Introduction to Petroleum Geology

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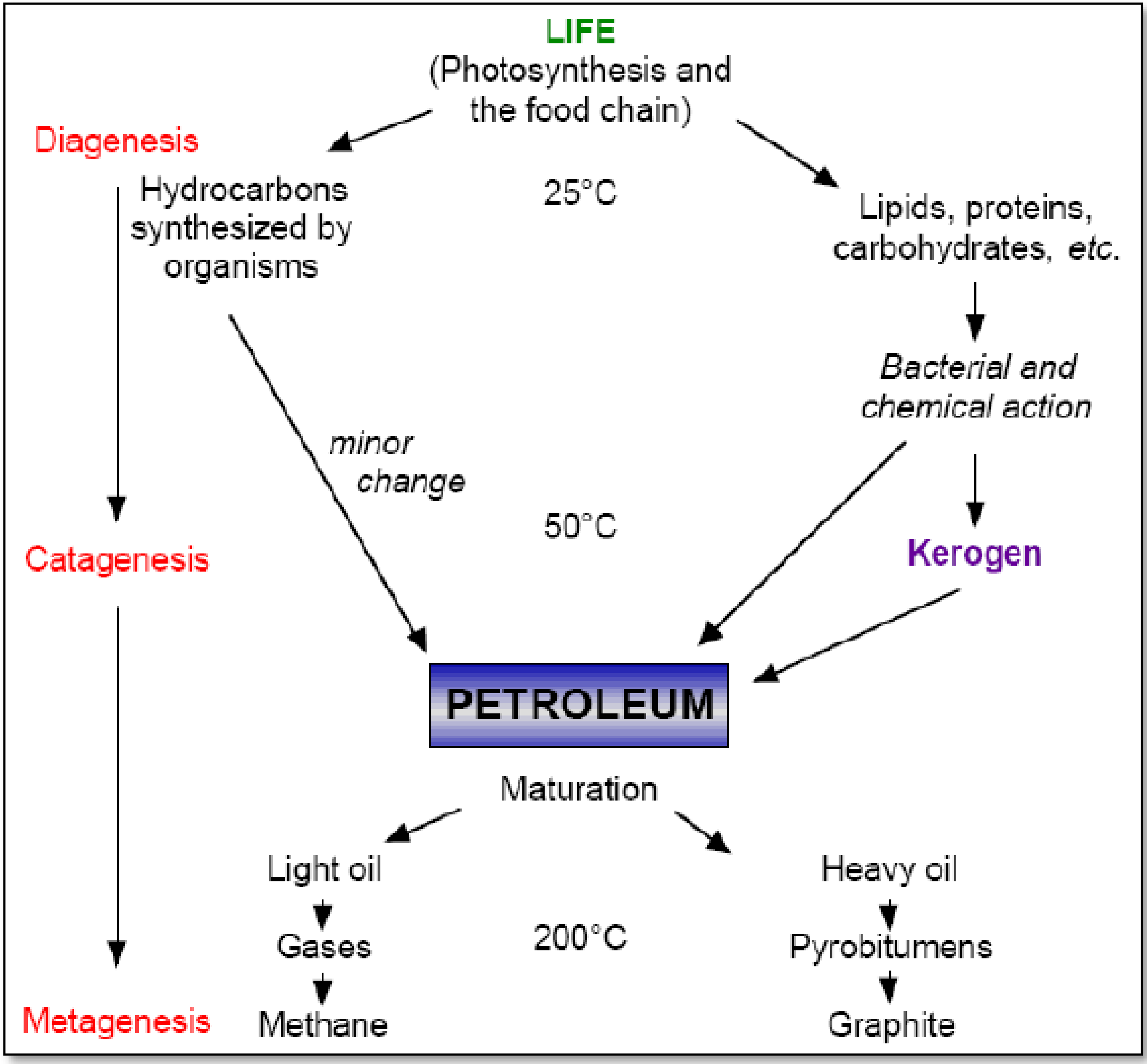
Maturation of Kerogen and formation of Petroleum

- 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.

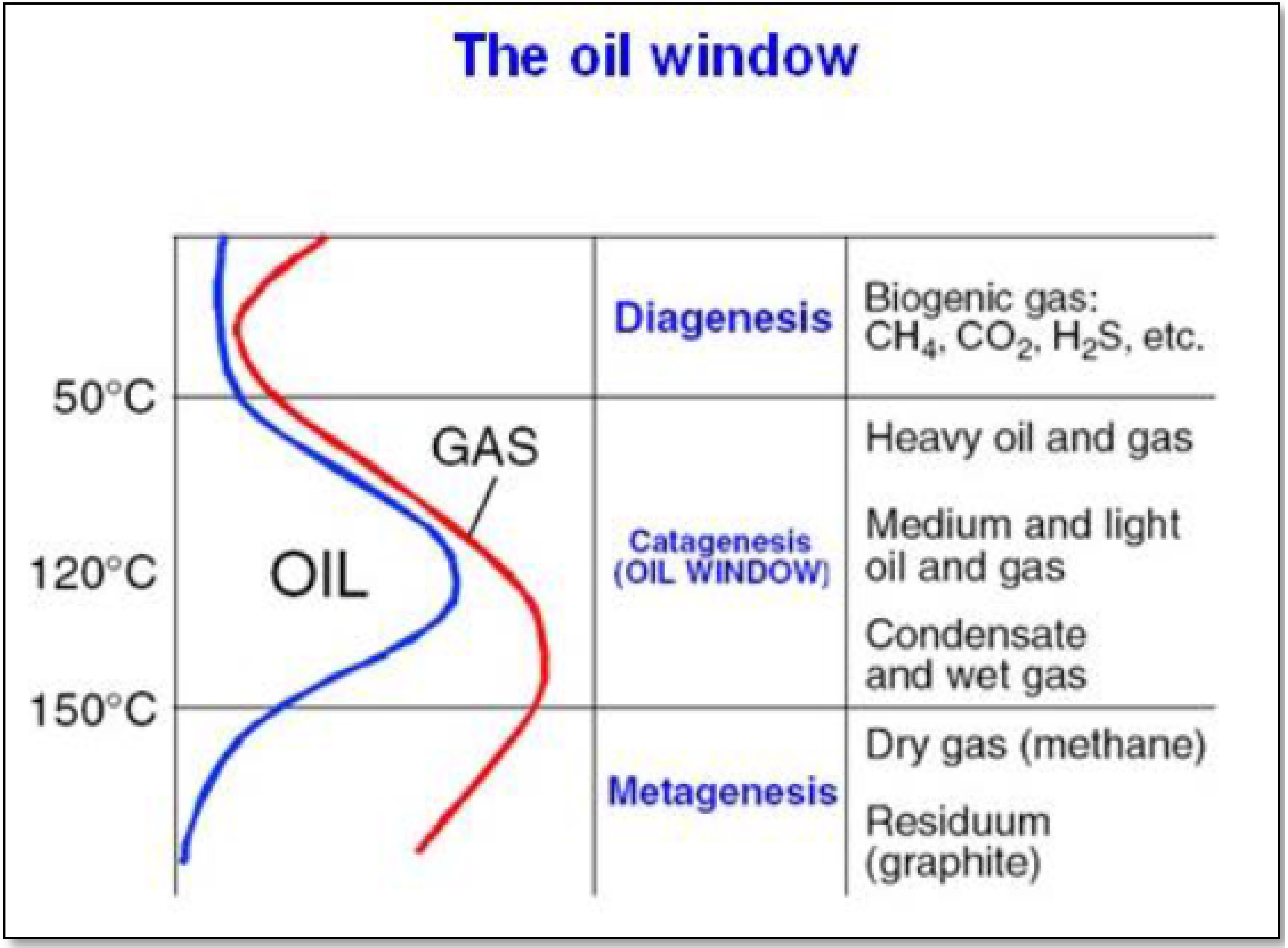
Formation of Petroleum in different depth zones in the subsurface

- 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.

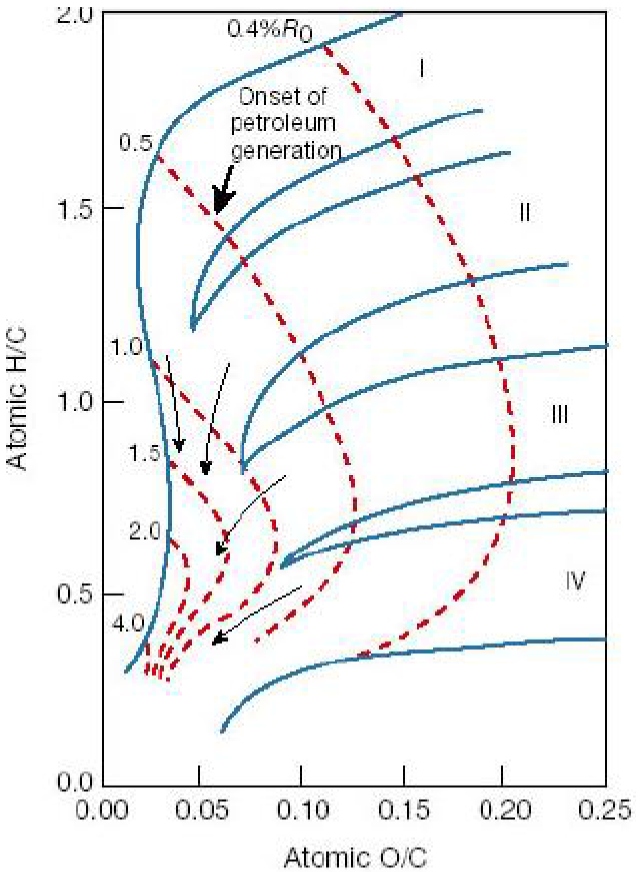


Oil window and the formation of different types of petroleum (modified after Tissot and Welte, 1984)

Kerogen Maturation

Van-Krevelen plot and kerogen maturation

- Kerogen matures with depth and time
- The maturation of kerogen and hydrocarbon production can be best studied using Van Krevelen diagram
- It is a cross plot between atomic H/C and O/C of kerogens
- Kerogen types I, II, III and IV can be distinguished in the Van-Krevelen plot



Van Krevelen plot and kerogen maturation (modified after Hunt, 1997)

Kerogen Maturation

Highlights of the salient aspects of Kerogen Maturation

- The reduction of H/C of kerogens indicates hydrocarbon generation. As the maximum reduction of H/C content is possible for type I kerogen, it forms most hydrocarbon.
- The reduction of O/C of kerogensis associated with carbon dioxide formation. Type III and IV kerogens reduce their O/C content faster than their H/C content. These kerogens produce more carbon dioxide with very less or no oil.
- Vitrinite reflectance values are superimposed in the figure to indicate the precise estimation of the oil window. Most oil is generated in the vitrinite reflectance range of 0.5 and 1.3. Most gas is formed at a slightly higher maturation range.
- At higher temperature kerogen, composition merges and they are no more distinguishable into different types.
- Vitirinte reflectance values more than 2 indicate inert kerogens, which are incapable to produce any oil.

Kerogen Maturation

- Potential hydrocarbon (oil and gas) source beds are formed dominantly by thermal maturation of organic matters present within sediment under the combined effects of thermal kinetic energy and geologic time as sediments undergo burial.

- In diagenesis, biogenic decay and abiogenic reactions suffered by organic matters release methane, CO_2, water and leave a complex hydrocarbon compound within sediments that is referred to as 'Kerogen', made up of carbon, hydrogen and oxygen with minor amounts of nitrogen and sulfur.

- It is differentiated from 'Bitumen' by its insolubility in normal organic solvents like carbon disulfide.

- The transformation of organic matter to kerogen takes place right from shallow burial (with near surface temperature) up to a depth of 1km and ~500C temperature.

- In a steadily subsiding sedimentary basin, the transformation (maturation) of organic matter to kerogen and its subsequent maturation to oil and gas happens under three different stages of burial viz. diagensis, catagenesis and metagenesis (Tissot, 1977).

Kerogen Maturation

- *Maturation* is a combination of complex processes through which complex biological molecules, created by living organisms, are first converted into simple bio-molecule and finally cooked to give petroleum.

- In the early stages of alteration, termed as diagenesis, an intermediate form of organic matter, called kerogen, is formed. Dehydration (release of H2O) and Decarboxylation (release of CO2) are the two main reactions at this stage, dominantly under the influence of bacterial action.

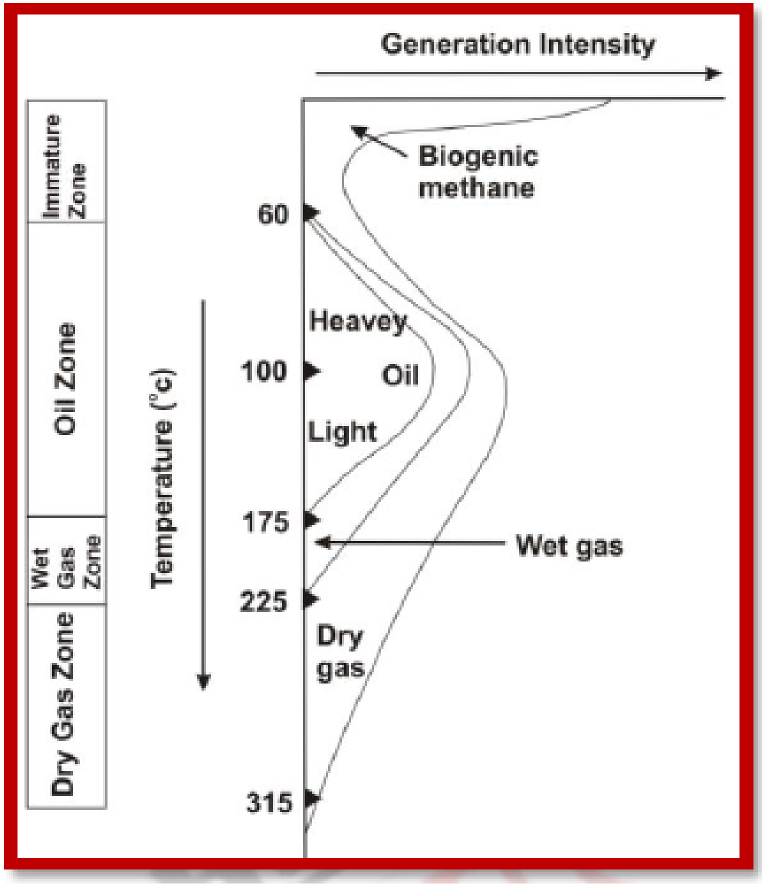
- The Eh - PH condition at the sediment-water interface principally guides bacterial action on organic matters. While free sulfur is released from sulfate ion with removal of oxygen under the action of *Desulfovibrio* bacteria in reduced condition below water table, oxydation of free sulfur by the bacteria *Thiobacillus* in an oxygenated condition result in formation of sulfate ions.

Agents of Transformation

- Biological transformation of organic matter to kerogen and chemical transformation of thermally reactive kerogen give rise to the generation of petroleum.
- Bacterial processes remain mostly effective in initial brake down of organic matters, while cooking of transformed organic matter i.e kerogen is guided by chemical processes.
- A combination of negative redox potential and alkaline Ph condition i.e between 7.5 and 8.4 favours liberation of petroleum.
- Both temperature and pressure increases as organic matters get buried. Transformation of organic matters is independent of pressure, in fact high pressure may counter rate of decomposition.
- In contrast, temperature plays pivotal role in organic matter transformation; higher molecular weight organic matters transform into simpler compounds by thermal cracking. Generation of petroleum is a rate-controlled, thermocatalytic process. In addition to temperature, time spent by organic matter at different temperatures also plays a key role

Temperature and Time

- Petroleum is generated when kerogen is subjected to the increased temperatures that accompany sediment burial
- Various transformation products with increase in temperature and burial. Principle oil producing zone is termed as 'Oil Window'
- The alteration of kerogen to petroleum is similar to other thermal cracking reactions.
- Large kerogen molecules decompose upon heating, to yield smaller molecules of petroleum These reactions usually require temperatures greater than 60 °C.
- At lower temperatures, during early diagenesis, natural gas, (called biogenic methane or marsh gas) is generated through the action of microorganisms that live near the earth's surface.



Temperature and Time

- The temperature range between about 60°C and 175°C is commonly called the *oil window*. This is the principle zone of oil formation. It begins at burial depths of 1 to 2 km and ends at depths of 3 to 4 km in most areas, depending on factors such as the geothermal gradient.

- The first oil generated is heavy and tends to be richest in aromatic and N-S-O compounds. As burial and temperature increases, oil becomes lighter and more paraffinic. At temperatures much above 175°C, the generation of liquid petroleum ceases and gas formation becomes dominant. When formation temperatures exceeds 225°C, most kerogen has used up its petroleum-generating capacity. Source rocks become overmature.

- However, some methane can still be created, even at these very high temperatures, by the breakdown of the larger, heavier molecules of previously generated crude oil.

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Any Questions??

Thank You !!!