Where is the oil coming from

18.06.2013
MINSC Workshop
Finn Engstrøm / Global Production Development
Where does the oil come from?
Or does oil come from big underground oil pools?
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

Migration Route

Sourcerock /Kitchen

Trap

Reservoir
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

Oil Migration
Chalk Reservoirs
Jurassic Source Rocks
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

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

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

**COOKING TIMES**
- (approximate)
- **Regular Cooker**
  - Whole chicken: 60 min.
  - Brown rice: 50 min.
  - Black beans: 60 min.

**IMPROVED SAFETY**
- Locking handle cannot be opened when under pressure.
- Multiple valves release pressure.
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.
Restricted basin into which the Kimmeridge Clay source rock is deposited
The Kimmeridge Shale contain so much kerogene that it may burn.
Terrestrial source rocks – responsible for many gas fields

Organic material preserved in swamp areas due to low oxygen content

Lena Delta, Siberia

Produces a predominantly gas prone source rock

The same setting in the Carboniferous produced much of the world's abundant coal deposits
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".
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.”
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
Or they can be stratigraphic:

And can contain oil and gas:

With a corresponding *Gas-Oil Contact (GOC)*
Migration – a dynamic entity

1) Early Generation

- Spill Point
- Migration from ‘Kitchen’
- Reservoir Rock (Sandstone)
- Gas beginning to displace oil
- Displaced oil accumulates

2) Late Generation

- Spill Point
- Seal Rock (Mudstone)
- Gas displaces all oil
Possible Source rocks

- Lower Miocene – Tamar reservoirs
- Gas window
- Peak oil expulsion
- Overmature
- Possible gas leakage

Messinian evaporites

BASE Plioene
BASE Messinian
BASE Middle Miocene
BASE Miocene
Near Eocene
Senonian unc.
Top Middle Jurassic

Oil Migration
Lower Miocene – Tamar reservoirs
Oligocene LST - turbidites
Detachment layer; over-pressured shale
Palaeogene LST - turbidites
Lower Cretaceous and Upper Cretaceous clastics

Gas Migration
Oil Migration
Possible Source rocks
Reservoir Zagros Fold-belt, Iran

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

Anticlinal trap

Zagros Fold-belt, Iran

Gas

Oil

Water

Reservoir
Hydrocarbon Trap Types

- Anticline
- Pinchout
- Unconformity
- Fault
- Salt Dome
The Reservoir

Reservoirs are rocks with *porosity* and *permeability*.
Reservoir Sandstone

Good Porosity = Lots of Space for Petroleum

Pores – the spaces between grains (blue)
Chalk Reservoir
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
- \( Sh = (0 \rightarrow (1-Swir) \text{ or } \sim Sor(w)f) \)
- Reservoir is not in equilibrium
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
Much of the gas on the NW Shelf is reservoired in rocks deposited in fluvial to deltaic settings.

Typical Triassic and Jurassic reservoirs of the North Sea
Triassic gas fields of the north sea (eg Statfjord)
These parameters can have a big impact upon economics.

Reservoir systems

- Porosity
- Permeability

- 0mD
- 100mD
- 1000mD

- 0%
- 10%
- 20%
- 30%

- Gas production
- Oil production

>10,000bopd
<1000bopd

MAERSK OIL
Seismic data – visualising the subsurface

Scale of the operations

Acquiring a marine 3D survey
Marine Seismic Acquisition

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
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 $1/2m per day
Max water depth ca 1500m

Drill ship
Ca $1m per day
Min water depth ca 500m
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.
Directional Drilling
Drilling – How Do We Know Where We Are?

Drill Floor

Samples collected on the shakers

Rock bit

Cuttings

Core (Diamond) Bit

Core
Coring
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
Sharp-based shoreface

Sunrise-1 GR

15 m

Unit 2: Sharp-based Shoreface Most Likely model

SW
Sunset-1 21 km Sunrise-2

NE

Unit 2: Sharp-based shoreface

Depositional dip

13 m

Sharp-based shoreface

Desert Member shoreface (Book Cliffs, Utah, USA)
Well Evaluation

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

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

Resistivity helps determine fluids

Caliper and Gamma – helps determine lithology
Drill cuttings
Logging while Drilling
RHO Bottom
RHO Top
Low Density formation
High Density formation
Data collection for steering of the well inside the reservoir
Bio-steering
Nano-fossils
Micro-fossils
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 discovery 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.
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)
  • $RF = RF_{\text{micro}} \times RF_{\text{macro}}$
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

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
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 $S_{or(w)}$ 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 $S_{or(w)f}$

- **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 $S_{or(w)f}$ 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 efficient process

- **NanoChalk**
  - Works potentially by re-crystalizing the chalk and thus releasing the trapped oil-droplets after a water flood plus enhancing the permeability.

- Etc.

Macroscopic sweep efficiency of all tertiary recovery methods are in general poor
Production and Utilisation of Oil and Gas

Separation of oil, gas and water

Oil Pipeline to shore

Gas pipeline
New oil and gas wells are drilled by mobile (jack-up) drilling rigs.
Completion of Horizontal Wells

[Image of a horizontal well completion setup]
Petrochemical Products

- Plastics
- Pharmaceuticals
- Cosmetics
- Synthetic fibres
- Detergents, solvents
- Fertilizers
- Agricultural products

- Resins
- Paints
- Dyes
- Detergents
- Water repellents
- Explosives
Thank you