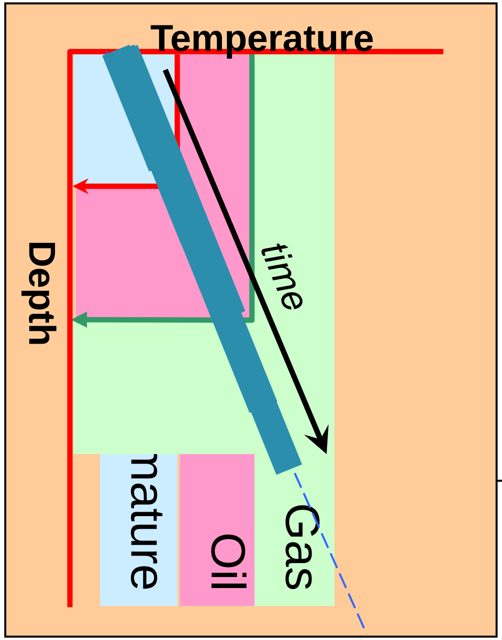
This is a dynamic process and is complicated by continuing subsidence and burial



A unit of rock will progressively pass through the immature, oil mature and gas mature "windows"



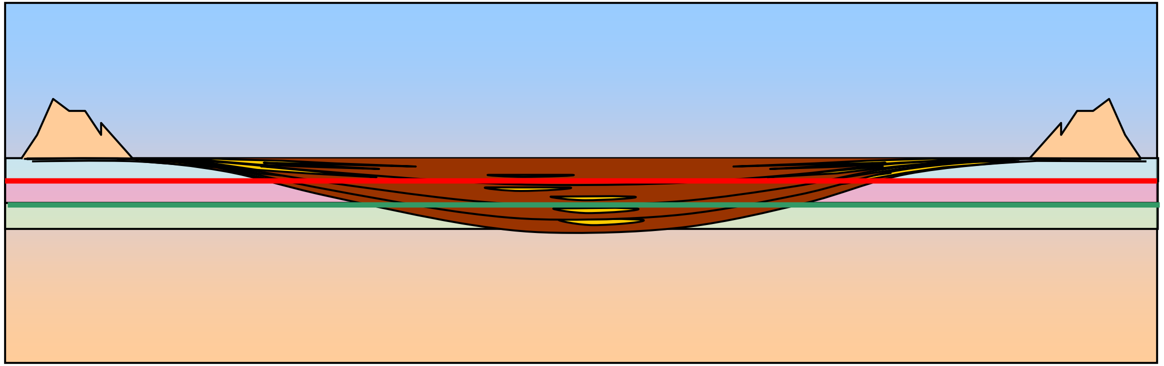
Source systems: Generation and Expulsion



And generate hydrocarbons of increasing *“maturity”*:

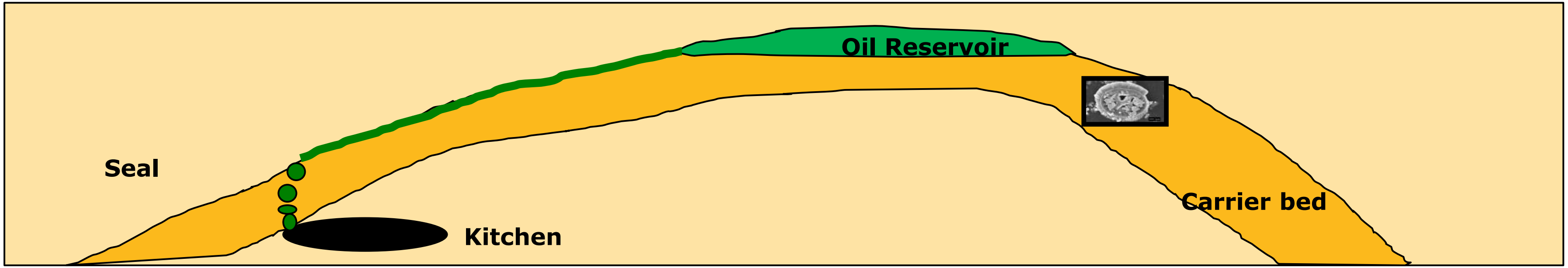
- *Heavy oil*
- *Light oil*
- *Gas condensate*
- *Dry gas*

↓ Increasing *“°API”*



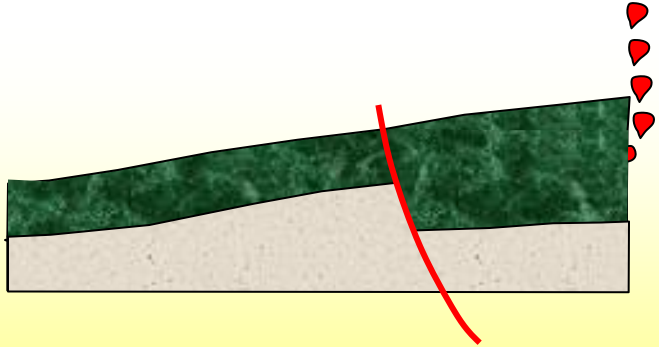
Oil Migration

- Oil is generated in a source rock (kitchen)
- Oil Migrates upwards by buoyancy/pressure differences over time - drop by drop or slug by slug through a carrier bed (migration route)
- Until it is stopped by a ”seal” and the oil is collected in a reservoir rock

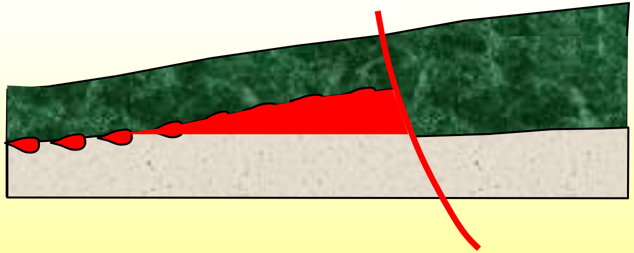


This takes time – Long Time

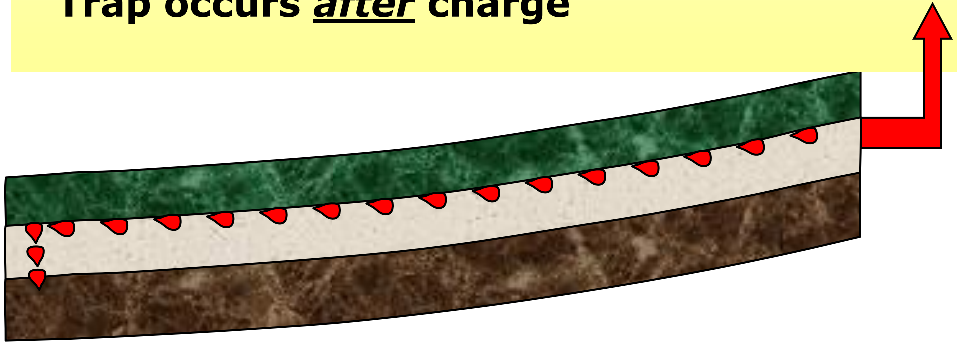
Migration & Trap



Trap occurs *after* charge



Trap occurs *before* charge

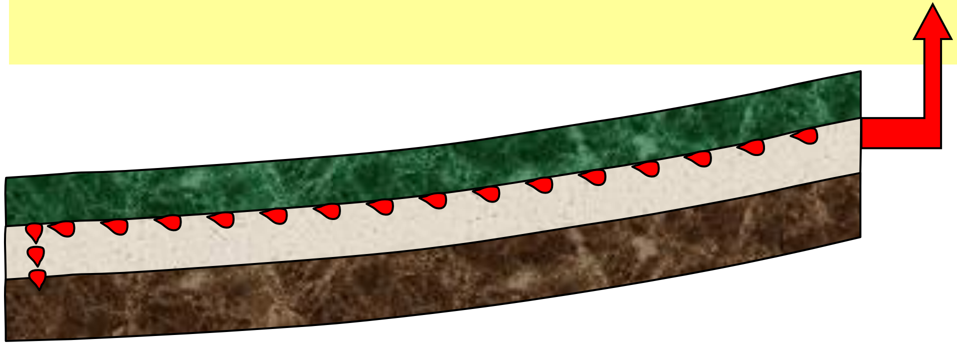


Migration & Trap

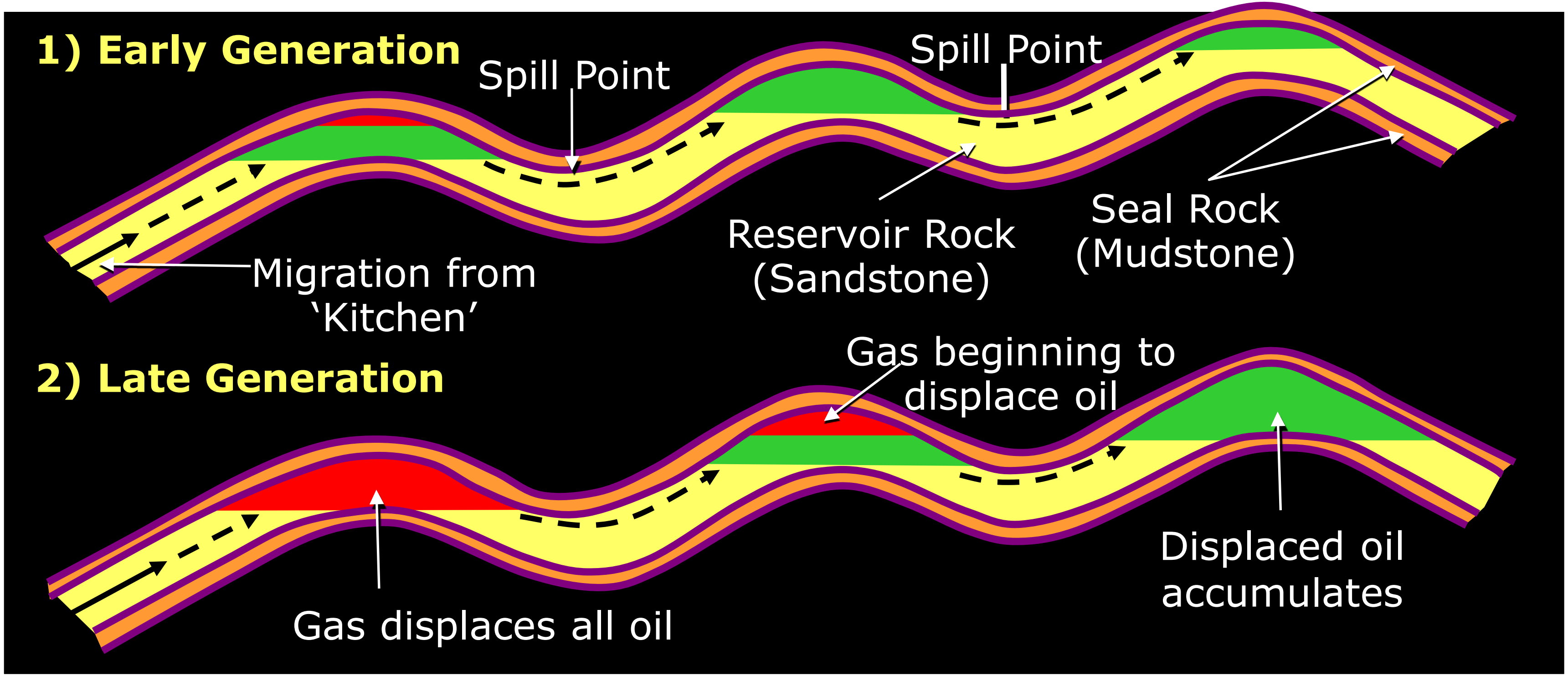
Or they can be stratigraphic:

And can contain oil and gas:

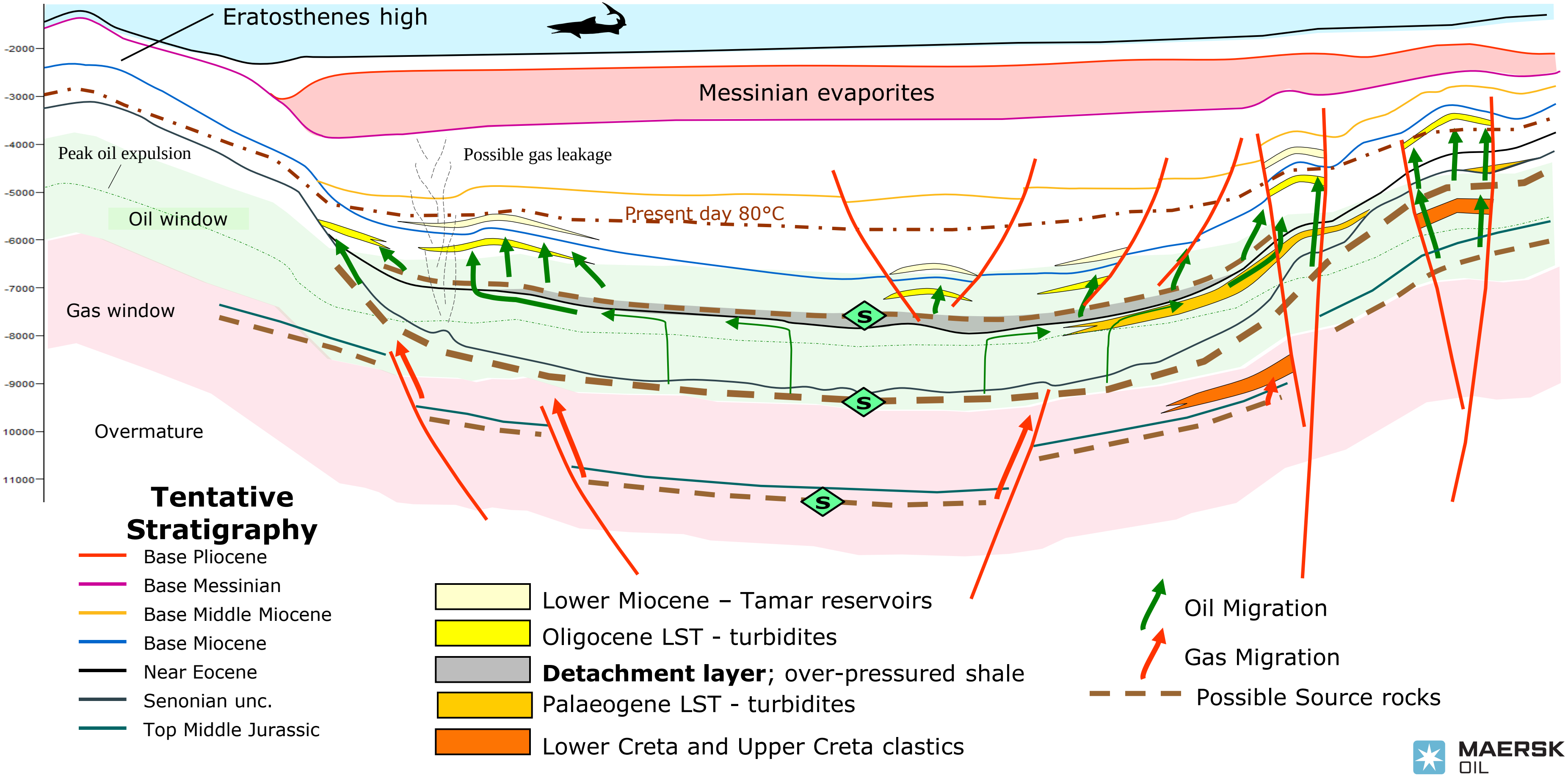
With a corresponding
Gas-Oil Contact (GOC)



Migration – a dynamic entity



Eastern Mediterranean



Tentative Stratigraphy

- Base Pliocene
- Base Messinian
- Base Middle Miocene
- Base Miocene
- Near Eocene
- Senonian unc.
- Top Middle Jurassic

- Lower Miocene – Tamar reservoirs
- Oligocene LST - turbidites
- **Detachment layer**; over-pressured shale
- Palaeogene LST - turbidites
- Lower Creta and Upper Creta clastics

- Oil Migration
- Gas Migration
- Possible Source rocks

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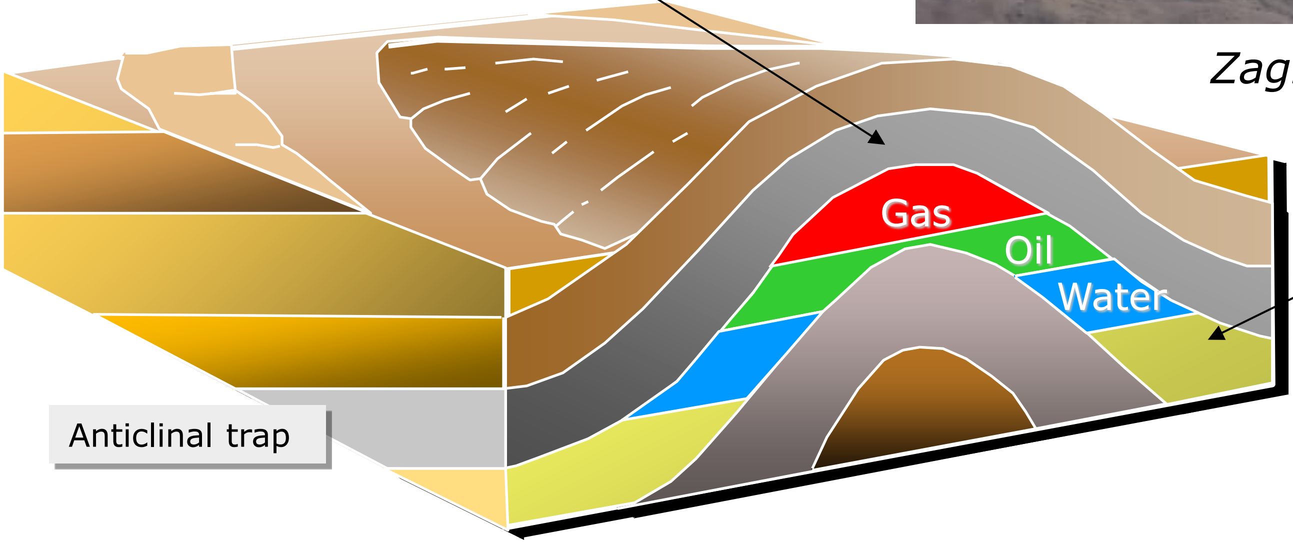
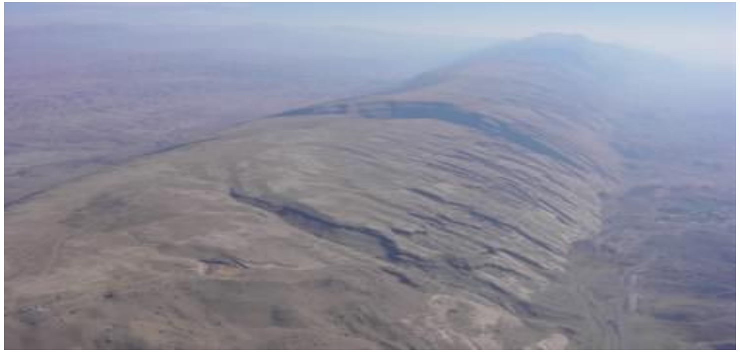
The trap

Represents the focus of migration and the accumulation. These can be structural, stratigraphic or a combination of the two

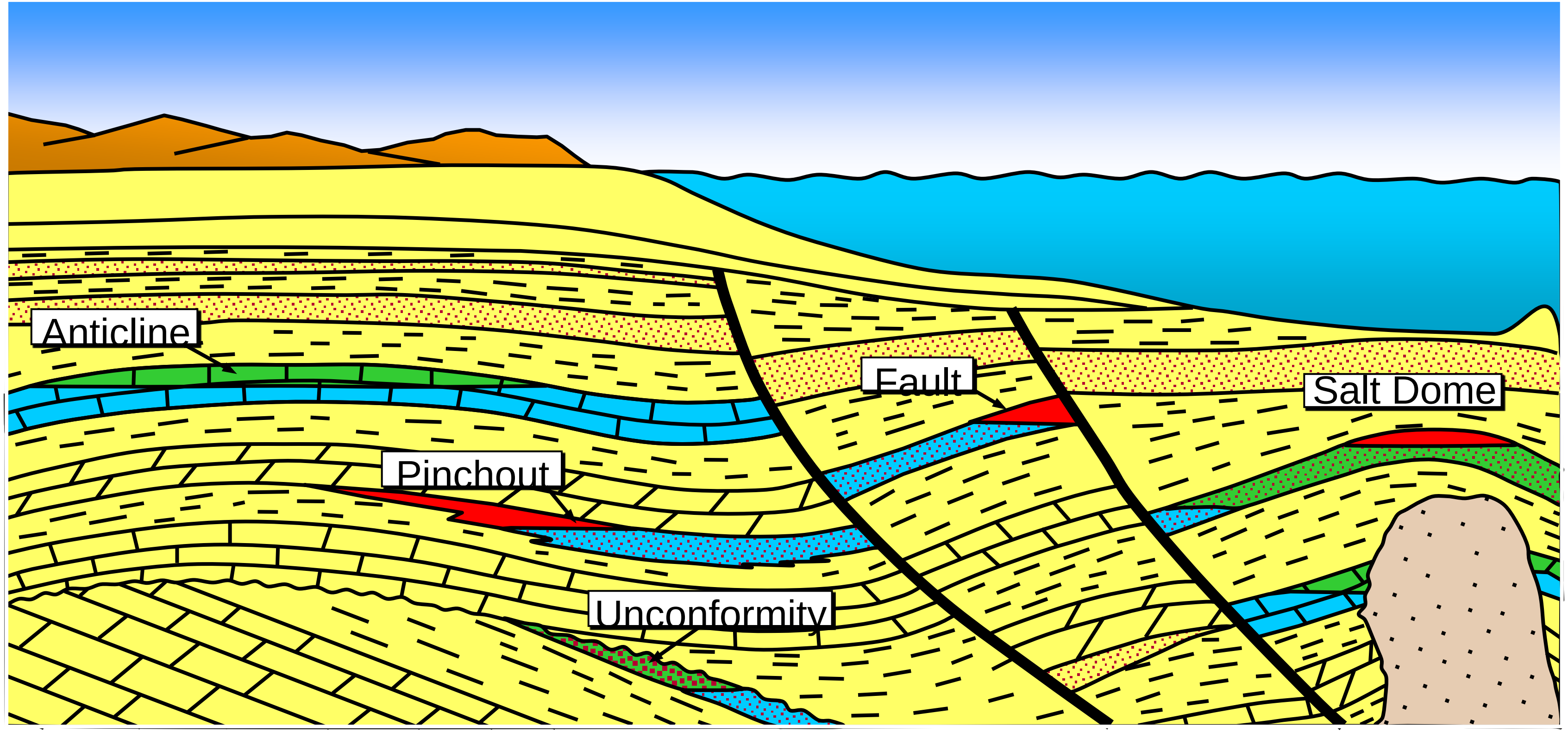

Seals – prevent further migration

Reservoir

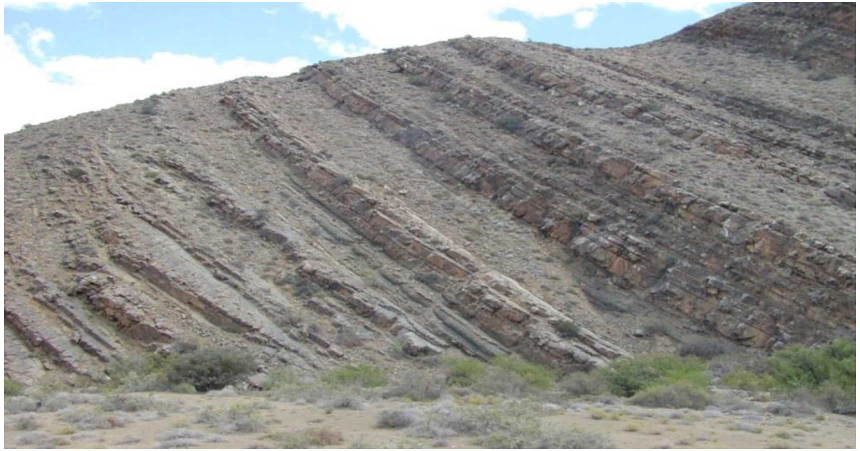
Anticlinal trap

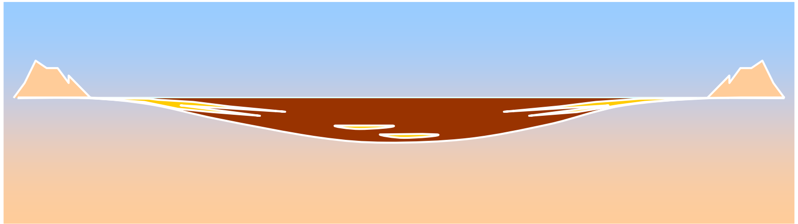

Zagros Fold-belt, Iran

Hydrocarbon Trap Types



The Reservoir

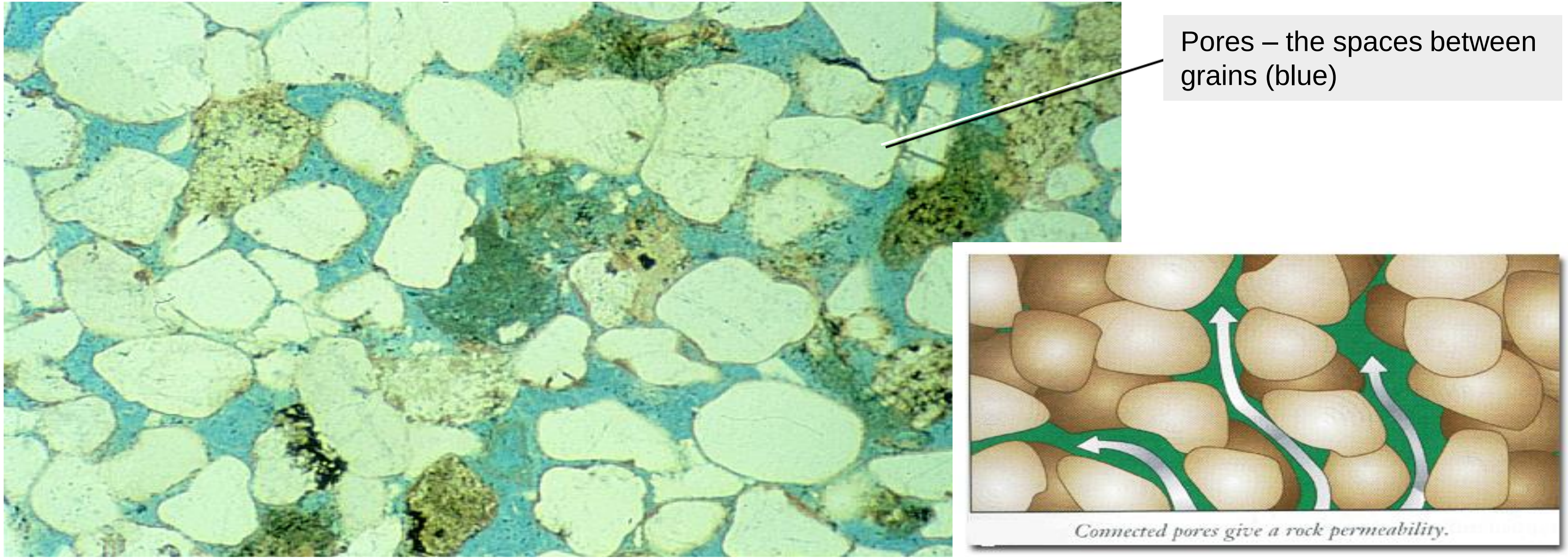




Reservoirs are rocks with *porosity* and *permeability*

Reservoir Sandstone

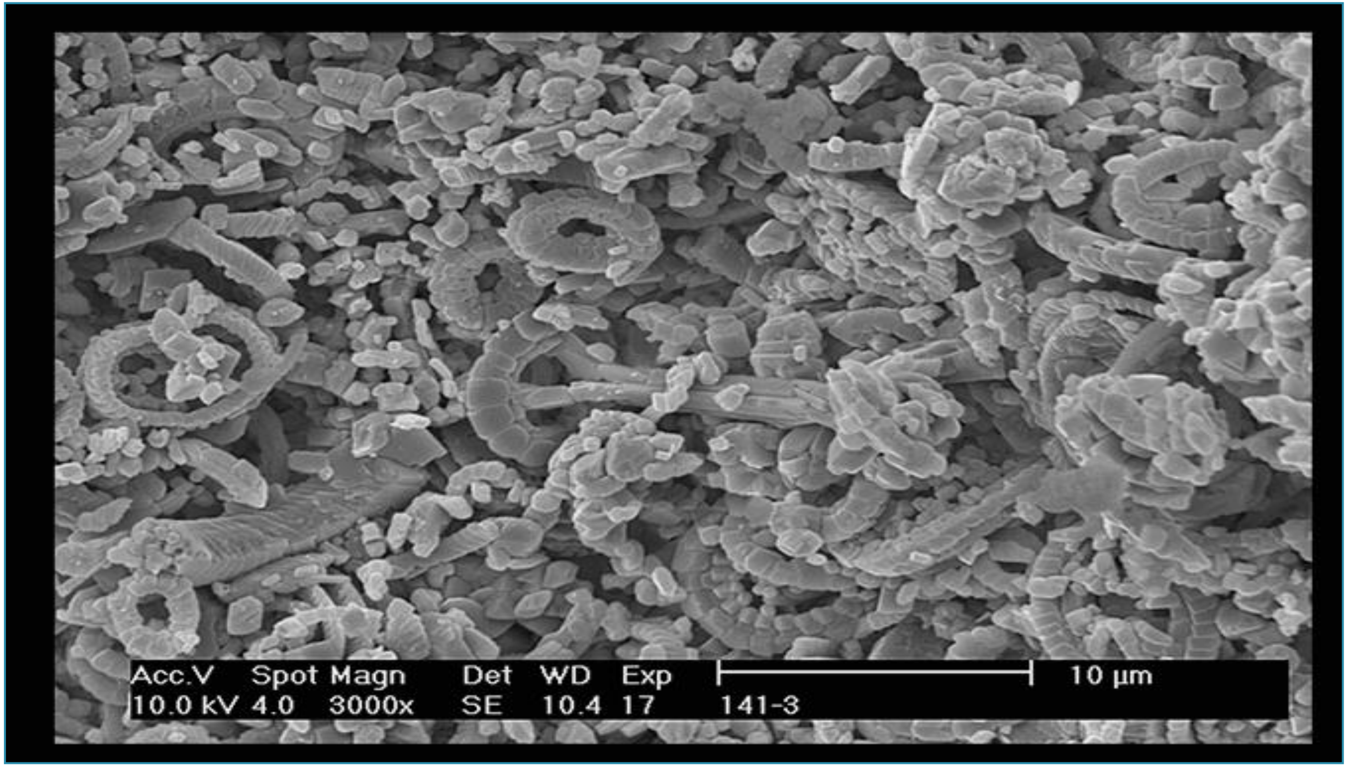
Good Porosity = Lots of Space for Petroleum



Pores – the spaces between grains (blue)

Connected pores give a rock permeability.

Chalk Reservoir



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Chalk and Other Rock Types: petrophysical characteristics

Typical Sandstone/Shale Reservoir

- Permeability contrast between reservoir rock and non reservoir rock is significant
- Few and well defined rock types
- Short transition zones
- OWC = FWL
- Sh = (0; (1-Swir); Sor(w)f)
- Reservoir is in equilibrium

Typical Chalk Reservoir

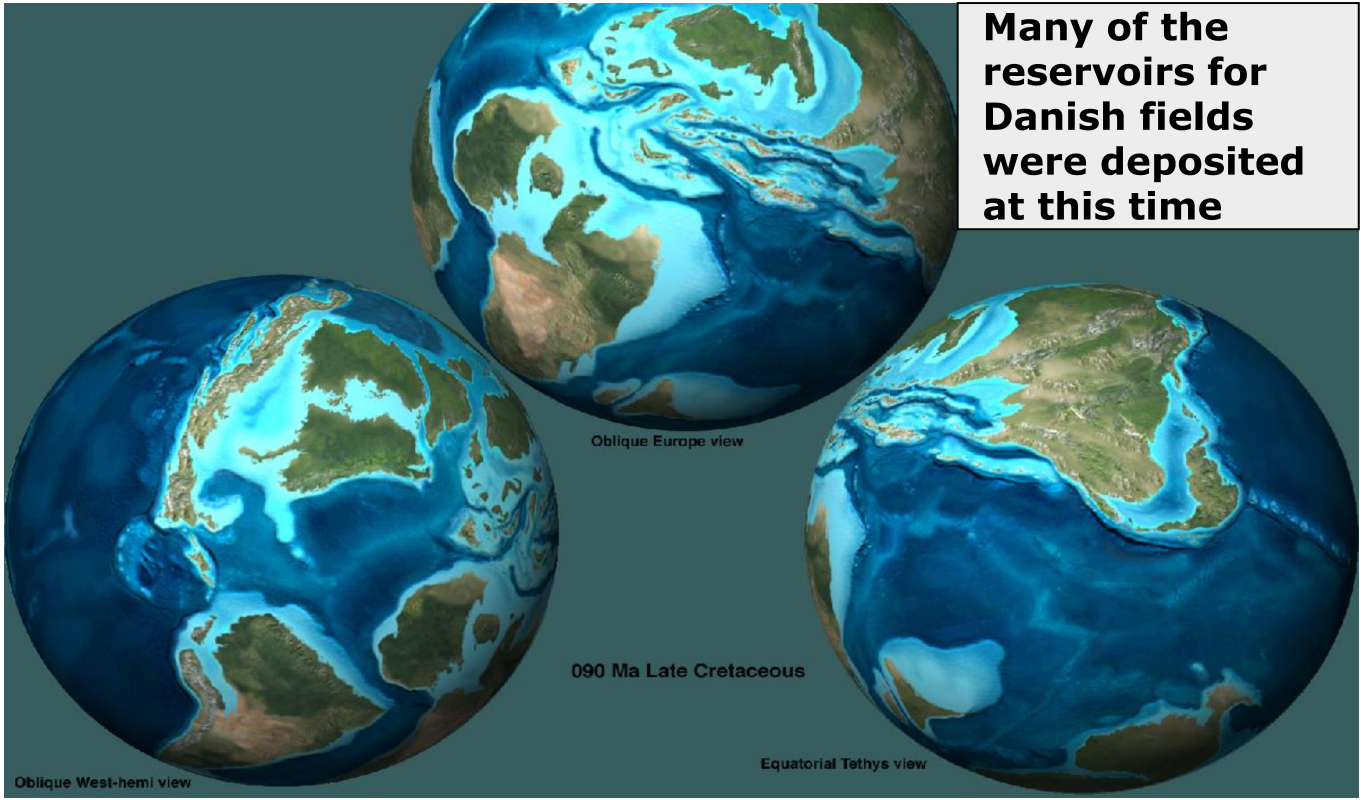
- Permeability contrast between reservoir rock and non reservoir rock is limited
- Continuous rock types
- Long transition zones
- FWL much deeper than OWC
- Sh = (0 -> (1-Swir) or ~ Sor(w)f)
- Reservoir is not in equilibrium

Carbonate Reservoirs

Carbonate reservoirs can have primary porosity (derived at deposition) or secondary porosity (created after deposition by dissolution or fracturing)

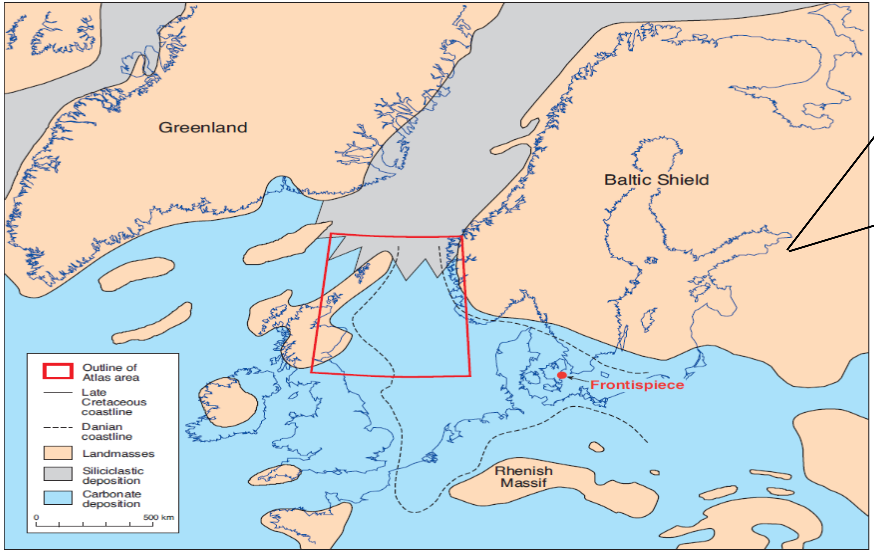
Late Cretaceous reconstruction

Many of the reservoirs for Danish fields were deposited at this time

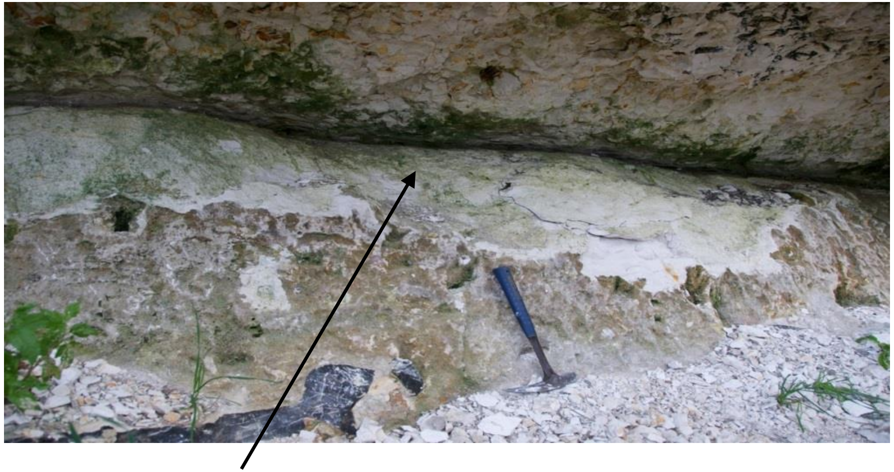


From Ron Blakely website: http://jan.ucc.nau.edu/~rcb7/

Late Cretaceous chalk seas



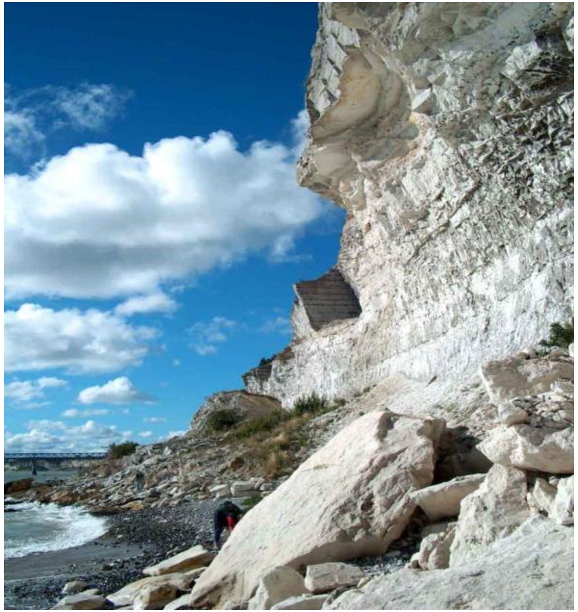
Last day of the Cretaceous – a bad day for dinosaurs…



Cretaceous – Tertiary boundary

Contains high amounts of Iridium – an element very rare in the Earth's crust but abundant in meteorites

North Sea Outcrop Carbonate Examples



Stevns Klint, Denmark

Møns Klint, Denmark

Typical Triassic and Jurassic reservoirs of the North Sea

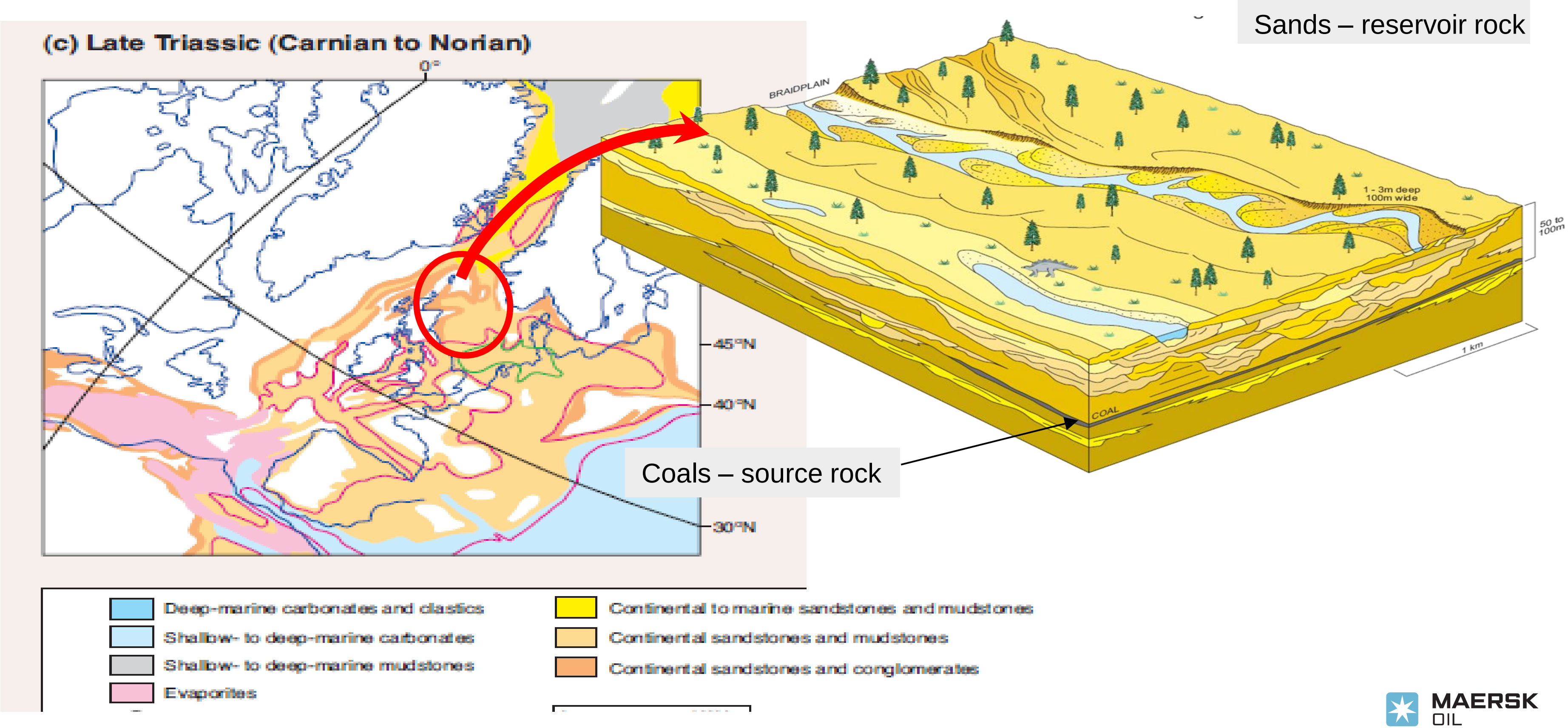
Much of the gas on the NW Shelf is reservoired in rocks deposited in fluvial to deltaic settings.

Braided river

Meandering river

Deltas

Triassic gas fields of the north sea (eg Statfjord)

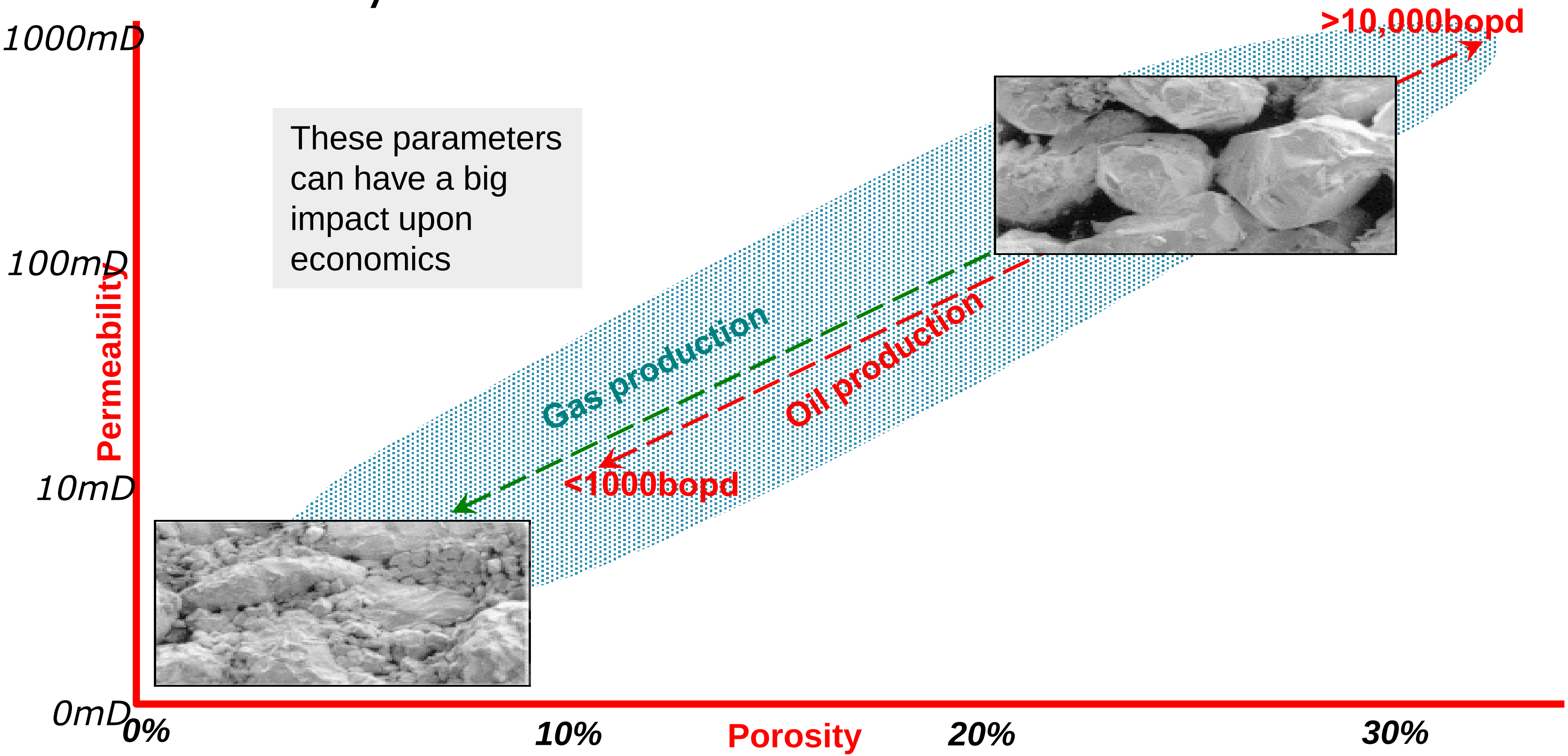


(c) Late Triassic (Carnian to Norian)

Sands – reservoir rock

Coals – source rock

Reservoir systems



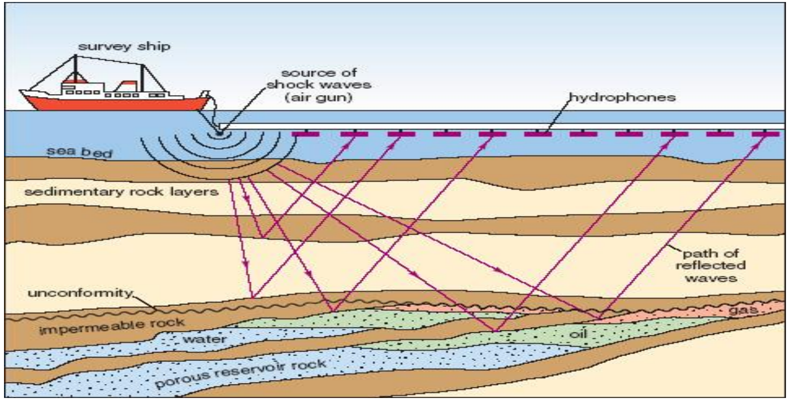
These parameters can have a big impact upon economics

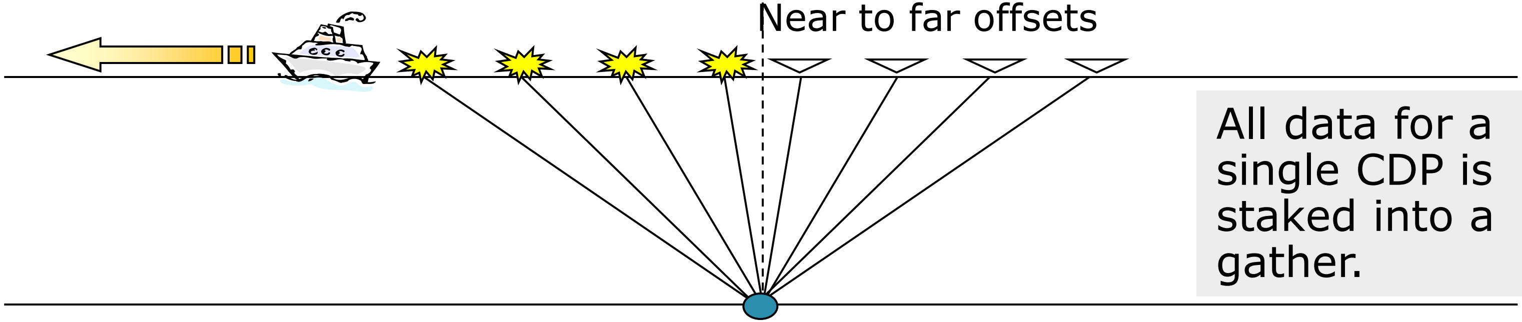
Seismic data – visualising the subsurface

Scale of the operations

Acquiring a marine 3D survey

Marine Seismic Acquisition





Near to far offsets

CDP (Common Depth Point)

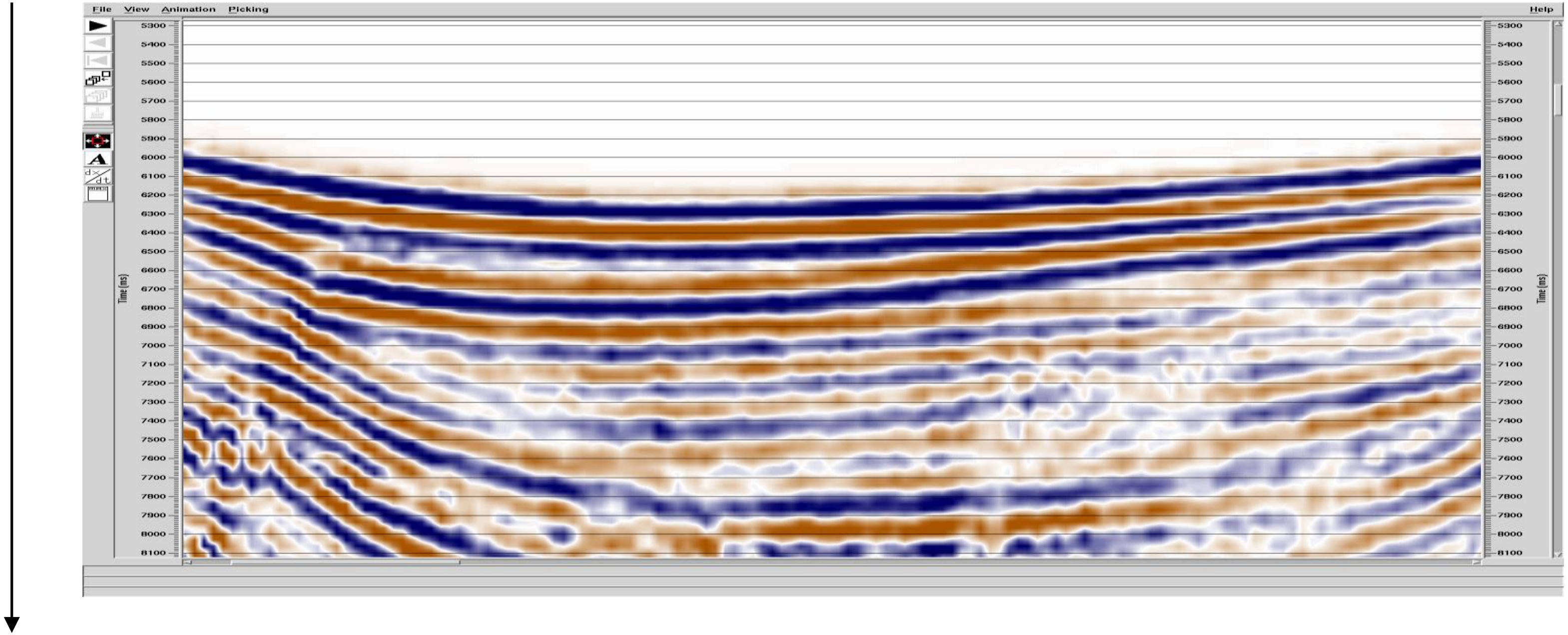
All data for a single CDP is staked into a gather.

Seismic Resolution

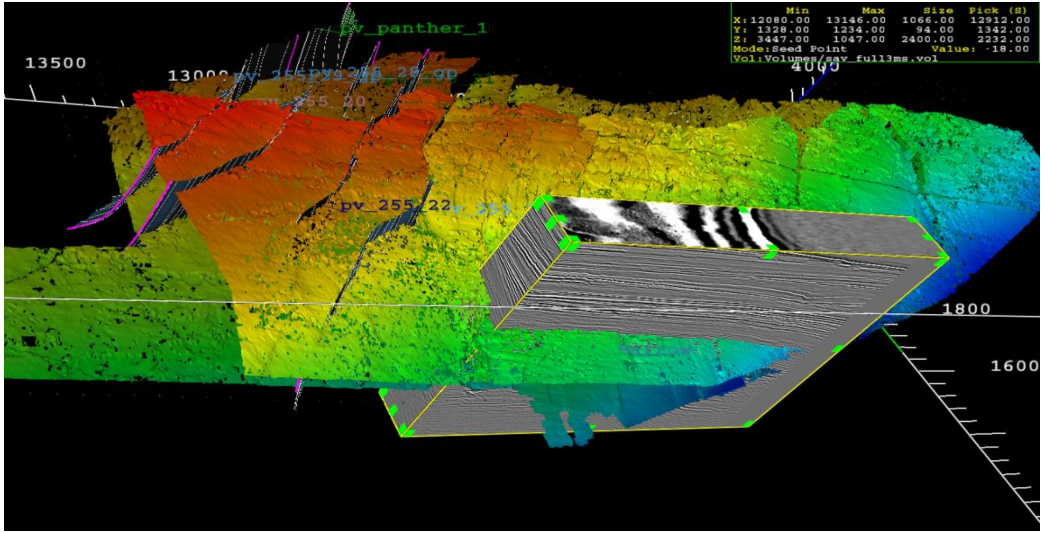
Herlev Hospital 120 m

Seismic display – colour variable density

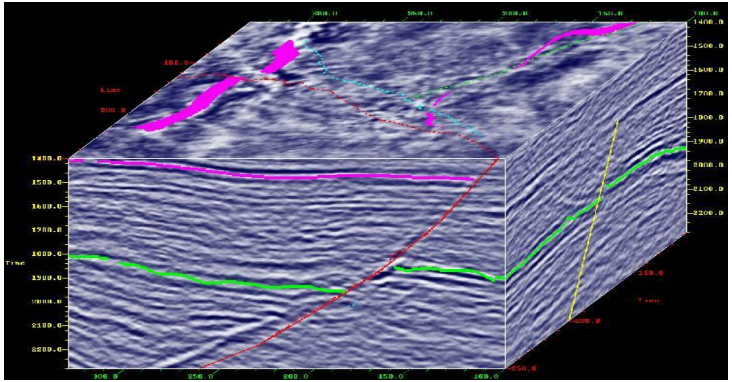
Two Way Time ms (1,000 ms = 1 second)



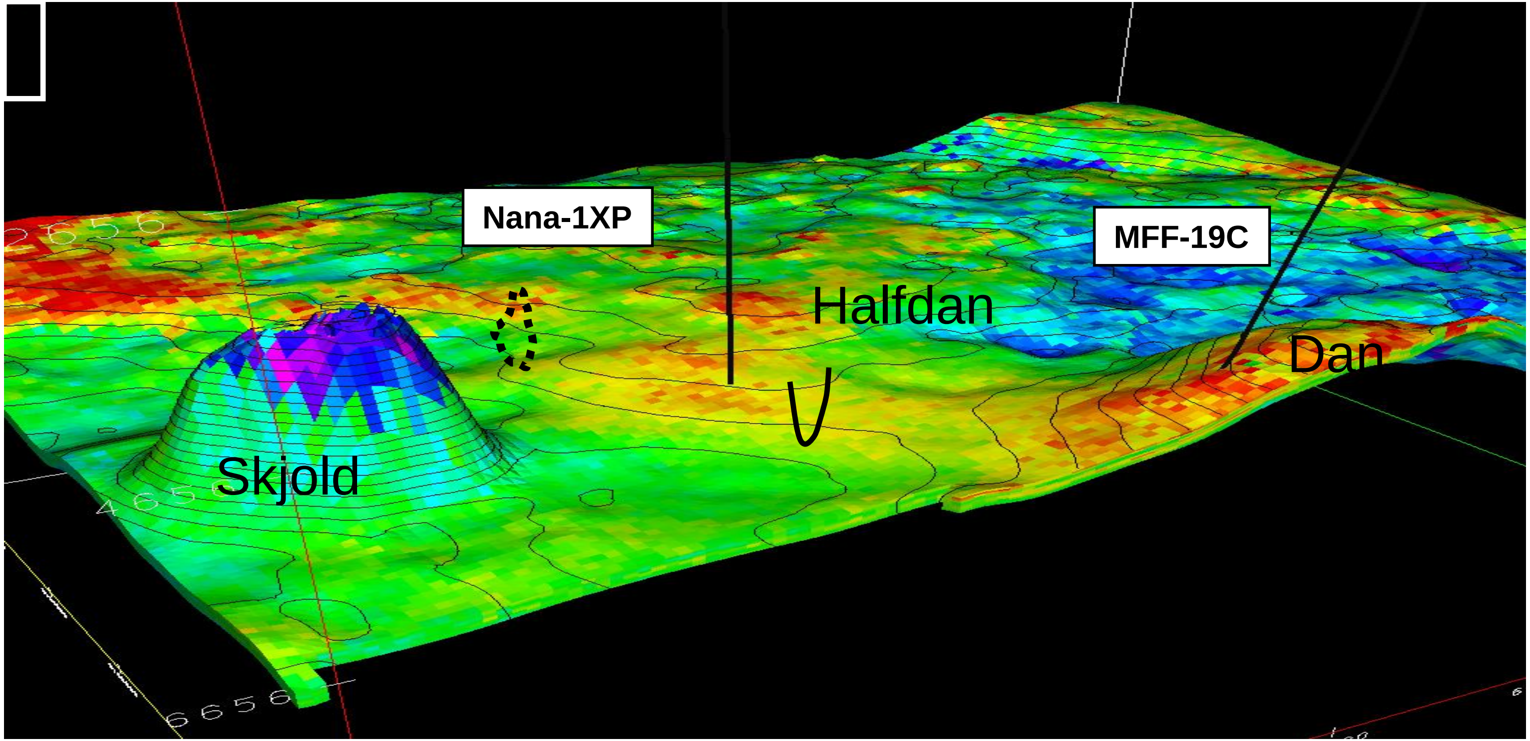
3D Seismic volume



```
         Min       Max      Size  Pick (S)
X:12080.00  13146.00   1066.00  12912.00
Y: 1328.00   1234.00     94.00   1342.00
Z: 3447.00   1047.00   2400.00   2232.00
Mode:Seed Point               Value: -18.00
Vol:Volumes/sav_full3ms.vol
```



Halfdan Porosity from seismic inversion



Drilling a well

Why do we Drill…

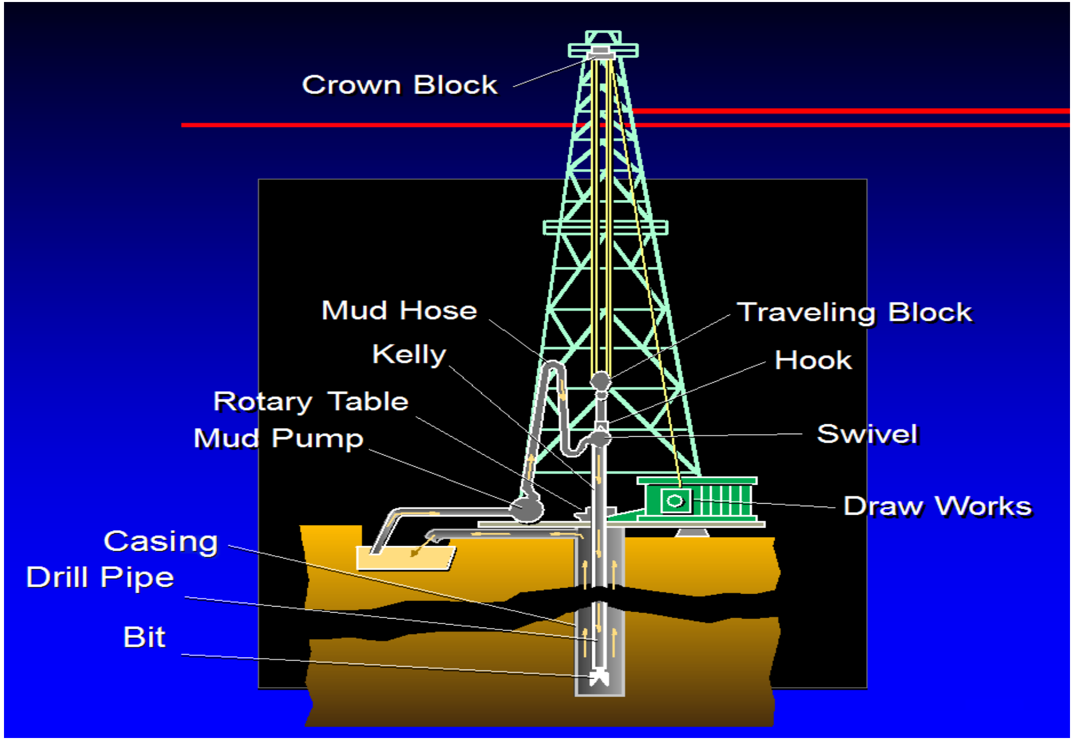
- To test a concept.
- To gather information.
- To add reserves.
- To fulfil commitments.

Drilling rig

The fluid circulated around the hole is called drilling mud.

The mud:

- Lubricates the bit
- Carries the samples to the surface
- Is balanced to the pressure of the rock formation



Offshore drilling

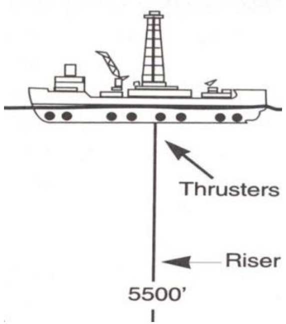
Semi-submersible rig

Ca $1m per day

Min water depth ca 500m

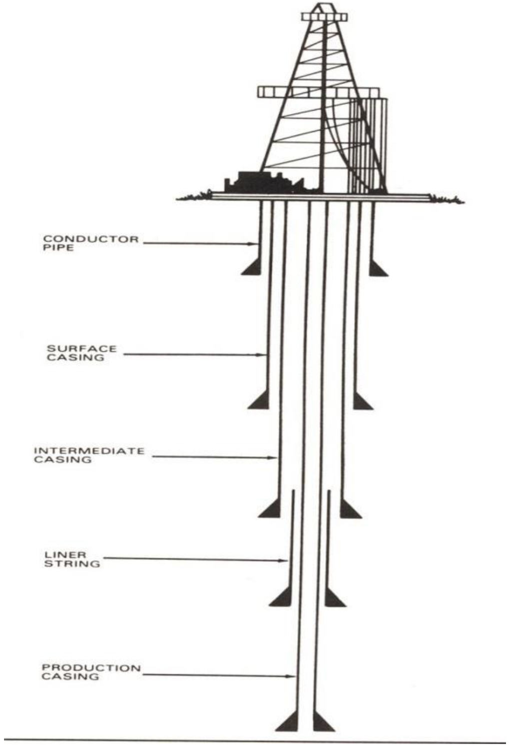
Ca $1/2m per day

Max water depth ca 1500m



Drill ship

Drilling and casing the hole



Drilling proceeds by drilling a section of hole and then casing this off to prevent collapse and to allow the mud weight to be increased as drilling further.

The circulation of mud in the hole brings samples to the surface and is calculated to be an adequate pressure to stop formation fluids flowing into the hole in an uncontrolled manner.

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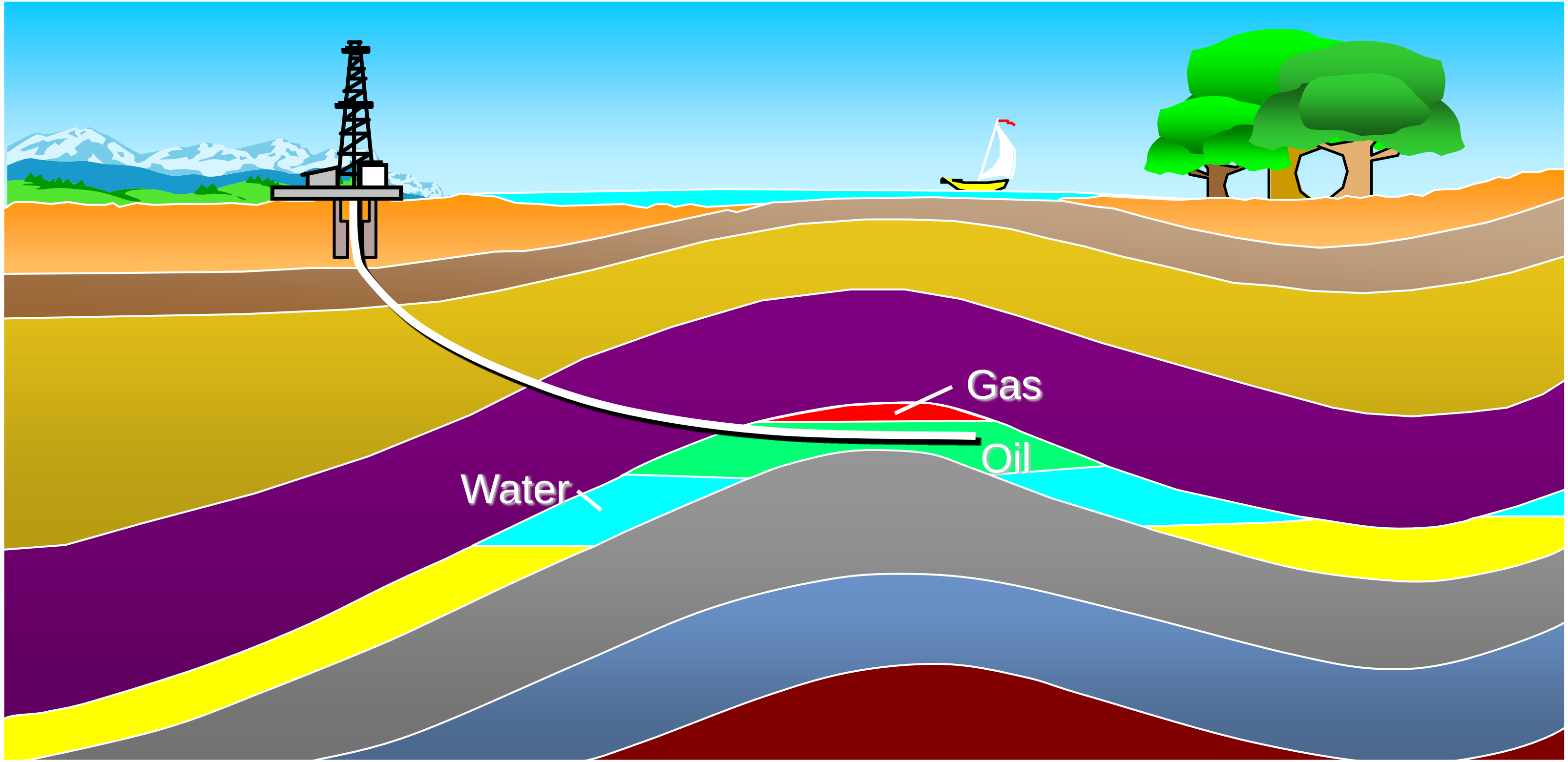
Directional Drilling



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Drilling – How Do We Know Where We Are?

Drill Floor

Samples collected on the shakers

Rock bit

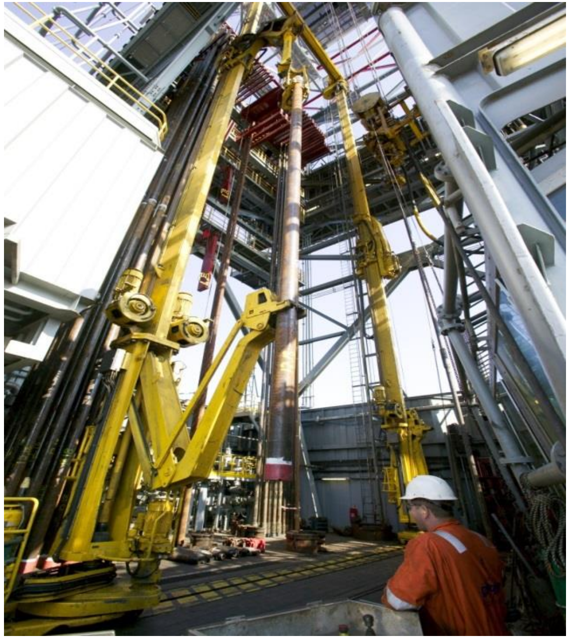
Cuttings

Core (Diamond) Bit

Core

Coring

Drill Floor



On modern offshore rigs much of the manual handling on the drill floor has become automated and highly sophisticated – and much safer!

Logging the hole

A suite of logs provides us with invaluable direct and indirect information on the well:

- Lithologies
- Fluids
- Formation pressures
- Rock samples
- Fluid samples

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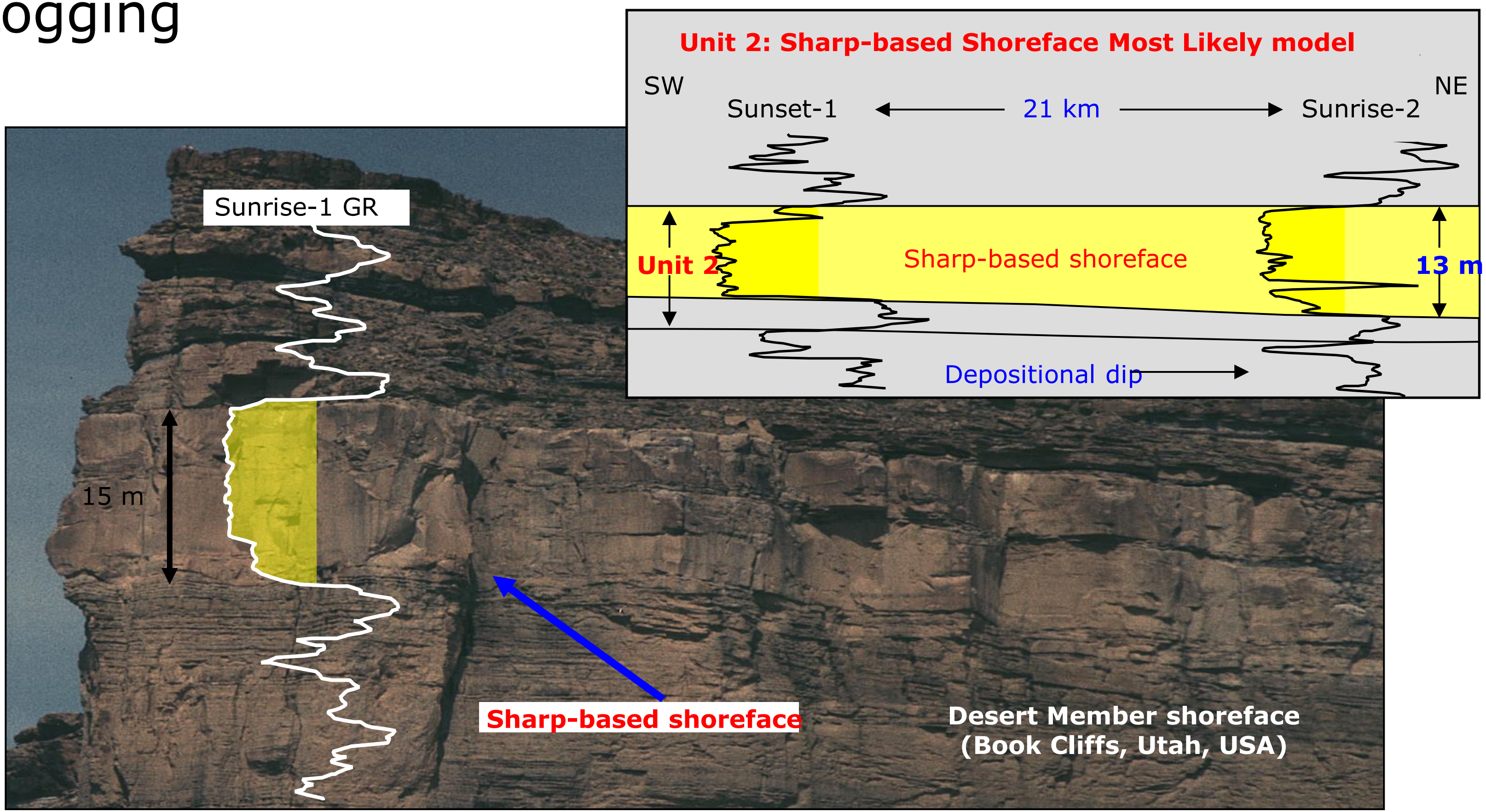
Logging


Unit 2: Sharp-based Shoreface Most Likely model
SW
NE
Sunset-1
21 km
Sunrise-2
Unit 2
Sharp-based shoreface
13 m
Depositional dip
Sunrise-1 GR
15 m
Sharp-based shoreface
Desert Member shoreface
(Book Cliffs, Utah, USA)

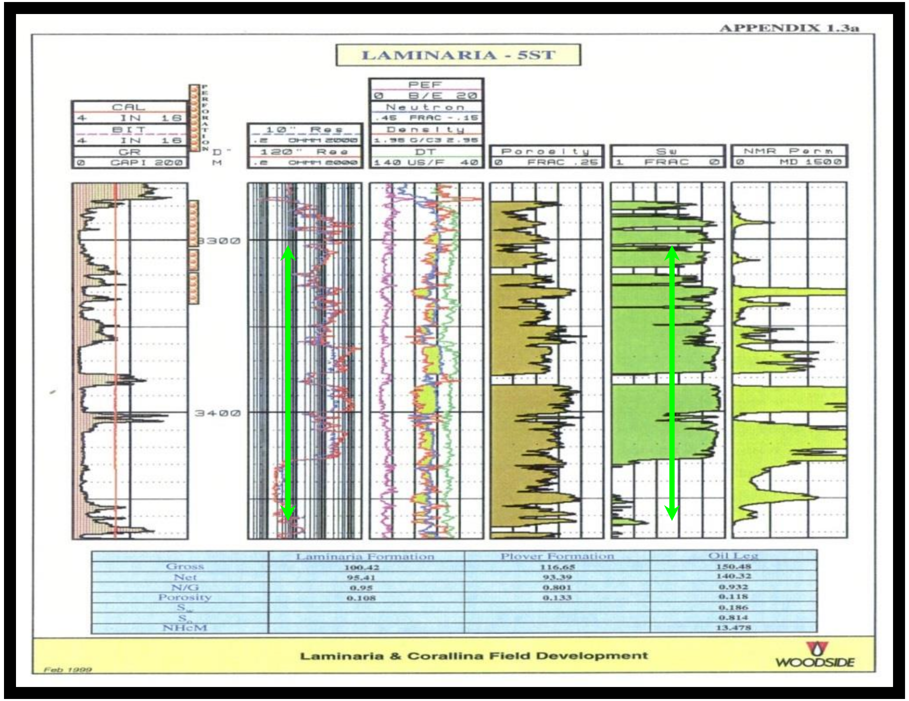
Well Evaluation

Density, neutron logs – help determine lithology, porosity and fluids.

Resistivity helps determine fluids

Caliper and Gamma – helps determine lithology

- Combining Log, Core & Test data.
- Determines the hydrocarbon in place.



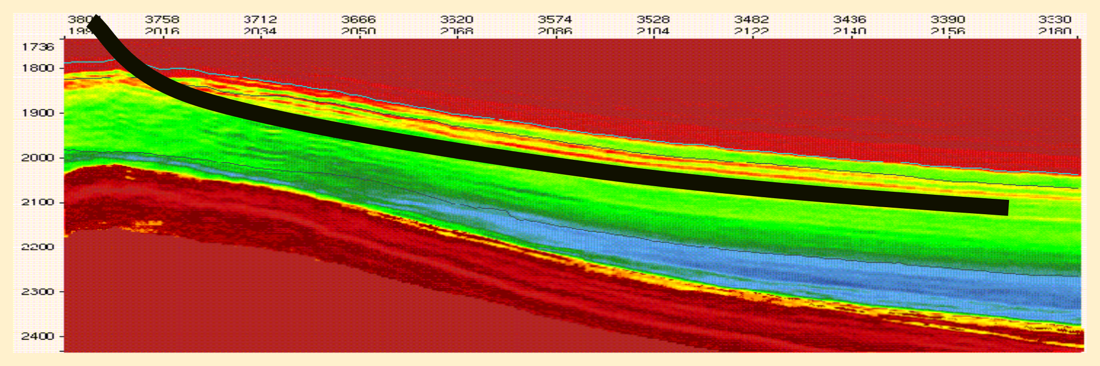
	Laminaria Formation	Plover Formation	Oil Leg
Gross	100.42	116.65	150.48
Net	95.41	93.39	140.32
N/G	0.95	0.801	0.932
Porosity	0.108	0.133	0.118
S_w			0.186
S_o			0.814
NHcM			13.478

Laminaria & Corallina Field Development

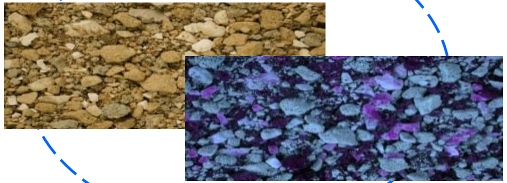
Feb 1999

WOODSIDE

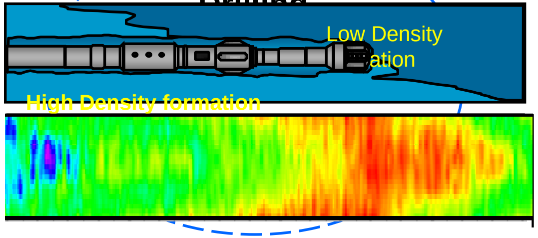
Data collection for steering of the well inside the reservoir



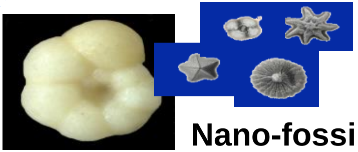
Drill cuttings



Logging while Drilling



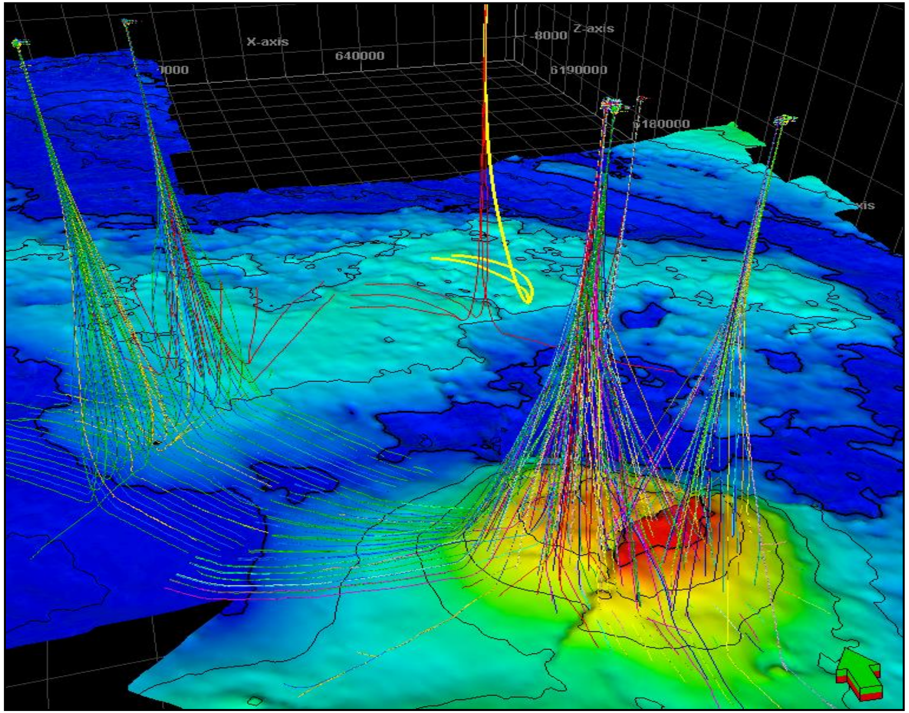
Bio-steering



Nano-fossils

Micro-fossils

Dan and Halfdan Field Development



Dan was discovered in 1971, first Danish oil and gas field on stream, production started in 1972

Halfdan was discovered in 1998 and put on production in 1999

Illustration shows underground topography and well pattern.

Discoveries pass through:

- Appraisal
- Development
- Production
- Abandonment

It can be many years from discover to production. This affects the value of the opportunity (time value of money)

Exploration is a long term and expensive business but is the life-blood of an oil company.

MAERSK OIL

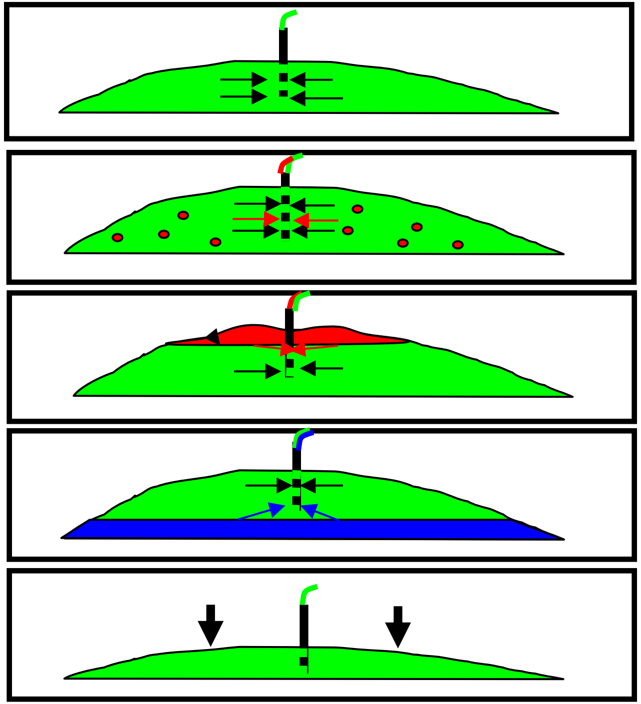
Microscopic & Macroscopic – Sweep Efficiency

- Microscopic Sweep Efficiency (RF-micro)
  - How large fraction of the local STOIIP is produced
  - Controlled by microscopic recovery process

- Macroscopic Sweep Efficiency (RF-macro)
  - How large fraction of the reservoir is affected by the microscopic recovery process(es)
  - Controlled by the volumetric effect of the microscopic recovery processes and number/location of wells

- Total Recovery Factor (RF)
  - RF = RF-micro x RF-macro

Primary recovery



- **Pressure depletion of oil above bubble point**
  ➔ RF = 2-5%
- **Solution gas drive in oil leg below bubble point**
  ➔ RF = 5-10%

  limited by gas fingering

  secondary gas cap formation is very limited
- **Primary gas cap expansion**
  ➔ RF =3-4%

  Limited by gas cusping
- **Aquifer expansion**

  ➔ RF < 5%

  limited by low permeability of chalk aquifer

  Risk of water coning
- **Plastic chalk compaction**

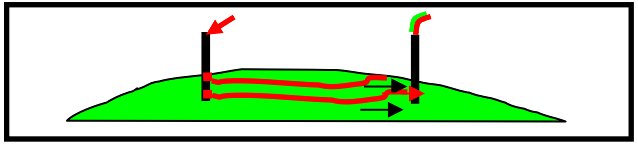
  ➔ RF = 0-(30)%,

  but only in very high porosity chalk reservoirs.

Secondary recovery

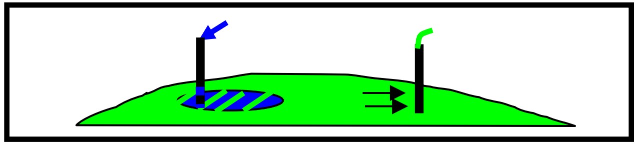
- **Simple Gas Injection: Limited recovery in chalk due to:**
  - Gas channelling from injector to producer through fractures
  - Gas fingering through matrix
  - No formation of a secondary gas gap
  - Limited imbibition of gas in fractures into matrix

  ➔ Low RF-macro



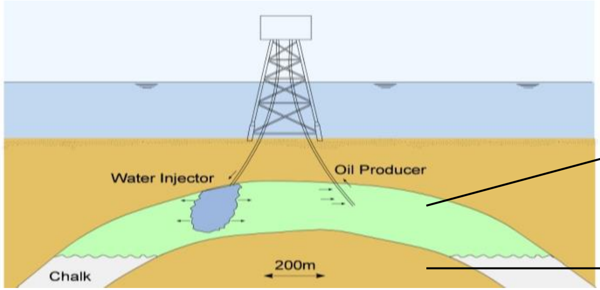
- **Water injection: Good recovery in chalk due to:**
  - Relatively stable displacement (near piston-like displacement)
  - Easy to control fracturing => potential of high injection pressure
  - High potential oil displacement fraction

  ➔ Potential High RF-macro



Oil production from chalk reservoirs with water injection

Simplified chalk reservoir

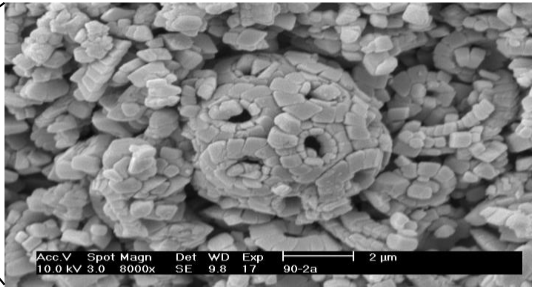


Oil is pushed towards the oil producer by injected water

Chalk reservoir analog
”Stevns Klint”

Complex reservoir architecture

Detailed picture
of chalk

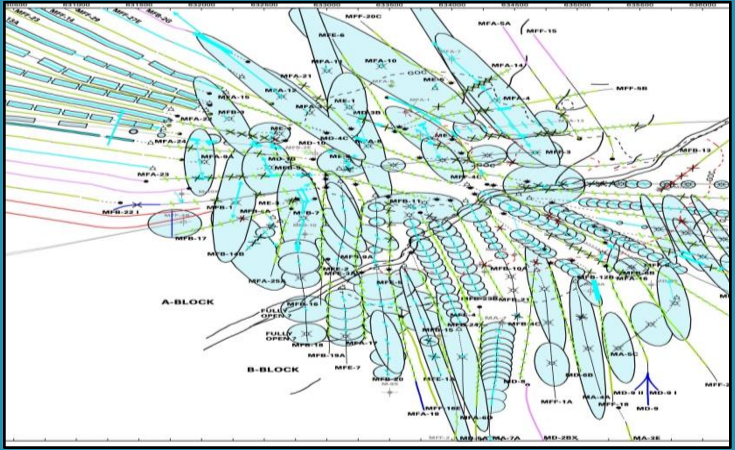


10 µm

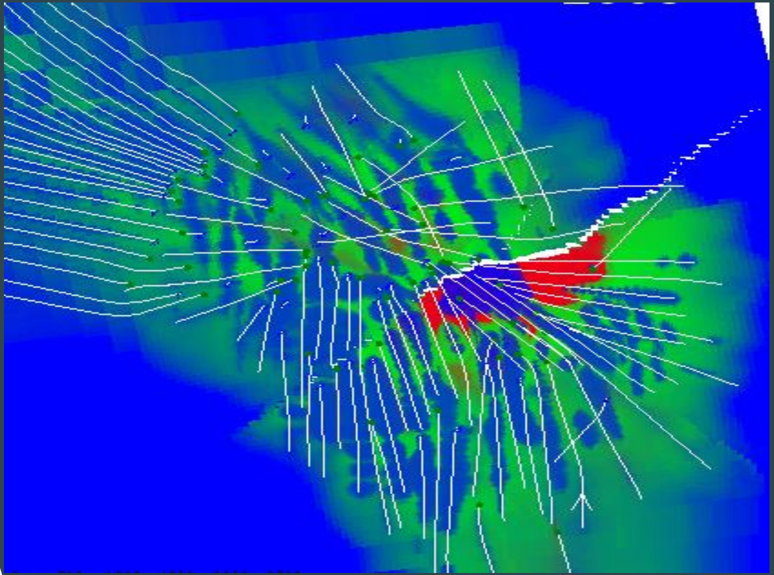
µm-size grains and pores

Maximise areal sweep

Analytical models

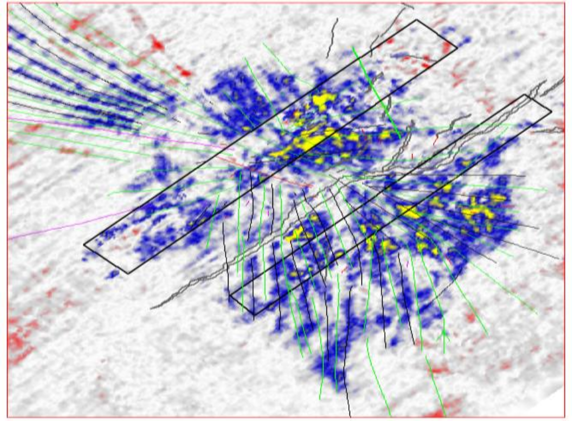


Reservoir Models

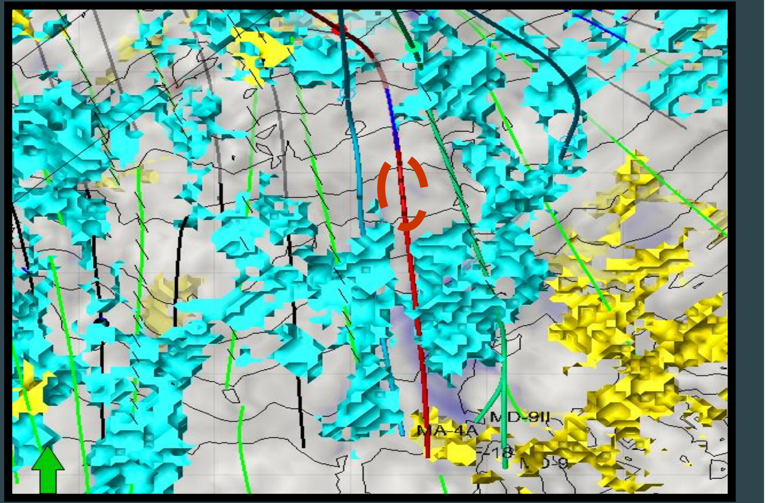


Monitor areal sweep

4D Seismic (2D)

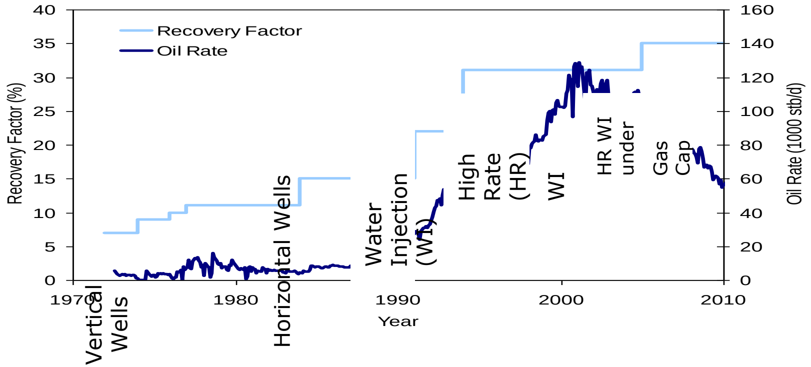


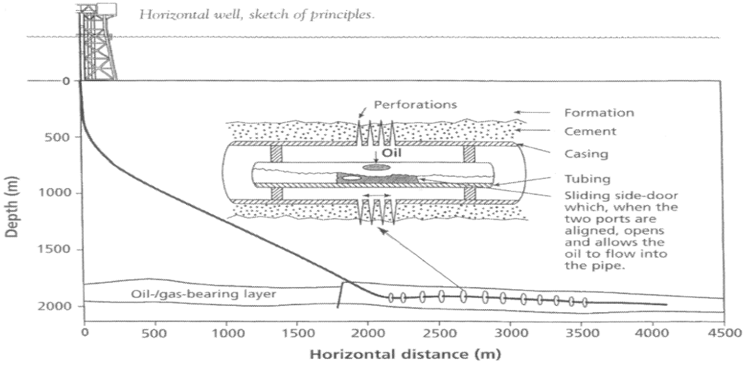
4D Seismic (3D)

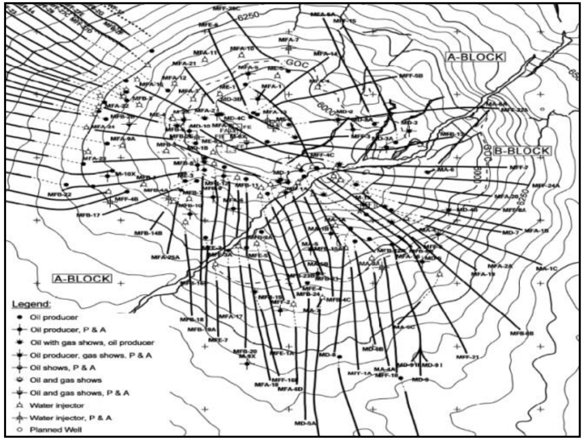


Fast water flood - Fracture Aligned Sweep Technology

Dan Experience



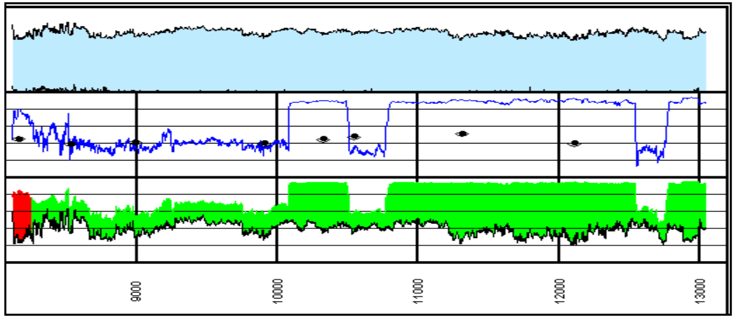


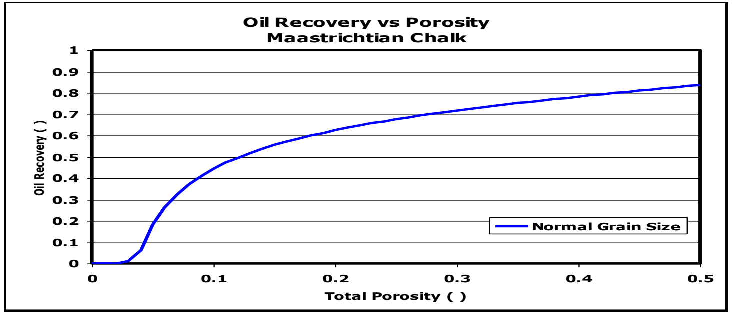


- 1972: Dan was discovered and developed using vertical wells
- 1987: Maersk Oil was one of the first oil companies drilling long reach horizontal well
- 1988: Maersk Oil was one of the first oil companies to start water injection
- 1994: Well spacing was reduced and high rate injection was increasing and accelerating recovery
- 1999: Development of the Dan West Flank was started
- Dan recovery is approaching 35%

Water flood experience

- Often stable displacement
- Displace oil saturation down to water-flood remaining oil saturation where water-flood works. The exact value of Sor(w)f as recorded in water-flooded zones still somewhat disputed due to petrophysical interpretation problems
- Cause gradually increasing water-cuts when flood-fronts break-through along horizontal wells



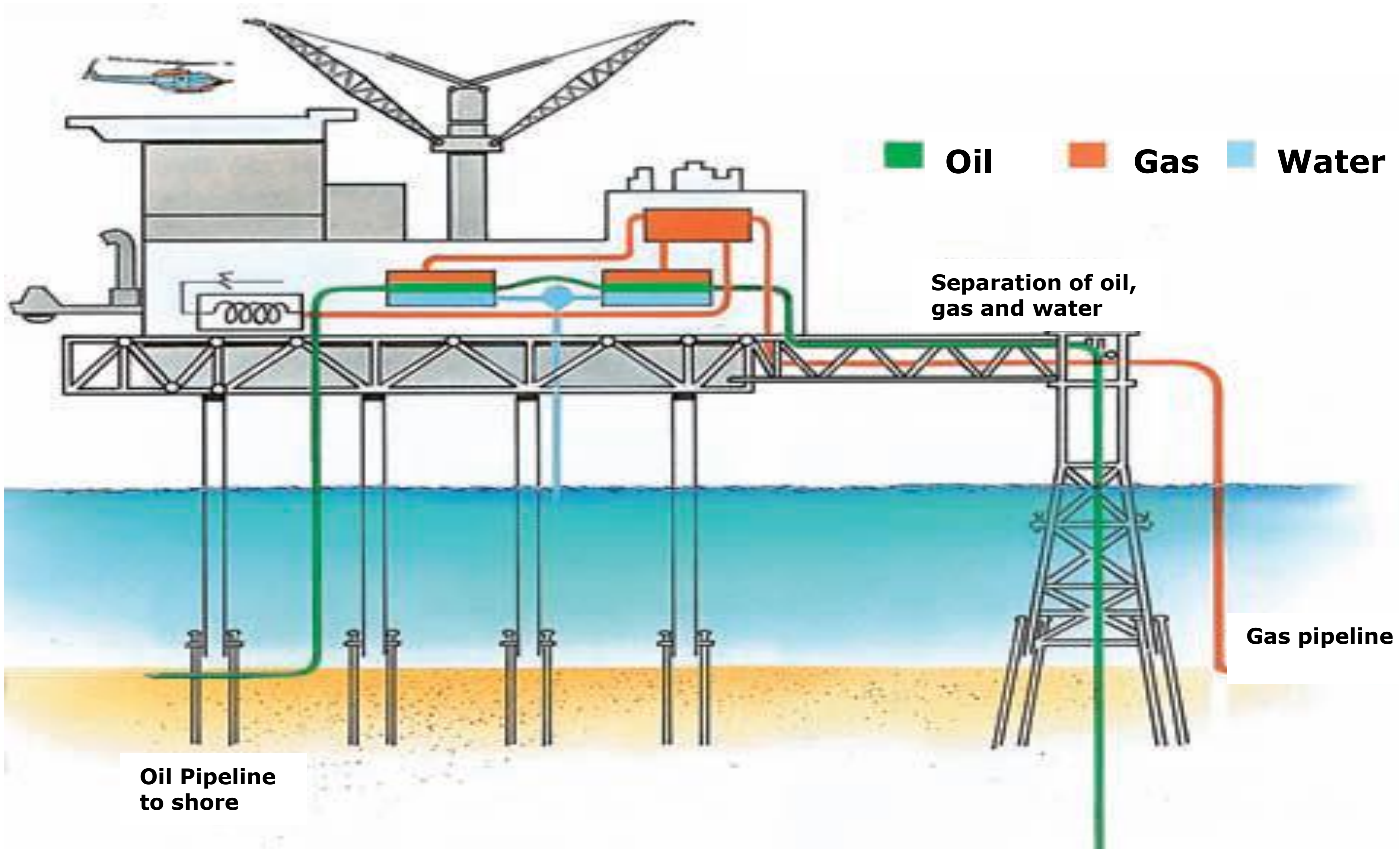


Tertiary Recovery Efficiency/Chalk Typically reduction of Sor(w)f

- **Injection of misciple fluids (CO_2, Rich HC-gas etc**.)
  - Injected fluids tends to dissolve the oil volume left by e.g. water flooding
- **Injection of alternating fluids (WAG ……)**
  - Injection of pulses of different fluid (e.g. water-gas-water-gas) tends to reduce Sor(w)f due to 3-phase relative permeability effects
- **Microbiological Enhanced Oil Recovery (MEOR)**
  - MEOR works typically by microbiological activity create biofilms that plug the rock and divert injected fluids
  - MEOR-technique is not used in chalk
- **Fire flooding**
  - Injection of air into a reservoir may allow the oil in a reservoir to ignite (even in a waterflooded zone) and burn. The burn-front vapourize all the fluids that condense after cooling ahead of the burn front.
  - Potentially very effecient process
- **NanoChalk**
  - Works potentially by re-crystalizing the chalk and thus releasing the trapped oil-droplets after a water flood plus enahncing the permeability.
- **Etc.**

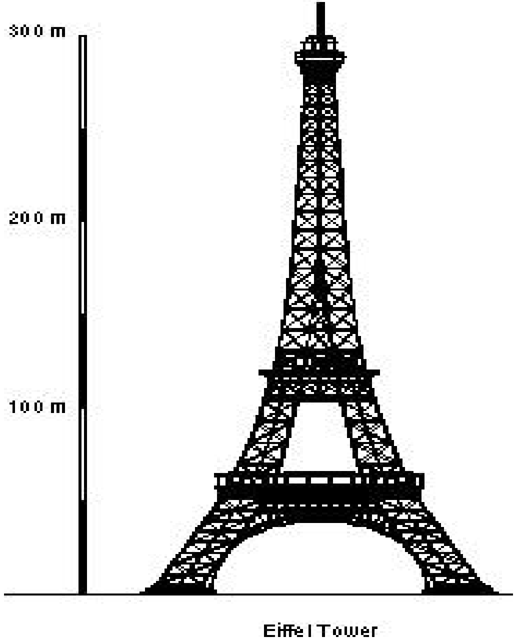
Macroscopic sweep efficiency of all tertiary recovery methods are in general poor

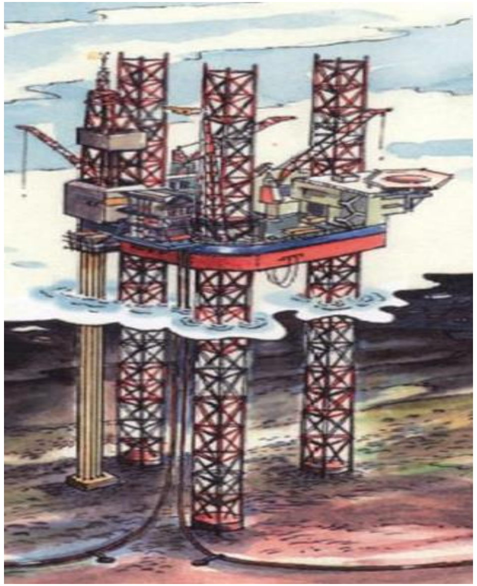
Production and Utilisation of Oil and Gas



New oil and gas wells are drilled by mobile (jack-up) drilling rigs

Jack-up rig during towage, with legs elevated





Jack-up rig in position, with legs on seabed and hull elevated


BLUE ORCA

MAERSK OIL

Petrochemical Products

- Plastics
- Pharmaceuticals
- Cosmetics
- synthetic fibres
- detergents, solvents
- Fertilizers
- Agricultural products

- Resins
- Paints
- Dyes
- Detergents
- Water repellents
- Explosives…….

Thank you

MAERSK OIL