Introduction to Petroleum Geology

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Introduction

- Petra: Rocks & Oleum: Oil. Therefore, the word 'petroleum' is derived from a Greek word, which means "rock oil".
- Petroleum is used since ancient times for various purposes. Crude oil is a mixture of several thousands of hydrocarbon compounds of various molecular weights.
- Petroleum can form by inorganic processes, organically formed petroleum is much more significant.
- Petroleum consists almost entirely of hydrogen and carbon, which has the ratio of 1.85 hydrogen atoms to one-carbon atoms in crude oil.
- Sulphur, nitrogen and oxygen comprises up to 3% of most petroleum.

Introduction

- In its strict sense, petroleum includes only crude oil, but it occurs as liquid, gaseous and solid hydrocarbons.
- Petroleum may occur as solid state in forms of tar sands, natural asphalt, gibsonite, albertite, grahamite, oil sands and oil shales.
- These are known as non-conventional hydrocarbon resources. The liquid state of petroleum includes the conventional heavy and light crudes and condensates.
- Condensates occur in the form of gases in the subsurface, but converts to liquid in the surface.
- Gaseous petroleum includes conventional hydrocarbon gases, methane hydrates, swamp gas, coal bed methane, shale gas.

States of Petroleum

State of petroleum	Examples
Solid	gibsonite, albertite, natural asphalt, tar sand, oil shale
Liquid petroleum	conventional light crude oil and heavy crude oil condensate
Gaseous hydrocarbon	conventional (natural gas) unconventional (methane hydrate, swamp gas, coal bed methane, shale gas)

Chemical Composition of Petroleum

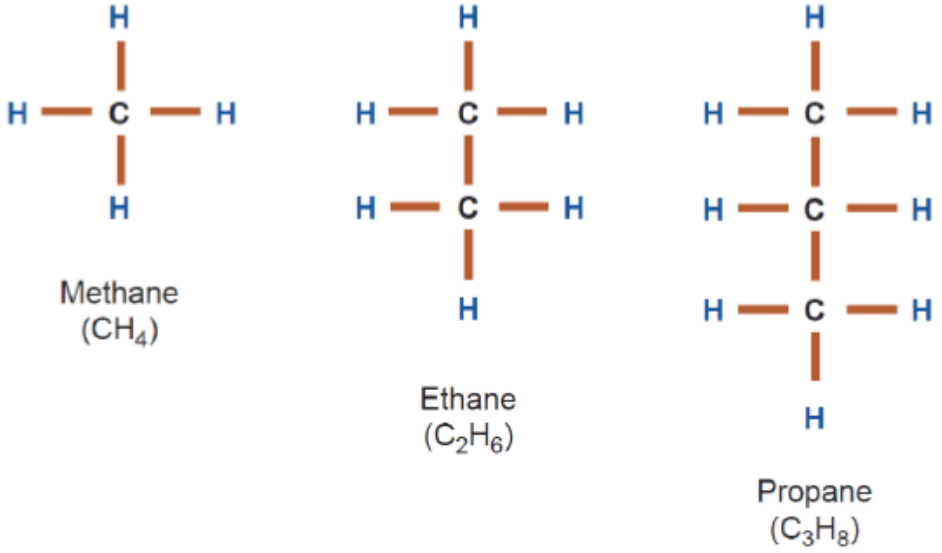
- Petroleum is essentially made up of carbon and hydrogen. The other elements that may be present are Nitrogen, Sulphur and Oxygen.
- A very small amount of metal is occasionally detected in liquid hydrocarbon.
- Hydrocarbon compounds maybe classified as
  - Paraffins
  - Naphthenes
  - Olefins
  - Aromatics
  - Naphtheno-aromatics
  - Ashphaltic compounds

Chemical Composition of Petroleum

- **Paraffins**: Paraffins are alkanes or straight-chained hydrocarbon. They are saturated hydrocarbon having the general formulae CnH2n+2. They form a homologous series where the next compound of the series is obtained by adding CH2 to the previous compound

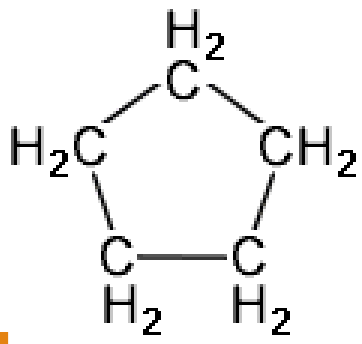
- The members of this series having low n value, i.e. from 1 to 4 are gaseous namely, methane, ethane, propane and butane.

- The paraffins with n values from 5 to 17 occur as liquid form. As the n value of paraffin increases, its wax content increases and ultimately it converts into a semi-solid form.

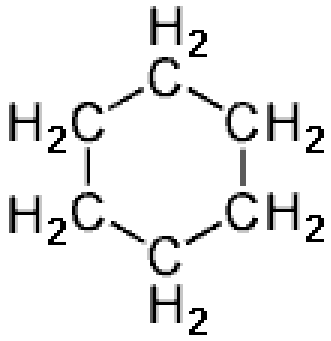


Chemical Composition of Petroleum

- **Naphthenes**: Naphthenes are cyclo-alkanes consisting of saturated hydrocarbons which have one or more carbon rings to which hydrogen atoms are attached according to the formula CnH2n.
- Naphthene is the most common hydrocarbon compound of crude oil constituting about 50%.
- Cycloalkane rings larger than C7 or smaller than C5 are not found in crudeoil. The hydrocarbon rings may merge together to form complex molecules.



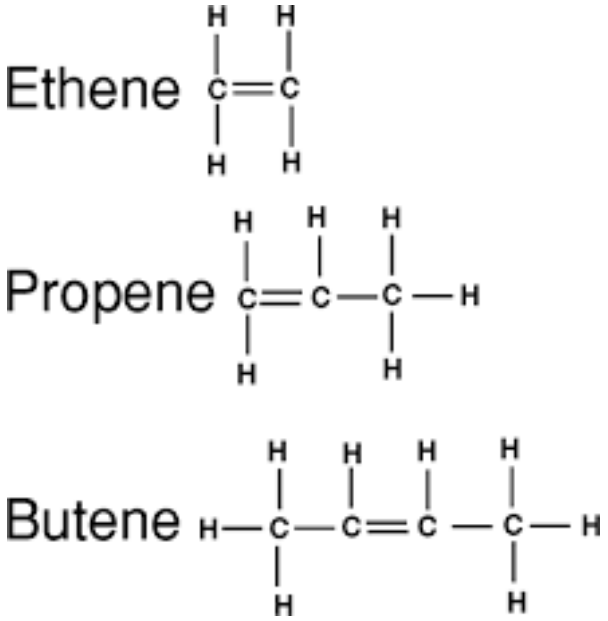
Cyclopentane



Cyclohexane

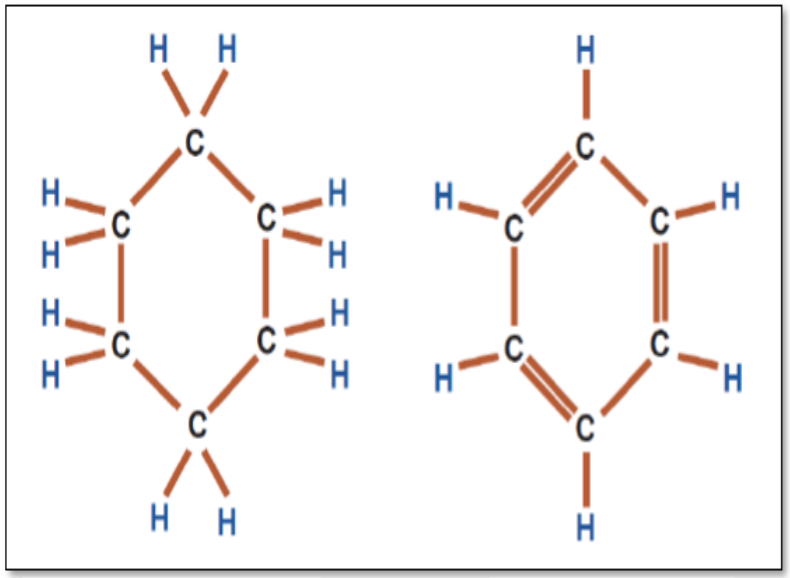
Chemical Composition of Petroleum

- **Olefins**: Olefins are unsaturated alkenes containing double bonds in their structure.
- They are isomer of cycloalkanes with the general formul CnH2n. They are very rare in crude oils.
- Olefins (ethene, propene,
- 2 butene, 2, 4 pentadiene)



Chemical Composition of Petroleum

- **Aromatic Hydrocarbons**: The aromatic hydrocarbons are unsaturated hydrocarbons, which have one or more six-carbon rings, called benzene rings, to which hydrogen atoms are attached having the general formula CnH2n-6
- They react to add H or any other element to ring and gain stability. Aromatic hydrocarbons are mainly found in the heavy fraction of the crude.
- Toluene is the most common form of this variety. The smell of crude oil is related to the presence of aromatic compounds.



Cyclo-Hexane (C_6H_{12})
(Naphthene Series)

Benzene (C_6H_6)
(Aromatic Series)

Chemical Composition of Petroleum

- **NSO Compounds**: NSO-compounds include nitrogen, sulphur or oxygen in the molecular structure of the hydrocarbon. They are mainly present in the heavy (large molecule) residual fractions of petroleum.

- The most important sulphur compounds are thiols and thiophenes. The free sulphur range in natural crude oils is less than 0.5-5% of petroleum.

- The nitrogen Compounds that may be present are pyridines, quinolenes, and indoles. The range of nitrogen in natural crude oils is 0.25 to 0.8%.

- The common oxygen compounds that are present in petroleum are organic acids, alcohol, phenol, esters etc. The range of oxygen in natural crudes is <0.1% to 2% of oxygen.

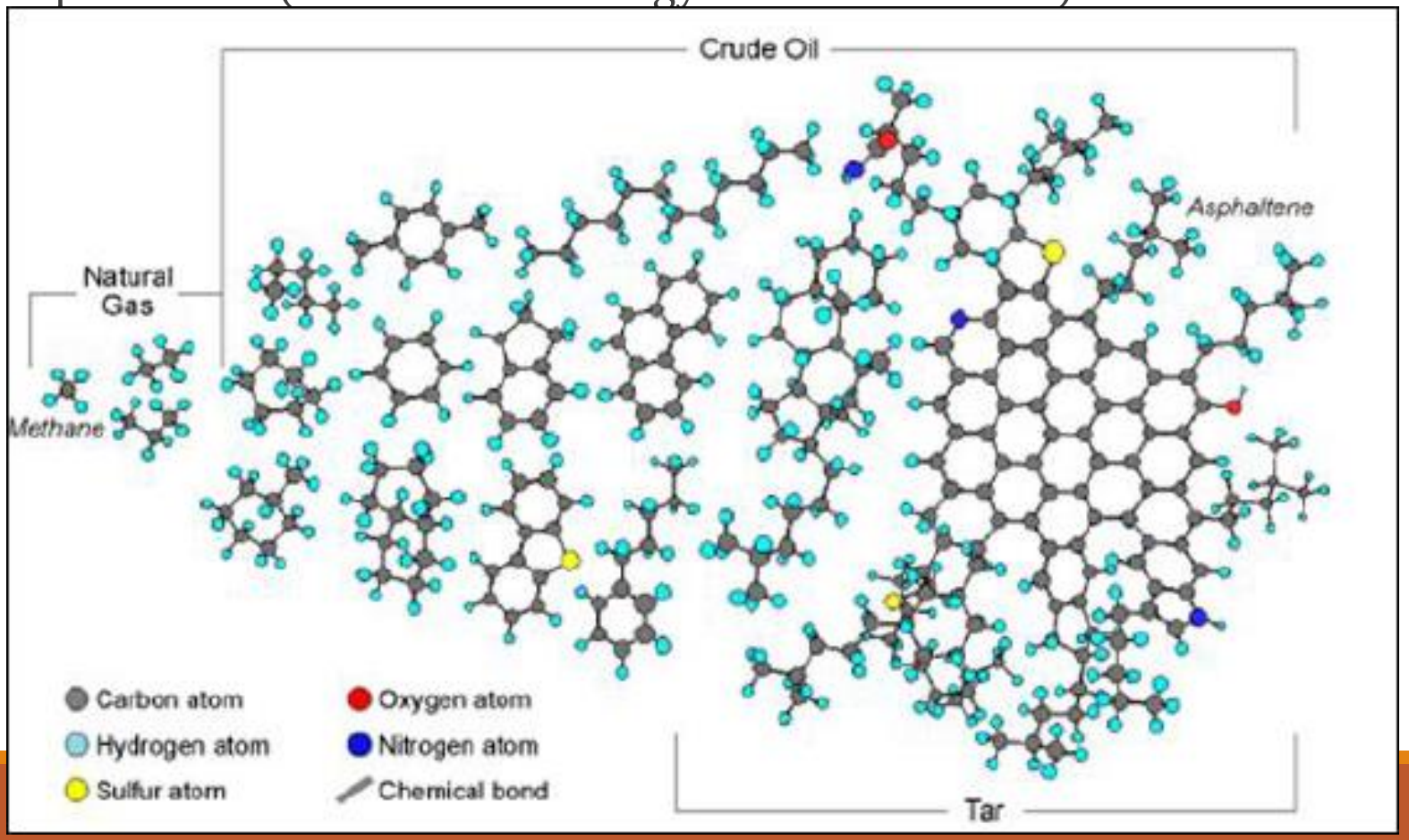
Chemical Composition of Petroleum

- Composition of crude oils based mainly on hydrocarbon groups in weight percent (modified from Selley, 2014).

Type	Paraffinic	Naphthenic	Aromatic	Asphaltic
Paraffinic	40	48	10	2
Paraffinic - Naphthenic	36	45	14	5
Average crude oil	30	49	15	6
Naphthenic	12	75	10	3
Mixed Asphaltic	8	42	27	23
Asphaltic	5	15	20	60

Chemical Composition of Petroleum

- Schematic representation of chemical compounds present in the petroleum (source USGS energy research website)



Classification of Crude Oil

- Natural crude oils are classified according to their density for commercial purposes. The density of crude oil is measured generally in API units.

- The American Petroleum Institute gravity, or API gravity, is a measure of specific gravity of crude oil compared to water.

- API values are used to compare densities of various petroleum-based liquids. API gravity is a dimensionless quantity mathematically but is referred to as 'degrees'.

The formulae for API is

$$API\ gravity = \frac{141.5}{specific\ gravity} - 131.5$$

- The specific gravity of oil fractions is usually determined at 15.6°C. API gravity values of most petroleum liquids range from 10 to 70 degrees.

Classification of Crude Oil

- API gravity greater than 10 indicates that it is lighter than water. API value less than 10 indicates extra heavy crude oil, which sinks under water. As the API gravity of crude oil decreases, it becomes dark.

Light, medium and heavy crude oils showing different colors

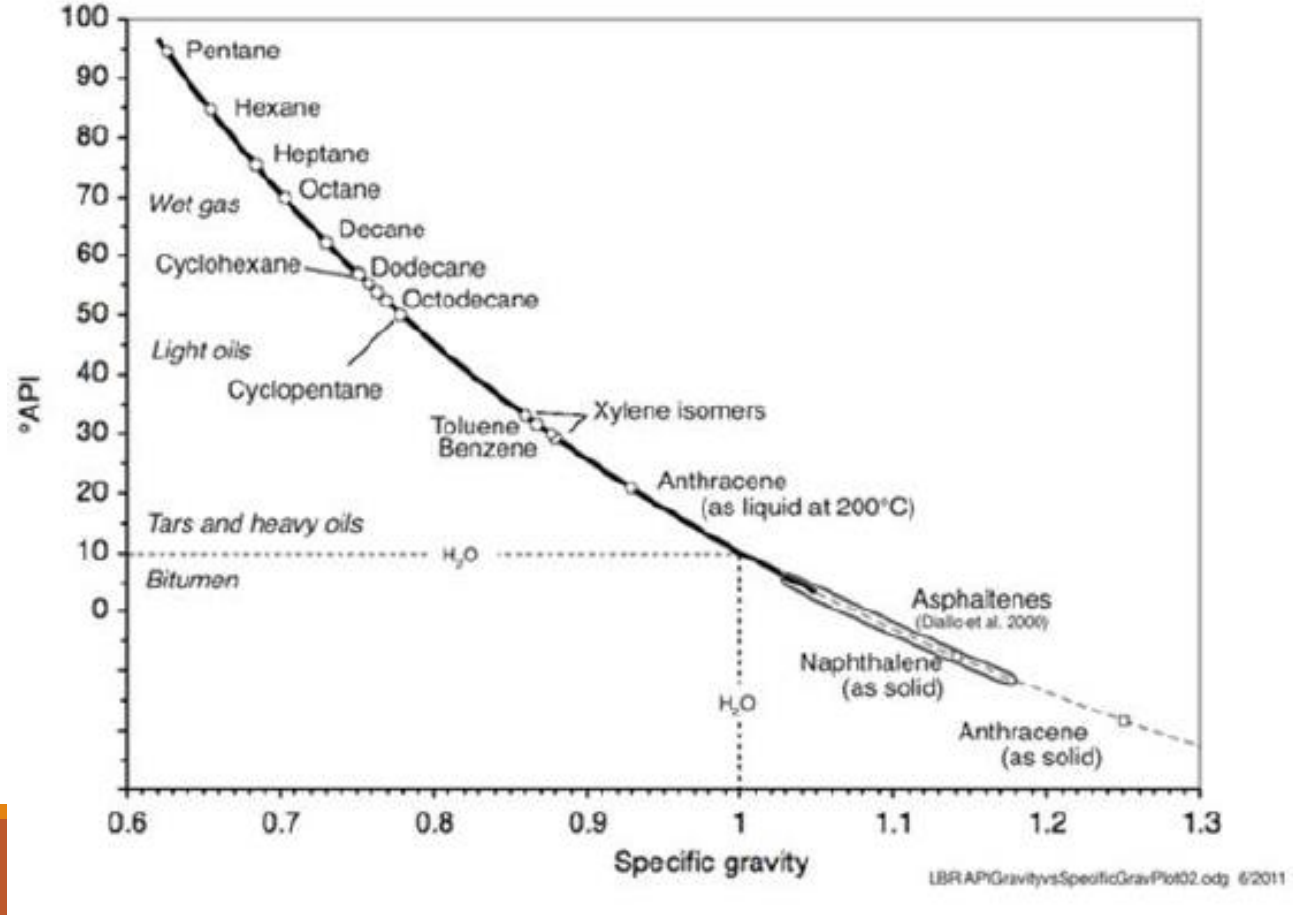
- Types of crude oil as per API value:

	API values	Density (kg/m^3)
Light crude oil	API $>31.1^0$	<870
Medium crude oil	$22.3\text{-}31.1^0$	870-920
Heavy crude oil	API$<22.3^0$	920-1000
Extra heavy crude oil	API$<10^0$	>1000

- On the basis of its sulphur content crude maybe referred to as sweet if it contains relatively little sulphur, or sour if it contains substantial amounts of sulphur.

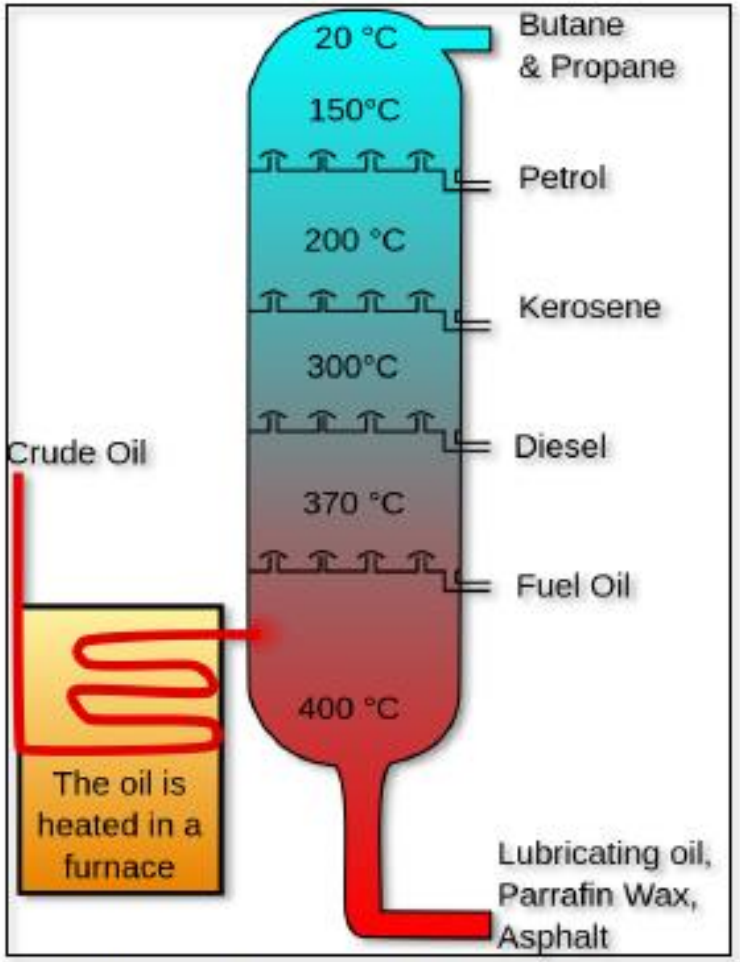
Classification of Crude Oil

- API value of some hydrocarbon compounds and the relationship between API gravity and specific gravity (modified from Hunt, 1997).



Classification of Crude Oil

- Crude oil is refined into useful products like petrol, kerosene, diesel, naphtha, fuel oil and lubricating oil by the method of distillation in a refinery.
- Crude oil is separated into fractions by fractional distillation. The crude oil fractions at the top of the fractionating column have lower boiling points than fractions at the bottom.
- All of the fractions are processed further in other refining units.



Distillation of crude oil in a distillation tower.

Types of Organic Matter and Hydrocarbon Generation

- There are two theories regarding the origin of petroleum, inorganic and organic. The stable isotope ratios of carbon and hydrogen clearly distinguish petroleum formed by two mechanisms mentioned above.
- While petroleum may be associated with igneous deposits in trace amount, the origin of most petroleum is linked organic matters. Organic matter may be of two types, autochthonous (produced in the depositional environment) or allochthonous (derived, detrital, washed in).
- The autochthonous organic matter predominantly comprises phytoplankton (algae, diatoms etc.), zooplankton, and bacteria. Allochthonous organic matters include terrestrial plant, spores and pollen and recycled (old) kerogen from earlier deposited sedimentary rocks.
- The origin of petroleum involves three stages - diagenesis, catagenesis and metagenesis.
- **Diagenesis** involves low temperature processes, which involve hydrolysis of complex organic compounds, removal of functional groups, hydrogenation of double bonds, condensation of molecular fragments to form complex macromolecules.

Types of Organic Matter and Hydrocarbon Generation

- The end product of diagenesis is kerogen, which is a mixture of complex organic compounds that dominate organic matter in sediments.
- **Catagenesis** involves thermal cracking of kerogen and formation of the majority of crude oil.
- In the **metagenesis** stage, natural gas (mostly *methane*) is produced and residual carbon is left in the source rock.

Types of Kerogen

- Kerogens are broadly divided into four types, I, II, III and IV on the basis of its H/C and O/C content.
- A single type or a mixture of types may be present in a hydrocarbon source rock.
- Type I kerogen is rich in hydrogen and it is the best source of oil. It's H/C ratio and O/C ratio varies from 1.0 to 1.9 and 0.02 to 0.1 respectively. It is generally found in the sediments formed in a lake enviroment.
- Type II kerogen is also a good source of oil and it is the main kerogen type associated with marine organic matter. Its H/C and O/C varies from 0.8 to 1.5 and 0.02 to 0.2 resepectively.
- Type III kerogen is mainly responsible for gas formation and produces less oil. Its H/C and O/C varies from 1.0 to 0.5 and 0.03 to 0.3 resepectively. It is mainly derived from continental land plants.
- Type IV kerogen is carbon-rich, remains inert during the catagenesis stage. It's H/C ratio is always less than 0.5. It is also known as inert kerogen.

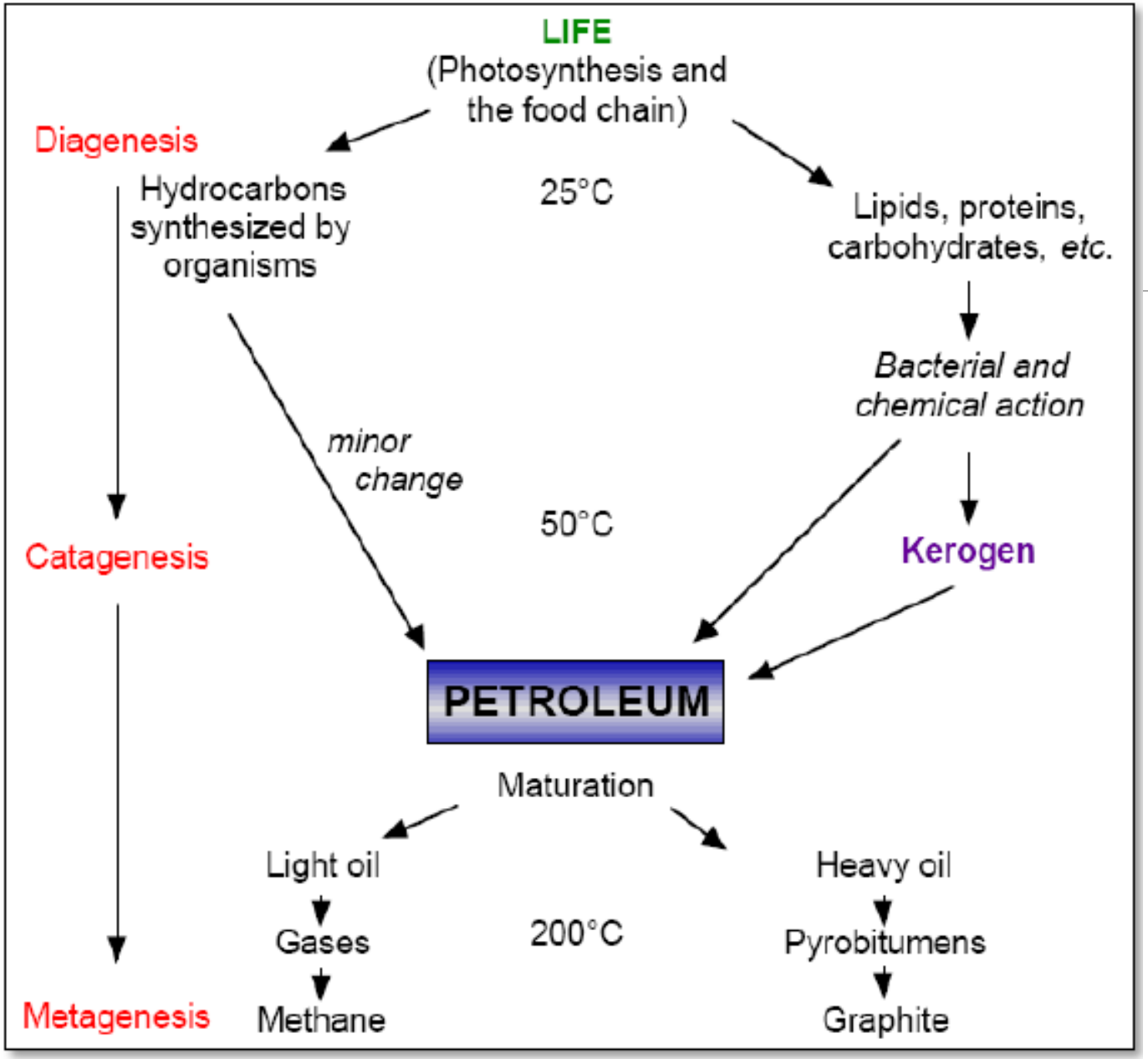
Types of Kerogen

Types of kerogen and their hydrocarbon potential

Enviroment	Kerogen Type	Equivalent coal maceral	Origin	Hydrocabon Potential
Lacustrine	I	Sporinite, alginite	algae	Oil and gas
Marine	II	cutinite	Marine phytoplankton and zooplankton, bacteria	Oil and gas
Fluvial	III	vitrinite	Fibrous and woody plant fragments and structureless colloidal humic matter	Mainly gas, some oil
	IV	inertinite	Oxidised, recycled woody debris	none

Maturation of Kerogen and formation of Petroleum

- Petroleum originates from organic matter following two separate pathways
- Approximately 10 to 20% of petroleum is directly formed from hydrocarbons synthesized by living organisms or from their molecules, which are readily converted to hydrocarbons (Hunt, 1997).
- This pathway involves an accumulation of hydrocarbons formed by minor bacterial activity and chemical reactions at low temperatures. Most of these early formed hydrocarbons contain more than 15 carbon atoms in their structure.
- The second pathway involves the thermal breakdown (maturation) of kerogen in the course of catagensis. With increasing burial depth and temperature, the organic matter progressively cracks to liquid petroleum through the intermediate stage of bitumen.



Orgin and evolution of hydrocarbon through different stages (modified after Hunt, 1997)

Oil Window

- **Oil Window:** The temperature range of oil formation (and corresponding depth) is referred to as 'oil window'. The temperature requirement depends on the age of the rock. A Mesozoic rock requires less temperature than a Cenozoic rock.
- As the most oil source rock is formed during the Mesozoic, all temperature data provide in the following discussion is valid for a Mesozoic source rock. Again, temperature requirement for oil and gas generation depends on the type of kerogen.
- Type II variety of kerogen, containing sulphur (i.e. type IIS) requires lower temperature range compared to type I kerogen. Oil generation in the appropriately mature source rock initiates at a temperature of about 60°C for a Mesozoic source rock and continues until at a temperature of 150°C.
- This range of temperature is called as 'oil window'. In areas of higher geothermal gradient, the oil window exists at a shallower depth and the depth range is less.
- For a Cenozoic source rock, the oil window temperature is slightly higher (90 to 200°C) than its Mesozoic counterpart.

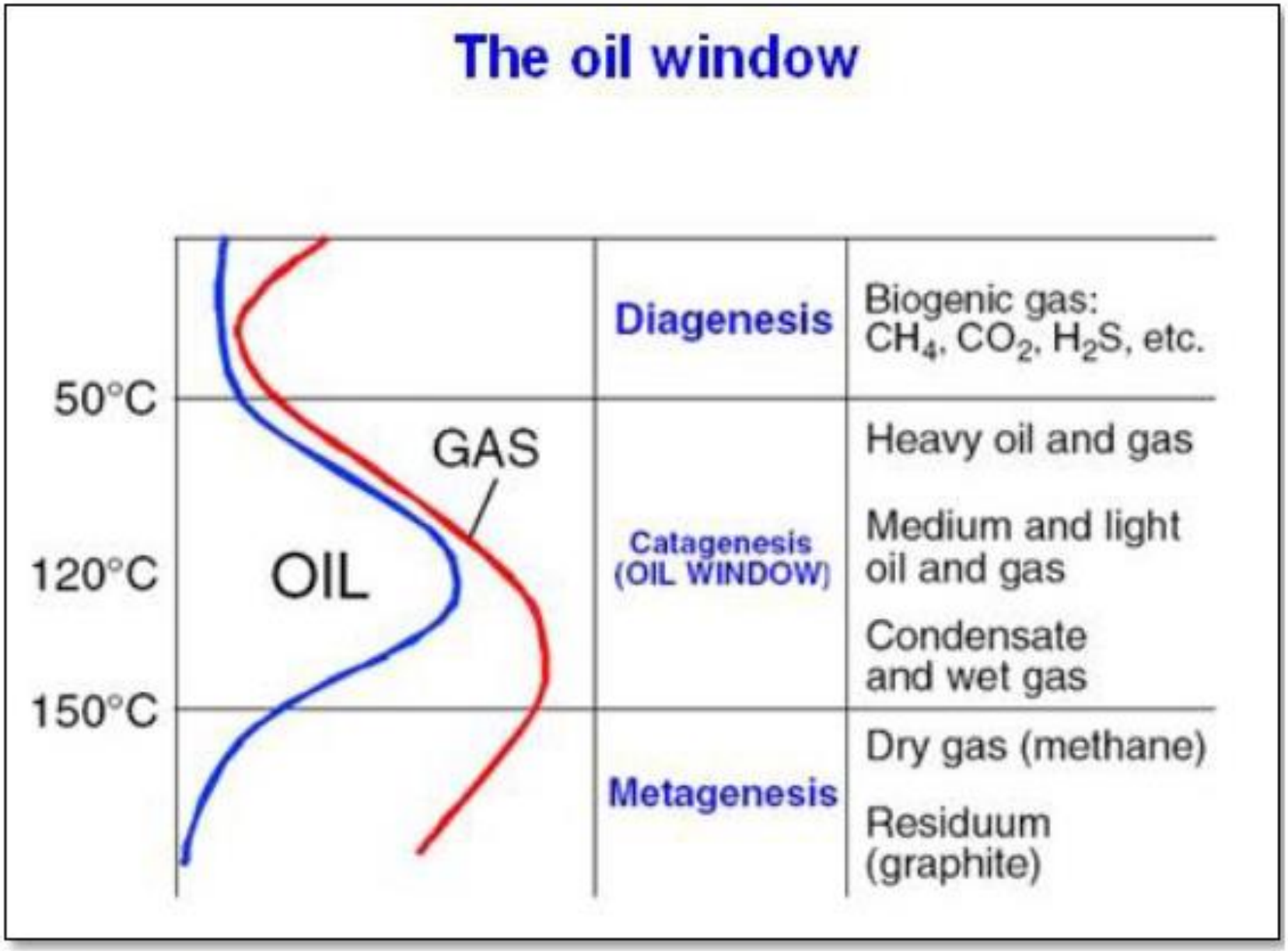
Formation of Petroleum in different depth zones in the subsurface

- The Figure below shows the formation of different types of hydrocarbons in different temperature/depth zones, which may be summarized as follows:

- **Diagenesis:** Bacteriogenic methane and a lesser amount of heavy crude oil are produced at this stage. Biogenic methane production is very high close to the surface because of the activity of methanogenic bacteria. Methane production decreases with depth.

- **Catagenesis:** Heavy oil and gas forms at the shallower part, followed by the formation of medium and light oil and gas. Condensate and wet gas forms at greater depth. The kerogen is converted into a carbon-rich residue at the end of catagensis.

- **Metagenesis:** Dry gas is formed at this high temperature. Both kerogen and crude oil is converted to a carbon-rich residuum at this stage.



Oil window and the formation of different types of petroleum (modified after Tissot and Welte, 1984)

Any Questions??

Thank You !!!