The 18th International Earth Science Olympiad

Individual Theoretical Test Part 1

ID Number:

Answer Sheet (Do Not Detach)

1	2	3	4	5
6	7	8	9	10
11	12	13	14	15
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Do NOT open the test paper until the invigilator announces the start of the test.

Test Instructions

1. **Exam Duration**: The total duration of part 1 is **180 minutes**. Once the exam ends, you must **stop writing immediately** and wait for the test papers to be collected.
2. **Answer Submission**:
   - All answers must be transferred to the corresponding numbered boxes on the **cover page**. **Do not exceed the borders** of the answer area.
   - Only the **uppercase letter** (A, B, C, etc.) of the correct option should be filled in.
   - Even if you mark the correct answer beside the question, you will **NOT** receive any points unless it is copied onto the cover page.
   - If you need to modify an answer, **draw a single line through the original answer** and write the new one in the designated box (e.g., ~~ABC~~ AB).

Section A: Oceans and the earth systems

The South China Sea is a geologically dynamic and ecologically diverse marginal sea located at the intersection of multiple tectonic plates and climatic regimes. Bordered by the Asian continent to the north and west and island arcs to the east and south, it hosts a wide spectrum of marine environments - from shallow continental shelves to deep-sea trenches and mid-ocean basins. As shown in Figure A-1, the topography of the South China Sea reveals a broad continental margin, scattered coral reefs and islands, and a vast abyssal plain reaching depth beyond 4,000 meters.

Marine processes in the South China Sea reflect the complex interactions among the lithosphere, hydrosphere, atmosphere, and biosphere. Figure A-2 illustrates a typical continental margin profile, showing the transition from the coastal plain and shelf to the continental slope, rise, abyssal plain, and submarine canyons. These structural elements control sediment distribution and energy gradients across the seafloor. Particularly important are turbidity currents - dense sediment-laden flows that move rapidly downslope through submarine canyons, often triggered by storms, earthquakes, or river floods. These flows play a key role in shaping continental slopes and abyssal fans, and have caused multiple underwater cable breakages in recent decades.

Figure A-3 shows the vertical stratification of oceanic water masses and benthic zones. The open sea is broadly defined as the ocean depth where light begins to fade, at an approximate depth of 200 m or the point of transition from continental shelves to continental slopes. Conditions within the deep sea are a combination of low temperatures, darkness, and high pressure. The deep sea is considered the least explored Earth biome as the extreme conditions make the environment difficult to access and explore. Light penetration, biological activity, temperature, and pressure vary significantly with depth, affecting both the pelagic ecosystems and seafloor processes.

In this section, you will explore how topography, sediment dynamics, and water depth interact to create different depositional and ecological environments across the South China Sea.

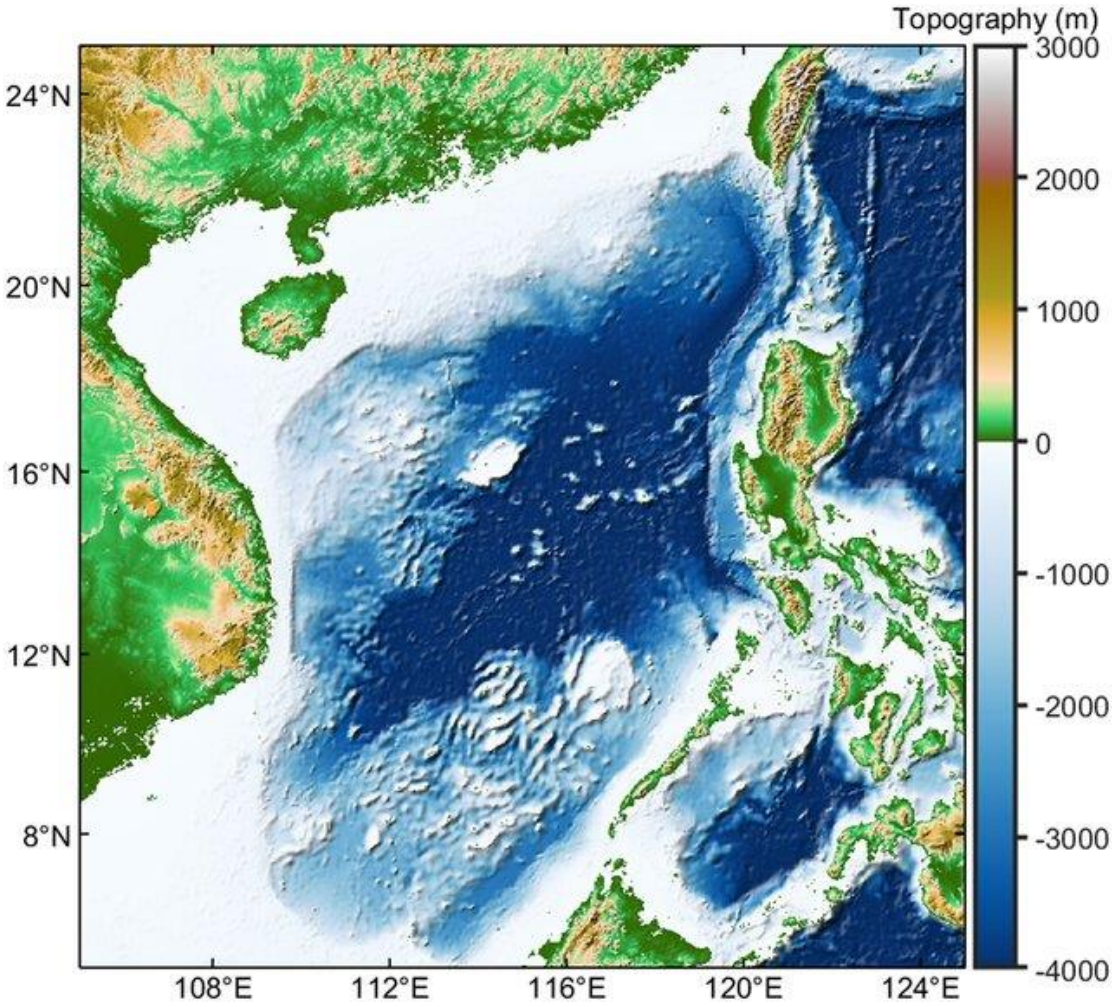


Figure A-1 Bathymetric (depth) map of South China Sea (Yuan et al., 2024, JGR: Oceans)

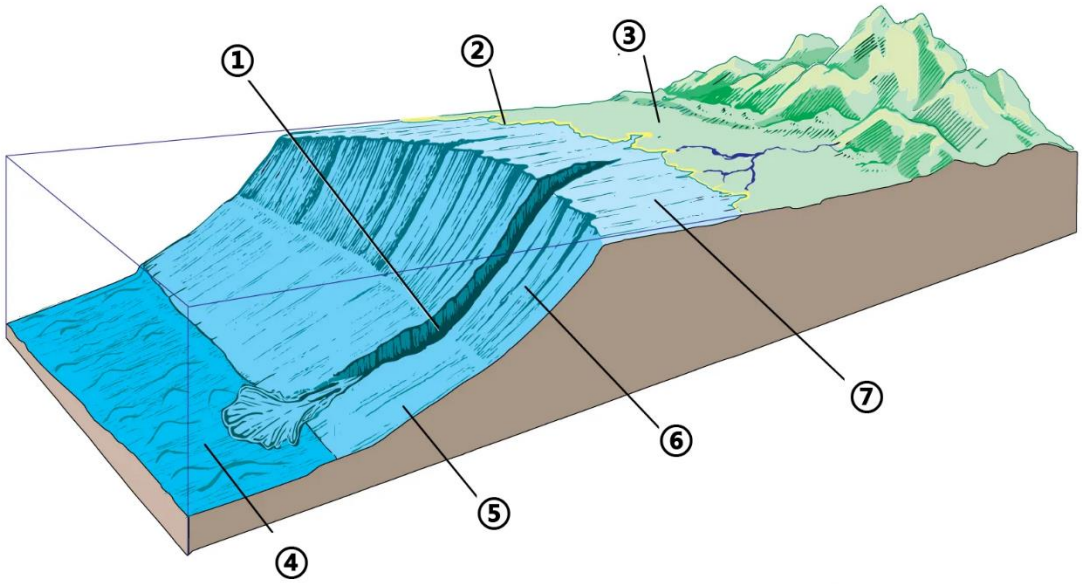


Figure A-2 A continental margin

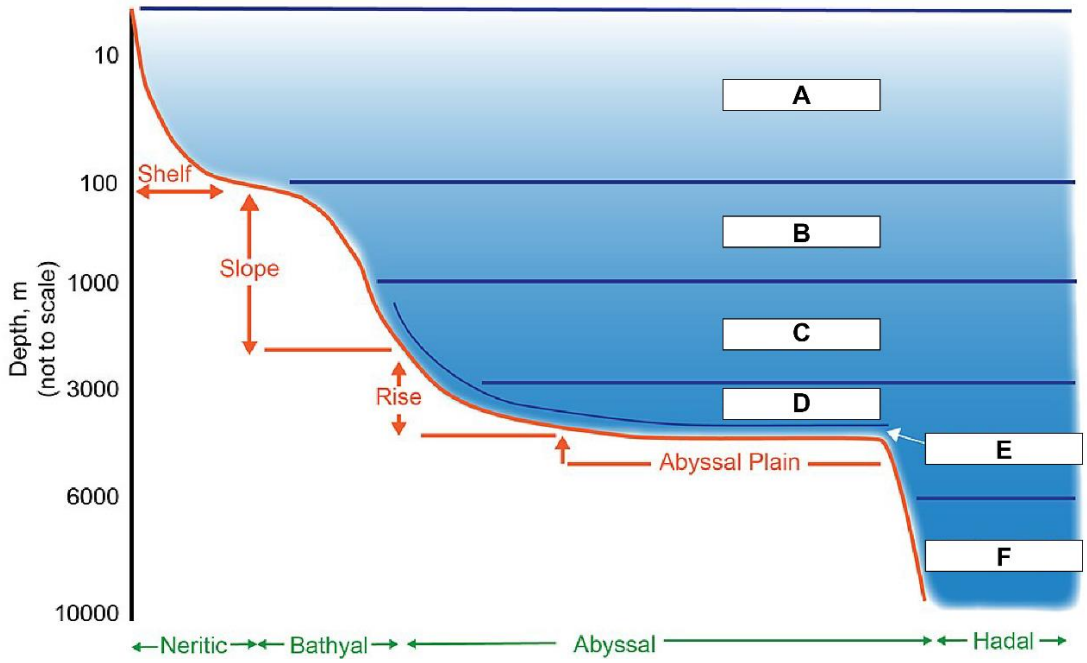


Figure A-3 Schematic representation of pelagic (in the water column) and benthic (seafloor) zones

Question 1:

Figure A-1 shows the bathymetric (depth) features of the South China Sea and its surrounding regions. Several zones are visible, including deep basins, continental slope, and shallow regions dotted with atolls and small islands.

Which of the following regions in Fig. A-1 are most likely to support carbonate sedimentation? (single correct answer)

A. A broad, flat deep-sea basin located in the central part of the map
B. A narrow, steep region sloping down from the continental margin
C. A shallow area in the southern part of the map, scattered with small islands
D. A deep abyssal zone southwest of the main basin

Question 2:

Figure A-2 illustrates the cross-section of a continental margin, showing the transition from coastal plain to continental shelf, slope, rise, and abyssal plain. Which of the following statements about deep-sea sedimentation and turbidity currents in South China Sea are correct? (single correct answer)

A. Turbidity current transport, aeolian dust falling, and ice-rafted detritus deposition are major mechanisms for terrigenous sediments entering the deep sea.
B. Turbidity currents are very rapid (up to tens of meters per second).
C. Sediments in hadal zones (over 6km of depth) are typically composed of fine-grained clay and gravity-flow deposits such as turbidites.
D. Coarse-grained siliciclastic sediments are not present in deep oceans.

Question 3:

Which earth systems may interact in the formation of sedimentary rocks such as limestone, chalk, and chert on the continental shelf? (single correct answer)

A. Only the Geosphere and Hydrosphere.
B. Only the Hydrosphere and Biosphere.
C. Only the Biosphere and Geosphere.
D. Only the Hydrosphere, Atmosphere, and Biosphere.
E. Only the Hydrosphere, Geosphere, and Biosphere.
F. The Atmosphere, Hydrosphere, Biosphere, and Geosphere.

Question 4:
Which earth systems may interact in the formation of sedimentary rocks such as clay and chert on the Abyssal Plain? (single correct answer)
A. Only the Geosphere and Hydrosphere.
B. Only the Hydrosphere and Biosphere.
C. Only the Biosphere and Geosphere.
D. Only the Hydrosphere, Atmosphere, and Biosphere.
E. Only the Hydrosphere, Geosphere, and Biosphere.
F. The Atmosphere, Hydrosphere, Biosphere, and Geosphere.

Question 5:
Which Earth systems interact least with the oceanic trenches? (single correct answer)
A. The Geosphere and Hydrosphere.
B. The Atmosphere and Biosphere.
C. The Biosphere and Geosphere.
D. The Hydrosphere, Atmosphere, and Biosphere.
E. The Hydrosphere, Geosphere, and Biosphere.
F. The Atmosphere, Hydrosphere, Biosphere, and Geosphere.

Question 6:
Which of the following zone in Figure A-2 is most likely to serve as an initiation point for turbidity currents? (single correct answer)
A. Zone ④
B. Zone ⑤
C. Zone ⑥
D. Zone ⑦

Question 7:
Which of the following processes or characteristics are commonly associated with sedimentation in Zone ②? (multiple correct answers)
A. Submarine debris flow accumulation forming thick graded beds
B. Dominance of calcite compensation depth (CCD) in controlling sediment preservation
C. Active bioturbation caused by burrowing organisms such as worms and crabs
D. Seasonal shifts in river plume dynamics affecting sediment supply and composition

Question 8:
Which of the following zones in Figure A-3 exhibits the highest level of biological

productivity? (single correct answer)

A. Zone A
B. Zone B
C. Zone D
D. Zone E

Question 9:

Figure A-3 includes Zone F, which corresponds to the hadal zone—the deepest layer of the ocean found within oceanic trenches. These environments are typically deeper than 6,000 meters and represent some of the most extreme conditions on earth. They are isolated, under immense pressure, and receive minimal organic input from the sea surface. Despite this, recent research has revealed the presence of highly adapted organisms and even microbial ecosystems associated with tectonic or geochemical processes.

Which of the following statements about Zone F (Hadal) is correct? (single correct answer)

A. Zone F supports coral reef ecosystems sustained by photosynthesis.
B. Sedimentation rates are high due to abundant organic production at the surface.
C. Organisms in this zone often rely on sinking organic matter or chemosynthetic energy sources.
D. The zone is characterized by carbonate ooze deposits derived from plankton.

Question 10:

The deep ocean—typically defined as depths below 200 meters—is an environment of extreme and stable conditions. It is characterized by low temperature, high pressure, very little light or complete darkness, and generally slow circulation. Below the thermocline, seawater properties become relatively uniform over large horizontal distances. These conditions influence not only the physical structure of oceanic water masses but also the distribution and adaptability of marine life.

Which of the following statements about deep ocean environments are correct? (multiple correct answers)

A. Salinity varies greatly in deep ocean water due to changing surface input.
B. Phytoplankton and rooted plants cannot survive in the deep ocean.
C. Temperature and density vary rapidly with depth in deep ocean zones.
D. Marine organisms living in the deep ocean are adapted to high hydrostatic pressure.

Section B: Energy and the earth systems

The world's growing energy demands, coupled with the need for sustainable and secure energy supplies, have driven the exploration and development of unconventional oil and gas resources. Unlike conventional hydrocarbons, which are extracted from porous reservoirs through traditional drilling, unconventional resources—such as shale gas, tight oil, coalbed methane, and gas hydrates—are trapped in low-permeability formations, requiring advanced technologies like hydraulic fracturing and horizontal drilling for extraction.

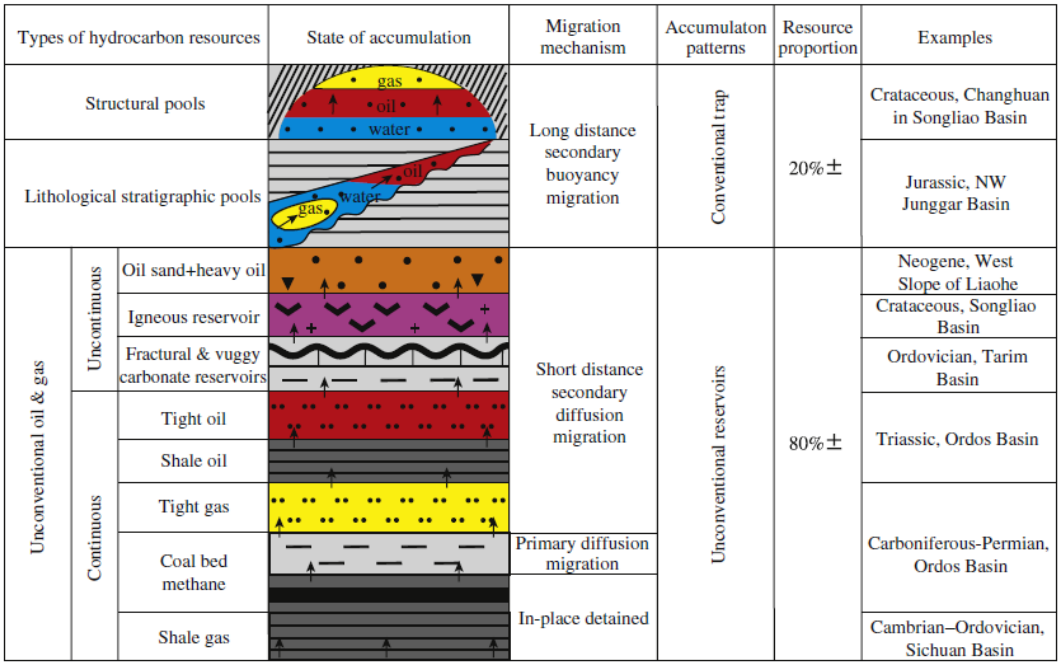


Figure B-1 Hydrocarbon resource types and accumulation patterns (Zou et al, 2013)

Question 11:

Which of the following descriptions correctly differentiate unconventional oil and gas from conventional oil and gas? (multiple correct answers)

A. Unconventional oil and gas reservoirs require higher hydrodynamic conditions for formation.
B. Conventional oil and gas reservoirs often have distinct boundaries.
C. Unconventional reservoirs are more abundant than conventional oil and gas.
D. Unconventional oil and gas are more closely related to tectonic activities.
E. Conventional reservoirs primarily store natural gas, while unconventional reservoirs primarily store oil.

Question 12:

Oil and natural gas are called "fossil fuels" because they originate from the remains of organisms that lived hundreds of millions of years ago. Under specific geological conditions, this organic matter undergoes long-term transformation, eventually forming the energy sources we use today.

Which of the following statements about the organic sources of oil and gas are correct? (multiple correct answers)

A. Primarily formed from the burial of ancient marine plankton and algal remains.

B. Primarily formed from the burial of large animal remains such as dinosaurs.
C. The lignin of terrestrial higher plants is the main source of petroleum.
D. Must be preserved in an oxygen-deprived (reducing) environment to eventually transform into oil and gas.
E. Carbon-rich gases from volcanic eruptions can directly condense into oil.
F. Organic remains from freshwater lakes can also form oil and gas resources.

Question 13:

Compared to conventional reservoirs, shale gas reservoirs exhibit lower permeability but can store substantial amounts of gas. For example, the Sichuan Basin in China has proven shale gas reserves exceeding 1 trillion cubic meters.

Why can shale store such large amounts of gas? (single correct answer)

A. Shale formations with intense tectonic faulting create open fractures that store free gas.
B. Shale formations are always adjacent to conventional reservoirs, allowing gas to migrate and accumulate.
C. Shale has nanoscale pores and contains abundant organic matter, which generates and traps gas through thermal maturation.
D. Methanogenic bacteria in shale convert carbonate minerals into methane.

Question 14:

The Ordos Basin, located in north-central China, is China's second-largest sedimentary basin (after the Tarim Basin) with an area of approximately 370,000 km². It contains abundant unconventional oil and gas resources and serves as a strategic pillar for China's energy security. Tight gas in the Ordos Basin accounts for over half of its total natural gas resources, primarily distributed in Upper Paleozoic sandstones with multiple reservoirs. During exploration of the He 8 Member of the Lower Shihezi Formation, it was observed that this stratigraphic unit exhibits an average sandstone thickness of 20 meters in the Ordos Basin. Logging data indicates that approximately 50% of the sandstone layers contain tight gas, with gas-bearing intervals showing a porosity of 10% and gas saturation of 60%.

Assuming these logging results are representative of the entire sandstone unit and given a gas formation volume factor of 0.007 (ratio of gas volume under reservoir conditions to standard surface conditions), estimate the tight gas resource volume at surface conditions stored in this

reservoir.
Select the closest option. (single correct answer)
A. 2.22×10^{11} m^3
B. 6.39×10^{11} m^3
C. 7.21×10^{12} m^3
D. 3.17×10^{13} m^3
E. 8.88×10^{13} m^3
F. 5.28×10^{14} m^3

Question 15:
Natural gas hydrate (NGH) is another energy source, with estimated reserves roughly twice the total known fossil fuel resources worldwide. However, its extraction technology remains immature and may pose environmental risks, including geological hazards and greenhouse gas leakage.
Which of the following statements about natural gas hydrate are correct? (multiple correct answers)
A. Natural gas hydrate belongs to conventional hydrocarbon reservoirs.
B. Natural gas hydrate belongs to unconventional hydrocarbon reservoirs.
C. The formation of Natural gas hydrate requires the combined action of the hydrosphere, biosphere, and lithosphere.
D. Improper exploitation of Natural gas hydrate may disrupt the stability of only the lithosphere and hydrosphere.
E. The formation of natural gas hydrate requires Earth to be in a long-term ice age.

The extraction of natural gas hydrates first requires dissociation of the hydrate to release free methane. Currently, four main dissociation techniques have been proposed and studied (Fig.B-2). All these techniques work by breaking the phase equilibrium of gas hydrates (Fig.B-3). Figure B-3 shows different principles involved in the dissociation of gas hydrates. These principles are shown in the figure as A, B, C and D.
Please match each dissociation technique ① to ④ with its corresponding working principles A to D.

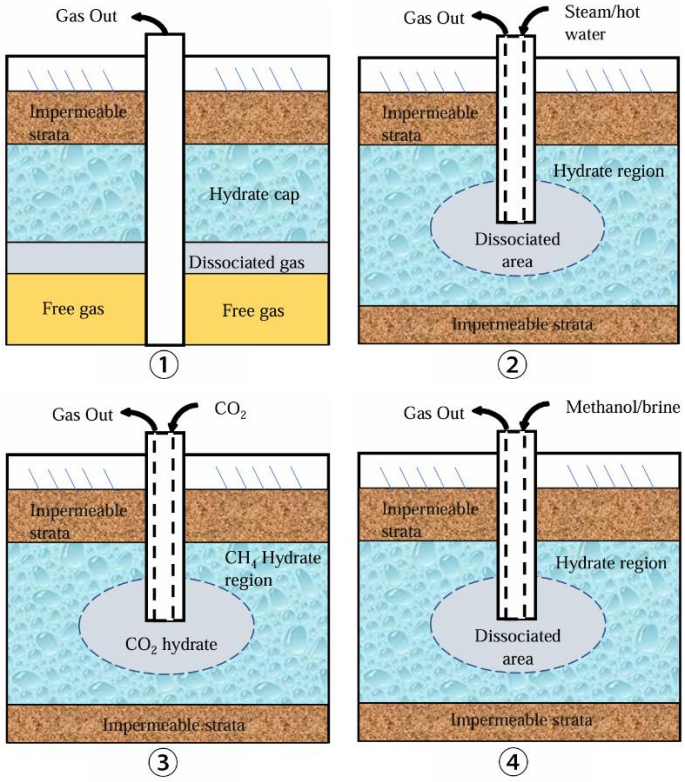


Figure B-2 Natural gas hydrate dissociation techniques (Shaibu et al., 2021)

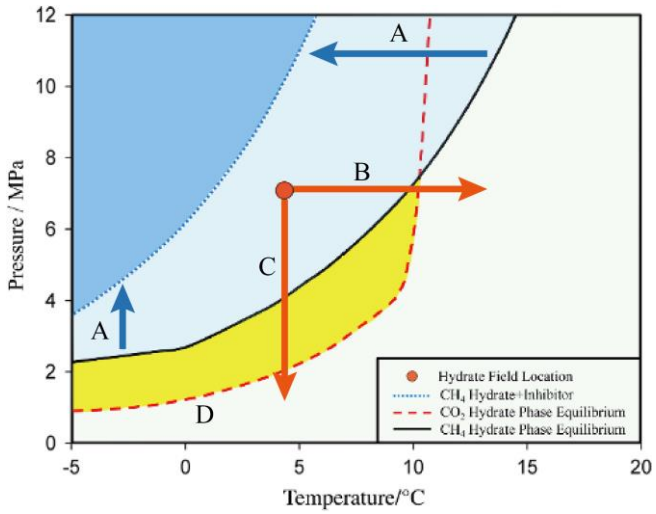


Figure B-3 Schematic diagram of breaking the phase equilibrium of gas hydrate (Yang et al., 2019).

The blue arrows (A) indicate the shift in the stability zone of CH_4 hydrate.

The horizontal orange arrow (B) represents temperature increase.

The vertical orange arrow (C) denotes pressure decrease.

The yellow area with red dashed lines (D) marks the stability field of CO_2 hydrate.

Question 16:

Technique ① corresponds to principle represented by the letter ( ). (single correct answer)

Question 17:
Technique ② corresponds to principle represented by the letter ( ). (single correct answer)
Question 18:
Technique ③ corresponds to principle represented by the letter ( ). (single correct answer)

Question 19:
Technique ④ corresponds to principle represented by the letter ( ). (single correct answer)

Question 20:
Coal bed methane (CBM), commonly referred to as "coal gas," is formed during the coalification process and primarily exists in an adsorbed state within coal seams or coal-bearing strata as an unconventional natural gas, with methane as its main component. The sources of methane include the biogenic decomposition of organic matter in coal and thermal cracking under high temperatures. A stable roof layer (impermeable rock above the coal seam) is crucial for CBM accumulation, as it prevents gas escape and maintains reservoir pressure. Which of the following descriptions of coal bed methane enrichment is correct? (single correct answer)

A. The thicker and deeper the coal seam, within the limits of coal bed methane enrichment, the more favorable it is.
B. Coal bed methane enrichment is solely influenced by the biosphere, whereas the lithosphere's role is limited to gas preservation.
C. Coal seams with sandstone roofs are more favorable for coal bed methane enrichment compared to those with mudstone roofs.
D. Hydrogeological conditions characterized by stagnant groundwater and slow exchange with surface water are unfavorable for coal bed methane enrichment.

Question 21:
In a folded stratigraphic sequence, the strain-neutral surface located at the middle position, where neither elongation nor shortening occurs, is termed the structural neutral surface. The strata above this surface are called the upper neutral surface, whereas those below are referred to as the lower neutral surface (Fig.B-4).

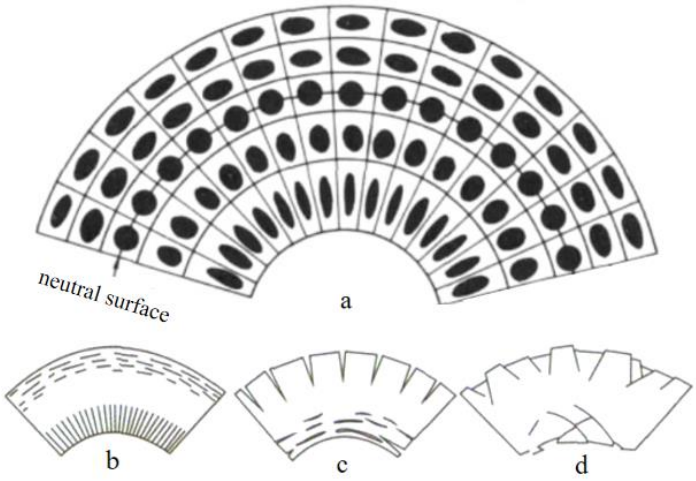


Figure B-4 Characteristics of neutral surface folds (J.G. Ramsay et al., 1987)

a. Pattern of strain distribution; b. Cleavage; c. Tension fractures; d. Shear fractures.

Assuming that Fig.B-4a depicts a thick coal seam, in which parts(s) of this coal seam would gas enrichment most likely occur, potentially forming a gas reservoir? (multiple correct answers)

A. The axial part below the neutral surface of an anticline
B. The axial part above the neutral surface of an anticline
C. The flank part below the neutral surface of an anticline
D. The flank part above the neutral surface of an anticline

Question 22:

Coal is one of the most important fossil fuels in China. Its formation process is relatively complex, as illustrated in the simplified diagram in Fig.B-5.

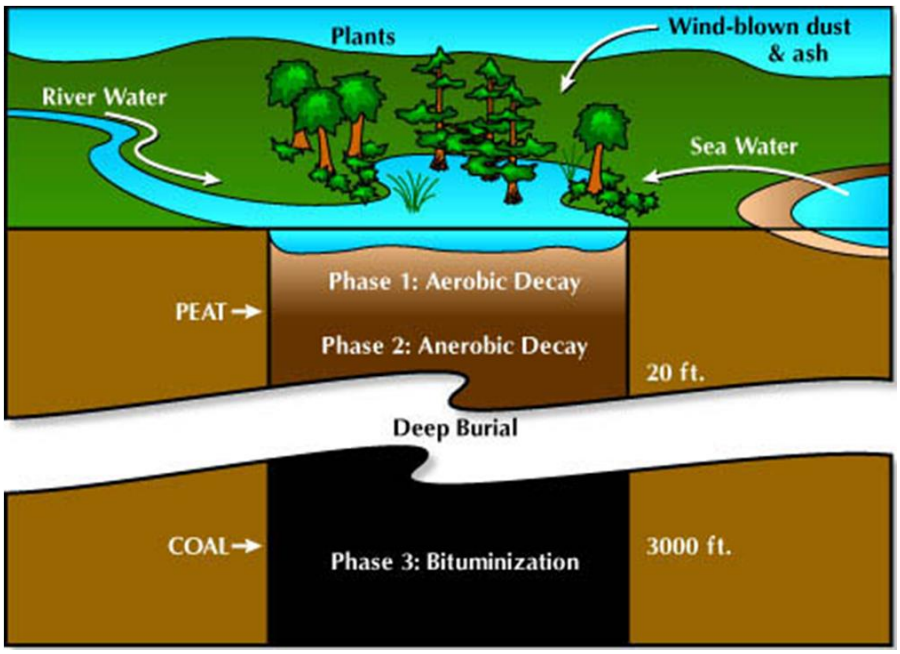


Figure B-5 Schematic diagram of the environment and process of coal formation

Which of the following statements is **incorrect**? (single correct answer)

A. After plants in swamps die, their remains accumulate in the swamp and gradually form peat, which is the precursor to coal.
B. The inorganic components in coal may originate from mud and sand carried by rivers, as well as dust carried by wind.
C. The formation of coal requires the combined interaction of the biosphere, hydrosphere, atmosphere, and lithosphere.
D. Coal can be formed shortly after plant remains undergo both aerobic and anaerobic decomposition.

Question 23:

We have known that the organic components in coal primarily originate from plants. As coal-forming materials are buried deeper, their degree of metamorphism continuously increases.

With increasing coal metamorphism, significant changes occur in the molecular structure of the organic matter in coal, as shown in Fig.B-6.

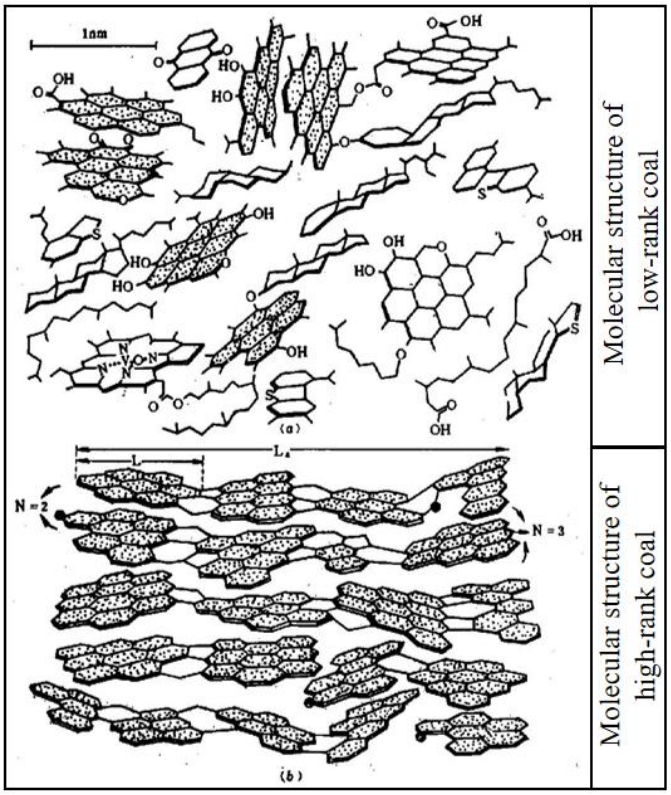


Figure B-6 Schematic representation of molecular structures in coals of different metamorphic grades.

Which of the following changes does **not** occur in the molecular structure of the organic matter in coal as the degree of metamorphism increases? (single correct answer)

A. The side chains of the organic molecules in coal become shorter and fewer in number.
B. The carbon structures become more tightly packed and organized, forming larger and more stable ring systems.
C. The average molecular weight increases, while the molar ratio of carbon to hydrogen atoms decreases.
D. The molecular arrangement gradually becomes more regular and ordered

Question 24:

Epicontinental sea basins were a common type of sedimentary basin in ancient times. These basins had gentle slopes, and during periods of regression, peat swamps could develop extensively. During transgression, large parts of the basin could be rapidly flooded, leading to the cessation of coal formation, and the basin quickly transitioned from a peat swamp to a shallow marine environment (Fig.B-7).

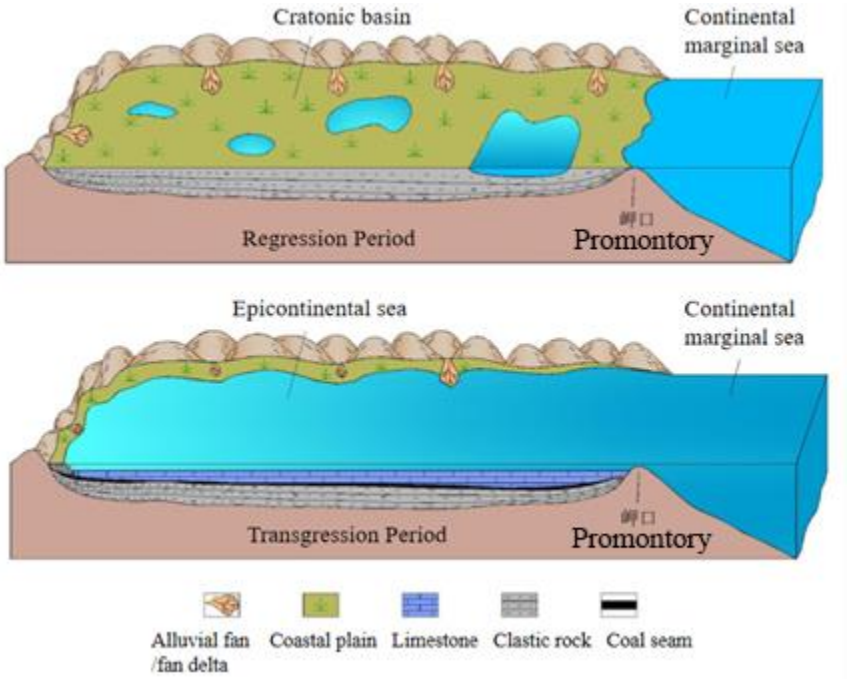


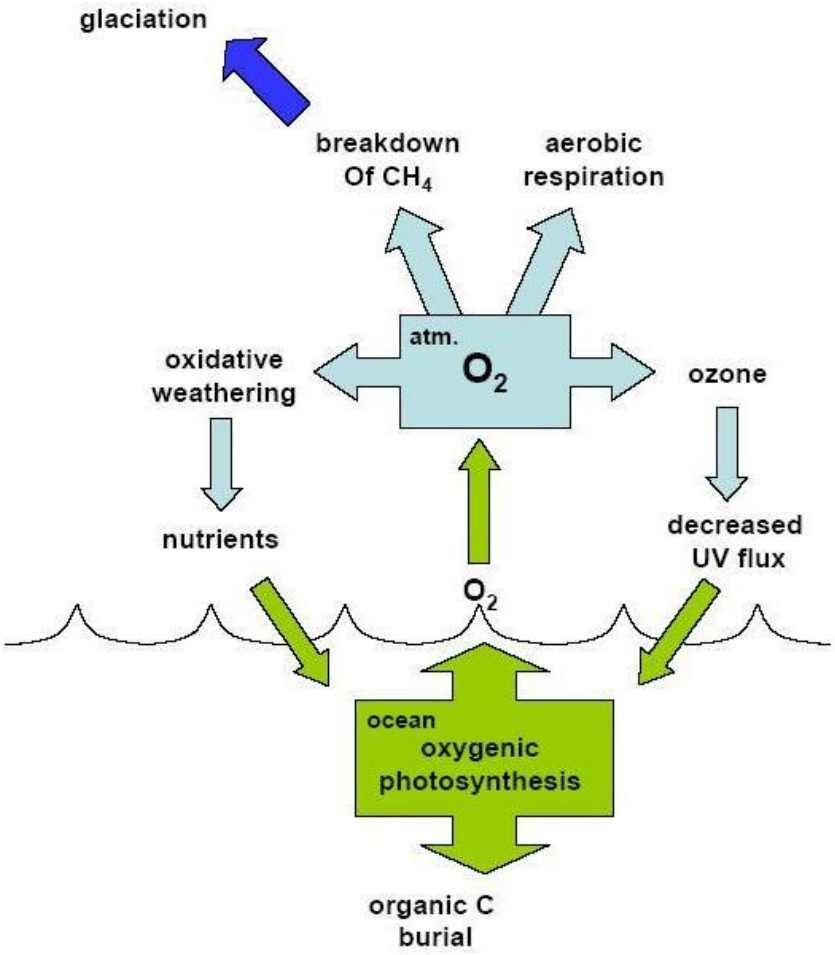
Figure B-7 Schematic diagram of coal formation in the Paleozoic epicontinental sea basin of North China.

Regarding the process of coal formation in the epicontinental sea basin shown in Fig.B-7, which of the following descriptions are correct? (multiple correct answers)

A. The uneven base of the basin during regression results in varying intensities of peat swamp development in different areas.
B. The top interface of the clastic rock and the bottom interface of the coal seam can be considered as isochronous surfaces.
C. The top interface of the coal seam and the bottom interface of the limestone can be considered as isochronous surfaces.
D. Epicontinental seas were widely distributed during the Cambrian period, so this coal-forming model was likely very common at that time.

Section C: The oxygen cycle within the earth systems

Oxygen is the most abundant element in the Earth's crust and the second most abundant element in the Earth's atmosphere. Throughout geological history, the long-term evolution of oxygen (O_2) levels in the atmosphere and oceans has been closely linked to the emergence and development of complex life, and is widely regarded as a major driving force behind animal evolution. The strong electron affinity of oxygen atoms makes it the most common oxidizing agent on Earth. In theory, any substance that can be oxidized by oxygen can participate in the oxygen cycle. Therefore, the oxygen cycle is one of the interfaces connecting the biosphere, atmosphere, hydrosphere, lithosphere, and anthroposphere. The diagram below shows a simplified model of the global oxygen cycle.



Question 25:

In the oxygen cycle, photosynthesis is one of the key processes linking the biosphere and the atmosphere.

Which of the following statements is **not** correct in describing the role of photosynthesis in the oxygen cycle? (single correct answer)

A. Photosynthesis is the primary biological process that releases oxygen into the atmosphere.
B. Terrestrial plants contribute more oxygen to the atmosphere than marine phytoplankton.
C. Without photosynthesis, atmospheric oxygen levels would gradually decline due to

respiration and combustion.

D. Photosynthesis exhibits seasonal fluctuations, with higher oxygen production in summer due to increased sunlight and longer days.
E. In winter, oxygen release is reduced in temperate/boreal ecosystems as deciduous trees lose leaves and ice cover reduces aquatic photosynthesis.

Question 26:

Oxygenic photosynthesis is believed to have evolved prior to atmospheric oxygenation. However, the oxygen produced was rapidly consumed by reductants, preventing its accumulation in the atmosphere.

Which of the following characteristics of early Earth's environment support this hypothesis? (multiple correct answers)

A. Absence of continent exposure.
B. Rapid dissolution of quartz.
C. Consumption by aerobic bacteria.
D. Abundant precipitation of Fe(III) in the early ocean.
E. Strong volcanic outgassing of reducing gases.

Question 27:

In the global oxygen cycle, marine organic carbon serves as the most significant long-term oxygen sink through burial and mineralization processes. In 1934, American oceanographer Alfred C. Redfield collected seawater samples from different depths of the Atlantic, Pacific, and Indian Oceans. He discovered that the molar ratios of carbon, nitrogen, and phosphorus in marine phytoplankton and deep-sea dissolved inorganic substances are statistically constant, approximately C:N:P = 106:16:1. This ratio is known as the famous Redfield ratio. Therefore, the average composition of organic matter in marine phytoplankton can be represented as $(CH_2O)_{106}(NH_3)_{16}H_3PO_4$.

What key insights does the Redfield Ratio provide about marine ecosystems? (multiple correct answers)

A. It reveals a universal stoichiometric balance in marine phytoplankton, reflecting evolutionary optimization for nutrient utilization.
B. The ratio indicates that carbon (C) is typically the limiting nutrient for phytoplankton growth in open oceans.
C. The ratio indicates that nitrogen (N) is typically the limiting nutrient for phytoplankton growth in open oceans.
D. The ratio indicates that phosphorus (P) is typically the limiting nutrient for phytoplankton growth in open oceans.
E. It suggests that deep-ocean dissolved inorganic nutrients maintain the same ratio as living phytoplankton due to remineralization.
F. Deviations from this ratio (e.g., N/P >16) in coastal waters often signal eutrophication or anthropogenic pollution (e.g., excess nitrogen from fertilizers).

Question 28:

Before the evolution of oxygenic photosynthesis, molecular oxygen (O_2) could have been generated on early Earth through which of the following processes? (multiple correct answers)

A. Volcanic outgassing, directly releasing O_2 from magma chambers through oxidation reactions in the mantle.
B. Abiotic oxidation of minerals such as iron ($Fe^{2+} \rightarrow Fe^{3+}$) by water at hydrothermal vents, with O_2 as a byproduct.
C. Photodissociation of water vapor (H_2O) by ultraviolet radiation in the upper atmosphere, releasing free oxygen atoms that combined to form O_2.
D. Cometary impacts delivering ice that sublimated and underwent photochemical reactions in the atmosphere.

Question 29:
At extremely high altitudes, gas molecules can escape Earth's gravity and be lost to space. During the escape, which of the following gas molecules would cause the net oxygenation of the atmosphere? (single correct answer)
A. H_2
B. H_2O
C. He
D. CO_2
E. N_2

Question 30:
Prior to the emergence of eukaryotes, aerobic weathering served as the most significant sink for atmospheric oxygen. During the Precambrian, which of the following minerals/rocks would consume atmospheric O_2 through continental weathering dissolution? (multiple correct answers)
A. Coal
B. Magnetite
C. Pyrite
D. Calcite
E. Quartz

Question 31:
While no definitive evidence of oxygenic photosynthesis has been found on Mars, the planet has developed a highly oxidized environment. This is evidenced by abundant ferric iron (giving Mars its characteristic red hue) and the presence of oxidizing compounds such as hydrogen peroxide (H_2O_2) and perchlorates in both the atmosphere and regolith.
Which of the following processes could have contributed to Mars' oxidized condition? (multiple correct answers)
A. Absence of ultraviolet radiation
B. Surface-atmosphere interactions (e.g., dust storms, impacts, cosmic rays)
C. CO_2 sequestration as carbonate rocks
D. Serpentinization reactions of Martian rocks (a water-rock reaction releasing H_2)
E. Outgassing of basaltic magma

Section D: Origin of life and the earth systems

The origin of life on Earth and the search for extraterrestrial life rank among the most profound scientific challenges of our era.

By investigating ancient geological records, biochemical signatures, and planetary environments—both within and beyond our solar system—scientists strive to decipher life's beginnings and its potential existence elsewhere in the cosmos.

This question set delves into Earth's early life, key abiogenetic processes, and astrobiology principles, synthesizing insights from earth science, chemistry, biology, and astronomy.

Question 32:

One of the oldest known pieces of evidence for life on Earth comes from the 3.7-billion-year-old stromatolite discovered in the Isua supracrustal belt, Greenland (Fig.D-1). A stromatolite is a rock with alternating biological and sedimentary layers.

Based on morphological, geochemical, and isotopic evidence, researchers have identified these stromatolites as products of cyanobacterial activity, supporting their biogenic origin and pushing back the timeline for life's emergence in Earth's history.

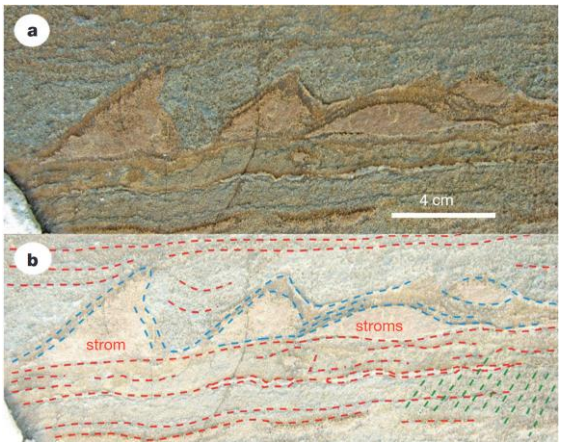


Figure D-1 a) Isua supracrustal belt stromatolite (strom). b) Field sketch of image in a).

Which of the following statements about stromatolites and the Earth system are correct? (multiple correct answers)

A. The stromatolites exhibit conical and domal morphologies with good symmetry, indicating that they were influenced by uniform Earth system processes in lateral directions.
B. Millimeter-scale laminations are preserved at the stromatolite margins, suggesting that the stromatolite growth responded to Earth system processes on decadal to centennial timescales.
C. The mineral composition of stromatolites is primarily derived from terrestrial inputs.
D. The stromatolites exhibit strong interactions with seawater, resulting in chemical element signatures similar to those of seawater.
E. The cessation of stromatolite deposition and their subsequent burial by ordinary sediments reflect changes in the marine environment.
F. Stromatolites are considered biogenic due to the detection of DNA fragments from cyanobacteria within them.

Question 33:

Early Earth's atmosphere lacked free oxygen, yet life emerged. Which of the following statements about the relationship between Earth's emerging life and oxygen are correct? (multiple correct answers)

A. Oxygen is essential for all known biochemical processes.
B. Cyanobacterial photosynthesis released oxygen, transforming the early Earth's atmosphere, hydrosphere, and even lithosphere.
C. The Great Oxygenation Event (~2.4 billion years ago) gradually enriched Earth's atmosphere with oxygen, promoting the evolution of aerobic organisms.
D. The ozone layer provided ultraviolet (UV) protection for the emerging life.

Question 34:

The foundation of life on Earth lies in complex organic molecules, which may have formed spontaneously in primordial environments, acting as the "spark" of life. On early Earth, which of the following environments were likely to produce the earliest complex organic molecules? (multiple correct answers)

A. Mantle
B. Soil
C. Atmosphere
D. Deep-sea hydrothermal vents
E. Terrestrial volcanic vents
F. Meteorite impact craters

Question 35:

The most famous experiment on the origin of organic compounds is the Miller-Urey experiment (1953), conducted by American chemist Stanley Miller and his advisor Harold Urey. They designed a closed glass apparatus to simulate early Earth's atmosphere, containing ammonia (NH_3), methane (CH_4), water vapor (H_2O), and hydrogen (H_2), with circulating water and electrodes (Fig.D-2). After one week, Miller observed the formation of various organic compounds, including amino acids such as glycine ($C_2H_5NO_2$) and alanine.
The experiment demonstrated that life's building blocks could arise from non-living chemical reactions, inspiring further research into abiogenesis.

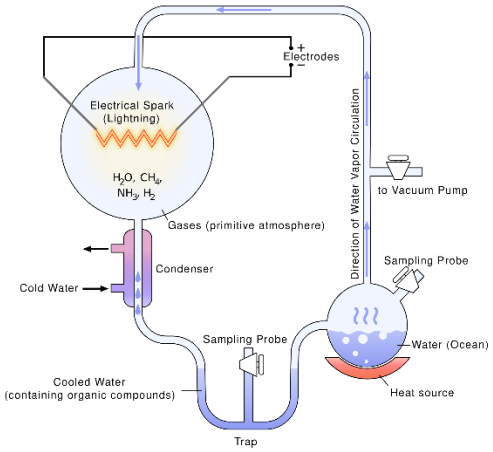


Figure D-2 Schematic diagram of the Miller-Urey experiment

What aspects of the early Earth system did the Miller-Urey experiment simulate? (single correct answer)

A. The earliest life forms originated in the atmosphere.
B. Lightning provided energy for the synthesis of the earliest organic compounds.
C. Terrestrial weathering supplied nutrients (e.g., N, P) to the oceans.
D. Generation of simple lifeforms.

Question 36:

While terrestrial processes like Miller-Urey synthesis and hydrothermal vent chemistry played key roles, extraterrestrial objects may have also contributed to Earth's earliest life. Which of the following statements best describes the potential role of extraterrestrial objects (e.g., comets, meteorites) in the origin of life on early Earth? (single correct answer)

A. Delivered prebiotic organic molecules (e.g., amino acids) through impacts, supplementing Earth's endogenous synthesis.
B. Provided the first living cells via panspermia, making life exclusively extraterrestrial in origin.
C. Catalyzed life's emergence by creating hydrothermal vent systems through impact-induced fracturing.
D. Prevented life's formation by sterilizing Earth's surface through frequent collisions.

Question 37:

The Archean Eon (4.0-2.5 billion years ago) witnessed life's first transformative impacts on our planet. While early microbes were microscopic, their collective metabolic activities irreversibly altered Earth's surface environments through innovative biogeochemical pathways. These changes were so profound that they set the stage for all subsequent evolution.

Which of the following processes could be driven by biological activity during this critical period? (multiple correct answers)

A. Formation of continental shelves through microbially mediated carbonate precipitation (e.g., stromatolite reefs).
B. Accelerated continental weathering induced by terrestrial plants.
C. Global cooling events triggered by photosynthetic drawdown of atmospheric CO_2.
D. Decrease of mafic components in crust due to biological utilization.

Section E: Why has Martian water disappeared?

Mars was once a warm and wet planet during its early formation, with the possibility of life forms existing. However, it has now transformed into a cold and dry world, with no liquid water on its surface and no signs of life. The disappearance of water on Mars is one of the key factors responsible for its transition from a warm and wet environment to a cold and arid one. Martian water escape refers to water molecules breaking free from Mars' gravitational pull and entering space, which is an important mechanism by which Mars loses water.

Question 38:

Which factor did **not** influence the escape of Mars' atmospheric water vapor? (single correct answer)

A. The gravity of Mars
B. Presence of magnetic field
C. Presence of solar wind
D. Presence of solar radiation

Question 39:

Actually, water molecules on the Martian surface, even if they have sufficient escape velocity, may collide with particles in the atmosphere during their upward movement. This may alter their direction and prevent them from escaping. Therefore, scientists introduced the concept of an escape surface, 'exobase'. Below this escape surface height, particle collisions are very frequent, whereas above the escape surface height, particle collisions can be completely ignored.

According to the idea of exobase, which celestial body has the highest altitude of exobase? (single correct answer)

A. Mercury
B. Venus
C. Moon
D. Mars

Question 40:

The concept of exobase represents an idealized scenario. In reality, planetary atmospheric density generally decreases gradually with altitude, leading to a corresponding reduction in collision effects. In recent years, scientists studying atmospheric escape have begun emphasizing the influence of escape probability—the likelihood of particles successfully escaping from a given altitude. For instance, Fig.E-1 illustrates both the altitude-dependent amount of water molecules that reach escape velocity (left) in the Martian atmosphere and their corresponding escape probabilities (right).

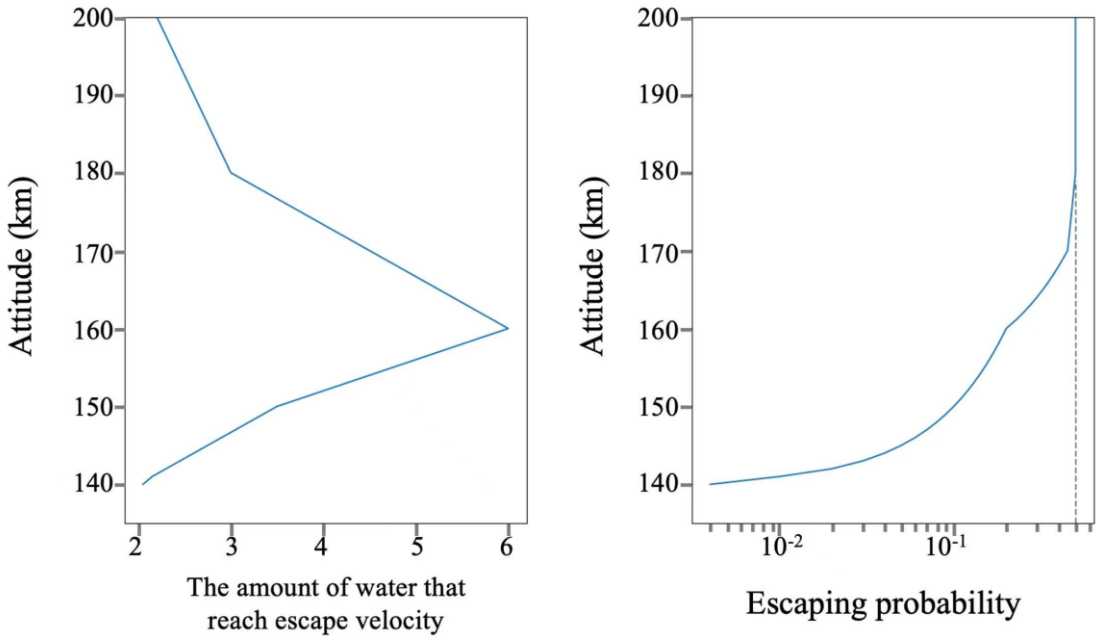


Figure E-1

Based on Fig.E-1, determine at which altitude the total flux of escaping water molecules reaches its maximum? (single correct answer)

A. 150 km
B. 160 km
C. 170 km
D. 180 km

Section F: From swimming to crawling

From water to land is a key step during vertebrate evolution. To adapt to the land environment, vertebrates have four limbs to lift up their body and walk around the land, lungs to breathe, and skin keratinized to keep water. They further evolved into amphibians, reptiles, dinosaurs, birds, mammals, etc.

Question 41:

The iconic *Ichthyostega* is known as the first land vertebrate. Its limb motion estimated by 3D reconstruction (Pierce et al. 2012) is more like paddle swimming, rather than walking, that lift up the body as extant land vertebrates.

Which of the following statements are correct for *Ichthyostega*? (multiple correct answers)

A. *Ichthyostega* lived in water.
B. Limbs of *Ichthyostega* are mainly functional for swimming.
C. *Ichthyostega* can be terrestrial as an extant land vertebrate.
D. *Ichthyostega* was a reptile.

Question 42:

What are the possible reasons for the vertebrates moving to the land? (multiple correct answers)

A. Foraging
B. Refuge
C. Rising sea level
D. Easier reproduction

Question 43:

Recent fossil discoveries further support a close relationship between dinosaurs and birds. Which of the following fossil discoveries would support this? (single correct answer)

A. Feathered dinosaurs
B. Armored dinosaurs
C. Toothless dinosaurs
D. Duck-billed dinosaurs

Question 44:

Non-avian dinosaurs went extinct at the end of the Mesozoic era in the Cretaceous-Paleogene Mass Extinction.

Which of the following lines of evidence support that the extinction event was also caused by an asteroid impact on a shallow marine shelf? (multiple correct answers)

A. Iridium anomaly worldwide
B. Glassy spherules distributed in a bullseye pattern around a gravity anomaly
C. An increase in oceanic biological activity
D. Global tsunami deposits
E. Thick fossiliferous dinosaur beds
F. Dinosaur footprints preserved in ash beds