Group 2 ore genesis: fossil fuels

Q 1: Explain the concept of *ore genesis of fossil fuels*. How does it differ from the genesis of metallic mineral deposits?

Answer:
Ore genesis of fossil fuels refers to the geological and biological processes that transform organic matter into economically viable deposits of coal, oil, and natural gas. While fossil fuels are **biogenic in origin**, their enrichment into reserves requires geological processes such as burial, compaction, thermal maturation, and trapping within impermeable structures. In contrast, metallic ore genesis usually involves magmatic, hydrothermal, or sedimentary processes that concentrate inorganic elements (e.g., Fe, Cu, Au) into ore bodies. The difference lies in **origin (organic vs. inorganic)** and **formation pathways (biothermal vs. hydrothermal/magmatic/sedimentary concentration).**

Q 2: Discuss the coalification process, from peat to anthracite, highlighting the physical and chemical changes.

Answer:
Coalification is the progressive transformation of plant-derived peat into higher-grade coal under increasing burial depth, temperature, and pressure.

- **Peat:** Water-rich organic matter with low carbon content (~60%).
- **Lignite:** First rock-like stage; compaction expels water and increases carbon to ~70%.
- **Sub-bituminous coal:** Further dehydration and compaction, with increased calorific value.
- **Bituminous coal:** Carbon content ~80–85%, volatile matter reduced, higher energy yield.
- **Anthracite:** Metamorphic grade; carbon ~90–95%, minimal volatiles, high density, highest energy efficiency.

Chemical changes involve **increased carbon concentration** and **loss of oxygen and hydrogen**, while physical changes include **hardening, reduced porosity, and darker colour. This process is controlled by burial depth, geothermal gradient, and tectonic conditions.**

Q 3: Compare the formation of conventional vs. unconventional oil and gas reservoirs.

Answer:

- **Conventional reservoirs:** Hydrocarbons migrate from source rock into porous and permeable reservoir rocks (e.g., sandstone, limestone) capped by impermeable seals (e.g., shale, evaporites). Traps may be structural (anticlines, faults) or stratigraphic.
- **Unconventional reservoirs:** Hydrocarbons remain within low-permeability source rocks (e.g., shale, tight sandstone, coalbeds). They require enhanced recovery methods like **hydraulic fracturing** or **horizontal drilling**.

Key differences:

- **Migration:** Conventional requires migration; unconventional does not.
- **Porosity/permeability:** Higher in conventional; very low in unconventional.
- **Extraction cost:** Lower for conventional, higher for unconventional.
- **Global importance:** Unconventional reserves (e.g., shale gas in USA) are reshaping global energy markets.

Q 4: Explain the role of source rocks in the formation of oil and gas. How do burial depth and geothermal gradients control hydrocarbon type?

Answer:
Source rocks, typically **organic-rich shales**, are the initial host of kerogen — the precursor to hydrocarbons. Under progressive burial, geothermal heating causes kerogen to undergo **catagenesis**, breaking down into liquid and gaseous hydrocarbons.

- At **~60–120 °C** “oil window”, kerogen generates liquid hydrocarbons.
- At **~120–200 °C** “gas window”, kerogen produces mainly methane and light hydrocarbons.
- Beyond ~200 °C, hydrocarbons crack and degrade into dry gas or carbon residue.

Thus, burial depth and heat flow dictate whether a basin yields oil, wet gas, or dry gas. Basins with high geothermal gradients reach maturity faster than those with low gradients.

Q 5: Describe the four types of kerogen and their typical hydrocarbon products.

Answer:
Kerogen is classified based on **origin, hydrogen-to-carbon ratio (H/C), and oil-generating potential**:

- **Type I (Algae Kerogen):**
    - Origin: Lacustrine algal material
    - High H/C ratio → oil-prone
    - Generates large quantities of liquid hydrocarbons
    - Depositional setting: Anoxic freshwater lakes
- **Type II (Planktonic Kerogen):**
    - Origin: Marine plankton mixed with some terrestrial organic matter
    - Moderate H/C ratio → oil and gas prone
    - Depositional setting: Marine shelf
- **Type III (Terrestrial Kerogen):**
    - Origin: Higher plant material (woody tissue
    - Low H/C ratio → gas-prone
    - Depositional setting: swamp, and terrestrial basins
    - Major contributor to coal and gas accumulations
- **Type IV (Inertinite):**
    - Origin: Highly oxidised organic matter (charcoal, degraded material)
    - Very low H/C ratio → non-generative ("dead carbon")
    - Depositional setting: Oxidising environments such as alluvial plains and weathered sediments

Group 3- Hydrothermal Deposit Types: Magmatic–Hydrothermal

Q 6: Contrast skarn and greisen deposits in terms of host rocks, alteration, and ore commodities.

A:

- **Skarns:**
    - Host rocks: Carbonates (limestone, dolostone).
    - Alteration: Calc-silicate minerals (garnet, pyroxene, wollastonite).
    - Commodities: Fe, Cu, Zn, W.
    - Process: Magmatic fluids react with carbonate wall rocks, replacing them with ore-bearing silicates.
- **Greisens:**
    - Host rocks: Granitic intrusions.
    - Alteration: Quartz + muscovite + topaz ± tourmaline.
    - Commodities: Sn, W, Mo, Ta.
    - Process: Late-stage magmatic fluids alter granitic rocks, producing vein-style mineralisation.

Key difference: Skarns are **exoskarn (contact-related)** systems in carbonate hosts, while greisens are **endoskarn (internal)** systems in granitic hosts.

Group 4- Ore Genesis: Metasomatic Hydrothermal Deposit Type

Q 7: Compare greisen deposits and replacement deposits as types of metasomatic ore systems.

A:

- **Greisen Deposits:**
    - Associated with granitic intrusions.
    - Alteration: Quartz–muscovite–topaz ± tourmaline.
    - Commodities: Sn, W, Mo, Ta.
    - Example: Matok Igneous Complex (Limpopo Mobile Belt).
- **Replacement Deposits:**
    - Occur when hydrothermal fluids replace host rock minerals.
    - Common in carbonate hosts (limestone, dolomite).
    - Commodities: Au, Fe, Pb, Zn, Mn.

  - Example: Doornhoek Gold Deposit (Limpopo Belt).

Key distinction: Greisen = *endoskarn-type alteration* in granites, while replacement = *exoskarn-type alteration* in carbonates/metamorphics.

Q 8: Evaluate the Qatruyeh Iron Deposits (SW Iran) as an example of replacement-type metasomatic mineralisation.

A:

- **Setting:** Sanandaj–Sirjan magmatic–metamorphic belt; hosted in carbonates.
- **Processes:**
  - Hydrothermal Fe-rich fluids replaced carbonates.
  - Alteration: Na–Ca metasomatism, oxidation, propylitic assemblages.
  - Textures: Replacement banding, brecciation, vein infilling.
- **Geochemistry:** Enrichment in Fe, HFSE, LREE; depletion of Ca, Mg.
- **Ore significance:** Major Fe resource supplementing BIF and magmatic Fe–Ti–V deposits; also contains Cu, Mo, W, REEs.

This deposit demonstrates how **metasomatism can diversify ore sources** beyond traditional magmatic or sedimentary iron systems.

Group 5 - Sedimentary Hydrothermal Deposits

Q 9: Describe the formation processes of sedimentary hydrothermal deposits, including the roles of temperature, pressure, and fluid sources.

Answer:
Sedimentary hydrothermal deposits form as hot, metal-rich fluids migrate through sedimentary basins and precipitate minerals when changes in temperature and pressure cause the dissolved metals to fall out of solution. Formation temperatures range widely, from about 500°C down to 50°C, with mineral precipitation typically occurring as fluids cool or experience a drop in pressure or chemical stability. The fluids originate from multiple sources: deep circulating brines released during sedimentation, meteoric waters infiltrating from the surface, and connate waters trapped during sediment deposition and later expelled during diagenesis. Fluid pathways include permeable sedimentary layers, faults, fractures, and permeability contrasts that focus fluid flow. Fluid movement is often driven by thermal convection related to magmatic heat or deep burial.

Q 10: Contrast Sedimentary Exhalative (SEDEX) deposits and Mississippi Valley Type (MVT) deposits in terms of mineralogy, geological settings, and economic significance.

Answer:
SEDEX deposits form by metal-rich hydrothermal fluids discharging into seawater, precipitating layers or sheets of sulfide minerals rich in lead, zinc, and silver, often in carbonaceous shales. They are typically stratiform and occur in sediment layers along continental margins or sedimentary basins. Examples include Broken Hill and Mt Isa. SEDEX deposits are significant for their large zinc and lead reserves and barite content.

In contrast, MVT deposits form in carbonate rock formations such as dolomites and limestones through epigenetic processes involving the replacement of carbonate layers. They include forms such as karst cavity breccias and cross-cutting veins and are mineralized mainly with galena and sphalerite, sometimes with silver and carbonates. MVT deposits occur in sedimentary basins with specific tectonic settings conducive to fluid flow and mineralization. Both deposit types are important sources of lead and zinc but differ in their formation mechanisms and host rocks.

Group 8 – Magmatic Ore Formation Magma Types and Metallogeny

Q 11: Explain the role of Bowen's Reaction Series in magma crystallization and its significance in orthomagmatic ore formation.

Answer:
Bowen's Reaction Series describes the sequence in which minerals crystallize from cooling magma based on their melting points and chemical composition. The minerals least soluble in the magma crystallize first as temperature drops. This sequential crystallization controls the mineral assemblages formed from magma. In orthomagmatic ore formation, early crystallizing minerals can segregate and concentrate economically important elements like Ni, Cu, and PGE (platinum group elements). This process influences the creation of ore deposits directly from the crystallizing magma without interaction with other rocks, making it a primary control on the distribution and concentration of metals in magmatic ores.

Q 12: Discuss the differences in metallogeny between S-type and I-type granitic magmas including typical ore metals and sources.

Answer:
S-type granites derive from sedimentary source rocks and are typically associated with ore metals such as tin (Sn), tungsten (W), uranium (U), and thorium (Th). These granites form in anorogenic or crustal melting settings and tend to produce deposits linked to the remelting of sedimentary crust, exemplified by Sn-W deposits like those found in Cornwall, UK.

In contrast, I-type granites have igneous source rocks and host a more diverse suite of ore metals including copper (Cu), molybdenum (Mo), lead (Pb), zinc (Zn), and gold (Au). These generally form in volcanic arc or subduction-related environments. A classic example is the Climax Mo porphyry deposit in the USA. The metallogenic signature of each granite type depends strongly on the composition of the source rocks from which the magma was derived, influencing the types of metals that can be incorporated into the resulting ore systems.

Group 9 – magmatic ore-forming processes (Fractional Crystallization, Filter Pressing, Liquid Immiscibility)

Q 13: Compare: Fractional Crystallization, Filter Pressing, Liquid Immiscibility)

Answer:

3. Fractional Crystallization

- **Definition**: A process where early-formed minerals are physically separated from the remaining melt, preventing equilibrium re-reaction. This changes the melt composition and can lead to ore concentration.
- **Ore Formation Mechanism**:
  - As magma cools, minerals with high metal affinity (e.g., chromite, magnetite, ilmenite, sulfides) crystallize early.
  - These dense minerals settle gravitationally, accumulating as **layered cumulates** (e.g., Bushveld Complex chromitite seams).
  - Residual melt becomes enriched in incompatible elements (Cu, Ni, PGE, REEs), potentially producing late-stage pegmatites and ore-rich veins.
- **Ore Deposit Examples**:
  - **Bushveld Igneous Complex (South Africa)** → chromite, magnetite, PGE reefs.
  - **Stillwater Complex (USA)** → Pt-Pd ores.
- **Key Features**:
  - Systematic zoning of mineral layers.
  - Strong link to gravity settling and crystal density contrasts.

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2. Filter Pressing

- **Definition**: Mechanical squeezing of magma due to compaction of a crystalline framework, tectonic stress, or gravitational loading.
- **Ore Formation Mechanism**:
    - Interstitial liquid (rich in volatiles and incompatible elements) is expelled and migrates into fractures or permeable zones.
    - This liquid often carries **concentrated ore metals (Sn, W, U, REE, Li)**.
    - It may solidify in veins, segregations, or pegmatitic pockets.
- **Ore Deposit Examples**:
    - **Greisen-associated Sn-W deposits** (Cornwall, UK).
    - **Pegmatites rich in rare metals** (Tantalite, Spodumene).
- **Key Features**:
    - Enrichment occurs **outside the main magma body** due to fluid expulsion.
    - Deposits often associated with late-magmatic to magmatic-hydrothermal transition stages.

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3. Liquid Immiscibility

- **Definition**: Separation of a silicate melt into two immiscible liquids (typically silicate + sulfide, or silicate + oxide) during cooling and crystallization.
- **Ore Formation Mechanism**:
    - Sulfide droplets form within a silicate magma when sulfur saturation is reached.
    - Metals (Cu, Ni, Co, PGEs) preferentially partition into the **sulfide liquid** due to their high chalcophile affinity.
    - Dense sulfide globules settle and accumulate at the base of intrusions or along feeder dykes.
- **Ore Deposit Examples**:
    - **Sudbury Igneous Complex (Canada)** → Ni-Cu-PGE ores.
    - **Noril’sk-Talnakh (Russia)** → world-class Ni-Cu-PGE sulfides.
- **Key Features**:
    - Extremely metal-rich deposits due to strong partitioning into sulfide phase.

    - Often associated with crustal contamination or sulfur addition from wall rocks.

Group 12- Fluid Inclusions

Q 14: Describe the different types of fluid inclusions and the mechanism by which they are trapped within minerals. what are the phases in each type of fluid

Answer:

1. What are Fluid Inclusions?

- Fluid inclusions are **microscopic volumes of fluid (liquid and/or gas, sometimes with a solid)** that become trapped within minerals during their growth or later through healing of fractures.
- They act as “time capsules” preserving the physical and chemical conditions of fluids present during **mineral formation, diagenesis, or metamorphism**.

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2. Mechanism of Trapping

Fluid inclusions can be trapped by several processes:

1. **Primary Inclusions**
    - Trapped **during crystal growth**.
    - As a mineral crystallises from a melt or solution, small pockets of the surrounding fluid are sealed off.
    - These inclusions provide direct evidence of the fluid composition at the time of mineral growth.
2. **Secondary Inclusions**
    - Trapped **after mineral growth**, typically along healed fractures or cleavage planes.
    - They reflect **later fluid events** (e.g., hydrothermal overprint, metamorphic fluids).
3. **Pseudo-secondary Inclusions**
    - Trapped during growth but along **incipient fractures that opened as the crystal grew**.

  - They can appear as aligned trails within crystals, sometimes mistaken for secondary inclusions.
  - Their composition often bridges characteristics of both primary and secondary inclusions.

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3. Types of Fluid Inclusions & Their Phases

Fluid inclusions are classified based on the **phases present at room temperature (25 °C)** and how they evolve upon heating/freezing.

(a) Aqueous Two-Phase Inclusions

- **Phases at room temperature**:
  - **Liquid water (H_2O)** + **vapour bubble**.
- **Origin**: Common in hydrothermal systems; represent boiling or phase separation.
- **Significance**: Used to determine **trapping temperature and salinity** via microthermometry (ice-melting and homogenisation temperatures).

(b) Single-Phase Inclusions

- **Phases at room temperature**:
  - Either all **liquid** (L) or all **vapour** (V).
- **Origin**:
  - All-liquid: trapped at low temperature, below liquid-vapour curve.
  - All-vapour: trapped at high T and low P, or by post-entrapment leakage.
- **Significance**: Provide limited quantitative data, but indicate extreme trapping conditions.

(c) Multi-Phase (Aqueous-Salt) Inclusions

- **Phases at room temperature**:
  - **Liquid H_2O + vapour + solid salts (daughter minerals)** such as halite, sylvite, or carbonates.
- **Origin**: Formed from saline brines at high temperature and pressure.
- **Significance**: Critical for identifying **ore-forming brines** (e.g., porphyry Cu, Mississippi Valley-type Pb-Zn).

(d) Carbonic or CO_2-rich Inclusions

- **Phases at room temperature**:
    - **Liquid CO_2 + vapour CO_2** (sometimes solid CO_2 upon cooling).
- **Origin**: Common in metamorphic terranes and gold deposits.
- **Significance**: Provide evidence of **deep crustal/mantle-derived fluids** and volatile-rich systems.

(e) Hydrocarbon Inclusions

- **Phases at room temperature**:
    - **Liquid hydrocarbons (oil)**, **gas (CH_4, C_2H_6, etc.)**, or both.
- **Origin**: Occur in sedimentary basins during petroleum generation and migration.
- **Significance**: Record petroleum system evolution.

(f) Mixed Volatile Inclusions

- **Phases at room temperature**:
    - Mixtures of **H_2O–CO_2**, **H_2O–CH_4**, or **H_2O–N_2**, showing multiple liquid-vapour equilibria.
- **Origin**: Result from immiscibility between aqueous and volatile phases.
- **Significance**: Provide information about **fluid immiscibility and ore deposition conditions**.

Q 15: What is an isochore in fluid inclusion analysis, and how is it used to estimate pressure-temperature conditions?

Answer:
An isochore is a line in pressure-temperature space along which the density of a fluid inclusion remains constant after entrapment. Since the fluid inclusion volume is sealed and its density is fixed (unless leakage or deformation occurs), plotting the homogenization temperature ThTh along this isochore defines possible pressure-temperature combinations for the trapped fluid. By combining ThTh with pressure constraints from geological or experimental data, the actual trapping temperature and pressure conditions can be estimated, helping reconstruct past geothermal conditions.