Organic Matter, Kerogen & Petroleum Generation

E-Content
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Organic Matter (OM)

- When an **organism (plant or animal) dies**, it is normally **oxidized**
- Under exceptional conditions: organic matter is buried and preserved in sediments
- **Composition of the OM** strongly influences whether it can **produce coal, oil or gas.**
- Early marine life forms on Earth => mainly (>95%) **Planktons (rich in Hydrogen & Carbon**)
- **Layers of Organic-rich Mud / Silt** => transformed on sea-floor into **fossil-rich OM i.e. remains** of earlier life.
- **Thermal Maturation process** (Decay, T & P) over millions of years slowly => converted **OM into Oil & Gas** .
- This **conversion of OM into Oil** is called **Catagenesis =>** occurs under **Anaerobic environment**.
- **Clay & Silt** along with **dead organic remains** are deposited under deltaic , lacustrine or marine conditions to produce => **Source Rocks**.

  Shale Rock = Clay Mineral (99%) + OM (1%)

- Black colored, organically rich Shales **(Black Shales) deposited in a non-oxidising, quiet marine environment are considered the best Source Rocks.**

Petroleum Source Rocks

- **Petroleum source beds are fine grained,**
  1. clay-rich siliclastic rocks (mudstones, shales) or
  2. dark coloured carbonate rocks (limestones, marlstones),
- **which have generated and effectively expelled hydrocarbons**.

- **A petroleum source is characterised by 3 essential conditions:**
  - ***a) sufficient content of finely dispersed OM*** of biological origin;
  - ***b) OM must be of a specific composition***, i.e. ***hydrogen-rich***

- *The criteria for a **sedimentary rock** to be **effective oil source** :--*
  - **i. TOC** should be > 0.4% (mostly 2 – 10 %)
  - **ii. Elemental C --** 75% and 90% (in weight)
  - iii. The ratio of **bitumen : TOC** should exceed 0.05
  - iv. The **kerogen type** should be **I or II (from lipids)**
  - **v. Vitrinite reflectance --** 0.6 to 1.3%

Basic components of organic matter

- **Lipids** => mostly fats, oils and waxes ;
  - **have the greatest potential to be hydrocarbon sources.**

- **Proteins** =>are giant molecules that make up the solid constituents of animal tissues and plant cells.
  - They are **rich in carbon + N, S and O.**
- **Carbohydrates** => are **based on sugars & their polymers (cellulose, starch, chitin).**
  - They are **common** in **plant tissue**.

- **Lignin** => (**aromatic in nature)** It is a **major constituent in land plants and converts to coal.**

Lignin, Proteins, Carbs, Lipids +Time +Temperature +Pressure = KEROGEN

Precursors of Petroleum

- ***Terrestrial Plant Matter*** (which contains Humic OM) => **forms Coal**
- **Oil is not derived, as Coal is, from terrestrial plant material**.
- **Humic OM** – ***(Carbohydrate – Lignin composition)*** **--** yielded by **terrestrial vegetation** has to be **replaced by Sapropelic material of aquatic origin** and by **OM of animal (Zooplankton) derivation.**

  (***Biochemical characteristics of Humic / Sapropelic OM are very different)***

- **Sapropelic OM --** Vegetable mud / slime (Alginite)

  -- Containing polymerized Lipid + Protein

  -- **Restricted marine (and lacustrine) basins** mainly have planktonic OM that is **oil-prone or Sapropelic**

  -- ***Lipids*** (from spores, cuticles etc.) have **high H-content** (>10%)

  -- associated with aquatic sedimentary facies (both marine & lacustrine)

  -- yield of volatiles is much greater than that of Humic OM

In conversion of OM, Kerogen is an intermediate product

- ***When OM is*** buried, it is subjected to **increased T & P.**
- **TOC in sedimentary rocks can be divided into** *two types* :--

1. **Bitumen** -- fraction that is **soluble in organic solvents (e.g. chloroform)**
2. **Kerogen -- insoluble, non-extractable residue** that forms in the transformation from OM

- Thus, Not all of **Total organic carbon (TOC) i.e. only Kerogen part of TOC,** is converted into **petroleum HC**.
- **The Process of Transformation of OM :--**

OM => Kerogen => Petroleum HC

- **Kerogen is an intermediate product formed during diagenesis**.
- **Kerogen** occurs in the **Source Rock** and **may form Hydrocarbons** upon **Thermal Cracking.**
- It is the **principal source (Precursor) of HC generation.**

Conversion of OM to HC

- **Principal condition => conversion in oxygen-free environment (from the very beginning of the process).**
- **In transformation of OM into petroleum => H and C => should not be destructed, i.e.**
  1. ***the nitrogen and oxygen (contained in the OM) must somehow be removed***
  2. ***at the same time preserving the hydrogen-rich organic residue.***
- **i.e. On burial => kerogen is first formed.**
- **Kerogen** gradually cracked to form smaller HC, with formation of CO2 and H2O.
- At higher temperatures, methane (CH4) is formed and HCs from C13 to C30.
- Consequently, the **carbon content of kerogen increases** with increasing temperatures.
- Simultaneously, fluid **products high in hydrogen** are formed and **oxygen is eliminated**.
- **i.e. Transformation of Kerogen into mature Petroleum involves progressive increase in H:C ratio**

Kerogen Types (based on OM)

3 types of kerogen (depending on the precursor Org. Matter) :--

- **(1) Type I- Algal (Sapropelic Kerogen)**
- Higher in H/O ratio than other kerogens- typically 1.2 to 1.7. (H/C ratio is 1.65).
- The organic compounds are typically lipids (fats).

- **(2) Type II- (Lipid-rich Kerogen) combination algal and zooplankton and phytoplankton**
- Has intermediate H/C and H/O ratio to those of Type I and Type III

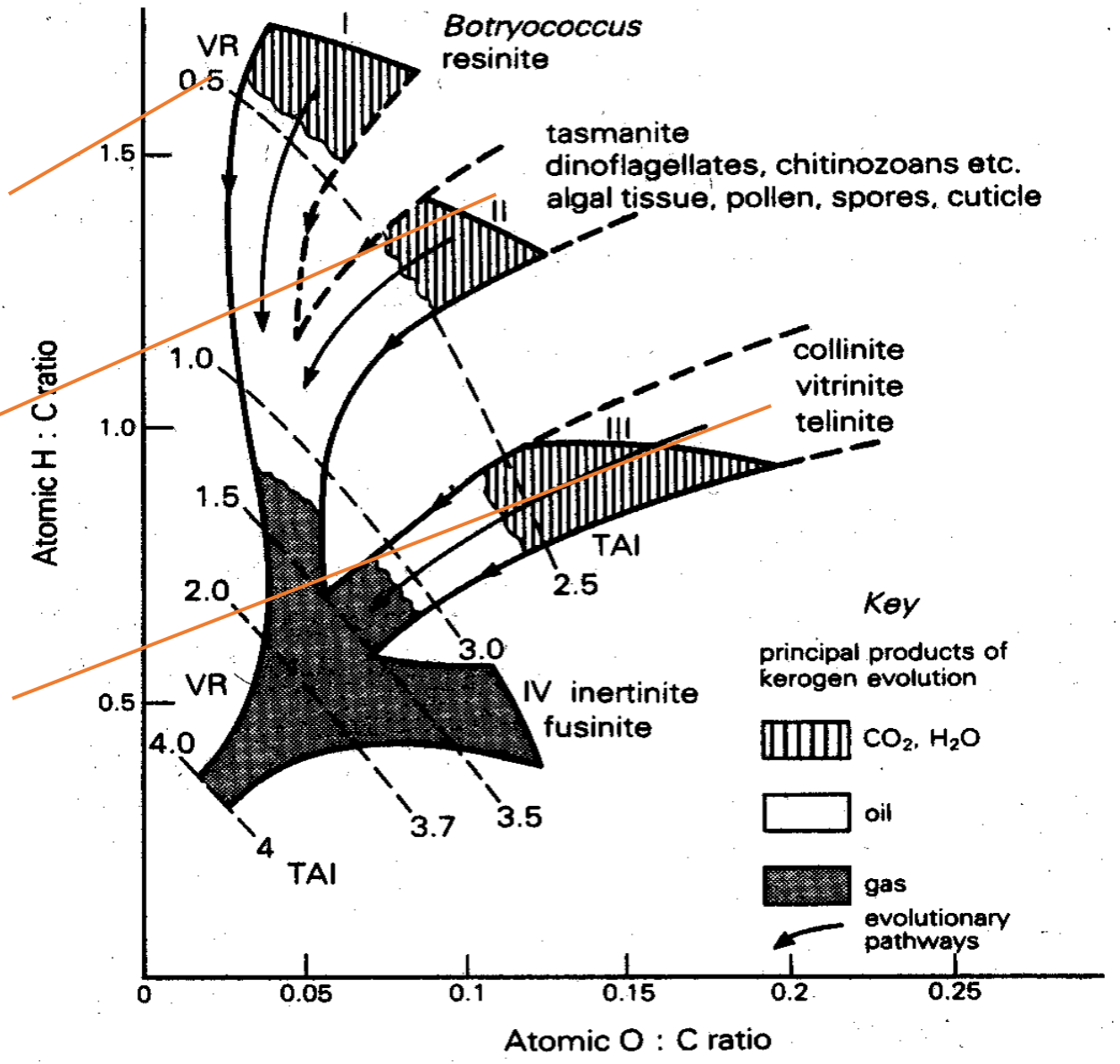
- **(3) Type III- (Humic Kerogen) -- generally from woody (land) plants- Humic material**

- **Rich in aromatics**, but **low in aliphatic** compounds.
- It has a **very low H/C ratio** and **higher H/O ratio**.
- Generally undergoes **diagenesis to form coal**- the **only liquid HC** it produces is **methane**

Sapropelic kerogen (algae)

Lipid-rich kerogen (phyto- and zooplankton)

Humic kerogen (land plants)



"Van Krevelen diagram"

(TAI, VR: Maturation indicators)

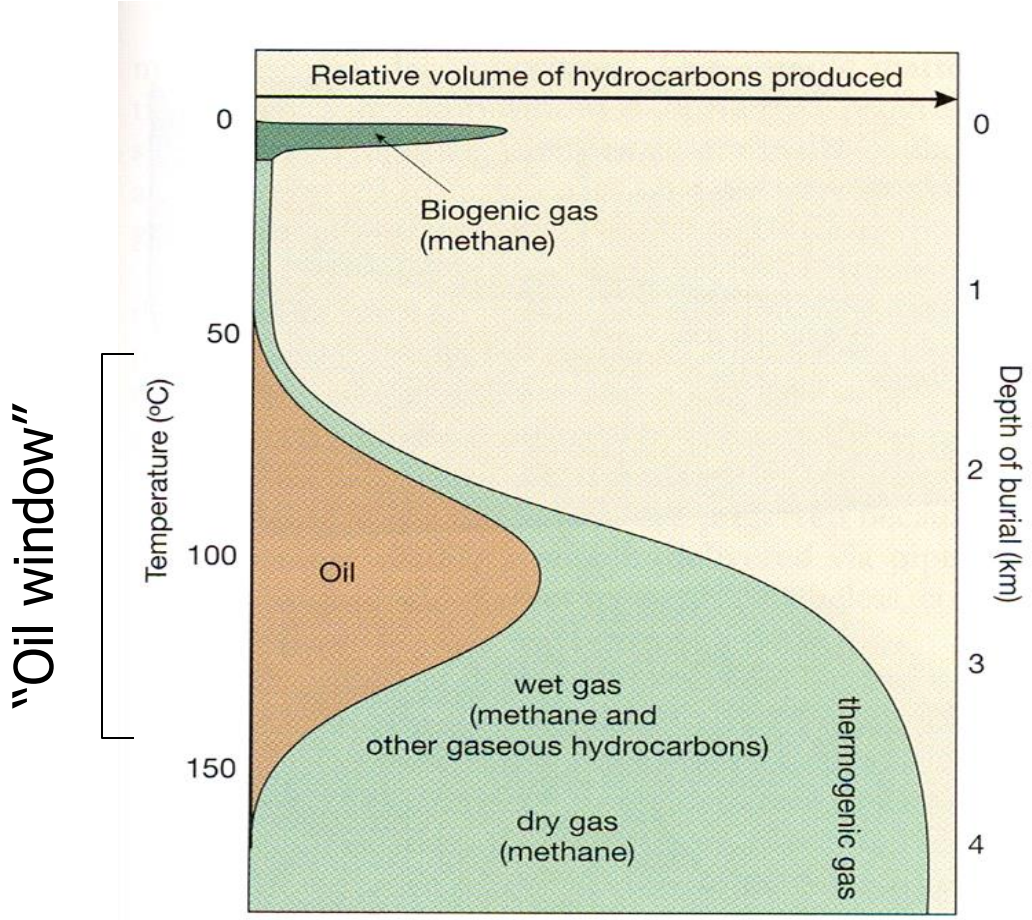
Formation of petroleum (oil and gas)

Oil and gas result from the breakdown of organic molecules (**kerogens**) under conditions of increasing temperature, from large complex molecules to smaller, shorter-chain molecules dominated by hydrogen and carbon: a process called **"cracking" or "pyrolysis".** This occurs largely through the breaking of C-C bonds.

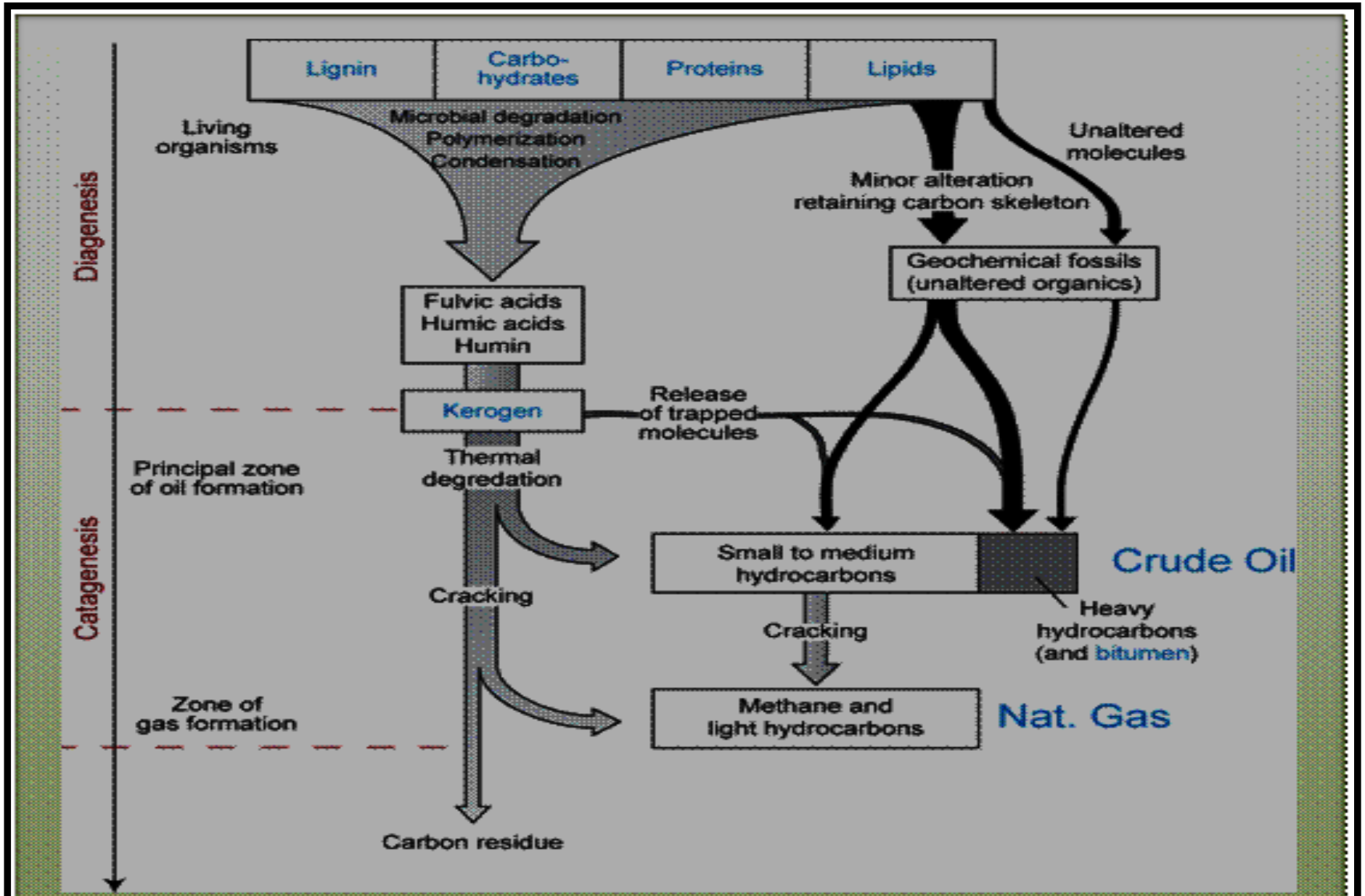
Some gas is produced by decomposition of organic matter by microbes (**biogenic gas)**

Most oil is produced at temperatures between about 60^{O} and 120^{O} C (**the oil window**).

Thermogenic gas is produced as oil is broken down to very small molecules
(the smallest being methane)



The Oil Window
T below: Organics remain largely unaltered.
T above: Thermal cracking transforms the petoleum into natural gas.



Modified from Tissot and Welte, 1984. *Petroleum formation and occurrence*, Springer –Verlag, 699 pp.
Summary of the oil formation process

3 Phases of Transformation into Hydrocarbons

- **Diagenesis – (Stage of Kerogen Formation)**
- **during initial deposition/burial, Biogenic decay by Bacteria**
- at **temperatures** => from near normal to < 60 deg C

- **Catagenesis – (Stage of Maturation of Kerogen)**
- **Non-biogenic stage, T-P controlled + Time;**
- **Transformation of Kerogen to Hydrocarbons**
- **Time factor =>** provides **stable conditions over long periods of time** that allows the **kerogen** sufficient **cooking time (Maturation)**

- **Metagenesis – (Stage of conversion of Kerogen to Graphite)**
- **Last stage, before metamorphism, Extreme Temperature & Pressure,**
- **Residual kerogen** is converted into ➔ **graphite.**

Factors for Transformation of OM into Petroleum

- **Required energy for transformation is supplied by :--**

1. **Bacterial Action** – ***Anaerobic bacteria (i.e.*** in ***absence of Oxygen)***

   => it reacts with CO2 to form => Methane (CH4)

2. **Heat & Pressure** – Temp. => ***350 – 400 deg C*** for transformation

   -- In ***most oil pools (*** temp. ***upto 93- 94 deg. C)***

   -- ***Geologic time*** => ***sufficient for transformation at low Temp***.

3. **Catalytic Reaction** – **Ni , Mo , V** (catalysts) in ***original sediments***

   => promote ***chemical reaction of transformation***.

4. **Radioactivity** – Bombardment of ***saturated fatty acids by alpha particles*** produce ***paraffin hydrocarbons & cyclic HC.***