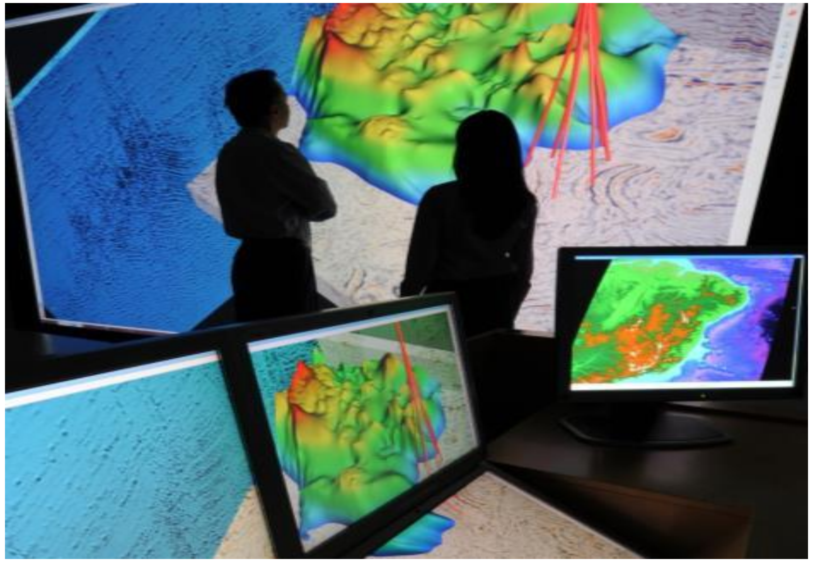
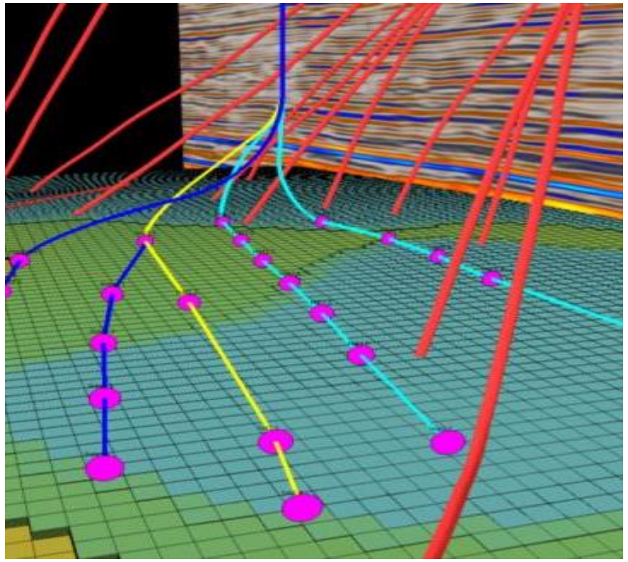
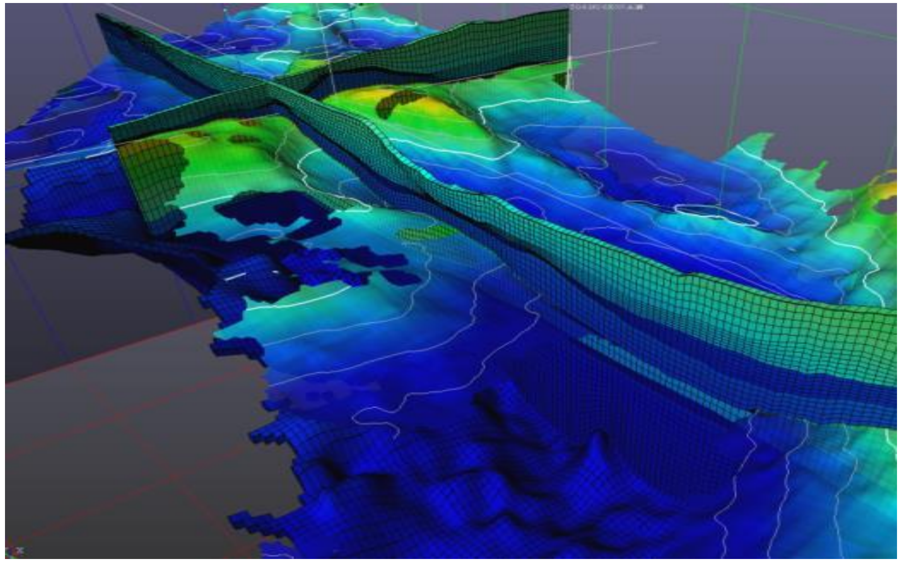
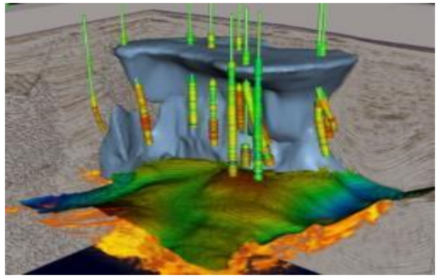

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Petroleum Systems

Ranjit Subudhi

Principal Consultant Geoscience

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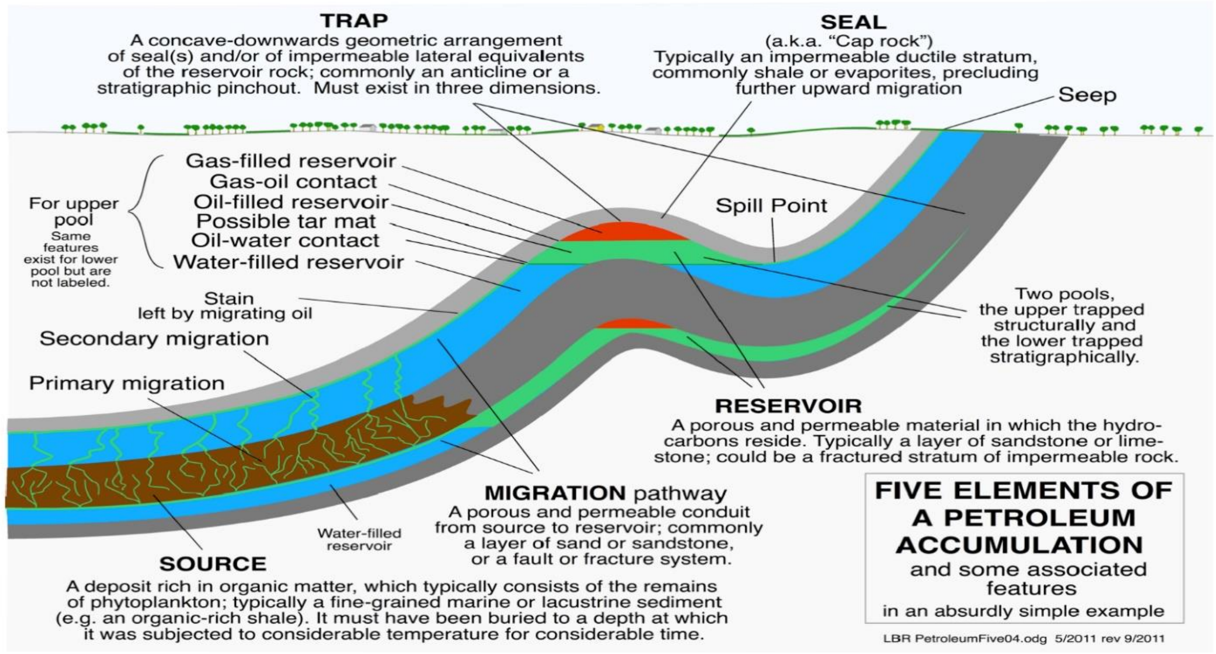
Agenda

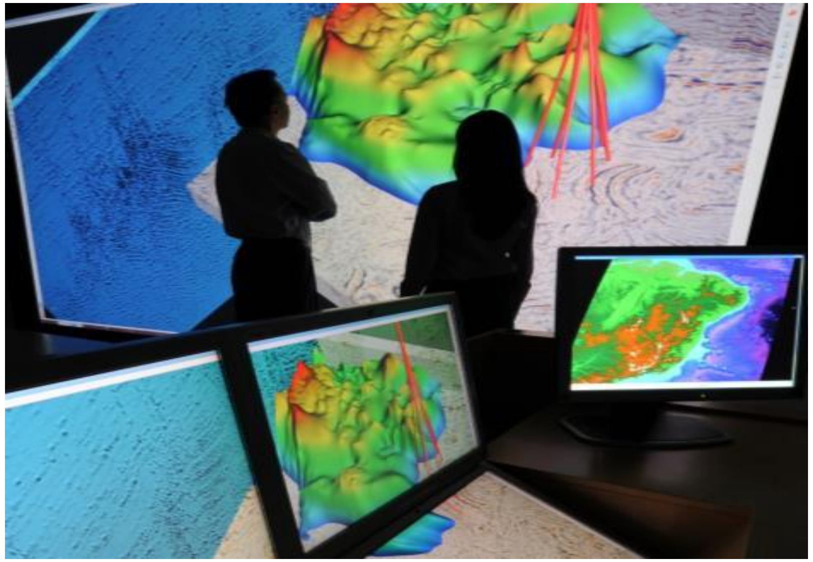
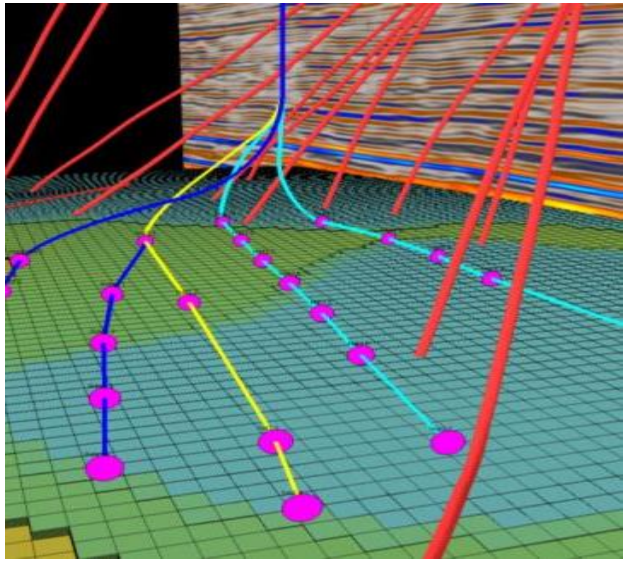
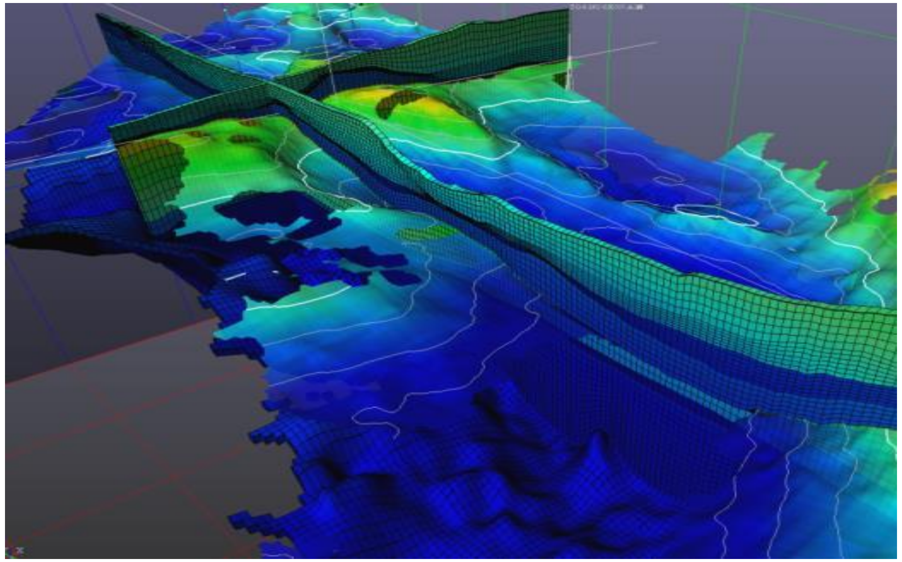
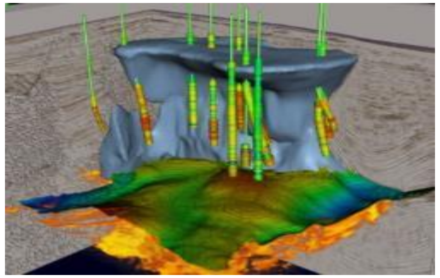
- Elements of Petroleum Systems
- TOC calculation from well log data (Demo & Exercise)

Petroleum System

- The petroleum system is a unifying concept that encompasses all of the disparate elements and processes of petroleum geology.
- A petroleum system encompasses a pod of active source rock and all genetically related oil and gas accumulations. It includes all the geologic elements and processes that are essential if an oil and gas accumulation is to exist.
- The essential elements of a petroleum system include the following:
  - Source rock
  - Reservoir rock
  - Seal rock
  - Overburden rock
- Petroleum systems have two processes:
  - Trap formation
  - Generation–migration–accumulation of hydrocarbons

Railsback's *Petroleum Geoscience and Subsurface Geology*



Source Rock Analysis

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Source Rock

- A source rock is a rock that is capable of generating or that has generated movable quantities
- Source rocks can be divided into at least four major categories:
  - Potential - Rock which contains organic matter in sufficient quantity to generate and expel hydrocarbons if subjected to increased thermal maturation.
  - Effective - Rock which contains organic matter and is presently generating and/or expelling hydrocarbons to form commercial accumulations.
  - Relic effective - An effective source rock which has ceased generating and expelling hydrocarbons due to a thermal cooling event such as uplift or erosion before exhausting its organic matter supply.
  - Spent - An active source rock which has exhausted its ability to generate and expel hydrocarbons either through lack of sufficient organic matter or due to reaching an overmature state.

Characterizing Source Rock

- To be a source rock, a rock must have three features:
  - Quantity of organic matter
  - Quality capable of yielding moveable hydrocarbons
  - Thermal maturity
- The first two components are products of the depositional setting. The third is a function of the structural and tectonic history of the province.
- The quantity of organic matter is commonly assessed by a measure of the total organic carbon (TOC) contained in a rock. Quality is measured by determining the types of kerogen contained in the organic matter. Thermal maturity is most often estimated by using vitrinite reflectance measurements and data from pyrolysis analyses.

To determine...	Measure...
Quantity of source rock	Total organic carbon (TOC) present in the source rock
Quality of source rock	• Proportions of individual kerogens • Prevalence of long-chain hydrocarbons
Thermal maturity of source rock	• Vitrinite reflectance • Pyrolysis T_{max}

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Evaluating Source Rock

- Source rock richness is determined by measuring the total organic carbon (TOC) present in a rock. The two most common techniques of analyzing a rock for TOC are Rock-Eval pyrolysis with TOC and the LECO method. Conventional well logs can also provide information for evaluating interval richness.

Rock Type	TOC Value, %
Average for all shales	0.8
Average for shale source rocks	2.2
Average for calcareous shale source rocks	1.8
Average for carbonate source rocks	0.7
Average for all source rocks	1.8

Generation Potential	Wt % TOC, Shales	Wt % TOC, Carbonates
Poor	0.0–0.5	0.0–0.2
Fair	0.5–1.0	0.2–0.5
Good	1.0–2.0	0.5–1.0
Very Good	2.0–5.0	1.0–2.0
Excellent	> 5.0	> 2.0

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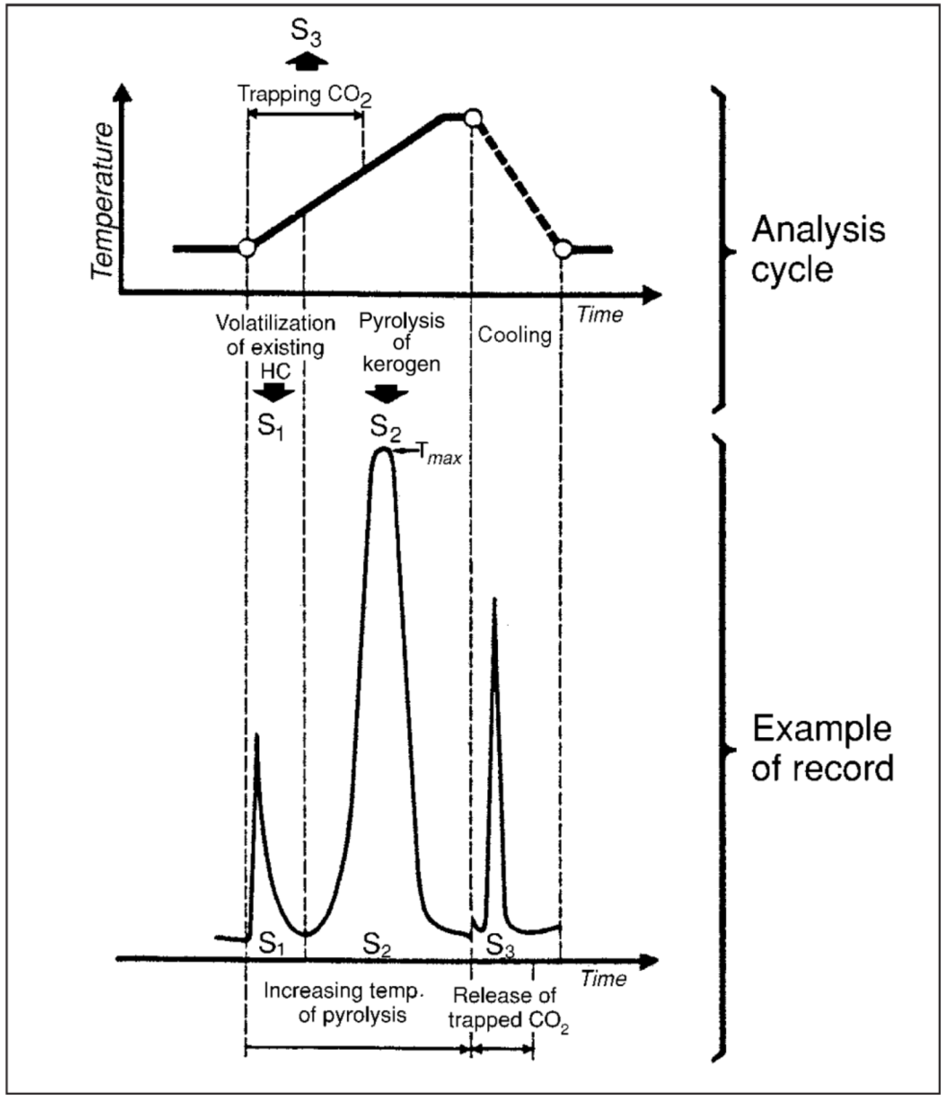
Rock Eval Pyrolysis

- Pyrolysis is the decomposition of organic matter by heating in the absence of oxygen.
- Organic geochemists use pyrolysis to measure richness and maturity of potential source rocks.
- In a pyrolysis analysis, the organic content is pyrolyzed in the absence of oxygen, then combusted. The amount of hydrocarbons and carbon dioxide released is measured.
- The most widely used pyrolysis technique is Rock-Eval.



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Pyrolysis Indices

- S1: The free hydrocarbons present in the sample before the analysis.
- S2: The volume of hydrocarbons that formed during thermal pyrolysis of the sample.
- S3: The CO2 yield during thermal breakdown rock of kerogen.
- S4: The residual carbon content of the rock sample
- The percent TOC is actually a value that is calculated, not measured directly, using the following formula:

$$\%\mathrm{TOC} = [0.082(S_1 + S_2) + S_4]/10$$

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LECO Method

- Measure TOC values by combusting the organic carbon and measuring carbon dioxide produced.
- Samples are powdered, weighed, and chemically treated prior to analysis to remove the inorganic carbon (carbonate) from the rock. The sample is then combusted in the presence of excess oxygen, allowing carbon dioxide to form from the free (organic) carbon in the rock.
- The amount of carbon dioxide is directly proportional to the amount of organic carbon or the TOC of the rock.
- The TOC measured by the LECO method does not include a measurement of the free hydrocarbons present in the sample.
- If a sample has a high free hydrocarbon content, the LECO TOC value will be smaller than a Rock-Eval TOC value, which includes free hydrocarbons (S1) in the TOC calculation.

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Using Conventional Well Logs to Estimate Richness

- Conventional well logs are useful for estimating source rock richness both qualitatively and quantitatively.
- Well logs allow a qualitative identification of organic-rich formations and a quantitative analysis of the amount of organic matter.
- The advantages of using well logs over cuttings are continuous sampling, more accurate depth control, and greater vertical resolution.
- The increasing concentration of organic matter in a rock directly affects its properties by lowering density, slowing sonic velocity, increasing radioactivity, raising resistivity, and raising hydrogen and carbon contents.
- Most widely used method to estimate the TOC from logs is Passey Method.

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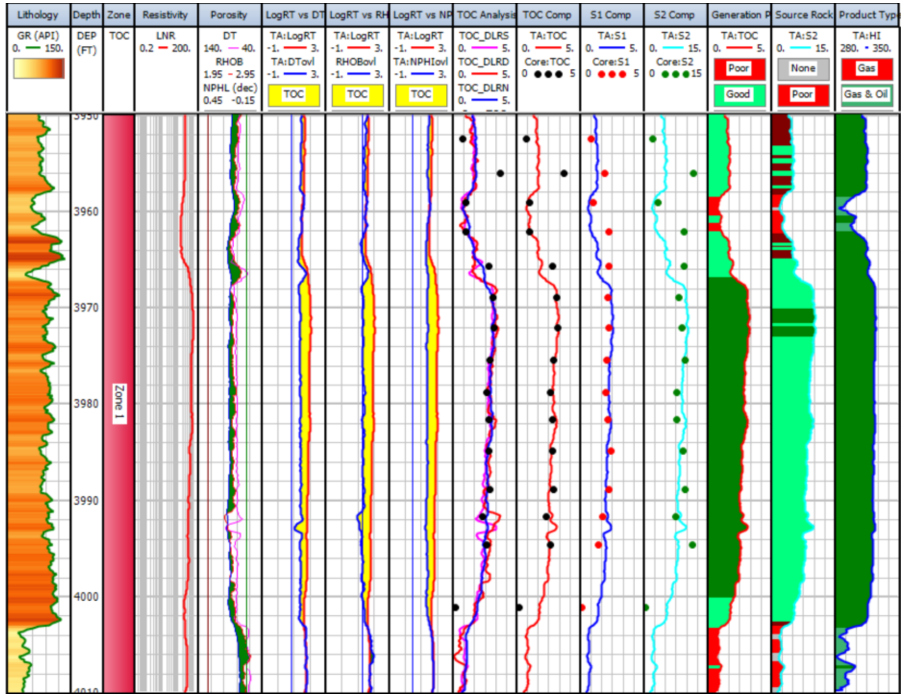
Passey Method

- Using the change in deep resistivity and porosity curves to highlight presence of organic-rich intervals in source rocks.
- In ‘lean’ source rocks the curves overlay
- Organic-rich intervals are highlighted by curve separation.
- The magnitude of the separation indicates amount of Total Organic Carbon (TOC).
- Requires laboratory measured TOC values and maturity data.



$$TOC = (\Delta logR) \times 10^{(2.297 - 0.1688 \times LOM)}$$

DeltalogR = log (RESD / RESDbase) + 0.02 * (DTC – DTCbase)

LOM = Level of Maturity

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Kerogen Types

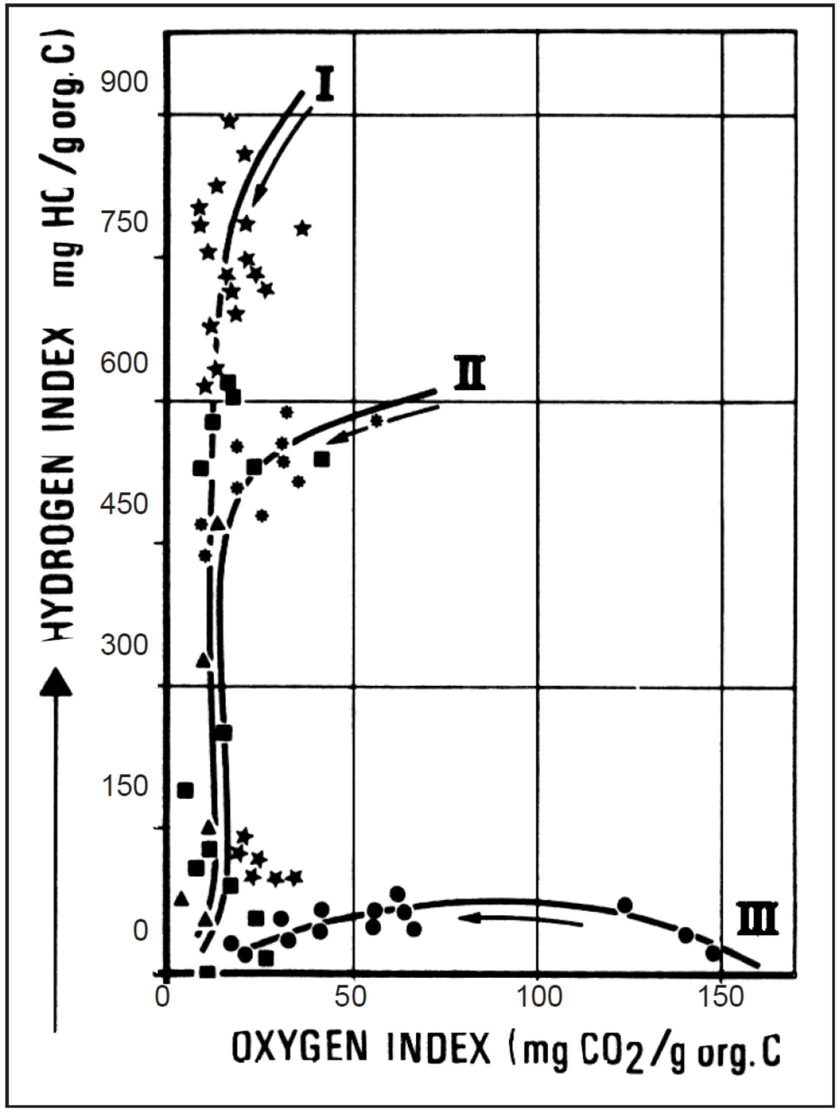
- Depositional environment is the dominant factor in determining the types of organic matter found in a rock.
- Only two types of organic matter are found in rocks: land derived and aquatic algae derived. Heat and pressure convert organic matter into a substance called **humin** and then into **kerogen**. Time and temperature convert kerogen into petroleum.
- Kerogens are composed of a variety of organic materials, including algae, pollen, wood, vitrinite, and structureless material. The types of kerogens present in a rock largely control the type of hydrocarbons generated in that rock.
- The type of kerogen present determines source rock quality. The more oil prone a kerogen, the higher its quality. Four basic types of kerogen are found in sedimentary rocks.

Kerogen Type	Predominant Hydrocarbon Potential	Amount of Hydrogen	Typical Depositional Environment
I	Oil prone	Abundant	Lacustrine
II	Oil and gas prone	Moderate	Marine
III	Gas prone	Small	Terrestrial
IV	Neither (primarily composed of vitrinite) or inert material	None	Terrestrial(?)

Evaluating Quality Using Rock-Eval HI/OI

- The hydrogen index (HI) represents the amount of hydrogen relative to the amount of organic carbon present in a sample.
- The oxygen index (OI) represents the amount of oxygen relative to the amount of organic carbon present in a sample.
- The type of kerogen present in a rock determines its quality.
  - Type I kerogen is the highest quality; Type I has the highest hydrogen content;
  - Type III, the lowest.

To determine the kerogen type present in a source rock, plot the hydrogen and oxygen indices on a modified Van Krevlen diagram



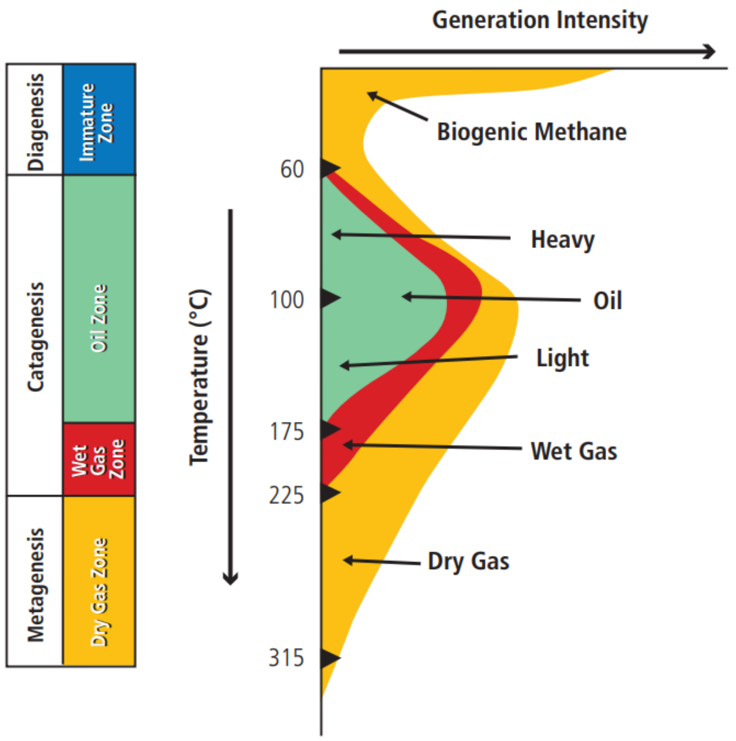
Visually Assessing the Quality

- To assess kerogen quality visually, we can separate it from the mineral matrix through acidification. We can then examine the kerogen using transmitted light through a microscope to determine its form (structured or amorphous) and origin.
- Structured kerogens include woody, herbaceous, vitrinite, and inertinite. Amorphous kerogens are by far the most prevalent and include most of the algal material.
- Visual kerogen estimates are usually presented in terms of the percentage of each type of kerogen in a sample.

Visual Kerogen Type	Hydrocarbon Potential
Woody	Gas prone
Herbaceous	Oil and gas prone
Vitrinite	Gas prone
Inertinite	No potential
Amorphous (dominantly algal)	Oil and gas prone

Evaluating Source Rock Maturity

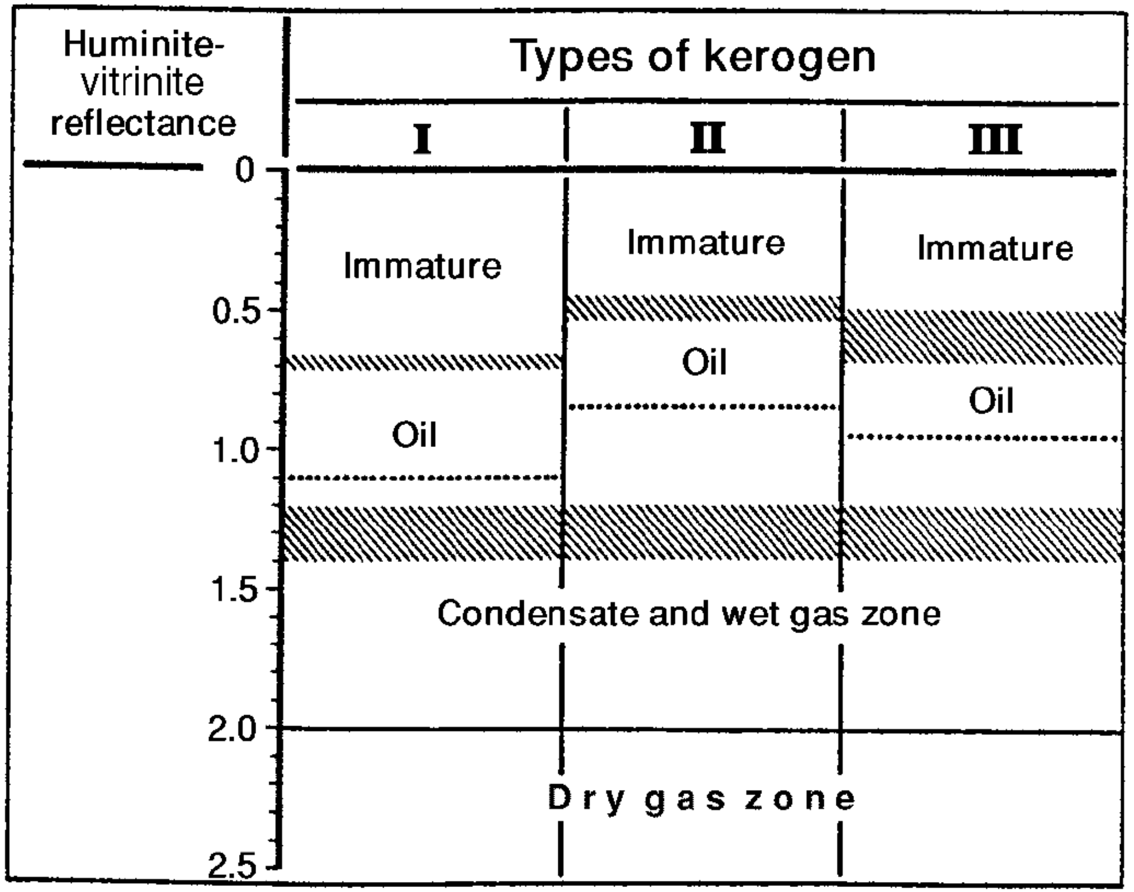
- The present-day maturity level is the product of a number of variables, such as tectonic setting, burial history, and thermal history.
- Tmax is the temperature at which the maximum rate of hydrocarbon generation occurs in a kerogen sample during pyrolysis analysis.
- The S2 peak represents the rate of hydrocarbon generation (the area under the curve represents the amount). The temperature at the time the S2 peak is recorded during pyrolysis is Tmax, given in °C.



Hydrocarbon Generation Zone	Rock-Eval Pyrolysis T_{max}, °C
Immature	< 435
Oil (from type II kerogen)	435–455
Oil (from type III kerogen)	435–465
Gas (from type II kerogen)	> 455
Gas (from type III kerogen)	> 465

Vitrinite Reflectance

- Vitrinite reflectance is a measure of the percentage of incident light reflected from the surface of vitrinite particles in a sedimentary rock. It is referred to as %Ro.



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Overburden Rock

- Overburden rock is the sedimentary rock above which compresses and consolidates the material below.
- In a petroleum system, the overburden rock overlies the source rock and contributes to its thermal maturation because of higher temperatures at greater depths.
- The age and thickness of the overburden rock determines the burial rate and thereby influences the heating rate.

Migration

- **Primary migration**
- **Secondary migration**

Primary migration:

Is understood as the emigration of hydrocarbons ***from the source rock*** (clay or shale) ***into permeable carrier beds*** (generally sands or limestones).

Secondary migration:

refers to subsequent ***movement*** of oil and gas within permeable carrier beds and reservoirs.

Notes:

a) secondary migration occurs when petroleum is clearly identifiable as ***crude oil and gas***
b) Secondary migration occurs by ***buoyancy due to the different densities*** of the respective fluids and in response to ***differential pressures***

Primary Migration

Theories:

The various theories for ***primary hydrocarbon migration*** can be grouped as follows:

1. Expulsion as proto-petroleum (still has ketones/acids/esters)
2. Expulsion as petroleum
   a. In solution
      i. Dissolved in water (derived from compaction, expelled from clays, or dissolved from meteoric flushing)
      ii. Expulsion of petroleum as micellar solutions: (Baker 1962, 1967)
      iii. Solution of oil in gas (Bray and Foster, 1980)
   b. Migration of petroleum hydrocarbon in continuous phase:
   c. Diffusion as a primary migration mechanism

Understanding Migration: Strongly dependent from their low solubility in water

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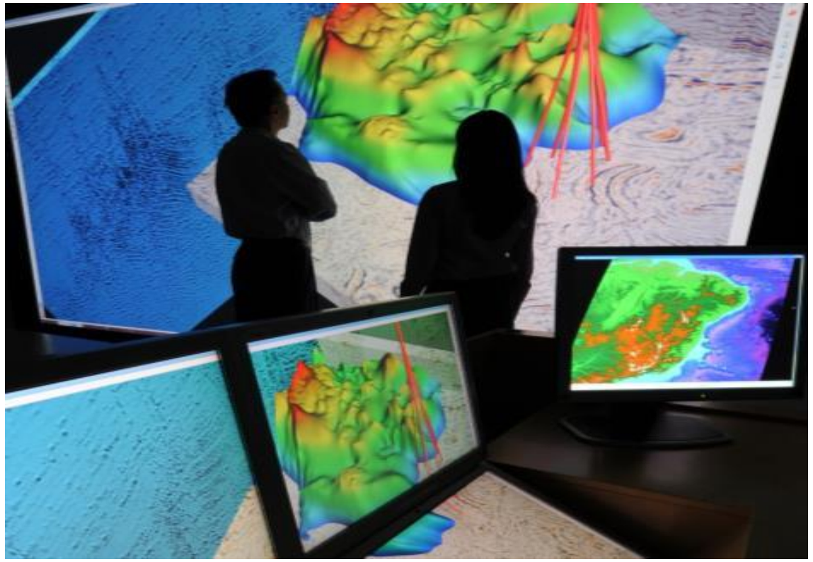
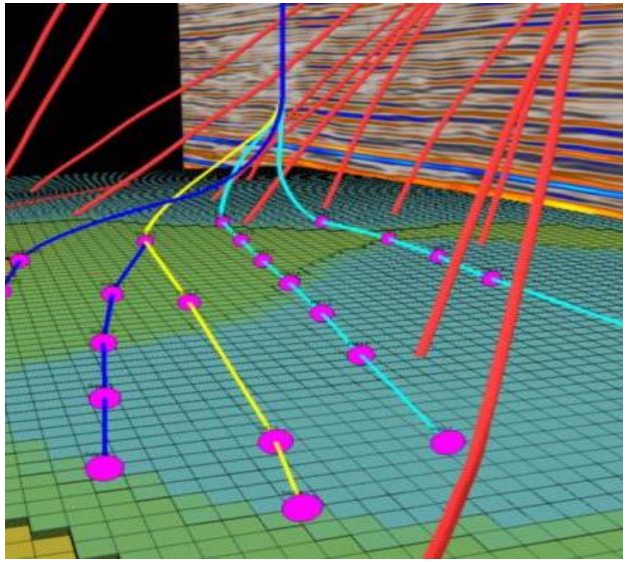
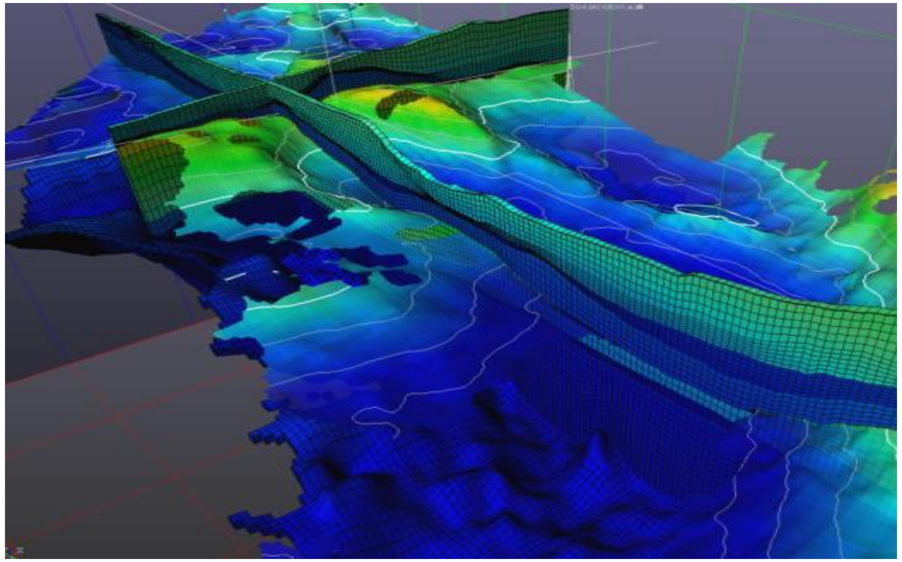
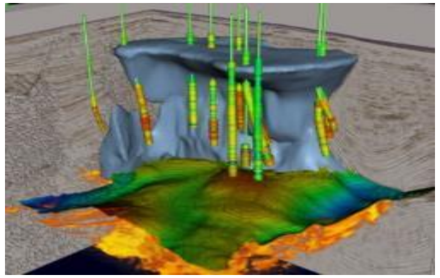

Reservoir Rock

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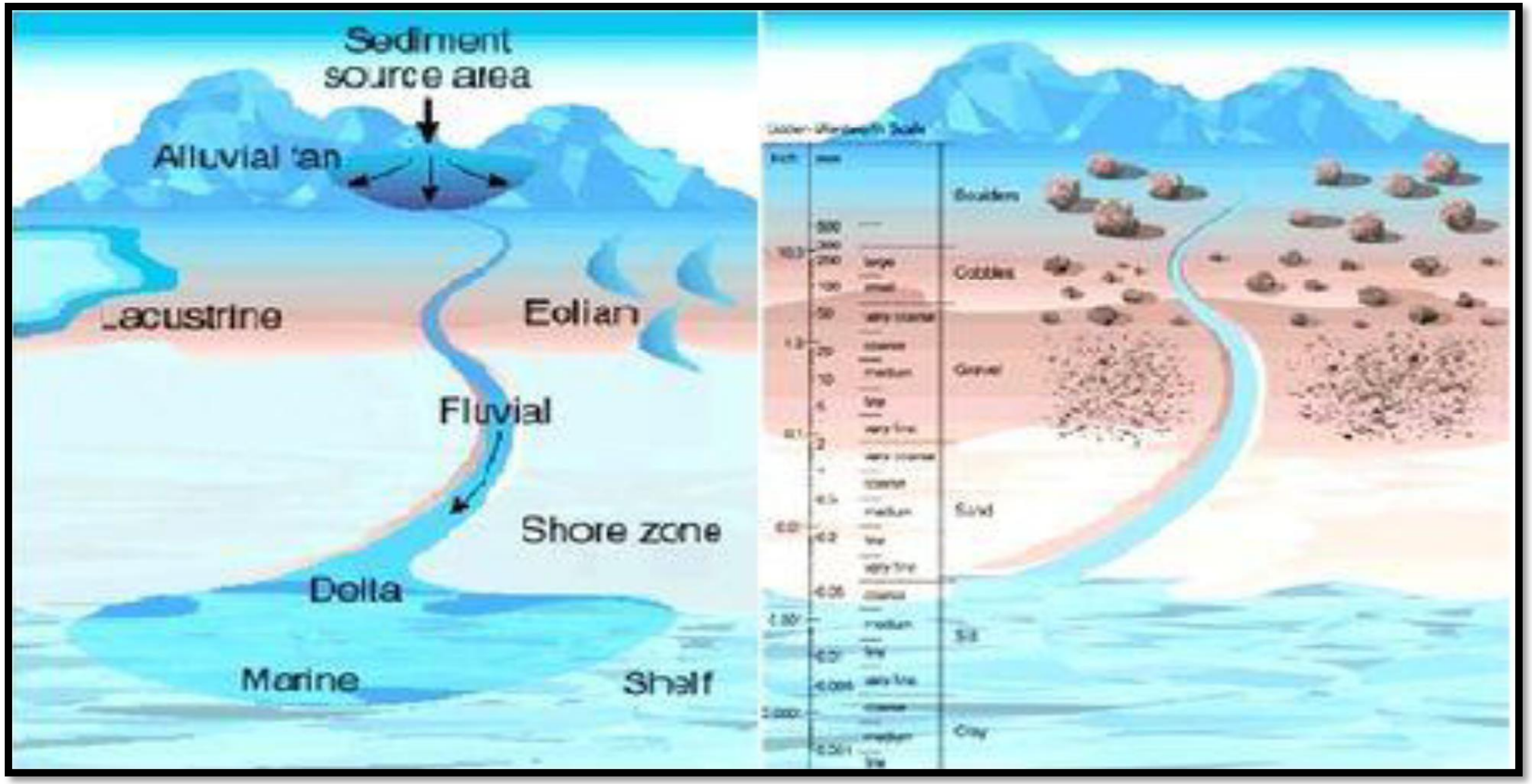
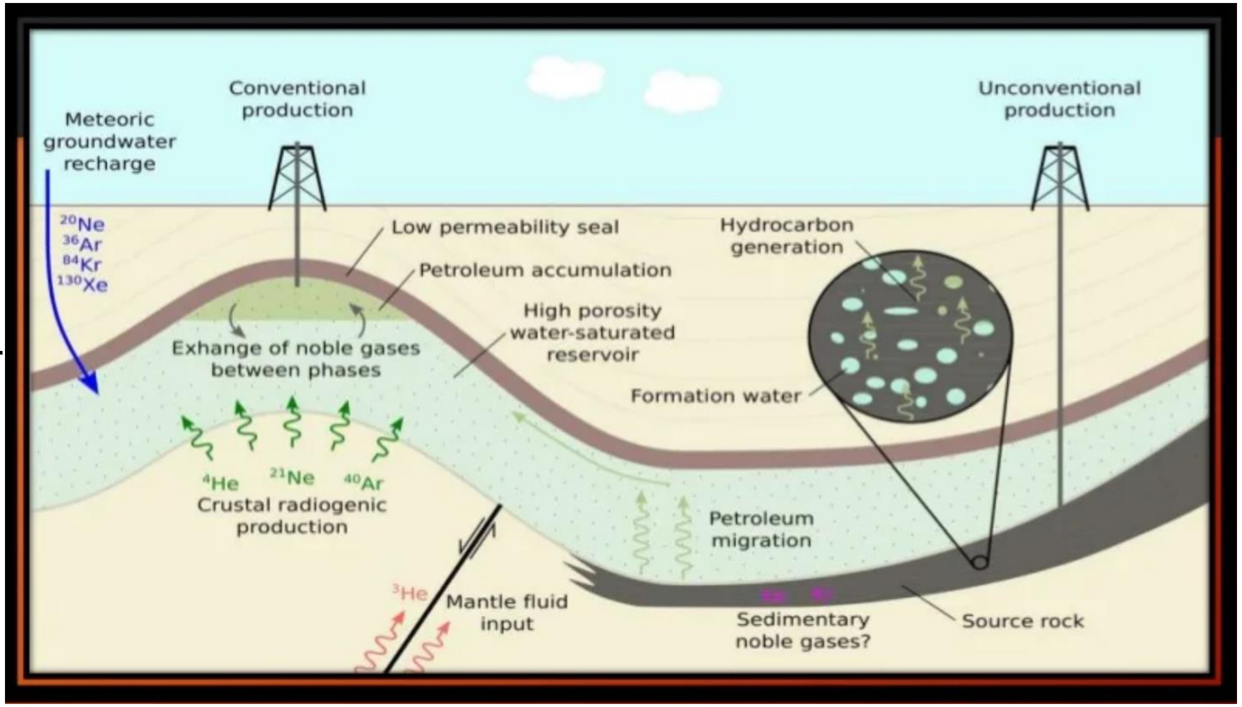
Reservoir Rock

- A reservoir rock is a subsurface volume of rock that has sufficient porosity and permeability to permit the migration and accumulation of petroleum under adequate trap conditions.
- Reservoir rock must have good porosity and permeability to accumulate and drain oil in economical quantities.
- Types of Reservoir Rock
  - Sandstone Reservoir Rock
  - Carbonate Reservoir Rock



Types of Petroleum reservoirs

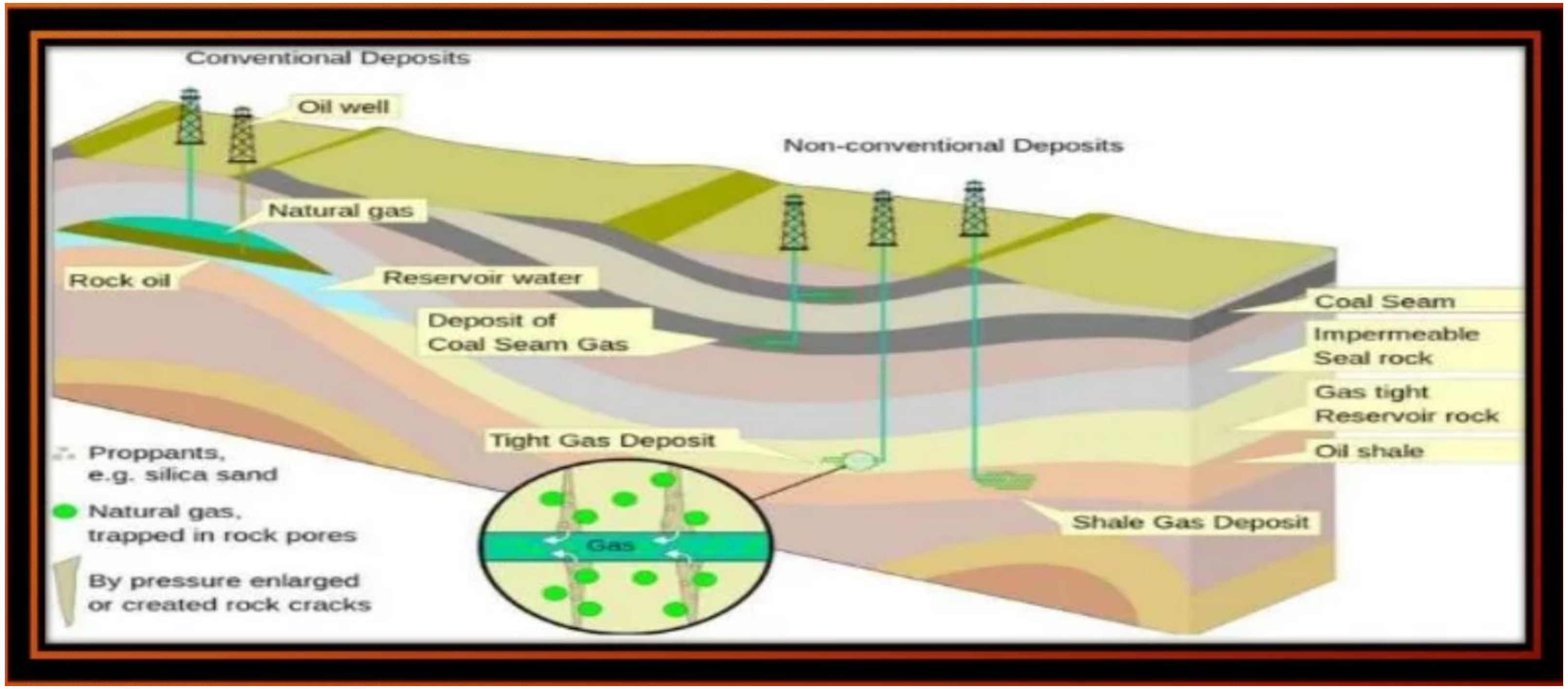
- **Conventional reservoirs** where hydrocarbon can easily flow and can be migrated from source rock.
  - By using traditional techniques they can extracted such as;
    - Drilling
    - Pumping
- **Unconventional reservoir** term can be used to refer the reservoirs with "low permeability" and "low porosity"
  - They can be produced at an economic rate.
  - Hydrocarbon can not flow easily due to low permeability, hence require stimulation technique
  - They can be quite challenging due to their low matrix porosity and permeability.



Different Types of Reservoir

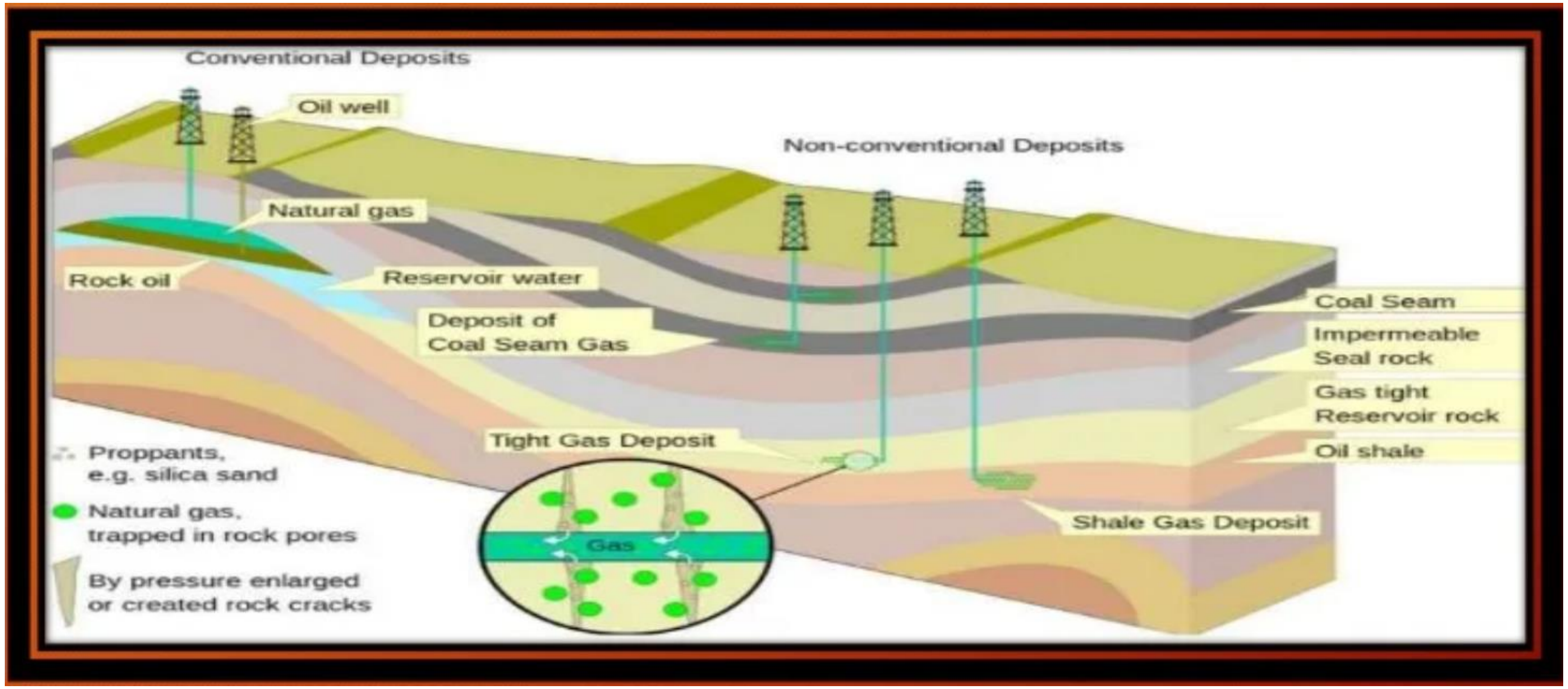
- Conventional Reservoir:
  - Clastic Reservoirs
  - Non-Clastic Reservoirs

- Unconventional Reservoirs:
  - Shale Oil or Gas
  - Tight Sands
  - Coal bed methane
  - Tar Sand



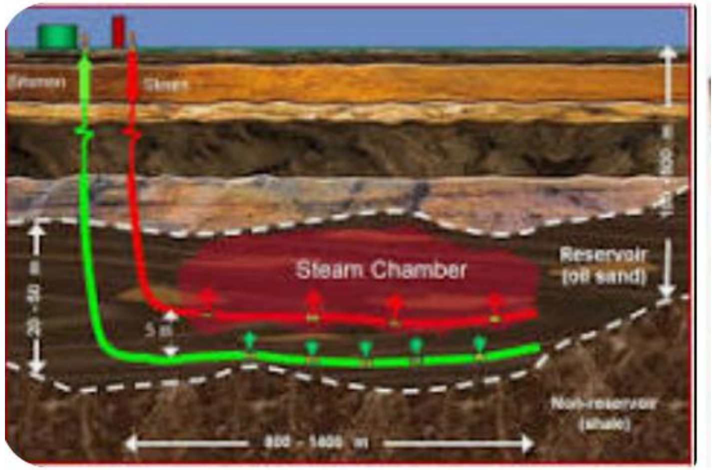
Shale Oil or Gas

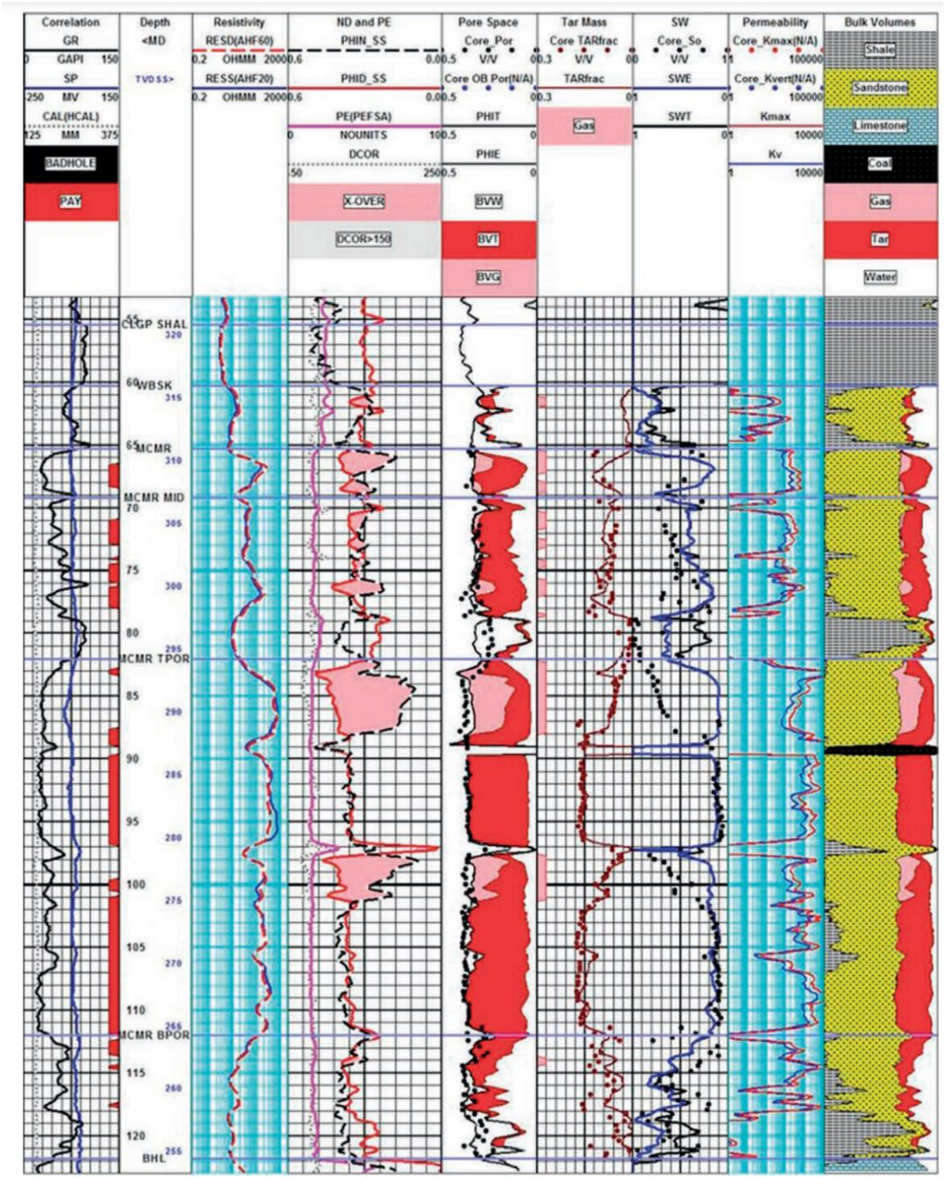
- Shale Oil or Gas is a natural occurring hydrocarbon formed and trapped in Shale.



Oil Sand

- Oil sands, tar sands, crude bitumen, or bituminous sands, are a type of unconventional petroleum deposit. Oil sands are either loose sands or partially consolidated sandstone containing a naturally occurring mixture of sand, clay, and water, soaked with bitumen, a dense and extremely viscous form of petroleum.





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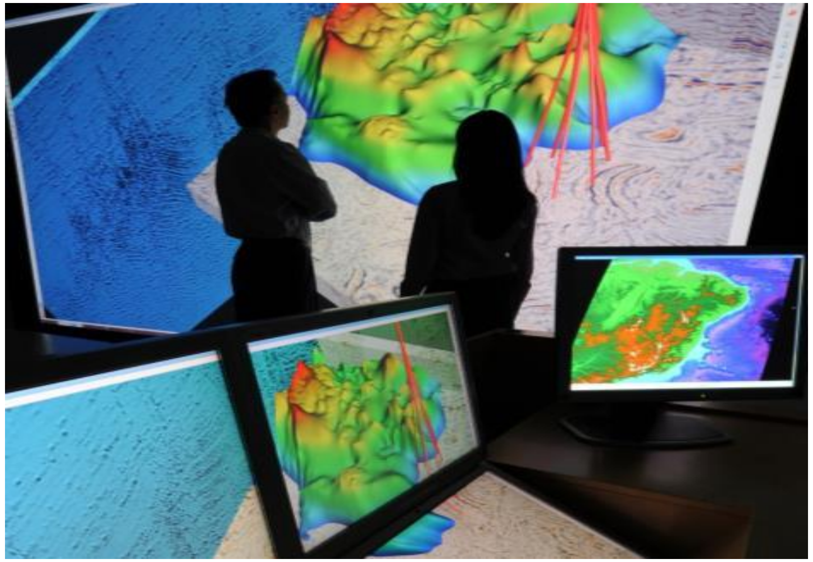
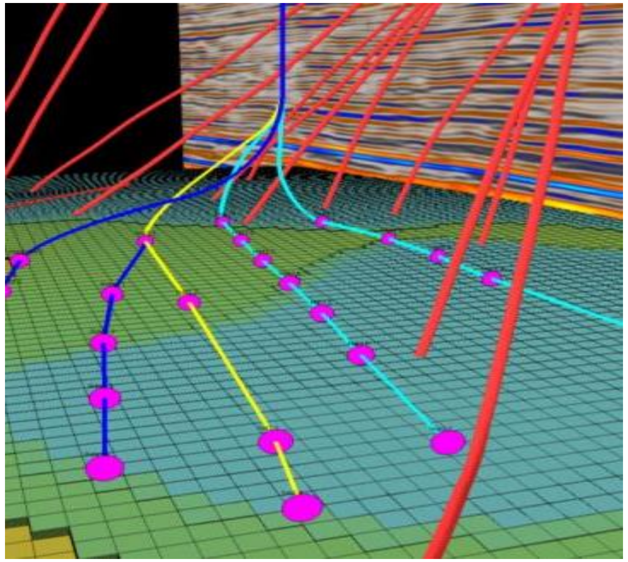
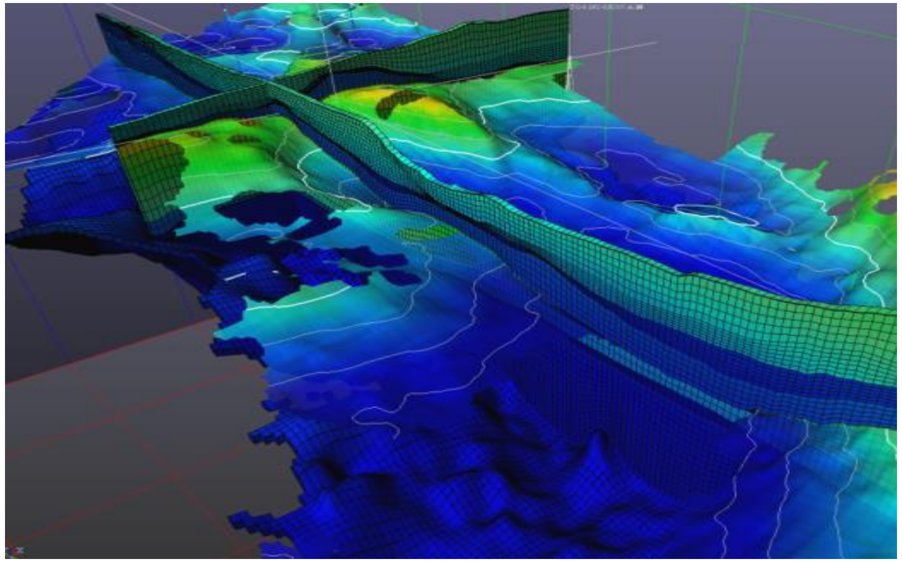
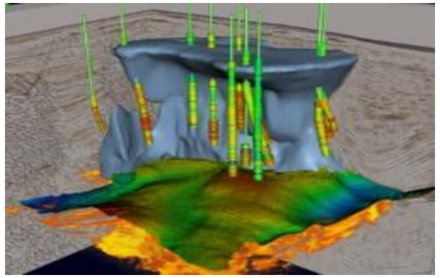

Trap and Seals

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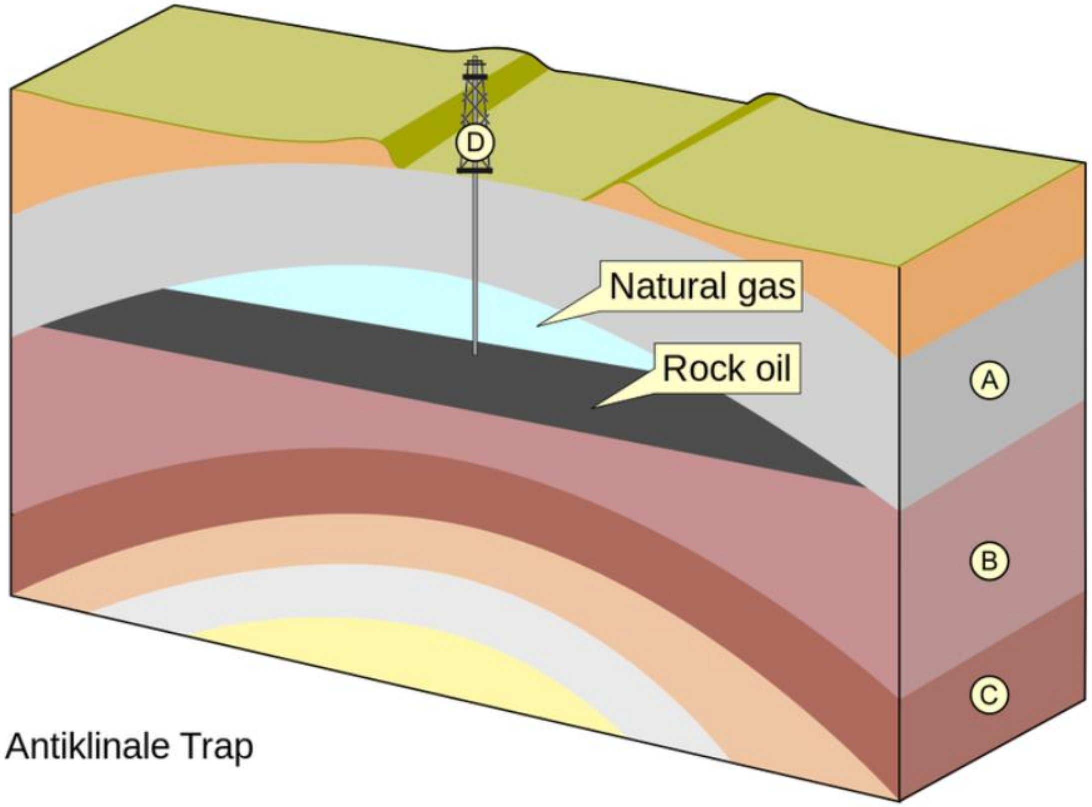
Oil & Gas Traps

- Oil and gas traps, sometimes referred to as petroleum traps are below ground traps where a permeable reservoir rock is covered by some low permeability cap rock.
- This combination of rock can take several forms, but they all prevent the upward migration of oil and natural gas up through the reservoir rock.
- Two major categories of traps
  - Structural Traps
  - Stratigraphic Traps

- Seal rock is a shale, evaporite, or other impervious rock that acts as a barrier to the passage of petroleum migrating in the sub-surface;
- It overlies the reservoir rock to form a trap or conduit. The seal rock is also known as roof rock or cap rock.
- A dipping reservoir rock overlain by a seal rock provides a migration path for petroleum.

Structural Traps

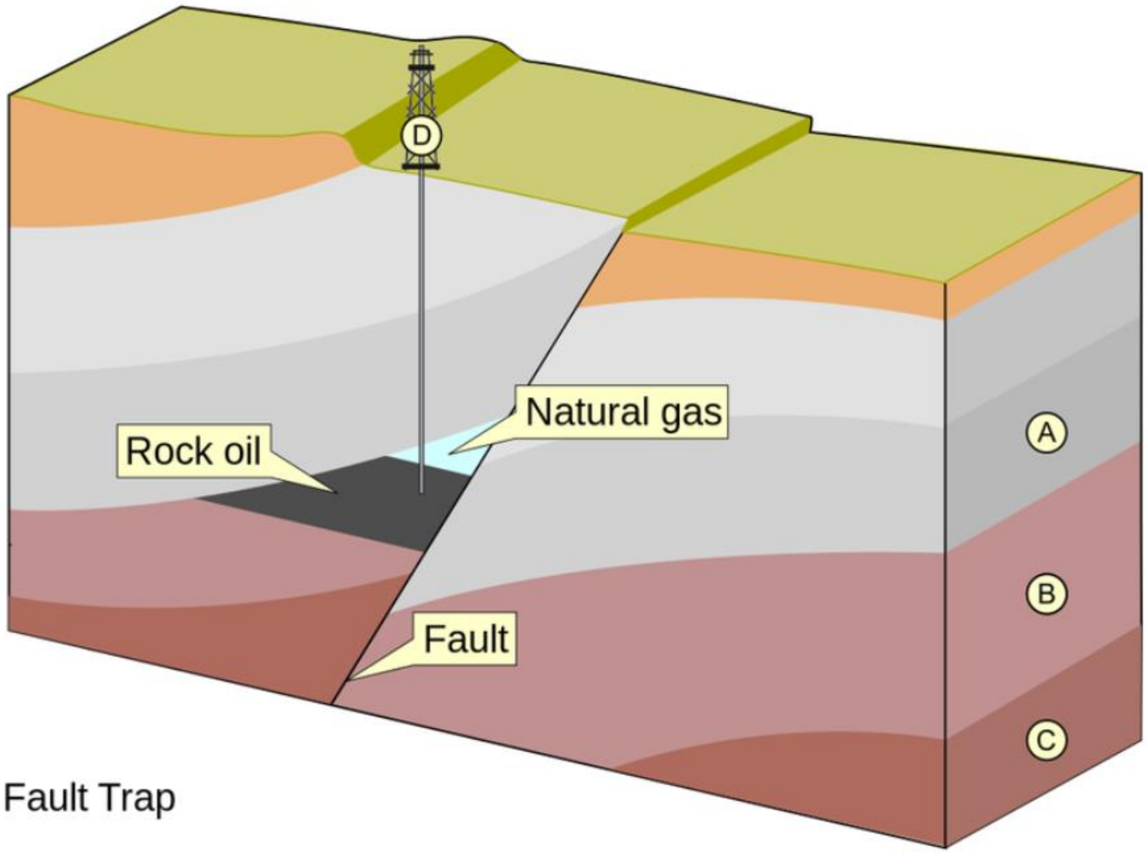
- These traps are types that form as a result of some structural deformation - a bend or dip - of rock. These traps take on several forms and shapes as a result of different types of deformation.
- **Anticline Trap**:
  - These types of traps are formed by a folding of rock. Specifically, a sandstone bed covered with low permeability shale is folded into a trap that contains petroleum products. Hydrocarbons are trapped in the peak of this fold.
  - Most anticline traps are created as a result of sideways pressure, folding the layers of rock



Antiklinale Trap

Fault Traps

- These types of traps are formed when reservoir rock is split along a fault line. Between the walls of the split reservoir, clay traps oil and prevents it from leaving the trap.
- Other times there exists a pressure differential across the two sides of the fault that prevents the fluids from migrating.
- Although faulting is common in many petroleum fields, traps that result from faulting alone are not very common.



Fault Trap

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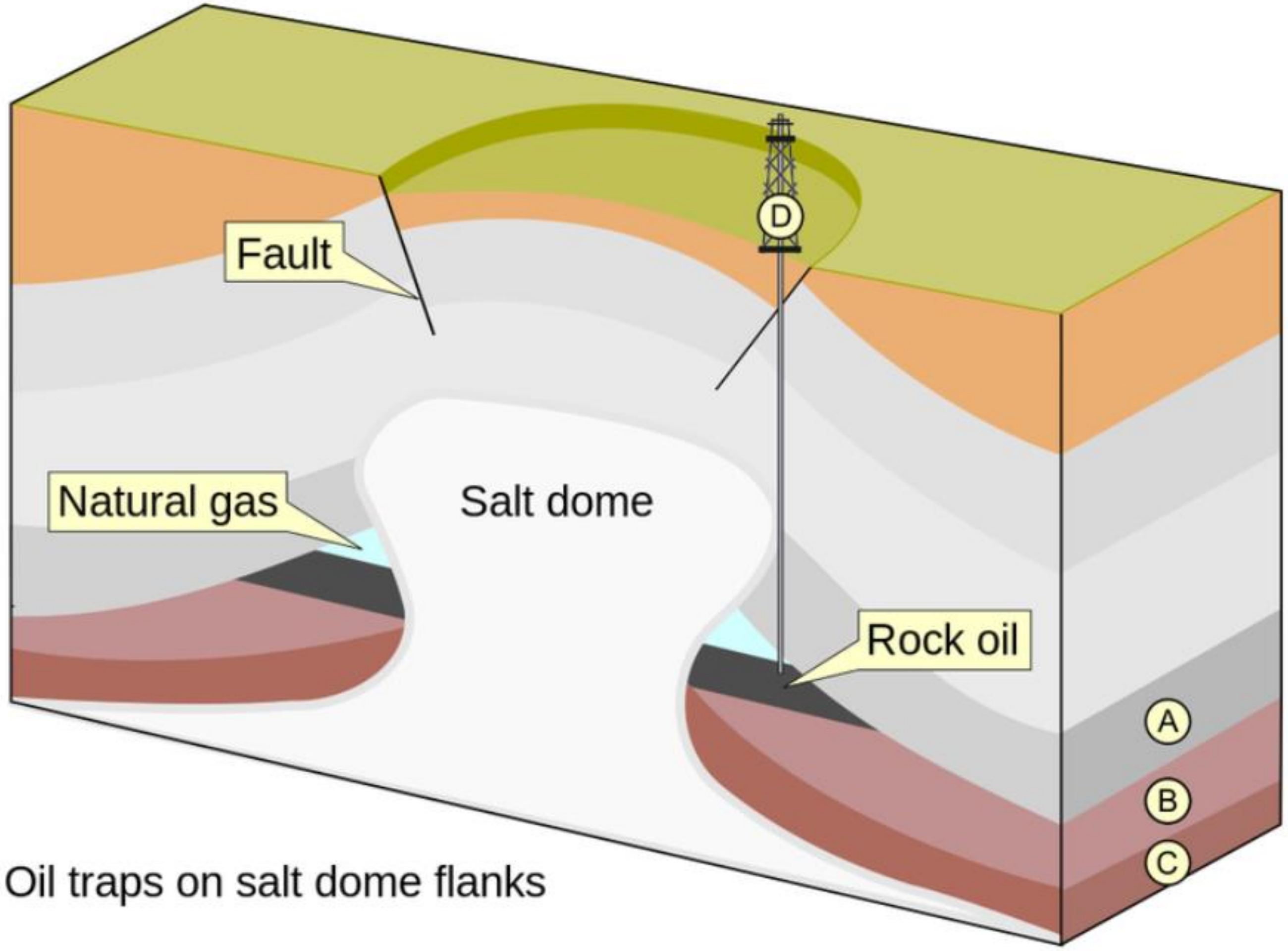
Salt Domes

- Salt dome traps are formed as a result of below ground salt - which is less dense than the rock above it - moving upwards slowly. This upward migration of the salt can deform and break u p rock along the way. The process of this salt deforming rock is known as salt tectonics, and take place over hundreds of millions of years.
- Oil and gas that flows through the reservoir rock will come to rest when it reaches the salt dome and is then trapped.



Oil traps on salt dome flanks

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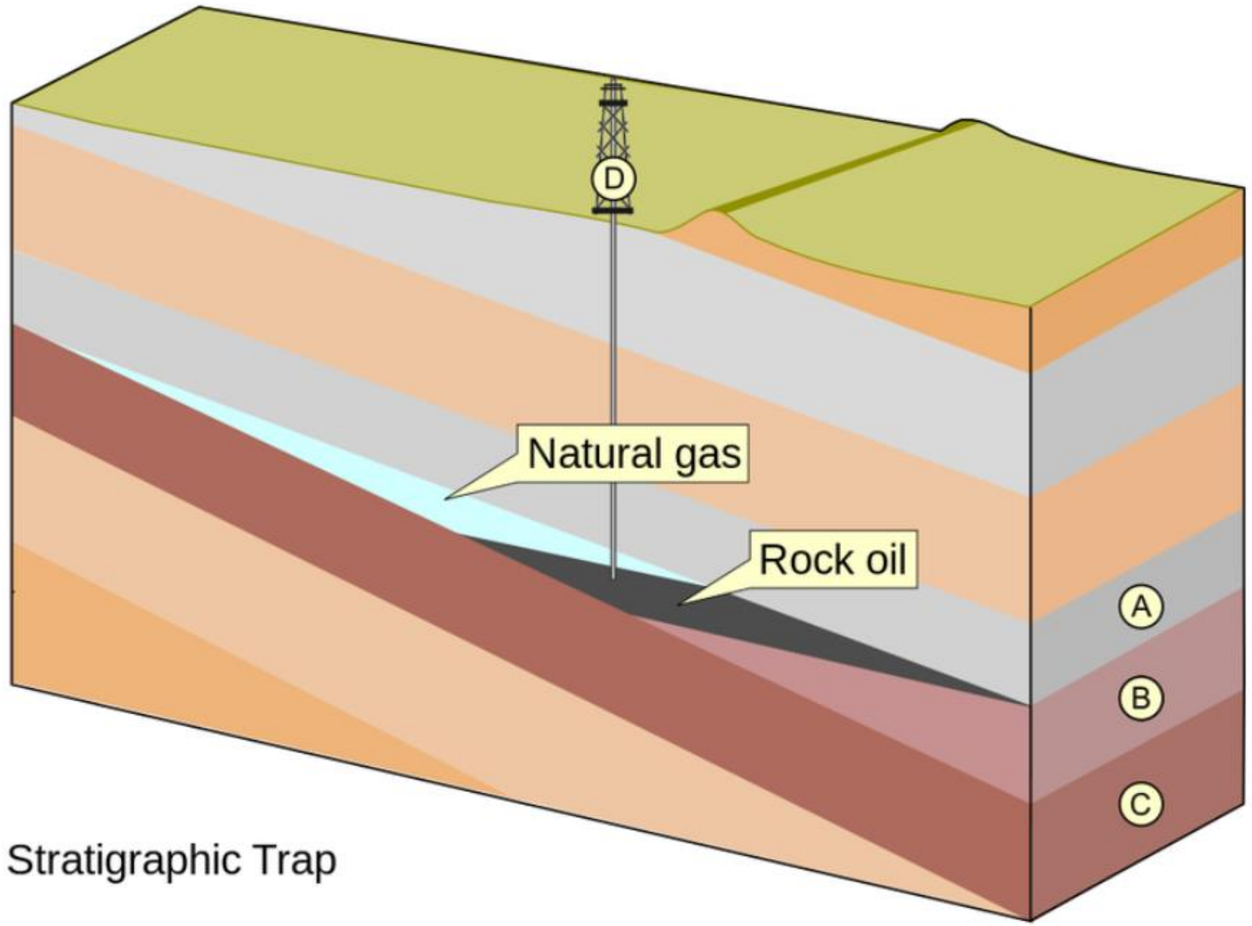
Stratigraphic Traps

- These traps are formed as a result of the deposition in sedimentary rocks. When the sediment that creates the reservoir rock is deposited in a discontinuous layer, the seals are created beside and on top of the reservoir.
- In some cases, these seals are made of impermeable or low permeability shale deposited around the reservoir, blocking the oil and gas inside. The seals themselves may also be source rocks.
- There are two main types of stratigraphic traps that are classified by when changes occur relative to the sedimentation process.
- Primary stratigraphic traps result from changes that develop during the sedimentation process.
- Secondary stratigraphic traps result from changes that develop after sedimentation has occurred.



Stratigraphic Trap

THANK YOU