Petroleum Geology lectures

Prepared By
Dr. Munther Dhahir Nsaif
Dr. Mutadhid Majeed

University of Diyala
College of Science
Petroleum and minerals geology Dept.

What is Petroleum Geology?

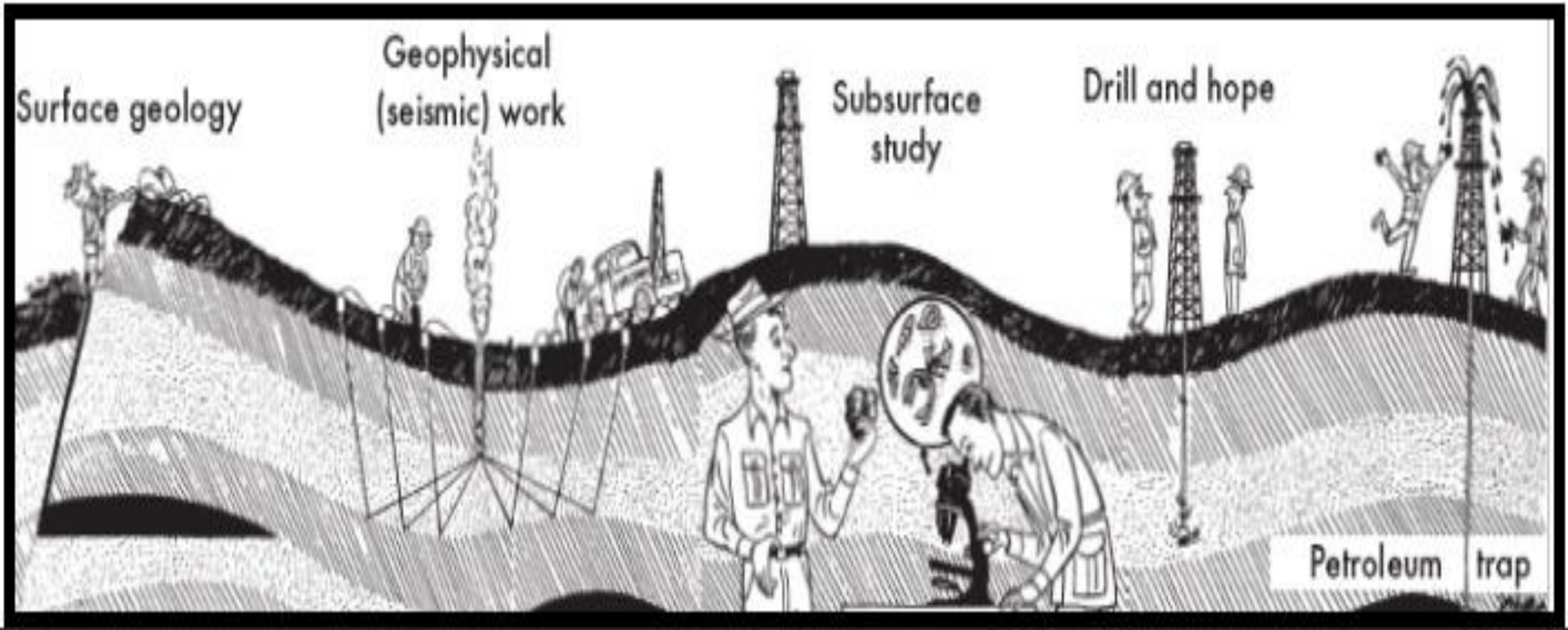
- is one branches of earth sciences refers to study of origin, occurrence, movement, accumulation, and exploration of hydrocarbon fuels. It refers to the specific set of geological disciplines that are applied to the search for hydrocarbons (oil exploration).

Who is petroleum geologist and what does he do ?

- petroleum geologist is a geoscientist who works in the field of petroleum geology, which involves all aspects of oil discovery and production. Or A geologist who specializes in the exploration, and the production of petroleum

- A petroleum geologist uses his or her expert knowledge of geological principles to determine the location and size of crude oil deposits. He or she might work for an oil or gas company, a governmental agency, or as an independent contractor, exploring different locations and pinpointing oil reserves. A petroleum geologist might use advanced computer technology to survey a region so that he or she can inform other experts how and where to drill.

- Scientists usually spend a great amount of time conducting field research. A petroleum geologist may work alone or with a team of other professionals, exploring land and ocean seabeds for oil deposits. He or she will look for signs that oil may be present in a certain location by taking samples of surface rocks and drilling a small sample well to collect subsurface sediments. Rock samples are evaluated using microscopes, geochemical analysis kits, and other laboratory equipment, to determine the presence of hydrocarbons and other minerals consistent with oil-rich areas.



Petroleum geologists make the decision of where to drill for petroleum. This is done by locating area within a sedimentary basin. Petroleum geologists determine a prospect's viability looking at seven main aspects:

1- **Source rocks**- The presence of an organic-rich source rock capable of generating hydrocarbons during deep burial.

2- **Reservoir rock** - The usually porous rock unit that collects the hydrocarbons expelled from the source rock and holds them inside a trap.

3- **Seal** - The rock unit that inhibits the oil or gas from escaping from a hydrocarbon-bearing reservoir rock.

4- **Trap**- Structural or stratigraphic feature that captures migrating hydrocarbons into an economically producible accumulation.

5- **Timing**- Geologic events must occur in a certain order, e.g. that the trap formed before migration rather than after.

6- **Maturation**- The process of alteration a source rock under heat and pressure, leading to the cracking of its organic matter into oil and gas.

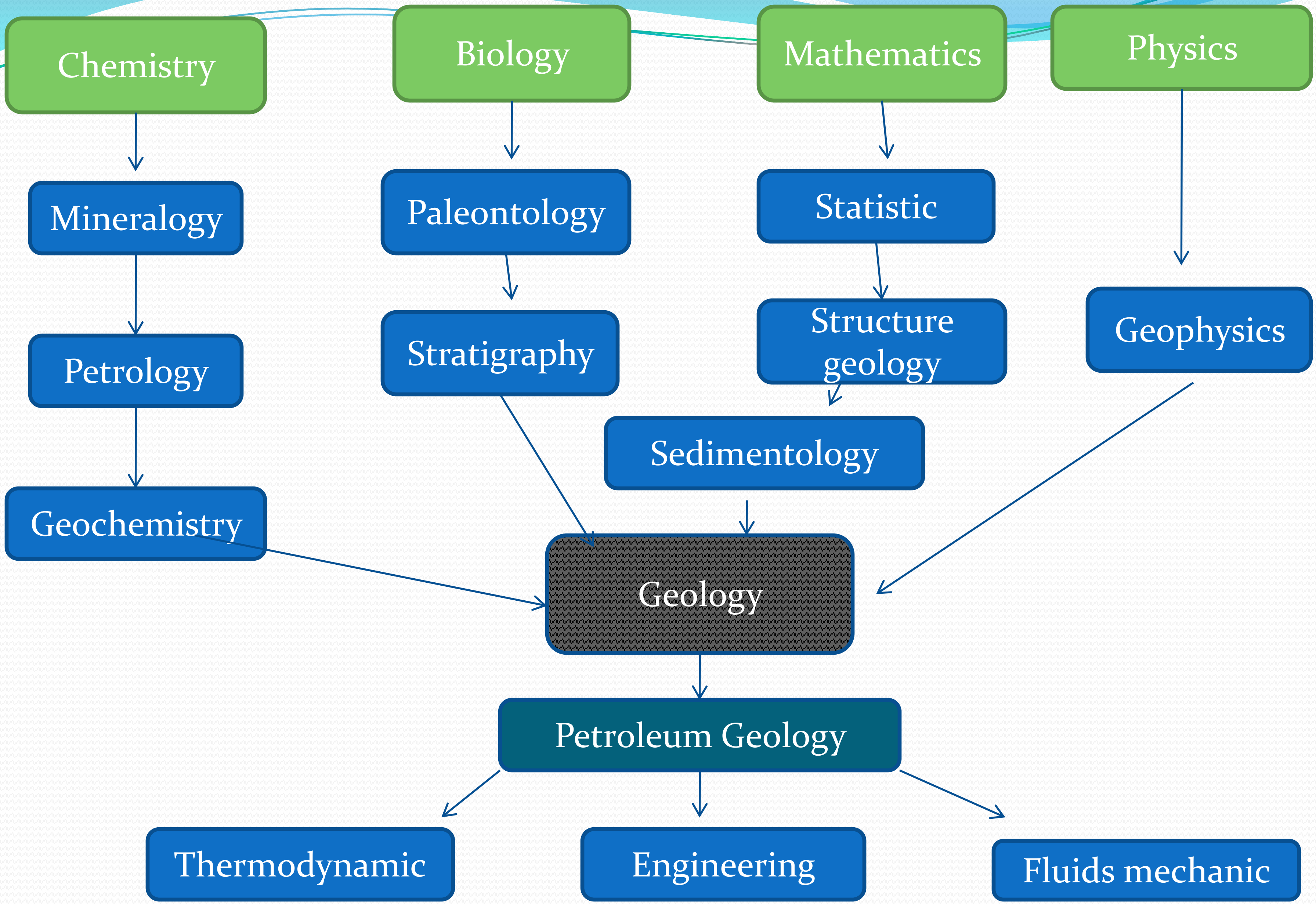
7- **Migration**- The movement of the (less dense) oil or gas from the source rock into a reservoir rock and then into a trap.

These seven key aspects require the petroleum geologist to obtain a 4-dimensional idea of the subsurface (the three spacial dimensions, plus time). Data may be obtained via Geophysical methods. Geophysical surveys show the seismology data of elastic waves, mainly seismic reflection. This provides a 3-dimensional look of the trap, and source rock. More data may be obtained from the mudlogger, who analyzes the drill cuttings and the rock formation thicknesses.

Relationship of petroleum geology to other geology sciences

- Petroleum geology is the application of geology to the exploration for and production of oil and gas .
- Geology itself is firmly based on chemistry ,physics and biology.
- The application of chemistry to the study of rocks (**geochemistry)** has many uses in petroleum geology: .
- A- detailed knowledge of the mineralogy of reservoir is essential for the accurate interpretation of geophysical well logs through reservoirs
- B - knowledge the chemistry of fluids and their effect on the stability of minerals
- C - organic chemistry is involved both in the analysis of oil and gas and in the study of diagenesis of plant and animals tissues in sediments and the way in which the resultant organic compound generates petroleum.
- The application of physics to the study of rocks **(geophysics)** is very important in petroleum geology
- A- physical concepts are required to understand structural geology (fold,fault,diaparis--)
- B- Modern petroleum exploration is unthinkable without the aid of magnetic, gravity and seismic surveys in finding petroleum traps.
- C- geophysical wireline logs used to measure lithology , porosity and petroleum content in reservoir.

- Biology is related with geology in
- A- study the fossils (paleontology) and establishing biostratigraphic zones for regional stratigraphic correlation.
- B- study the relationship between living organisms and their environment.
- C- study the transformation of plant and animals tissues into kerogen during burial and the generation of oil and gas.
- - oil companies exist not only to find oil and gas but to make mony thus every step of journey from leasing to drilling to production and finally to enhanced recovery is monitored by accountants and economists.


Chemistry
Biology
Mathematics
Physics
Mineralogy
Paleontology
Statistic
Petrology
Stratigraphy
Structure geology
Geophysics
Sedimentology
Geochemistry
Geology
Petroleum Geology
Thermodynamic
Engineering
Fluids mechanic

Some terms in petroleum geology

- **Oil field :-** An area consisting of a single reservoir or multiple reservoirs all grouped on, or related to, the same individual geological structural feature and/or stratigraphic condition.

Or is a region with an abundance of oil wells extracting petroleum (crude oil) from below ground.

- **Hydrocarbons** : are chemical compounds consisting wholly of hydrogen and carbon.
- - **Petroleum** : is a complex mixture of gaseous, liquid, and solid hydrocarbons. In addition there are
- compounds which contain oxygen, nitrogen, and sulphur. Frequently, relatively small amounts of water and inorganic matter are present.

- **Natural Gas** is the portion of petroleum that exists either in the gaseous phase or is in solution in crude oil in natural underground reservoirs, and which is gaseous at atmospheric conditions of pressure and temperature. Natural Gas may include amounts of non-hydrocarbons.

- **Crude Oil** is the portion of petroleum that exists in the liquid phase in natural underground reservoirs and remains liquid at atmospheric conditions of pressure and temperature. Crude Oil may include small amounts of non-hydrocarbons produced with the liquids.

- **Dry Hole** - Any exploratory or development well that does not find commercial quantities of hydrocarbons.
- **Reservoir** - Any rock having enough porosity and permeability to contain appreciable hydrocarbons. Most often reservoirs are sandstone and limestone (limestone/dolomite).
- - **Reserves:-** general sense represents the oil in the ground that have not extracted yet, including oil, which has not been explored . reserves classified into three types, **proven reserves**, **probable reserves**, and **possible reserves**.
- - **Inventory(Resourse):** is the oil extracted and represents quantities of crude oil and oil derivatives saved by firms and governments to business objectives or strategy. Usually affect inventory changes on oil prices, while does not have a direct link between the reserves and oil price

- Oil and gas consist of group of compounds that differs chemically and physically ,termed the hydrocarbons.
- - in physical side , the hydrocarbons graded from gases, liquids, plastic to solid.
- - gases hydrocarbons include:-
- 1- dry gas (methane) 2- wet gases (ethan,propan, butan,-ets.)
- 3- condensates: are hydrocarbons that are gaseous in the subsurface but condense to liquid when they are cooled at the surface
- - Liquid hydrocarbons include oil (crude oil) or termed just crude to differentiate from refined petroleum products.
- - plastic hydrocarbons include asphalt and related substances.
- - solid hydrocarbons include coal and kerogen.
- - The earth atmosphere is composed of natural gas
- - Natural gas :- is a mixture of hydrocarbons and varying quantities of non hydrocarbons that exists either in the gaseous phase or in solution with crude oil in natural underground reservoirs.
- - natural gases encountered in the subsurface can be classified according to its origins into :-
- **1-organic origin gases**:- which include Methane, Ethane, Propane and Butane
- **2- inorganic origin gases:-** which include Helium, Argon, Krypton and Nitrogen
- **3- Mixed origin gases** :- which include Carbon dioxide (CO_2) , Hydrogen sulfide (H_2S) and Hydrogen (H_2)
- - The first and second classes termed as **hydrocarbons** and **inert gases** respectively . Tables below illustrated the classification of natural gases according to its origin , water vapor content and Hydrogen sulfide (H_2s)content :

Clasification of natural gases

1- according to the origin of gases

origin (Dominant source)		Gas
Organic	Methane(dry gas) Ethane Propane — wet gases Butane Hydrogen (H_2)	**Hydrocarbon gases**
Inorganic **(Non hydrocarbon gases)**	Helium Argon Krypton Radon Nitrogen	Inert gases
Mixed	Carbon dioxide (CO_2) Hydrogen sulfide (H_2S)	

2- according to water vapor content

A- Dry gas :- which contain 0.1 gallon/1000ft of condensate , chemically dry gas is largely methane.

B- Wet gas :- which contain more than 0.3 gallon /1000ft of condensate , chemically this gas contain ethane ,butane and propane

3- according to the absence or presence of hydrogen sulfide (H_2S)

A- sweet gas

B- sour gas

Chemical constituents of natural gas

- -from defination of natural gas it is a mixture of hydrocarbon and non hydrocarbon that exists either in the gaseous phase or in solution with crude oil in natural underground reservoirs(gases can be classified to hydrocarbon gases and nonhydrocarbon gases).
- 1- Hydrocarbon gases

- The major constituents of natural gas are the hydrocarbons of paraffin series (C_nH_{2n+2}), which consist to:- Methane(CH_4)(the most abundant) , Ethane (C_2H_6), Propane (C_3H_8) , Butane (C_4H_{10}) and Pentane (C_5H_{12})
- Methane is also known as (marshes gas)if present at the surface or (fire damp) if present down a coal mine.
- Methane is a colorless , flammable gas ,chemically nonreactive, sparingly soluble in water and lighter than air .
- Methane is created in several ways (source of Methane):
- 1-it may derived from mantle
- 2- it may derived from the thermal maturation of burial organic matter
- 3- it may form by the bacterial degradation of organic matter at shallow depth.
- Geochemical and isotope analysis can differentiate the source of Methane in a reservoir.
- Biogenic Methane
- 20% of the natural gas produced is of biogenic origin.
- Biogenic methane is commonly formed in the shallow subsurface by the bacterial decay of organic –rich sediments . In the deep reservoir s methane is produced by thermal maturation of organic matter.
- The other major hydrocarbon gases are Ethane, Propane, Butane , and Pentane .
- Unlike methane these heavier members of paraffin series don't form biogenically .They are only produced by the thermal maturation of organic matter.
- If their presence is recorded by a gas detector during the drilling of a well , it often indicates asginificant petroleum accumulation or source rocks.

2- **Non Hydrocarbon gases**:- consist **to Inert gases,** Nitrogen,**Hydrogen**,Carbon dioxide and Hydrogen Sulfide.

- 1- Inert Gases

-Helium is a common minor accessory in many natural gases

- Helium has been found in oil field gases in amount of up to 8%
- The origin of helium is widely believed to have emanated from deep igneous rocks especially granite
- Helium also occurs from break down of uranium ore within sedimentary sequence
- Argon and Radon are by-products of the radioactive disintegration of potassium and radium respectively and are believed to have an origin similar to that of helium.
- 2- Nitrogen
- - Nitrogen is another nonhydrocarbon gas that frequently occurs naturally in the earth crust. It is commonly associated with both the inert gases and hydrocarbons gases.
- -the percentage of Nitrogen in some gases fields is about 1-14%
- -**The origin of nitrogen**
- A- from volcanic emanations
- B- some studies have suggested that the thermal metamorphism of bituminous could generate both nitrogen and carbon dioxide
- C- several information suggest that the major source of nitrogen is igneous rocks.
- These various evidence suggest that nitrogen natural gases are inorganic origin , although organic processes may be aids in generators of atmospheric and shallow nitrogen. some atmospheric nitrogen may have been trapped in sediments during deposition.

3- Hydrogen

- - free hydrogen gas rarely occurs in the subsurface because of its reactivity and because its mobility
- -hydrogen is commonly dissolved in subsurface water and in petrolum.
- - the subsurface hydrogen is probably produced by thermal maturation of organic matters.
- **4- carbon dioxide**

- co2 is often found as a minor in hydrocarbon natural gases, it also associated with nitrogen and helium.
- (co2) is appear in natural gas accumulations in areas of volcanic activity ,and also in metamorphic carbonate sediments, and other igneous intrusive.
- Co2 is normal product of the thermal maturation of kerogen, generally being expelled from kerogen before petroleum.
- - co2 is also given during oxidation of mature organic matter due to either fluid invasion or bacterial degradation.
- - co2 is produce also during oxidation of methane with the aid of water as illustrated in following chemical equation

$$3CH_4+6O_2 \longleftrightarrow CO_2 + H_2O$$

-The recent application of (Co2) to enhance oil recovery has increased its usefulness.

4- Hydrogen sulfide

- **H2S occurs in the subsurface <u>either</u> as free gas <u>or</u> in solution with oil and brine.**
- It is poisonous , eve smelling gas ,whose presence causes operation problems in both oil and gas field ,where it is highly corrosive to steel , quickly attacking production pipes , valves and flow lines.

- The terms sweet and sour gas are used in the field to designate gases that are low or high, respectively, in hydrogen sulfide

- H2S is commonly expelled together with sulfur dioxide (SO2) from volcanic eruption.

-Crude Oil

- Crude oil is defined as " a mixture of hydrocarbons that existed in the liquid phase in natural underground reservoir and remains liquid at atmospheric pressure after passing through surface

- Crude oil occurs in many colors vary from yellow ,green, and brown to dark brown or black.
- - Crude oil have widely varying viscosities. In the surface crude oil tend to be more viscous than in warm subsurface reservoirs and its viscosity vary not only with temperature but also with the age and depth of crude oil.
- - Generally oils are lighter than water, although the density of the oil may be measured as the difference between its specific gravity and that for water ,it is often expressed in gravity units defined by (API) according to the following formula:-
- API= (141.5 / specific gravity 60/60F)-131.5

Where (60/60F) is the specific gravity of the oil at 60F compared with that of water at 60 F.

- (Specific gravity is a ratio of the density of one substance to the density of water).
- Although (API) values do not have units, they are often referred to as degrees
- The API gravity is used to classify crude oils as light, medium, heavy, and extra heavy, as below
- **Light – API > 31.1**
- **Medium – API between 22.3 and 31.1**
- **Heavy – API < 22.3**
- **Extra Heavy – API < 10.0**
- An (API) of 10 degree is equivalent to water, which means any oil with an API above 10 will float on water while any with an API below 10 will sink.

- **Note that API degree are inversely proportional to density and viscosity**

- API gravity moves inversely to density, which means the denser an oil is, the lower its API gravity will be.

Chemistry of Crude oil

- In terms of elemental chemistry ,crude oil consists largely of carbon and hydrogen with traces of vanadium ,nickel and other elements, as shown in table below.
- Elemental composition of crude oils (by weight%)

Element	Minimum	Maximum
Carbon	82.2	87.1
Hydrogen	11.8	14.7
Sulfur	0.1	5.5
Oxygen	0.1	4.5
Nitrogen	0.1	1.5
Other	Trace	0.1

-No two oils are identical in the compounds contained or in the various proportions present.however,certain compositional trends are related to the Age ,depth, source, and geographic location of the oil.

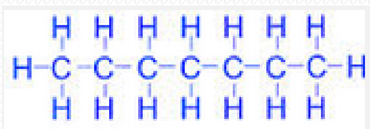
- The compound found in oil may be divided into two major group:-
- 1- The hydrocarbons which contain three major subgroups
- 2- The heterocompounds :- which contain other elements.

- 1- The hydrocarbons : the hydrocarbons present in crude oil contain three major subgroups these are:- a-paraffins b-naphthenes, c-and aromatics In addition, there is a fourth type,olefins, that is
- formed during processing by the dehydrogenation of paraffin's and naphthenes

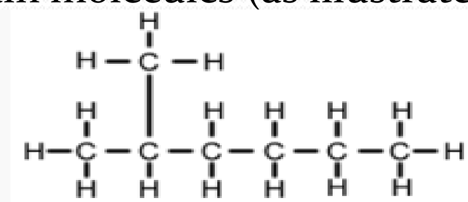
A- Paraffin's

The paraffin's ,(often called alkanes), are saturated hydrocarbons ,with a general formula (C_nH_{2n+2})

- **If n< 5** the paraffin's are **gaseous** at normal temperatures and pressures.(these compounds consist methane, ethane, propane and butane)
- **If n=5** (pentane C_5H_{12}) to **n=15**(pentadecan,$C_{15}H_{32}$), the paraffin's are **liquid** at normal temperatures and pressures
- If **n > 15 ,** the paraffins graded from **viscous liquids** to **solid waxes**.
- - Two types of paraffin's molecules are found within the series both are Isomers.
- 1- the first one series consists of straight –chain molecules
- 2- the second series consists of branched- chain molecules (as illustrated below)

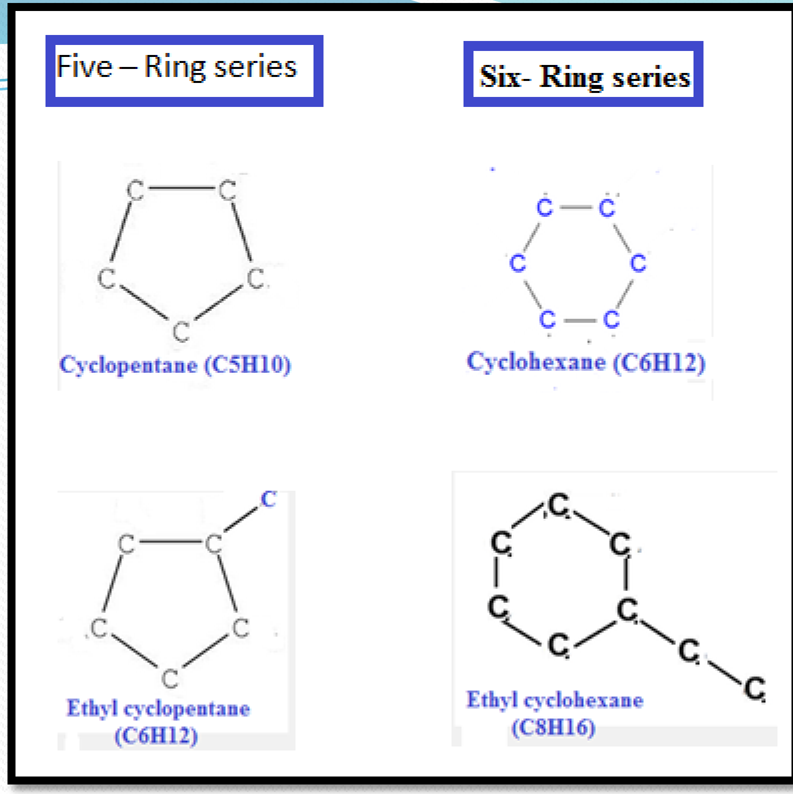


Heptan C7H16



Methylhexane (C7H16) (isoheptane)

- For a given molecular weight the normal paraffin's have higher boiling point than do equivalent weight isoparaffins.
- **B- Naphthens**
- - The second group of hydrocarbons found in crude oils are the nephthenes or cycloalkanes.
- This group has a general formula C_nH_{2n}.
- Like the paraffins they occur in ahomologous series consisting of five- and six –memberd carbon rings termed the cyclopentanes and cyclohexanes, respectively (as shown below).

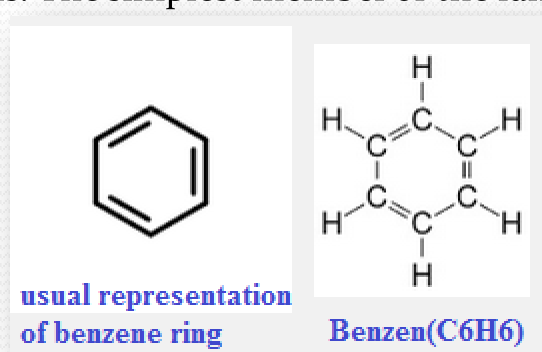


- Naphthenes , unlike the paraffins all the naphthenes are liquid at normal temperatures and pressure. The make up about 40% of both light and heavy crude oil.

-**C- Aromatics**

--aromatic compounds are the third major group of the hydrocarbons commonly found in crude oil

-Their molecular structure is based on a ring of six carbon atoms. The simplest member of the family is benzene (C_6H_6), whose structure is



- Aromatic hydrocarbons are liquid at normal temperatures and pressures.
- They are present in relatively minor amounts (about 10%) in light oils , but increase in quantity to more than (30%) in heavy oils with decreasing API gravity.
- Toluene (C_6H_5 CH_3) is the most common aromatic component of crude oil , followed by Xylenes ($C_6H_4(CH_3)_2$) and benzene.

2- The heterocompounds

- crude oil contains many different heterocompounds that contain elements other than hydrogen and carbon, such as oxygen , nitrogen and sulfur , additional to rare metal atoms , commenly nickel and vanadium.
- Nickel and vanadium occur as organo-metallic compounds, generally in porphyrin molecules .
- the porphyrin contain carbon ,nitrogen and oxygen as well as metal radical.
- The presence of porphyrins in crude oil is genetic because they may be derived **either** from the chlorophyll of plants or the **hemoglobin** of blood.
- Traces of other elements have been found in crude oils, but determining whether they occur in **organic compounds** or they are contaminants from the reservoir rocks, or formation water is difficult.
- These traces include silica , calcium , magnesium, together with numerous metals , such as iron , aluminum, copper, lead, gold and silver.
- Metals are **rare** in old,deep, marine oils and are relatively abundant in shallow ,young oils.

- **Classification of Crude oil.**

- Many schemes have been proposed to classify the various types of crude oils. The classification fall in **two** categories :-

1- chemical engineering classification interested in refining crude oil

2- geological and geochemistry classification to aid to understanding the source , maturation, history and other geological parameters of crude oil occurrence.

- The first type of classification concerned with the quantities of the various hydrocarbons present in a crude oil and their physical properties.
- The geochemistry classification (by Tissot and welte 1978) based on the ratio between paraffins ,naphthenes, and aromatic including asphaltic compounds (table and figure below).
- The classification based on geological occurrence was proposed by **Biederman** (1965). This classification based on depth and age as follow:-
- 1- Mesozoic and Cenozoic oil at depth less than 600m
- 2- Mesozoic and Cenozoic oil at depth more than 3000m
- 3- Paleozoic oil at depth less than 600m
- 4- Paleozoic oil at depth more than 3000m.

- Essentially , the geological classification recognized four classes of oil these are :-
- a-young-shallow b-young –deep c- old –shallow   d- old –deep.
- A detailed study of many oil showed significant chemical and physical differences between these groups:-

A- young –shallow oil:- tend to be heavy and viscous they are generally sulfurous and relatively low in paraffin's and rich in aromatics.

B- young – deep oil:-less viscous from (A group) higher of API gravity , more paraffinic and low in sulfur content .

C- old – shallow oil:- are broadly similar to young – deep crude oil in viscosity and paraffinc nature .like young –shallow oil they tend to be sulfurous.

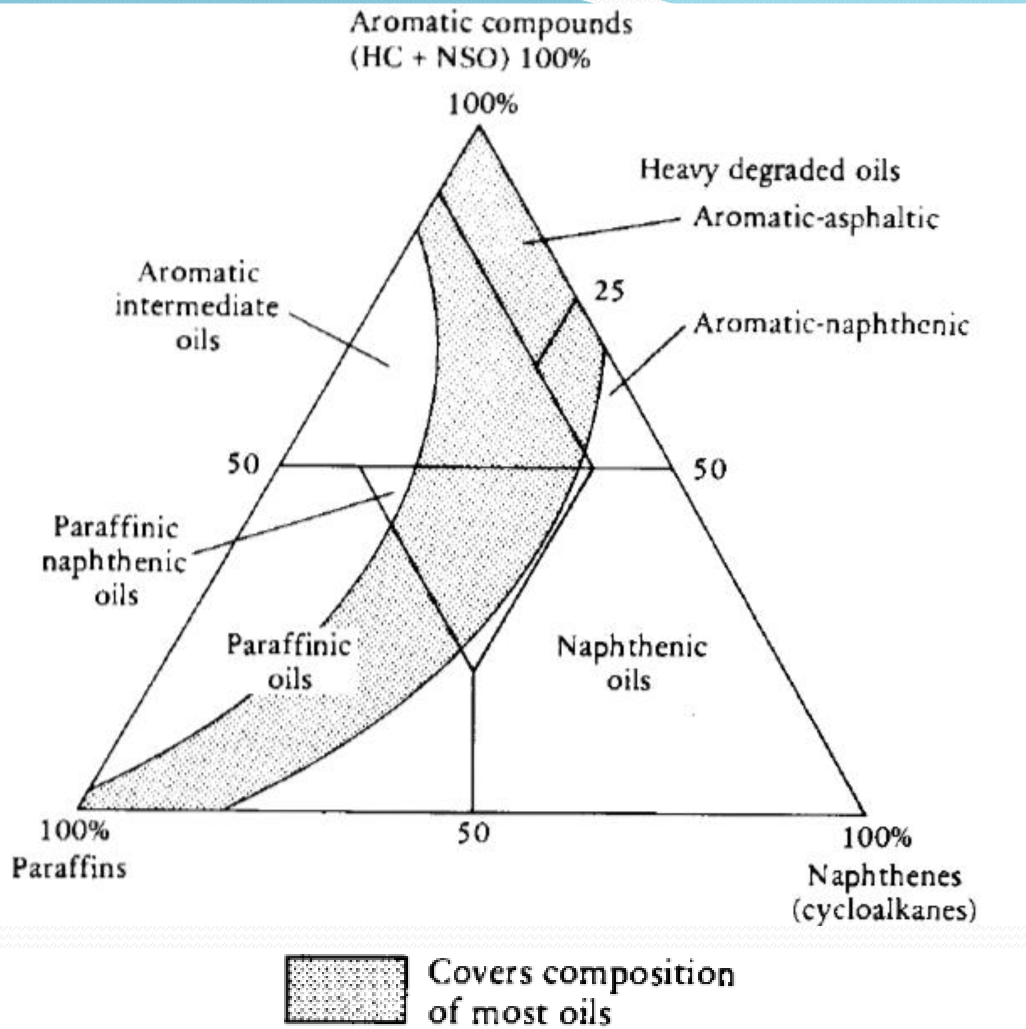
D- old- deep oil :- tend to have the lowest viscosity ,density and sulfur content of the four groups.

- Note , oils vary not only with age and depth , but also with variations in their source rocks .

Classification of Oils

CONCENTRATE	TYPE OF CRUDE OIL	S CONTENT
S > 50% (P>N & P>=40%)	PARAFINNIC OIL	<1%
A<50% (P>=N & N<=40%)	PARAFINNIC-NAPHTHENIC OIL	<1%
A<50% (N>P & N>40%)	NAPHTHENIC OIL	<1%
S<=50% (P>10%)	AROMATIC INTERMEDIATE	>1%
S<=50% (P>10% & N<=25%)	AROMATIC ASPHALTIC	>1%
A>=50% (P>=10% & N>=25%)	AROMATIC NAPHTHENIC	<1%

S-SATURATE
A-ASPHALTENE
P-PARAFFIN
N-NAPHTHENE



Ternary diagram showing the classification of oils proposed by Tissot and Welte (1978). (Reprinted with permission from Springer-Verlag.)

- **Generation and Migration of petroleum**
- Any theory regarding the origin of petroleum must explain two sets of observation or facts these are:-
- **A- geological facts B- chemical facts.**

A- Geological facts in petroleum generation:- consist number of geological observations such as:-

1- major accumulations of hydrocarbons occur in sedimentary rocks.

2- Many hydrocarbon deposits occur in porous and permeable sandstones and carbonate reservoirs, which are totally enclosed (in all directions(above, below and laterally)) by impermeable rocks

3- there are a minor geologic occurrences for petroleum in igneous and metamorphic rocks.

4- traces of hydrocarbons occure in stony chondrite meteorites

B- Chemical facts in petroleum generation:- consist number observations such :-

(1) old oils differs from young oils as follows :

a) Old oils contain even-carbonic chains than young oils (these tend to have odd carbonic chains).

b) Old oils contain more than 50% light hydrocarbons, which are rare or absente in young sediments.

(3) Old oils contain a complex melocules and contain modren organic matter or produce from degradation of these organic matter

Origin of petroleum theories :-

There are two theories of origin of petroleum these are

1- inorganic (abionic) 2- organic (bionic)

1- inorganic theory

Inorganic theories were the first advanced to account for the formation of petroleum

This theory state that the petroleum is inorganic origin , The owners of this theory depended on a number of phenomena, including:-

1- occurrence of hydrocarbon gases in surrounding parts of earth and outer planets

2- gaseous hydrocarbons have been recorded to emanate from volcanoes in many parts of the world

3- occurrence of hydrocarbon deposits near thermal springs

4- occurrence of solid petroleum deposits filling dikes as igneous rocks cutting sedimentary rocks.

5- particular class of meteorites (carbonaceous condrites) contain traces of various hydrocarbons

6- capability of preparing the oil from inorganic material that available in the earth

Inorganic theory can be divided to :-

(a) ***Metal Carbide Theory***

- This theory based on the assumption that the interior of the Earth contained free alkaline metals with which carbon dioxide could react at high temperatures to form carbides and acetylides.

The carbides or acetylides would then react with water to form acetylene,

$$CaC_2 + 2H_2O = C_2H_2 + Ca(OH)_2$$

- when acetylene heated to approximately 900C, polymerizes to form benzene, one of the hydrocarbon series.
- The problem with this theory is the lack of evidence for the existence of iron carbide in the mantle. These theories are referred to as the deep-seated terrestrial hypothesis.

-(b) **cosmic origin theory**

- In 1890, Sokoloff proposed a **cosmic origin** for petroleum. His theory was that hydrocarbons precipitated as rain from original nebular matter from which the solar system was formed. The hydrocarbons were then ejected from earth's interior onto surface rocks.
- In modern terminology he simply suggested that petroleum originated from meteorites
- . Later, he claimed, this petroleum was ejected from the earth's interior into the surface sediments
- Recently this idea has been supported by F. Hoyle, who proposes that not only oil, but life itself has extra-terrestrial origins

THE ORGANIC THEORY

- The organic theory holds that the first stage of the genesis of petroleum Involves plants and animals remains or/and plankton (single-celled organisms that float on the oceans).
- These organism die and gradually accumulate on the ocean floor. Other sediments start accumulating too, and after a few million years the plankton are buried under several km of sediment.
- The plankton, which have remained unoxidised, under the increased values of pressure and temperature, are now transformed into kerogen.
- Under favorable conditions of time and temperature this kerogen, after further burial and heating, is transformed, via cracking, into petroleum and natural gas.
- These then migrate towards the surface and end up either reaching it (and drying up to yield bitumen or tar) or being arrested on the way in traps.
- The biological, chemical and geological processes necessary for the conversion of the organic matter of plants and animals into hydrocarbons are not completely understood
- Traditionally, the following points have been considered as supporting of the organic theory:

1- 99% of hydrocarbon deposits occurs into sedimentary rock, in which organism are buried in the basins during deposition

2-optical activity is property of most petroleum, and it is due to the presence of cholesterol which is found in both plant and animal matter.

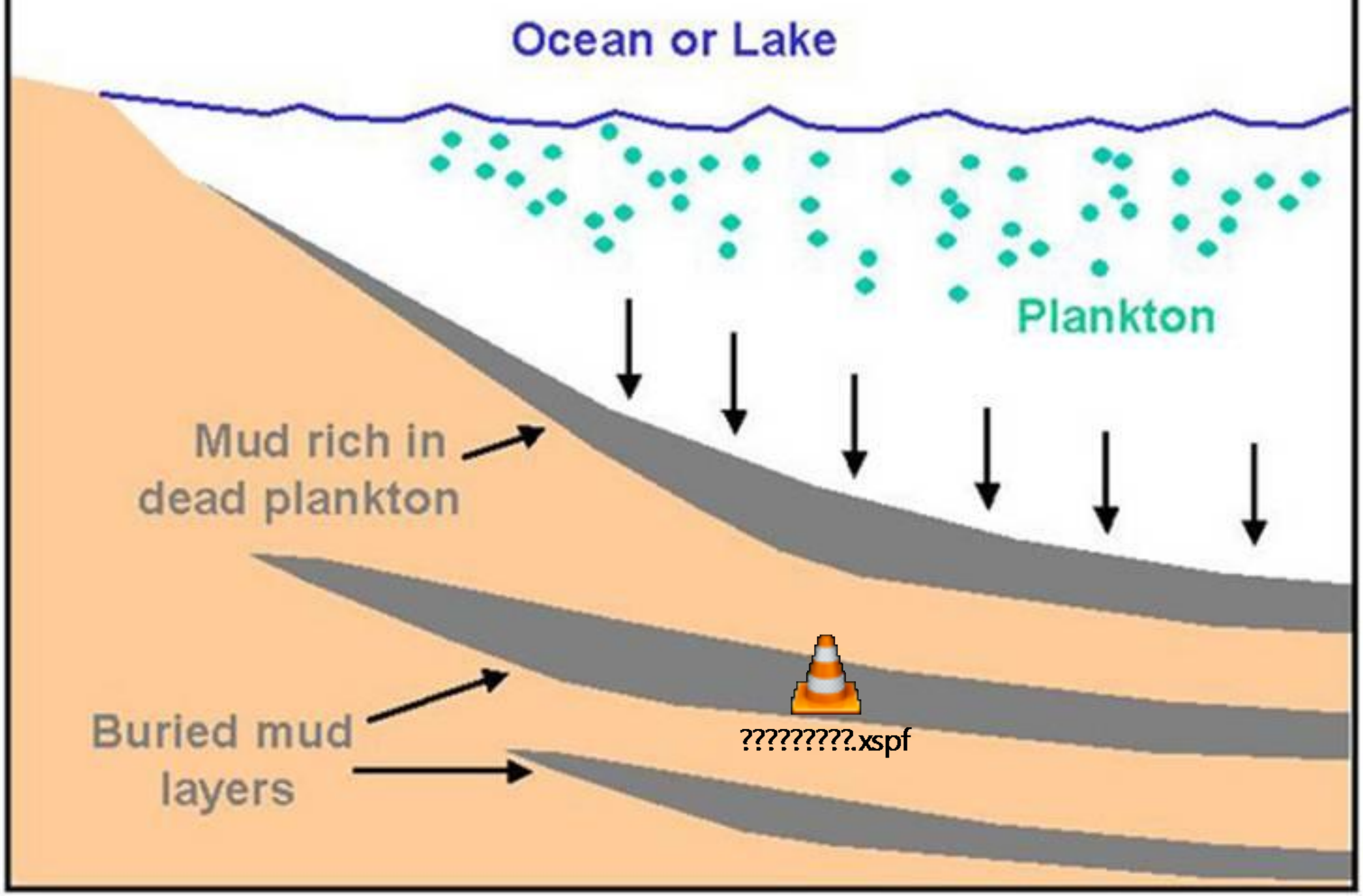
3- Petroleum contains nitrogenous compounds. All such compounds found in nature are either of plant or animal origin

4- . Some petroleum contains chlorophyll porphyrins, which are derivatives obtained from the chlorophyll of plants or from the blood cells of animals.

5- Some petroleum contain hydrogen sulfide gas which results from bacterial decomposition of plants and animals.

Origin of Petroleum

http://youtube.com/watch?v=_PDOD_FEnNk



Oil is a fossil fuel that is formed from plankton that is deposited in the sediments of oceans and lakes, and then buried deeply in the earth.

oceanexplorer.noaa.gov/.../media/fig1.html

- ***Organic matter :-*** is organic compound that has come from the remains of organism such as plants and animals and their waste products in the environment .

- The **chemical composition** of organic matter is diverse because the organisms from which it is derived are complex.

- **The major chemicals groups that occur in organic matter are proteins, carbohydrates , Lipids and Lignin**

A- The proteins :-

- **1- found largely in animals and to a lesser extent plants**
- **2- they contain the elements Hydrogen ,Carbon, Oxygen ,and Nitrogen with some sulfur and phosphorus. this combination of elements occurs in the form of amino acids.**

B- The Carbohydrates :-

- **1- found in both animals and plants**
- **2- They have the basic formula Cn(H2O)n and include Sugars , and glucose and their polymers- cellulose, starch.**

C- The Lipids :-

1- found also in both animals and plants

2- They are recognized by their insolubility in water and include the fate ,oil , and waxes.

3- The lipids contain Carbon , Hydrogen and Oxygen atoms.

D- The Lignin

1- found only in higher plants

2- high molecular weight , consisting of various types of aromatic carbon ring

<u>Stages of Organic Matter Maturation</u>(formation of kerogen)

Tissot (1977) defined three major phases in the evolution of organic matter in response to burial :-

1. Shallow Diagenesis 2.Catagenesis 3.Metatgenesis

1- Shallow Diagenesis (phase of kerogen formation)

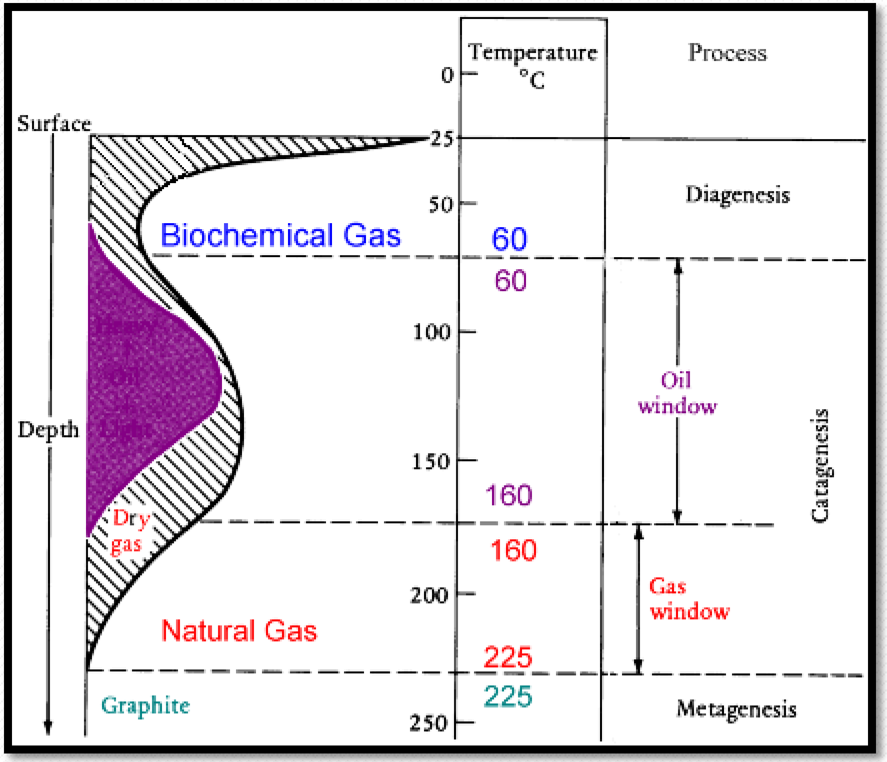
- This phase occurs in the shallow subsurface at near normal temperature(50-60C) and pressures .
- It includes both biogenic decay aided by bacteria and abiogenic reaction .
- Formation of kerogen phase
- The net result of the diagenesis of organic matter is the reduction of its oxygen content , leaving the hydrogen: carbon ratio fixed.

2.Catagenesis (phase of oil and gas formation)

- This phase occurs in the deeper subsurface(intermediate depths) as burial continues and temperature
- and pressure increase
- Thermal cracking of bonds in kerogen
- Formation of oil and gas in Catagenesis phase (first oil and later gas)
- The hydrogen : carbon ratio declines with no change in the oxygen :carbon ratio.

3.Metatgenesis

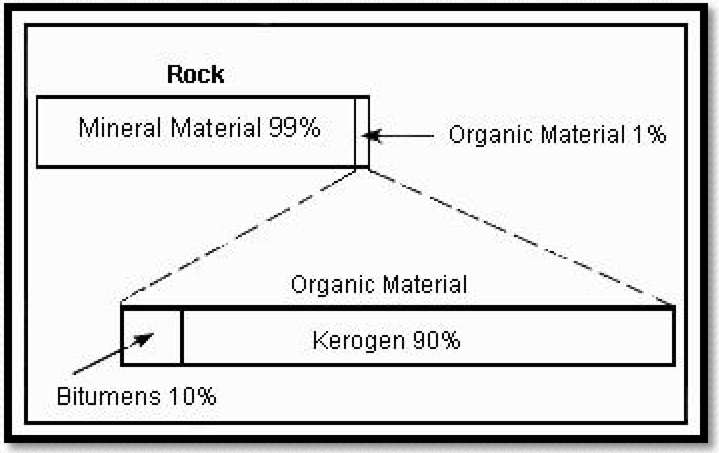
- This third phase occurs at high temperature and pressures leads to metamorphism
- The last hydrocarbons only methane are expelled
- The hydrogen: Carbon ratio declines until only carbon is left in the form of graphite
- Porosity and permeability are negligible in this phase because of compactions.



- ***Kerogen/Bitumens***
- Shale rock volume is composed of99% clay minerals and 1% organic material.
- petroleum is derived mainly from lipid-rich organic material buried in sediments. Most of this organic matter is in a form known as kerogen
- **Kerogen :- is that part of** the organic matter in a rock that is insoluble in common organic solvents
- Example.(Cs_2).

(It owes its insolubility to its large molecular size and heat is required to break it down.)

-As kerogen thermally matures and increases in carbon content, it changes form an immature light greenish-yellow color to an over mature black, which is representative of a progressively higher coal rank



- Maturation of kerogen is a function of increased burial and temperature and is accompanied by chemical changes.
- Different types of kerogen can be identified, each with different concentrations of the five primary elements, **carbon**, **hydrogen**, **oxygen**, **nitrogen**, and **sulphur**, and each with a different potential for generating petroleum.

- The organic content of a rock that is soluble in organic solvents is known as **bitumen.**

Bitumen normally forms a small proportion of the total organic carbon in a rock.

- **Bitumen** forms largely as a result of the breaking of chemical bonds in kerogen as temperature rises

- Kerogen is of no commercial significance except where it is so abundant (greater than 10%) as to occur in oil shales. It is, however, of great geological importance because it is the substance that generates hydrocarbon oil and gas. A source rock must contain significant amounts of kerogen.

Types of kerogen

-Four basic types of kerogen are found in sedimentary rocks. A single type or a mixture of types may be present in a source rock. The table below lists and defines these four basic kerogen types.

-**Type 1:**- is essentially **algal** in origin

- It has higher H:O ratio (about 1.2 -1.7) than other types .
- The H:C ratio is about 1.65
- Lipids are the dominant compound in this kerogen type
- Typical depositional environments in this types is lacustrine environment
- petroleum types is oil
- **Type11:-** liptinitic type, kerogen of intermediate composition
- The H:C ratio greater than one
- The original organic matter of this type is algal detritus , but also contained material derived from zooplankton and phytoplankton.
- depositional environments in this types is marine environment
- petroleum types is oil and gas
- **Type 111** :- Humic type, kerogen has a lower H:C ratio (about< 0.84)
- Humic kerogen is produced from the lignin of the higher woody plants ,which grow on land
- This type of kerogen tend to generate largely gas and very little oil or not oil
- depositional environments in this types is terrestrail
- **Type 1v:-** the origin of this type is **carbonized wood tissues**
- Non hydrogen only (C)found , therefore no oil and /or gas generate in this type
- - this review of these types of kerogene have two importants
- 1- shows the importance of identifying the nature of organic matters in source rocks to assess its potential for generating hydrocarbons.
- 2- the second importance factor to consider is not just the quality of kerogen but also the quantity necessary to generate significant amount of oil and gas suitable for commercial production.

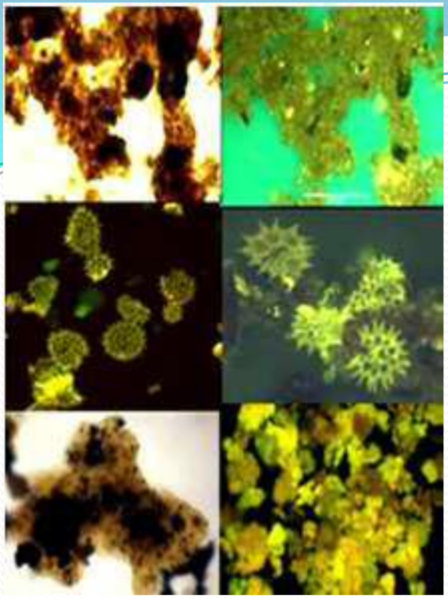


Plate 1

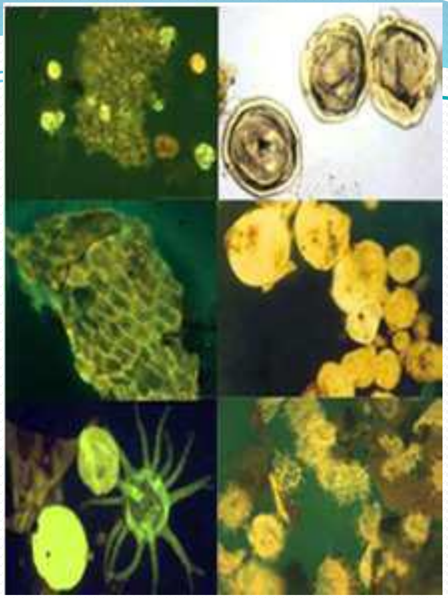


Plate 2

Plate 3

Plate 4

Plate 1: Organic matter (AOM, *Pediastrum and Botryococcus Algae) related to the Kerogen Type I*
Plate 2: Organic matter (AOM, Pollen Grain, Cuticle, Prasinophyte Algae, Acritarchae and Dinocysts) related to the Kerogen Type II
Plate 3: Organic matter (wood tissues: non-opaque phytoclasts) related to the Kerogen Type III
Plate 4: Organic matter (carbonized wood tissues: opaque phytoclasts) related to the Kerogen Type IV

The table below lists and defines the basic four kerogen types.

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(?)

Maturation of kerogen (thermal maturation)

- **When sedimentary organic matter is buried in basins it is exposed to increasingly higher subsurface temperatures. At temperatures of approximately 60°C and higher (catagenesis phase), the thermal degradation of kerogen yields hydrocarbons under reducing conditions .**
- **Depending to the rate of maturation there are three stage of maturity these are , *immature* ,*mature* , and *over mature*.**
- When kerogen is immature no petroleum has been generated
- With increasing maturity ,first oil and then gas are expelled.
- When the kerogen is over mature neither oil nor gas remains.

Stage of Thermal Maturity	Temperature	Process	Product
Immature	<60 C	Bacterial and plant organic matter converted to kerogens and bitumen	Methane generated by microbial activity
Mature (early , peak, late)	60 C -160 C	Rock generates and expels most of it's oil	Oil
	160 C-225C	Post mature for oil/mature for gas	Gas
Post mature	> 225	metamorphism	Graphite

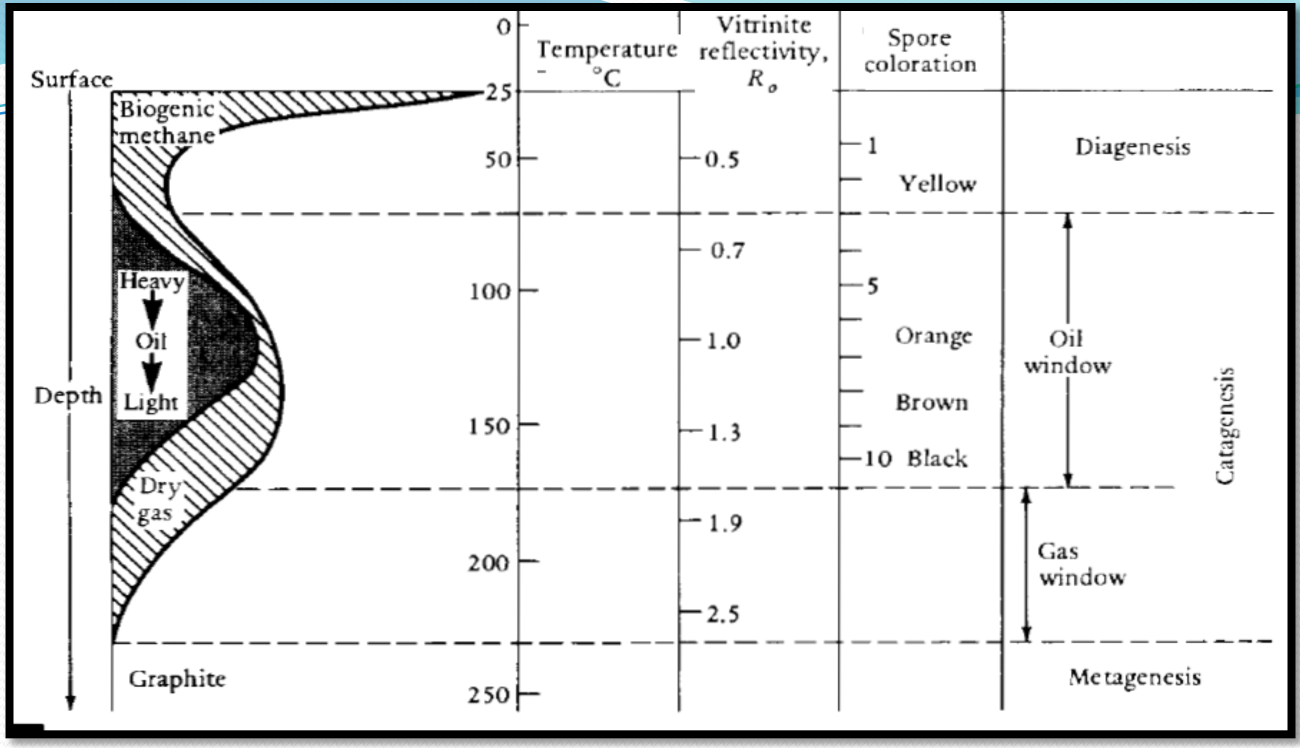
- The rate of maturation may be depend on **temperature**, **time** and **pressure**.
- The maturation of kerogen can be measured by several techniques
- generally two techniques can be used to measure maximum paleo temperature at which soure rocks is heated at these period, which consist to :-

1- Biological paleothermometer 2- chemical paleothermometer

- Biological paleothermometer technique consist to:-
- **A- pollen coloration** **B- Vitrinite reflectivity.**
- **A- Pollen coloration technique** :- is to measure the color of organic matter in the source rocks
- Kerogen has many colors and shades , which are depend on both **maturation** and **composition**
- Spores and pollen ,begin its life essentially **colorless** , as they gradually heated they change **to yellow** ,**orange** , brown (light to dark) and then to **black.**
- More recently studies has been realized that these color changes related by the degree of maturation.
- There are an index consist to (10 – point spore color) used by palynologists in this aspect(Fig. below).

B- Vitrinite reflectivity technique:- is a very well established technique used by coal petrographers to assess the rank of coal samples

- Basically , the shininess of coal increase with rank from peat to anthracite.
- Vitrain occurs widely throughout sedimentary rocks.
- Kerogen , which include vitrain , is separated from sample by solution in hydrofluoric acid or hydrochloric acid (HCL). The residue is mounted on a slide , a reflecting – light microscope is then used to measure the degree of reflectivity (Ro).
- An empirical relationship has been noticed between vitrinite reflectance and hydrocarbon generation.
- a- Crude oil generation occurs for (**Ro**)values between (0.6- 1.5)
- b- Gas generation take place for **(Ro)** values between (1.5-3)
- c- at **(Ro)** values above 3 the rocks are essentially graphitic and devoid of hydrocarbons.
- Note :- all these alteration occur in the source rocks.



Colour changes within spores and the Spore Colour
Modified from Marshall (1990, fig. 2).

Spores colour	SCI
Pale yellow	1
Pale yellow- lemon yellow	2
Lemon yellow	3
Golden yellow	4
Yellow orange	5
Orange	6
Orange brown	7
Dark brown	8
Dark brown- black	9
black	10

-**Source rock** refers to the formation in which oil and gas originate.

-Hydrocarbons are generated when large volumes of microscopic plant and animal material are deposited in marine, deltaic, or lacustrine (lake) environments

- The organic material may either originate within these environments and/or may be carried into the environment by rivers, streams or the sea.

- The microscopic plant and animal material generally is deposited with fine clastic (**silt and/or clay) sediments**

- **During burial the sediments protect the** organic material by creating an anoxic (oxygen depleted) environment. This allows the organic material to accumulate rather than be destroyed by aerobic organisms such as bacteria.

- Over time, the organic remains are altered and transformed into gas and oil by the high temperatures and increased pressure of deep burial, this process can take tens of thousands of years to occur.

- The amount of petroleum generated is a function of the **thickness** of the accumulated sediments and organic material, the **burial** of these materials, and **time.**

- **Organically rich, black-colored shale deposited in a quiet marine, oxygen depleted environment are considered to be the best source rocks.**

- Petroleum Systems

-**Petroleum System** is defined as a natural system that consist to a pod of active source rock and all related oil and gas and which Includes all of the geologic elements and processes that are essential if a hydrocarbon accumulation is to exist

- Petroleum system elements and processes as illustrated below:

Elements	Processes
Source Rock	Generation
Migration Pathways	Migration
Reservoir Rock	Accumulation
Seal Rock	Preservation
Trap	

Petroleum System Elements

Source Rock - A rock with abundant hydrocarbon-prone organic matter

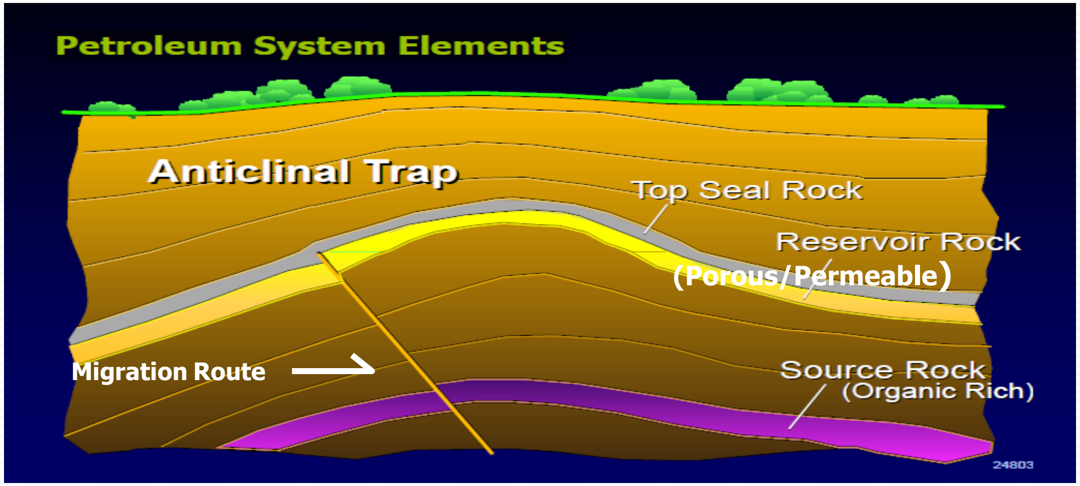
Reservoir Rock - A rock in which oil and gas accumulates which characterized by its porosity and permeability :

-***Porosity*** **- space between rock grains in which oil accumulates**

-***Permeability*** **- passage-ways between pores through which oil and gas moves**

Seal Rock - A rock through which oil and gas cannot move effectively (such as mudstone and clay stone)

- **Migration Route – A pathway in rock througn wnicn oil and gas moves from source rock to trap**
- **Trap - The structural and stratigraphic configuration that focuses oil and gas into an accumulation**



Petroleum System Processes

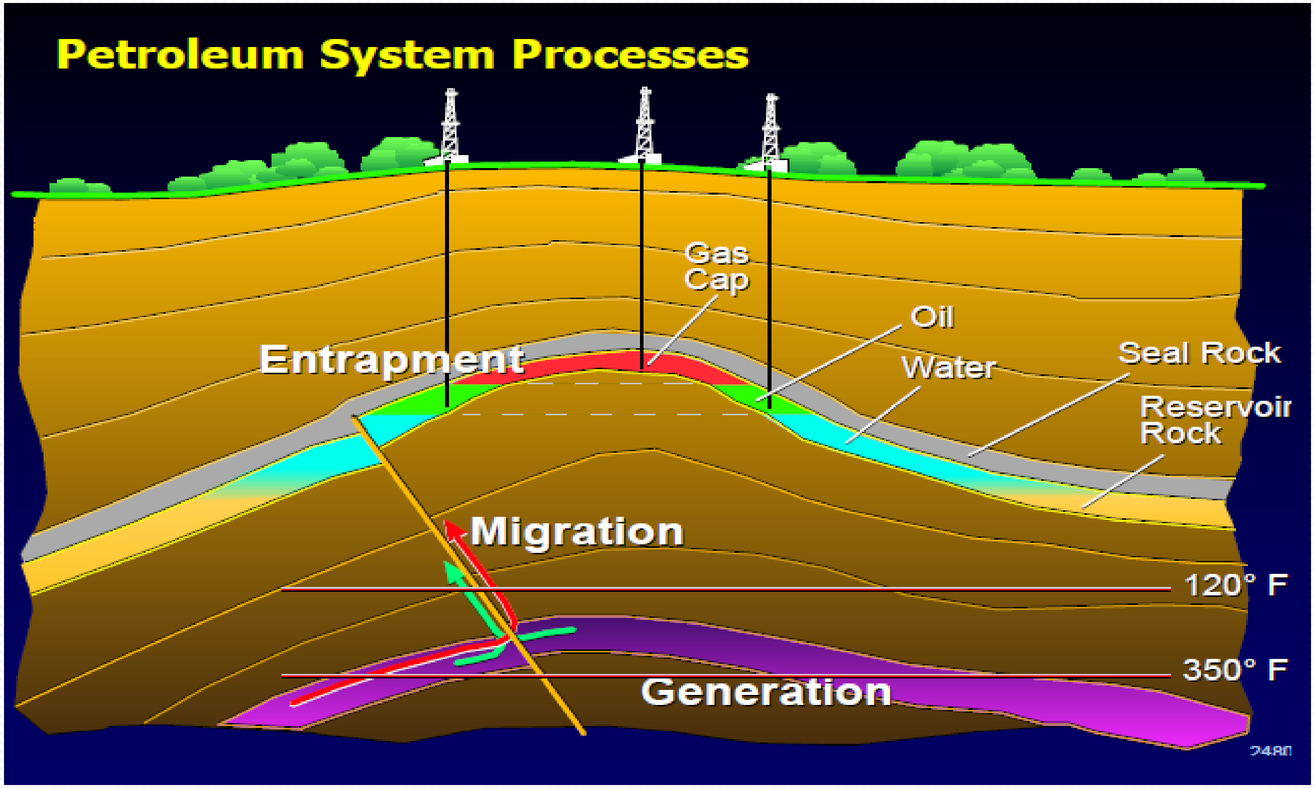
Generation - **Burial of source rock to temperature and pressure regime sufficient to convert organic matter into hydrocarbon**

Migration - **Movement of hydrocarbon out of the source rock toward and into a trap**

Accumulation - **A volume of hydrocarbon migrating into a trap faster than the trap leaks resulting in an accumulation**

Preservation - **Hydrocarbon remains in reservoir and is not altered by biodegradation or "water-washing"**

Timing - **Trap forms before and during hydrocarbon migrating**



Migration of petroleum

- The hydrocarbons generated from source rocks are expelled within other pore fluids due to continuing effects of compaction , and start moving upwards towards the surface. A process known as Migration.

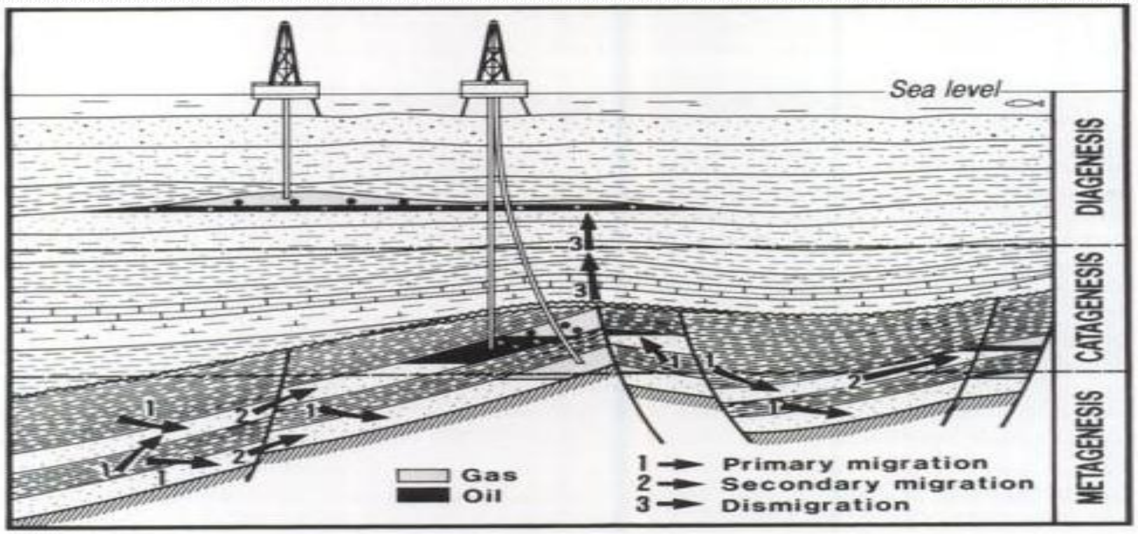
- *Migration is the movement of oil and gas within the subsurface layers*

- Migration can be divided into two types or in some references three types

A- *Primary migration*:- is the process by which petroleum moves from source rocks to reservoir rocks.

B- Secondary migration: is the process by which petroleum moves within reservoir after it has accumulated.

C- Tertiary migration (dismigration or remigration) :- leakage of accumulated hydrocarbons from one trap to another or up to the surface.



- Schema of the main migration steps.

Petroleum is first expelled from source rocks (primary migration, 1). Then it moves inside carried beds up to traps (secondary migration, 2). It may also leak through cap rocks (dysmigration, 3). (Tertiary migration)

- According to the direction of migration ,it can be classified in to two types :-

(1) transverse migration
(2) longitudinal migration

- transverse migration:- it is the migration in a transverse (vertical) direction to the stratification planes
- longitudinal migration :- it is the migration in a longitudinal (parallel) direction to the stratification planes

- Generally, the primary migration from source rock to reservoir rock is transverse, and the secondary migration through the reservoir to the trap is longitudinal.
- Transverse migration (primary migration) can be upward or downward.
- **If** movement is taking place because of differences in the specific gravity of **oil** and **water**, the migration direction of oil will be upward.
- **if** the oil is being squeezed from a rock by compaction it will move in a path of least resistance whether that be **upward**, **downward**, or sideways.
- Downward transverse (Primary) migration is responsible for the occurrences of petroleum in basement igneous and metamorphic rocks.
- Other examples of transverse migration are the accumulations of petrole beneath unconformities,
- **Longitudinal (secondary) migration** is possible where a porous and permeable rock layer
- occurs in the sedimentary section
- **Longitudinal migration** is by no means confined to widespread sandstones or regional porous limestone. Sand-filled channels and bars in thick shale sections also may be used.
- The confinement of oil accumulations to the highest levels in the reservoir rock is the evidence that petroleum moved through the rock until those levels were reached.
- Migration can be divided according to the distance to local migration and regional migration .
- -A number of observation show that oil and gas do not generally originated in the rock in which they are found, but they have migrated into it from elsewhere. This theory is proved by the following observations:-

1- organic matter is easily destroyed by oxidization in porous ,permeable sediments at the earth surface , this mean it have invaded the reservoir rock after deep burial and raised temperature.

2- oil and gas often occur in solution pores and fractures that formed after the burial and lithification of the host rock.

3- oil and gas are trapped in the highest point of permeable rock unit, which indicate upward and lateral migration.

4- oil and gas and water occur in porous , permeable reservoir rock stratified according to their relative density , this stratification indicate that they were free to migrate vertically and laterally within the reservoir.

5- Petroleum presence in some cases in igneous or metamorphic rocks confirms its emigration to such rocks, because it is impossible that the oil consists in those rocks that entirely devoid of organisms.

6 - Visual evidence of migration is provided by oil and gas seepages found in many parts of the world.

- These observation all points to conclusion that hydrocarbons migrate into reservoir rocks at considerable depth below surface and some time after burial.

Q / Most source rocks are black shales which have very low permeability. How can the hydrocarbons move through these rocks?

- Answer;- There are several forces that cause such migration:
- **(a) compaction of sediments as the depth of burial increases;**

Compaction of the source rock by the weight of the overlying rocks provides the driving mechanism to expel the hydrocarbons causing them to move, where they will take the easiest route *i.e. (through the most porous beds or fractures) moving to regions of lower pressure (that normally would be at shallower depths.).*

- The mineral grains do not compact when burial increase , but their pore spaces are decreased. Any petroleum generated is therefore squeezed out of the source rock.

- **(b) excess pressure** inside the pores of the source rocks with respect to hydrostatic pressure in drains. This excess pressure is mainly due to tectonic stresses which creates an over pressuring of the pore fluids in the source rocks causing movement of hydrocarbons out of source rocks.
- **C-capillary force:** is the force that cause movement of free hydrocarbon from fine-grained to coarse-grained layers. However at the interface between coarse-grained rocks(carrier rocks) and fine –grained rocks (source rocks) the capillary pressure gradient is directed towards the coarse grained rocks. This means that at the interface between source rocks and carrier rocks ,the capillary pressure become a driving force for the movement of hydrocarbons out of the source rocks.

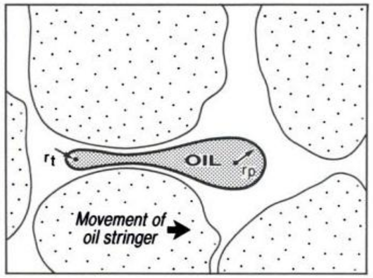


Fig. 5-7 - Capillary pressure as a driving force for movement of oil globules from small pores to big ones.

Once the throat of the small pore r_t has been crossed, the capillary pressure at the back of the stringer, which is proportional to $1/r_t$, is higher than at the front of the stringer (proportional to $1/r_p$) and thus forces it to enter the big pore.

- **D- Diffusion forces** :- is the force in which hydrocarbons dissolved in water transfer from areas of higher concentration to adjacent areas of lower concentration. Because hydrocarbon concentration in the source rocks is higher than in surrounding carrier bed ,the diffusion force was also proposed as driving force for primary migration. This process leads to dispersal rather than accumulation. Diffusion

rates in porous media are very low. diffusion may play a role to some extent for high solubility components and specially for methane at high pressure

- .

- **E- Migration along Microfractures in the source rock.**

During compaction the fluid pressures in the source rock may become so large that spontaneous "micro fracturing" occurs.

- the development of microfractures in source rocks relieves pressure and permits trapped hydrocarbons to escape. microfracturing may be caused by a build up of the ground water pressure in rocks of very low permeability.

F - Increase in volume due to maturation

The maturation of a liquid or gas from a solid, causes an enormous increase in volume which may cause fracturing of the source rock. The hydrocarbons generated, therefore, escape upwards through such fractures that are created.

G- Buoyancy force

- The main force driving secondary migration is the buoyancy of hydrocarbons . There is a tendency for oil and gas to segregate from aqueous phase liquids because of density differences.
- - In most cases, the action of gravity leads to acolumn of gas over oil over water.
- - Capillary pressure is the excess pressure required for oil or gas to displace water from pores.
- - If capillary and buoyancy forces are matched, hydrocarbon can be trapped within a particularl ithology
- **Accumulation** : is the end of migration -- that is the hydrocarbons have reached a trap and are stored in the reservoir.

- Traps:-

- it is any geometric arrangement of rocks that permits significant accumulation of hydrocarbons in the subsurface . Or it is Structural or stratigraphic feature that captures migrating hydrocarbons into an economically producible accumulation.

- A traps must include a reservoir rocks in which to store hydrocarbons and seal(cap rocks) or set of seals that stop migration of petroleum out of the reservoir .

- Hydrocarbon traps form where permeable reservoir rocks (carbonates, sandstones) are covered by rocks with low permeability (**cap rocks)** that are capable of preventing the hydrocarbons from further upward migration.

- Typical cap rocks are compacted shale, evaporates, and tightly cemented sandstones and carbonate rocks.

- -The cap rock need *not be 100% impermeable to water, oil or gas. If the upward loss of* hydrocarbons is less than the supply of hydrocarbons from the source rocks to the trap, hydrocarbons may still accumulate…

Nomenclature of Traps

- Many terms are used to describe the various parameters of a traps .These terms are defined as follow and illustrated with reference to an anticline trap ,the simplest type (figure below):-

1- **Crest or culmination** :- the highest point of the trap

2- **Spill point :-** the lowest point at which hydrocarbons may be contained in the the trap .

3- **closure** :- vertical distance between the crest and the spill point

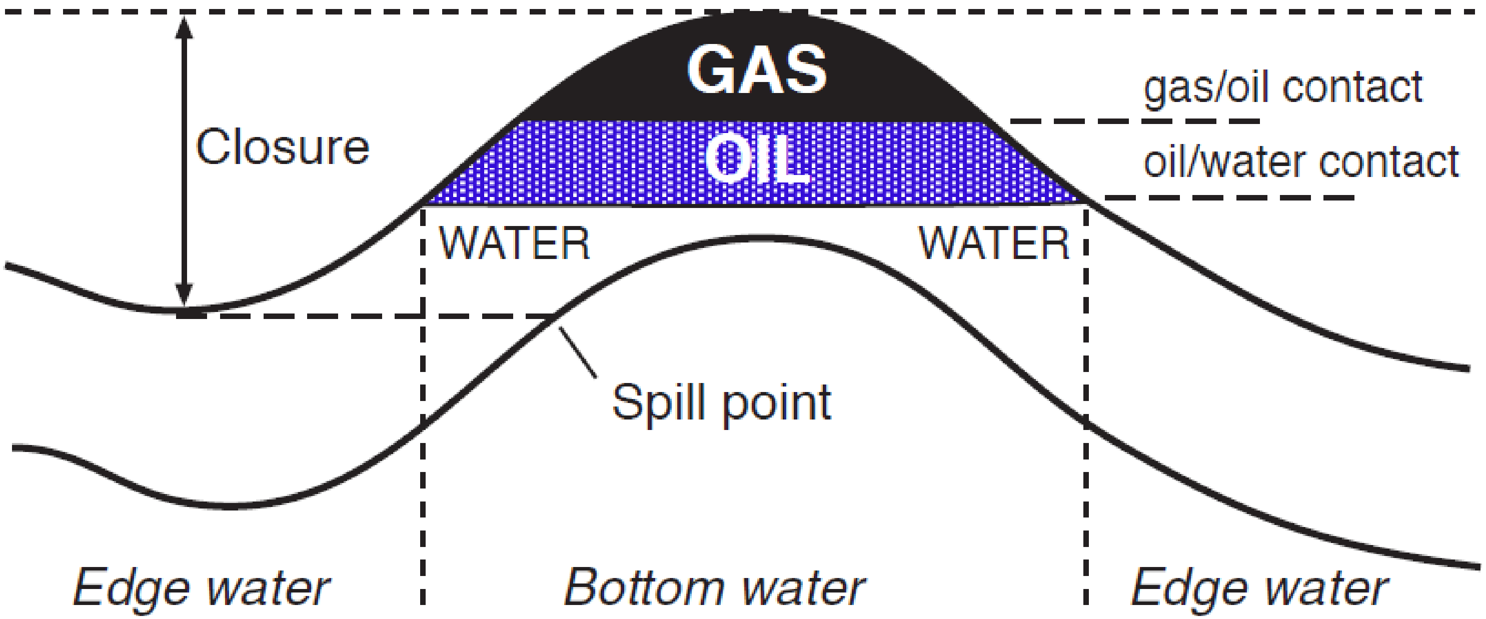
4- **Pay :**– thickness of productive reservoir

5- **Gross pay :**– total vertical distance from the top of the reservoir to the petroleum/ water contact (OWC)

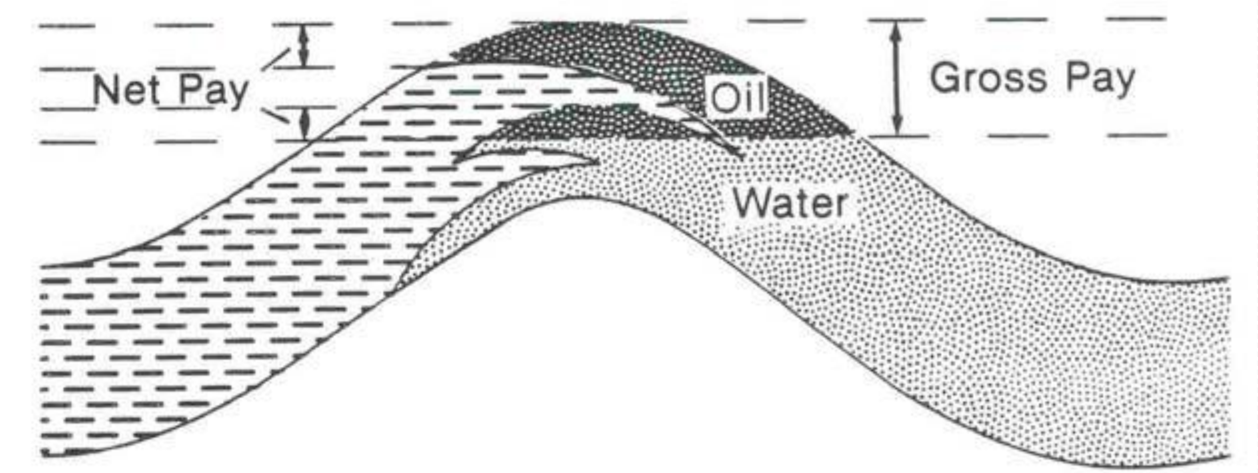
6- **Net pay :**– is the cumulative vertical thickness of a reservoir from which petroleum may be produced. Or is the thickness of actual productive intervals, excludes intervening non-productive layers.

- The net pay may be less than or equal to gross pay

7- **Bottom water** :- The zone immediately beneath the petroleum



Cross - section through a simple anticline Trap.



Difference of gross pay and net pay

- # Distribution of petroleum within A trap.

- A Trap may contain oil , gas or both .
- The oil :water contact (OWC): is the deepest level of producible oil.
- Gas oil contact (GOC) or gas water contact (GWC) :-is the lower limit of producible gas.
- Where oil and gas occur together in the same trap, the gas overlies the oil because the gas has a lower density.
- whether a trap contain oil and /or gas depends both on the chemistry and level of maturation of the source rocks and on the pressure and temperature of the reservoir itself.

- The identification of traps is one of the most important tasks of the exploration geologist.

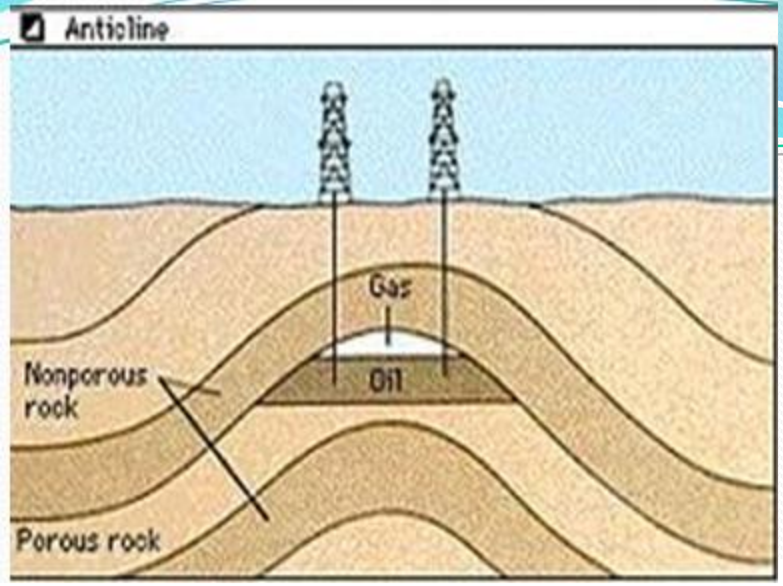
- For a trap to be efficient and commercially viable, a large variety of factors have to be considered. These include:

• The presence of a porous permeable structure
• The imperviousness of the seal
• The absence of leaking faults
• The migration of sufficient quantities of HC

- ## Classification of Trap
- Many systems have been proposed for the classification of traps; one simple system divides them into structural traps ,stratigraphic traps , Hydrodynamic traps and combination traps.
- ### 1- Structural traps :-

- - is a type of geological trap that forms as a result of changes in the structure of the subsurface, due to tectonic, diapiric, gravitational and compaction processes. These changes block the upward migration of hydrocarbons and can lead to the formation of a petroleum reservoir.
- - Structural traps are the most important type of trap as they represent the majority of the world's discovered petroleum resources. The three basic forms of structural traps are the anticline trap, the fault trap and the salt dome trap.

- **- Anticlinal (fold)trap**
- - An anticline is an area of the subsurface where the strata have been pushed into forming a domed shape. If there is a layer of impermeable rock present in this dome shape, then hydrocarbons can accumulate at the crest until the anticline is filled to the *spill point* - type of trap is by far the most significant to the hydrocarbon industry. Anticline traps are usually long oval domes of land that can often be seen by looking at a geological map or by flying over the land.



CLASSIFICATION OF TRAPS

I Structural traps—caused by tectonic processes

- Fold traps
  - Compressional anticlines
  - Compactional anticlines
- Fault traps

II Diapiric traps—caused by flow due to density contrasts between strata

- Salt diapirs
- Mud diapirs

III Stratigraphic traps—caused by depositional morphology or diagenesis

IV Hydrodynamic traps—caused by water flow

V Combination traps—caused by a combination of two or more of the above processes

- **Fault trap**

- This trap is formed by the movement of permeable and impermeable layers of rock along a fault line. The permeable reservoir rock faults such that it is now adjacent to an impermeable rock, preventing hydrocarbons from further migration. In some cases, there can be an impermeable substance smeared along the fault line (such as clay) that also acts to prevent migration. This is known as clay smear.
- **2- Diapiric Traps.**
- Diapiric traps are produced by the upward movement of sediments that are less dense than those overlying them. In this situation the sediments tend to move upward diapirically and may form hydrocarbon traps.
- Diapiric traps are generally caused by the upward movement of **salt** or less frequently , over pressured **clay**.
- **Salt dome Trap**
- Salt domes are large masses of salt rising from the subsurface through overlying sediments to form dome shape structure.
- Salt is a type of solid that flows slowly as a viscous liquids under pressure .
- When the salt is originally deposited , it has density of 2.2 gm/ccc . It is then buried by loose sediments such as sand and mud with densities of 1.9 gm/ccc.
- As the sediments are buried deeper , the weight of the overlying sediments generate more and more pressure.
- The sand and mud compact by squeezing water out of the pore space . The salt layer ,however , dose not compact ,since it is crystalline sediments with out pore space . There is nothing to give in salt layer .
- Eventually the overlying sediments are denser than the underlying salt layer (figure below) .
- The salt flows and rises by buoyancy through the overlying sediments to form salt dome , as the salt dome rises , it uplift and pierces overlying sediments.
- This salt is impermeable and when it crosses a layer of permeable rock, in which hydrocarbons are migrating, it blocks the pathway in much the same manner as a fault trap. This is one of the reasons why there is significant focus on subsalt imaging, despite the many technical challenges that accompany it.

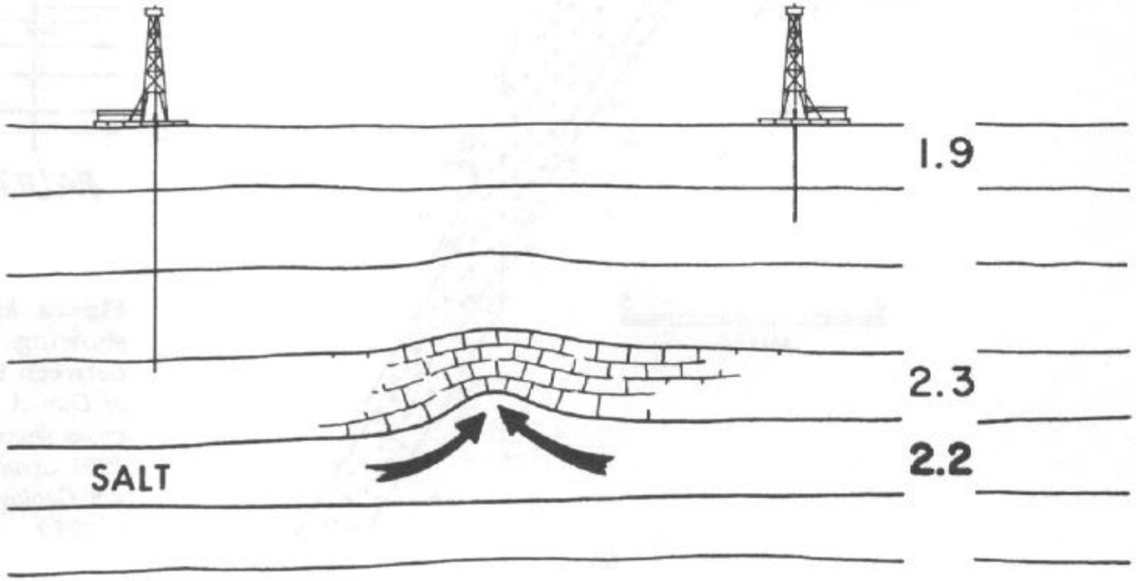


Figure 15-37 Cross section showing a buried salt layer covered with compacting sediments.

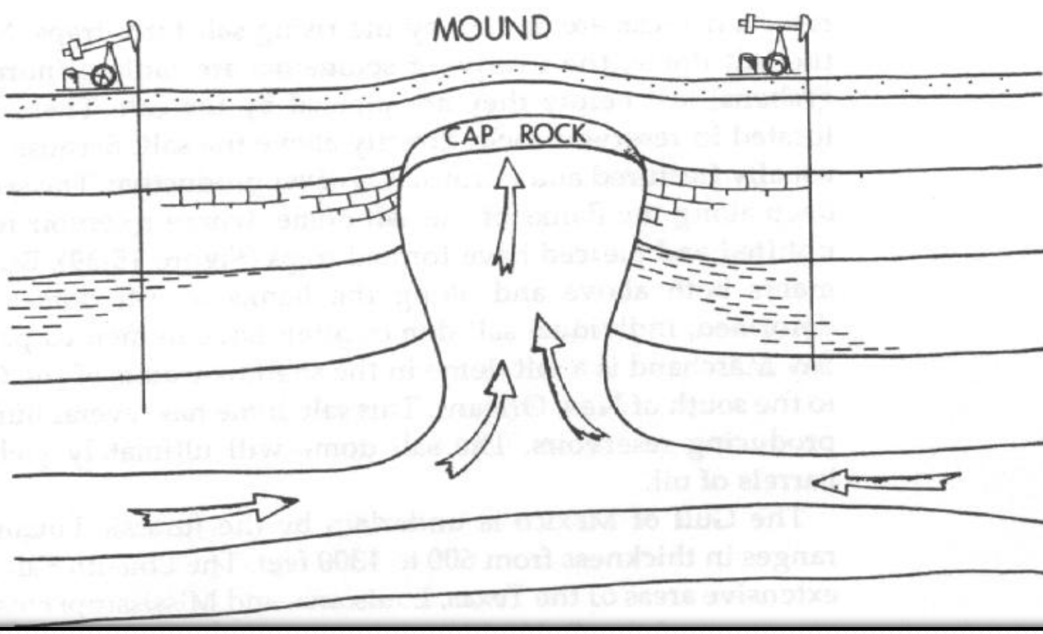
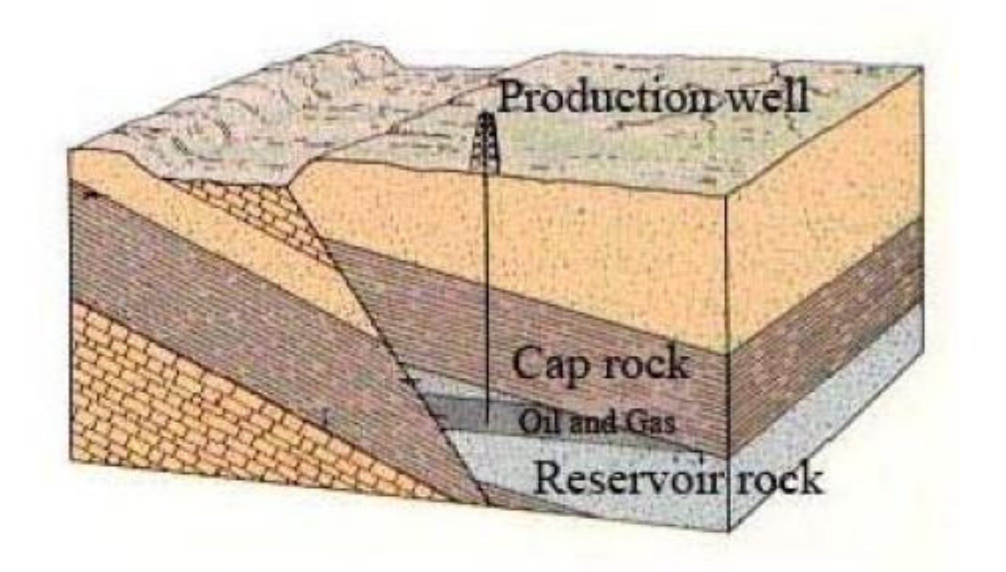
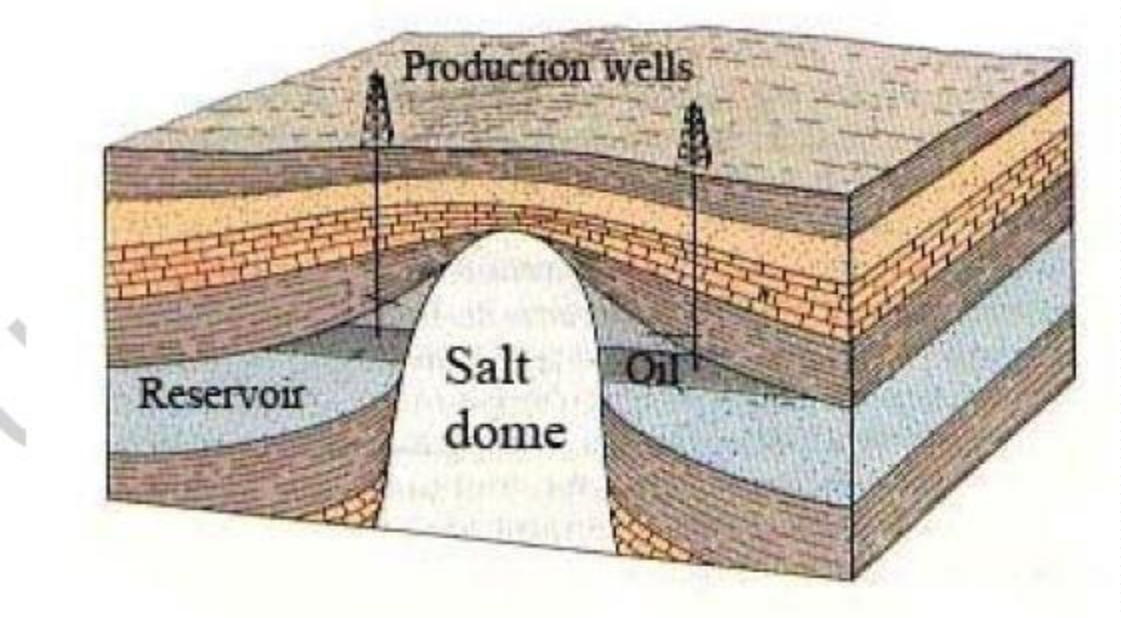
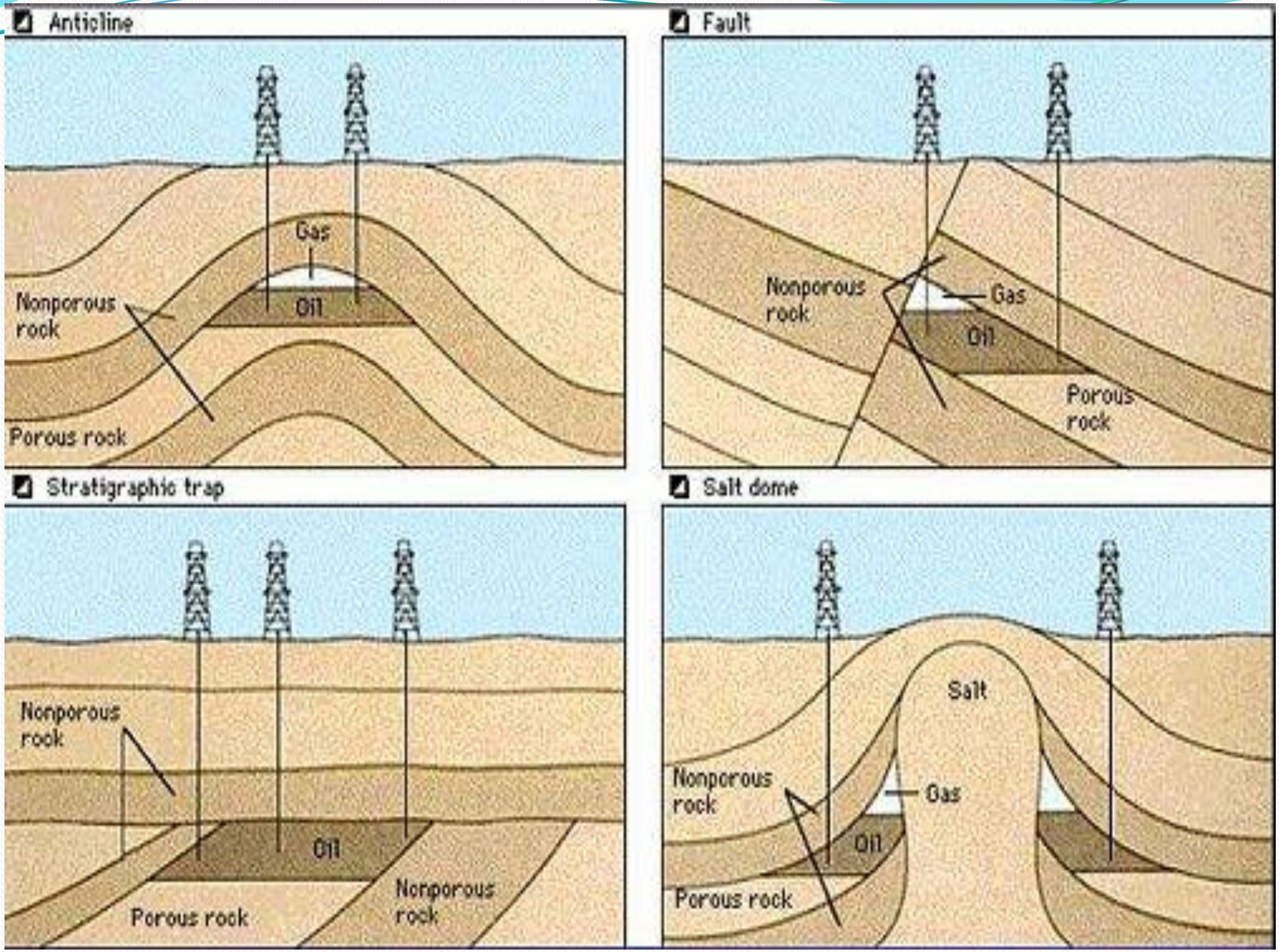


Figure 15-38 Cross sectio showing the formation of salt dome as buoyant, risin salt pierces the overlyin sediments.



- **Fault trap.** A trap formed when the movement of the earth's crust causes different rock strata to offset or shear off. In a fault trap, a nonporous rock formation that has shifted stops the movement of oil or gas within an offsetting formation that




Anticline
Gas
Oil
Nonporous rock
Porous rock
Fault
Nonporous rock
Gas
Oil
Porous rock
Stratigraphic trap
Nonporous rock
Oil
Porous rock
Nonporous rock
Salt dome
Salt
Nonporous rock
Gas
Oil
Porous rock

- **Stratigraphic Traps**
- Stratigraphic traps are formed as a result of lateral and vertical variations in the thickness, texture, porosity or lithology of the reservoir rock. Examples of this type of trap are an unconformity trap, a lens trap and a reef trap.
- **Stratigraphic traps** are produced by the processes of sedimentation not faulting or folding. In this situation, a combination of permeable and impermeable layers were originally deposited close to each other in a sedimentary environment.
- **Two main groups of stratigraphic trap can be recognized :**
- **1- Primary stratigraphic trap**
  it is a stratigraphic trap result from variations in facies that developed during sedimentation. These include features such as lenses, pinch-outs, and appropriate fancies changes.
- Examples include:
- Primary pinch out of strata, e.g., strata that pinch out updip in less permeable

rocks such as shale;

- • Fluvial channels of sandstone that are isolated and surrounded by impermeable clay-rich sediments;
- • Submarine channels and sandstone turbidities in strata rich in shale;

• Porous reefs that are surrounded by shale, etc.

- ***2- Secondary stratigraphic traps*** *result from variations that developed after sedimentation, mainly* because of diagenesis. These include variations due to porosity enhancement by dissolution or loss by cementation
- **- below some types of stratigraphic traps**
- - **Lenticular trap— A porous area**surrounded by non-porous strata. They may be formed from ancient buriedriver sand bars, beaches, etc

- - **Pinch-out or lateral graded trap— A trap** created by lateral differential deposition when the environmental deposition changes up-dip
- .
- **Angular Unconformtiy Trap— An** angular unconformity is one in which older strata dips at an angle different
- from that of younger strata.
- - An angular unconformity trap occurs when inclined, older petroleum bearing rocks are subjected to the forces of younger
- non-porous formations. This condition may occur whenever an anticline, dome or monocline are eroded and then overlain withyounger, less permeable strata.

- .

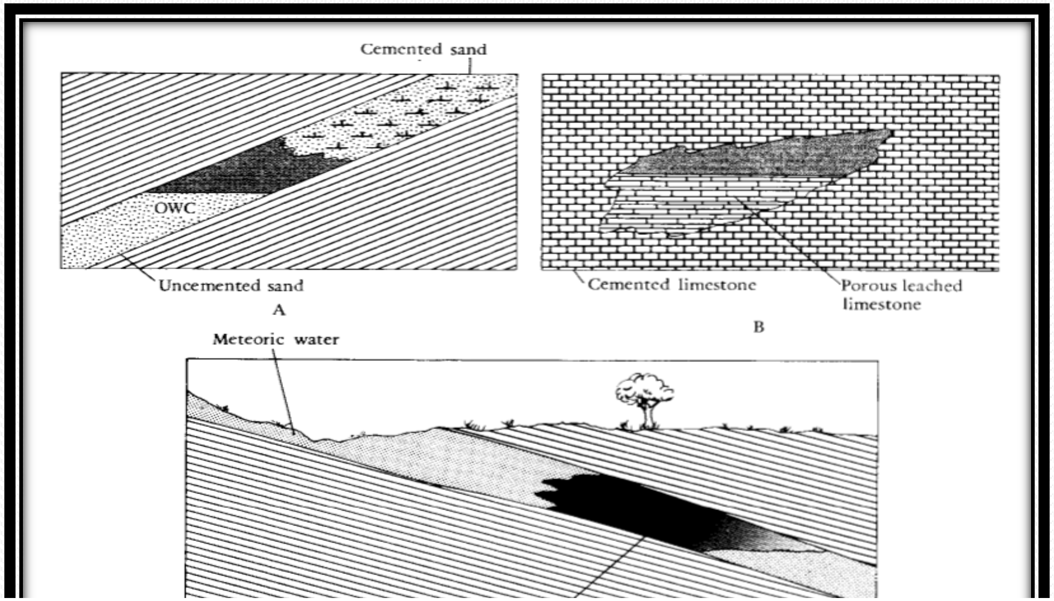
Diagenetic Traps

Diagenesis plays a considerable role in controlling the quality of a reservoir within a trap. , solution can enhance reservoir quality by generating secondary porosity, whereas cementation can destroy it. In some situations diagenesis can actually generate a hydrocarbon trap

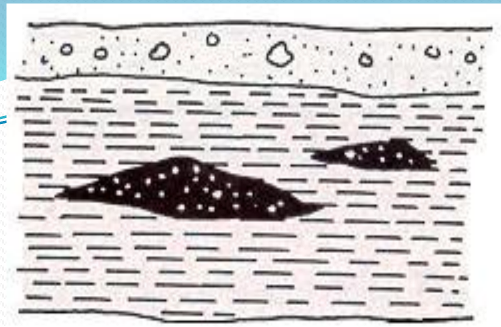
Oil or gas moving up a permeable carrier bed may reach a cemented zone, which inhibits further migrat Conversely, oil may be trapped in zones where solution porosity has locally developed in a cemented rock

Diagenetic traps are not only formed by the solution or precipitation of mineral cements. As oil migrates to the surface, it may be degraded and oxidized by bacterial action if it reaches the shallow zone of meteoric water. Cases are known where this tarry residue acts as a seal, inhibiting further up-dip oil

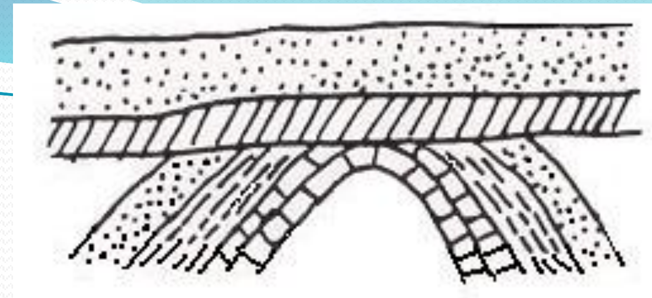
Traps that owe their origin purely to diagenesis are rare,



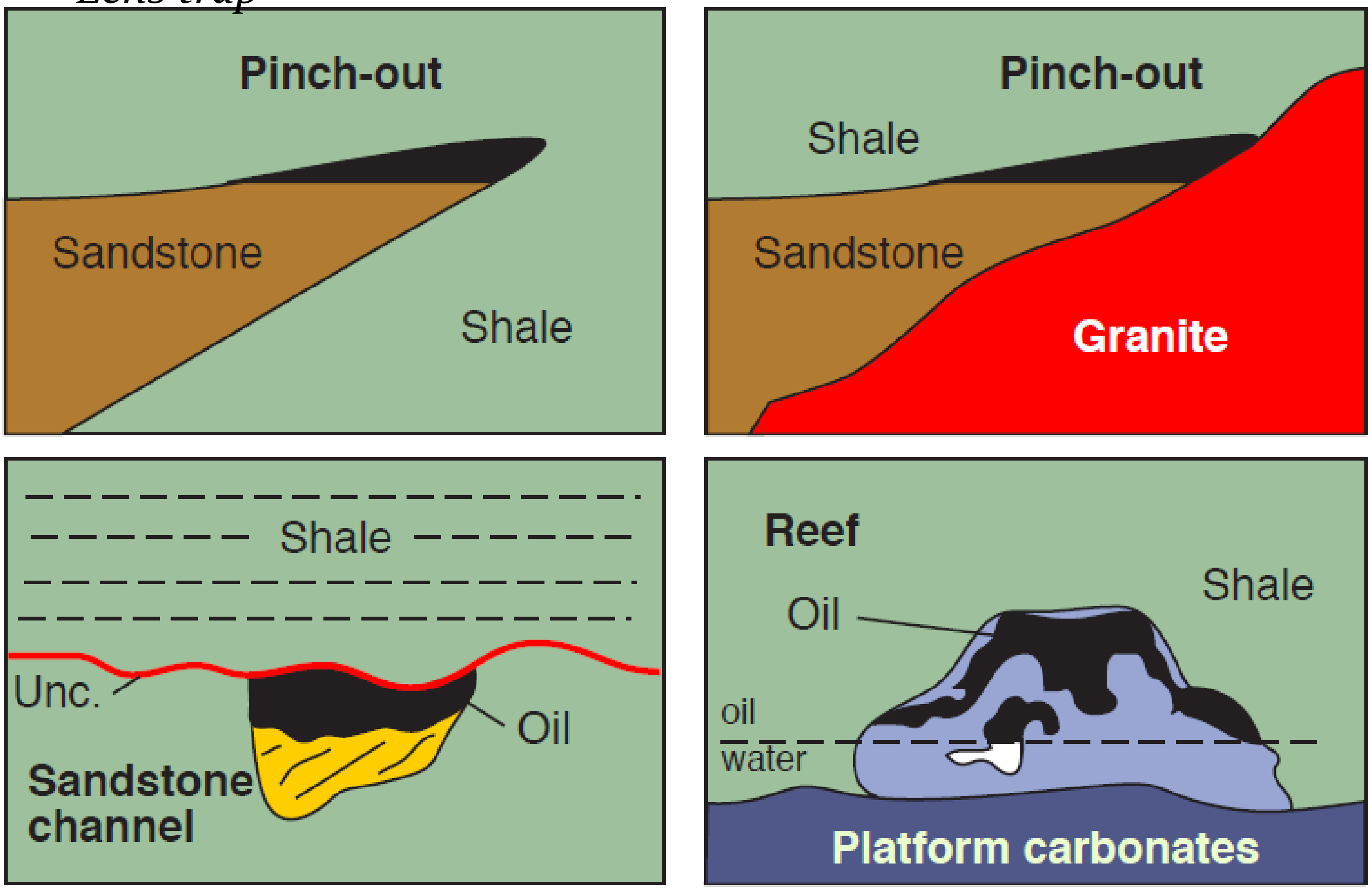
Configurations for diagenetic traps caused by (A) cementation, (B) solution, and (C) shallow-oil degradation.



Lens trap



Unconformity trap

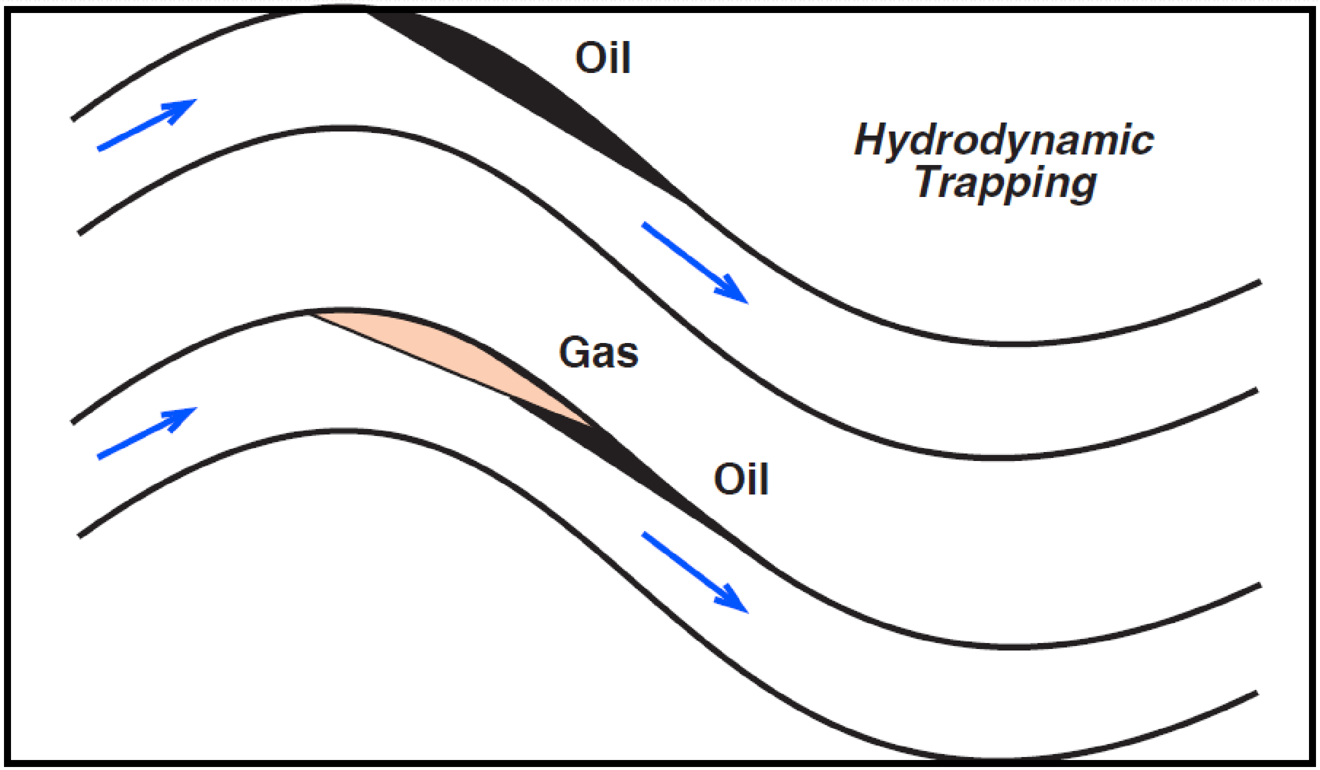


Examples of stratigraphic traps.

HYDRODYNAMIC TRAPS

The other group of traps to consider, in addition to structural and stratigraphic ones, are the hydrodynamic traps. In these traps hydrodynamic movement of water is essential to prevent the upward movement of oil or gas.

Where water is moving hydrodynamically down permeable beds, it may encounter upward-moving oil. When the hydrodynamic force of the water is greater than the force due to the buoyancy of the oil droplets, the oil will be restrained from upward movement and will be trapped within the bed without any permeability barrier.



COMBINATION TRAPS

Many oil and gas fields around the world are not due solely to structure or stratigraphy or hydrodynamic flow, but to a combination of two or more of these forces. Such fields may properly be termed *combination traps*. Most of these traps are caused by a combination of structural and stratigraphical processes. Structural–hydrodynamic and stratigraphic–hydrodynamic traps are rare.