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
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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.

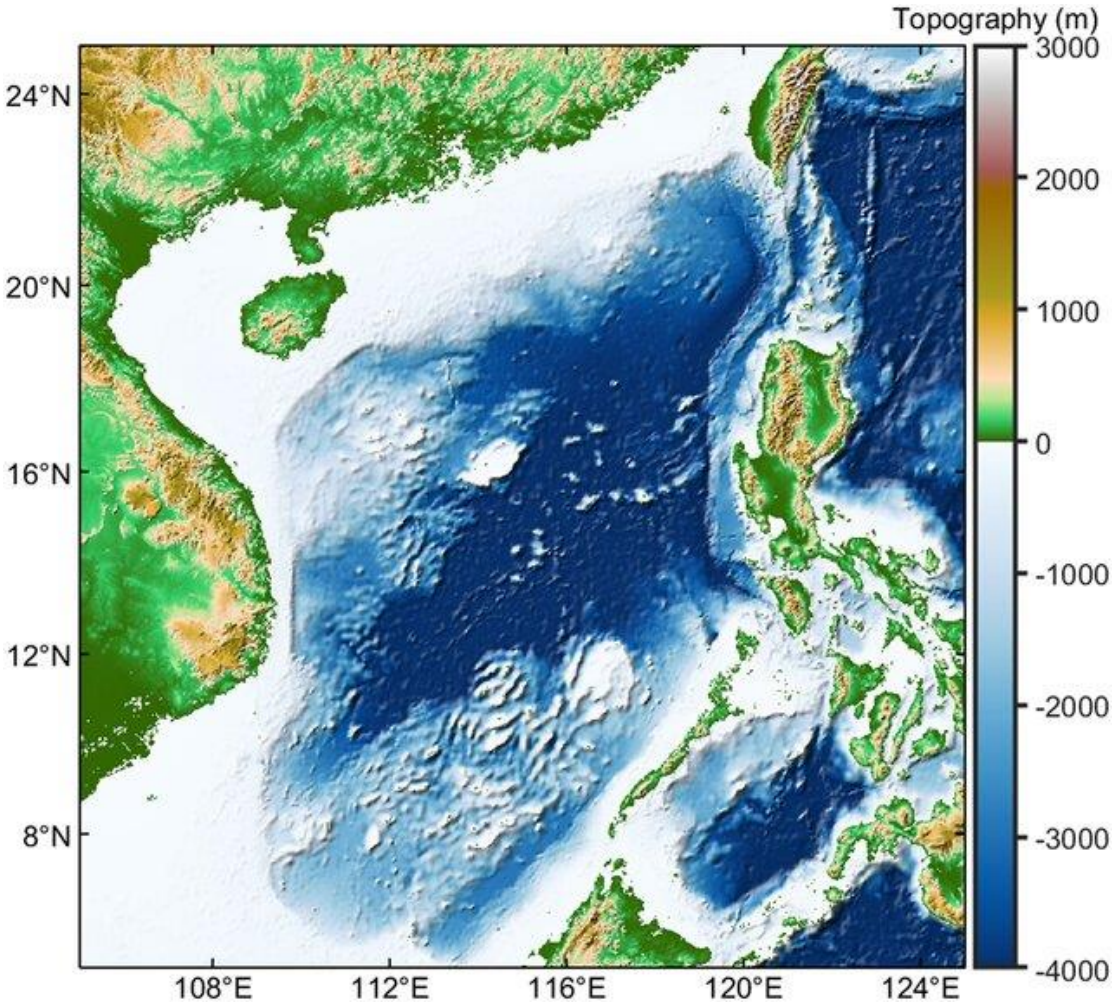


Figure A-1 Bathymetric (depth) map of South China Sea (Yuan et al., 2024, JGR: Oceans)

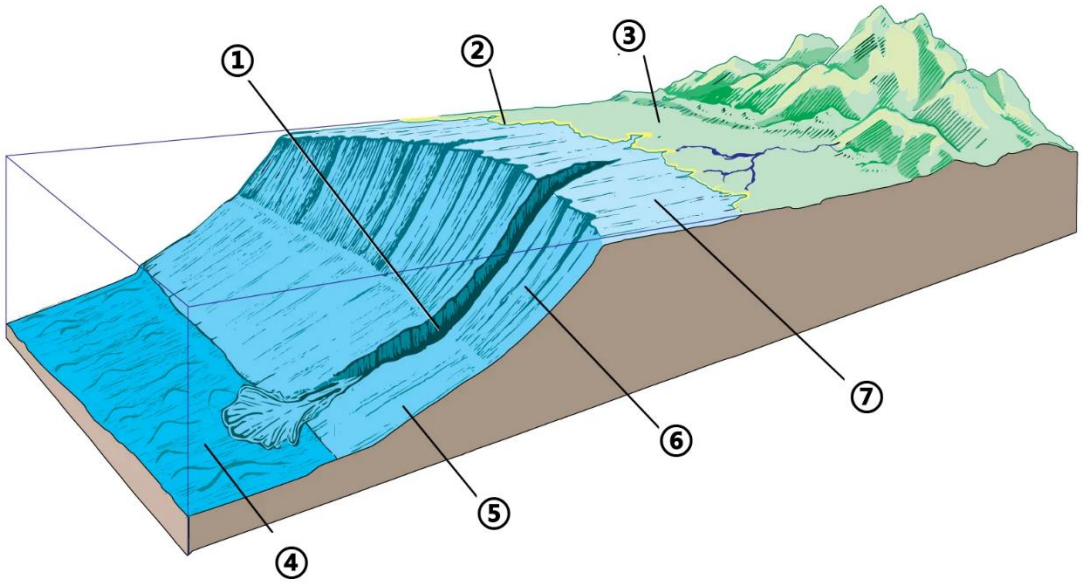


Figure A-2 A continental margin

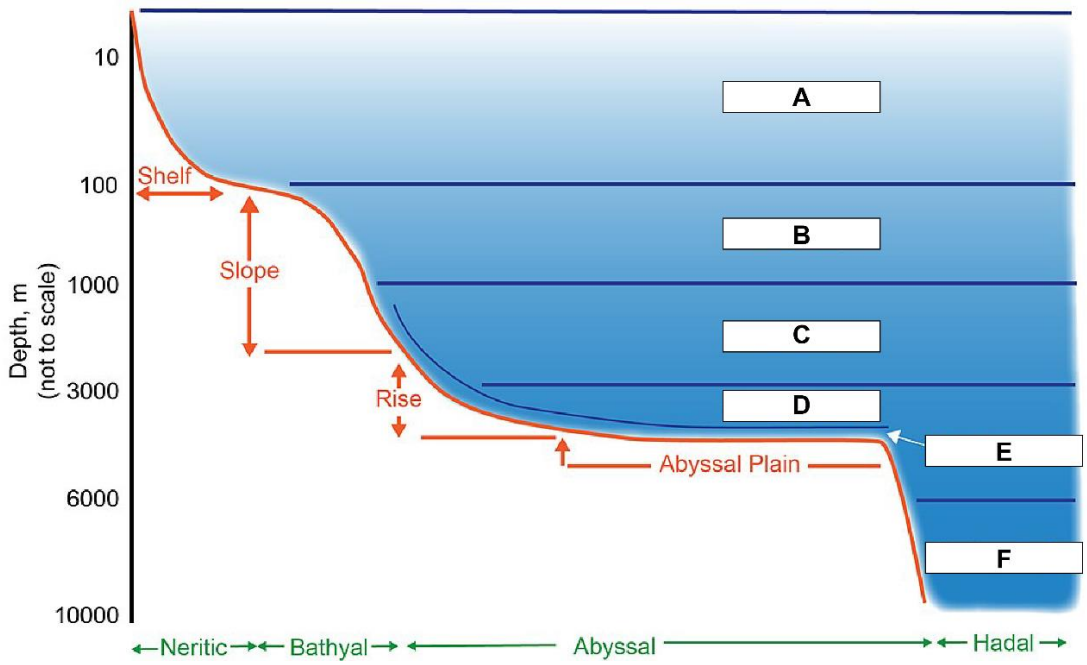


Figure A-3 Schematic representation of pelagic (in the water column) and benthic (seafloor) zones

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.

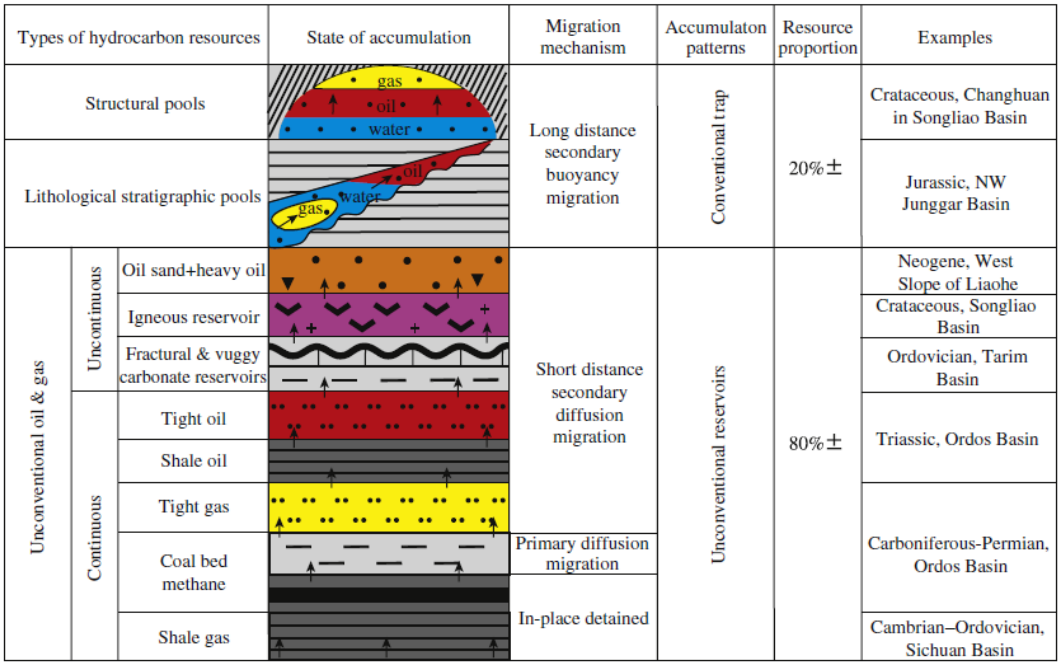


Figure B-1 Hydrocarbon resource types and accumulation patterns (Zou et al, 2013)

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.

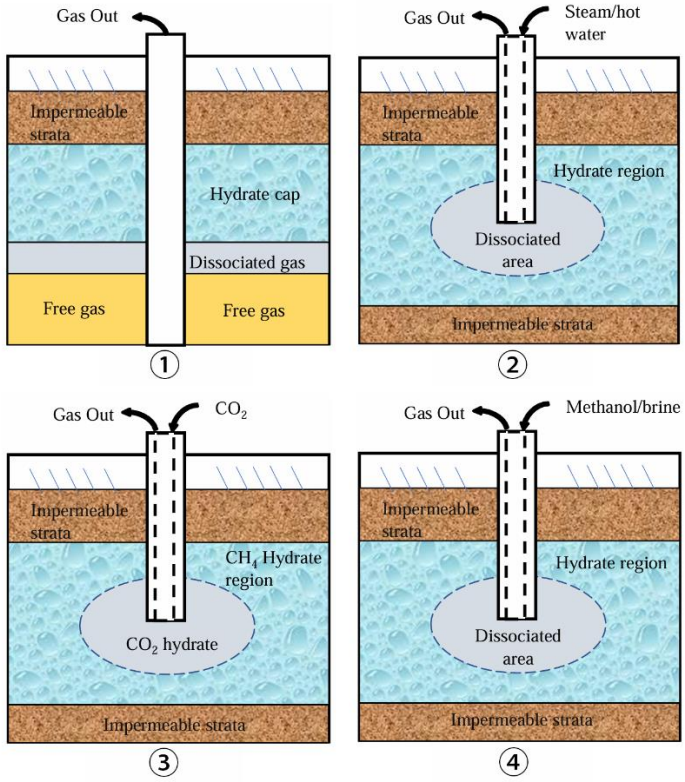


Figure B-2 Natural gas hydrate dissociation techniques (Shaibu et al., 2021)

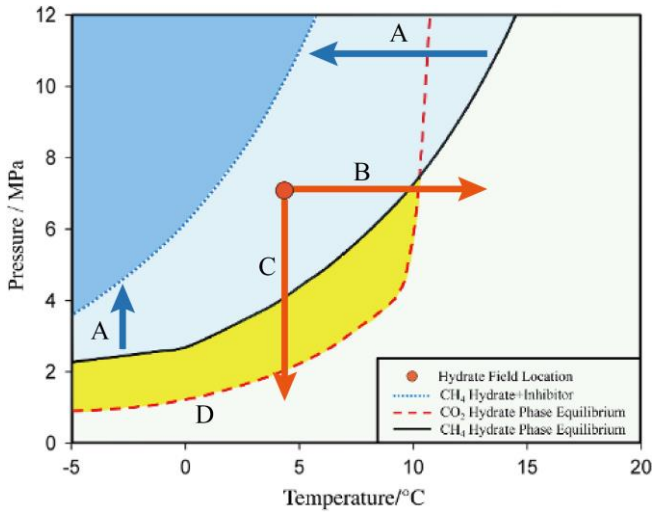


Figure B-3 Schematic diagram of breaking the phase equilibrium of gas hydrate (Yang et al., 2019).

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).

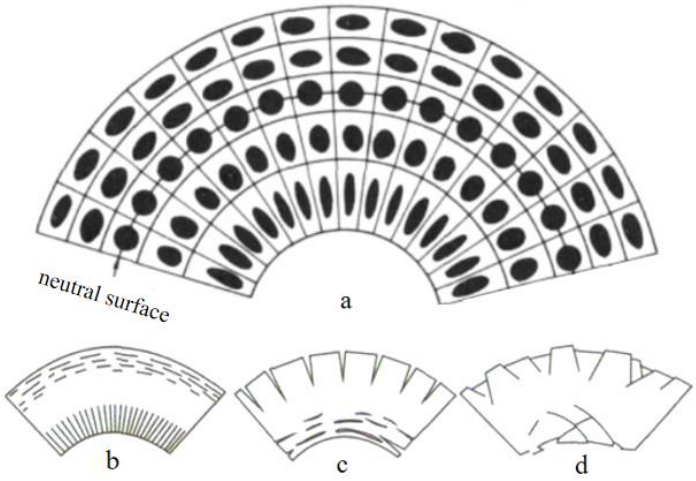


Figure B-4 Characteristics of neutral surface folds (J.G. Ramsay et al., 1987)

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.

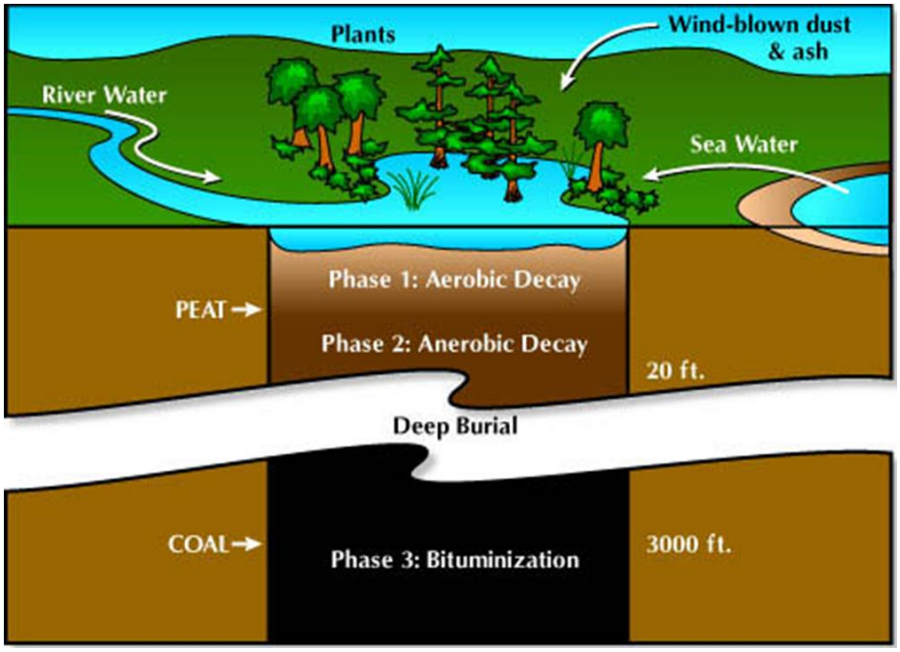


Figure B-5 Schematic diagram of the environment and process of coal formation

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.

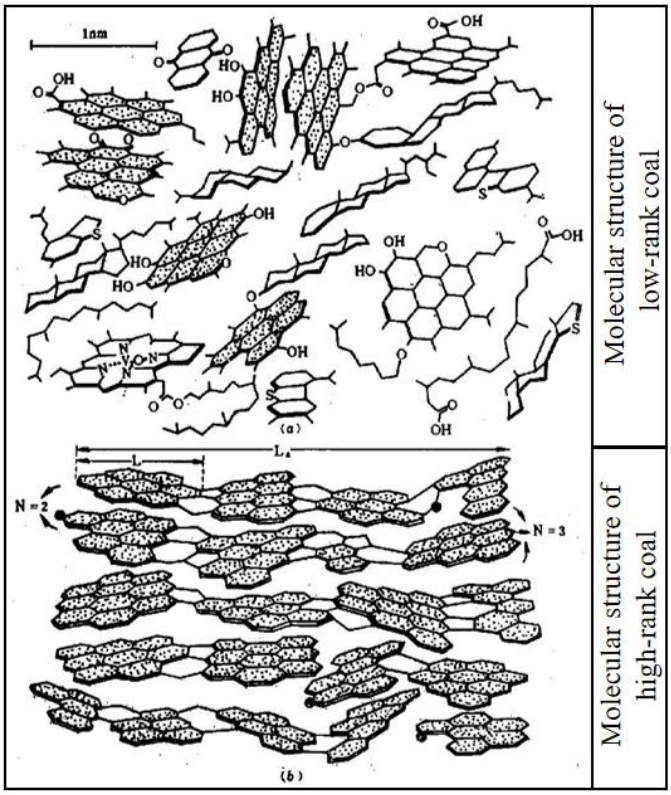


Figure B-6 Schematic representation of molecular structures in coals of different metamorphic grades.

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).

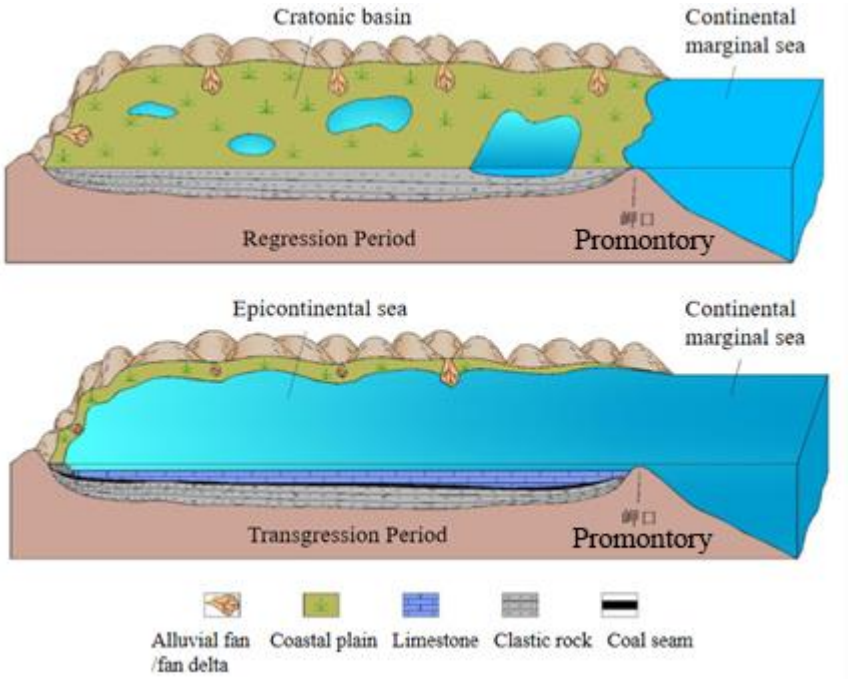


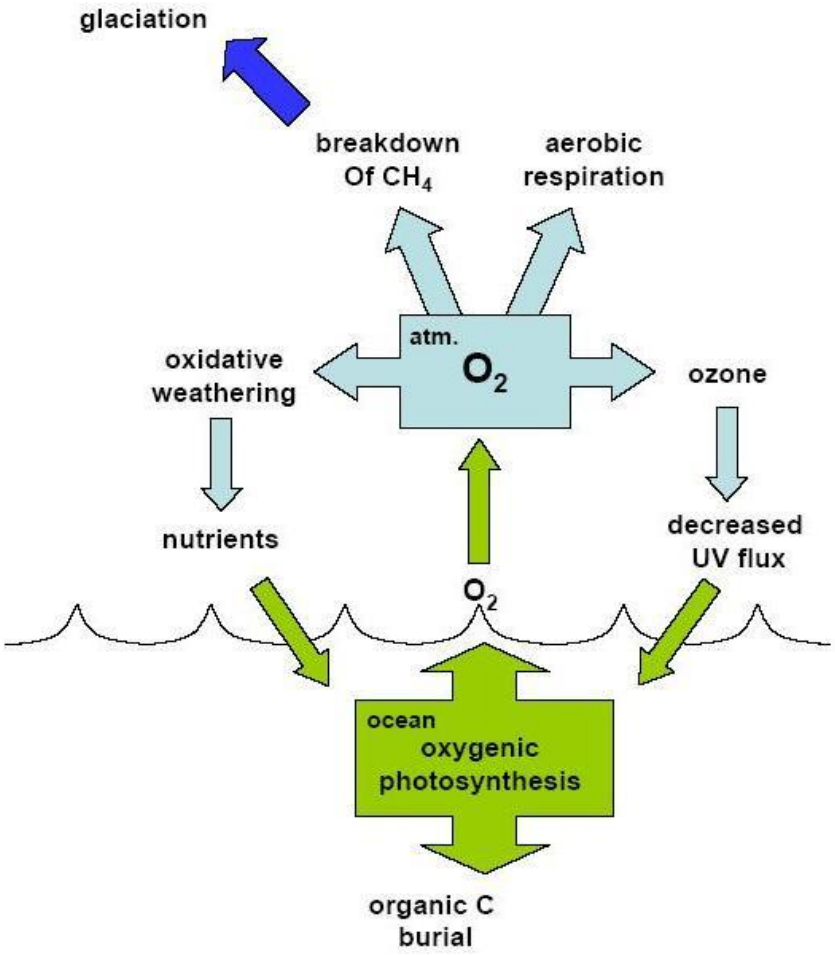
Figure B-7 Schematic diagram of coal formation in the Paleozoic epicontinental sea basin of North China.

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.

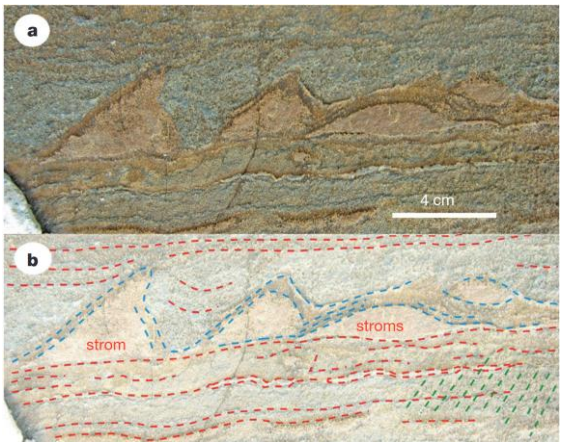


Figure D-1 a) Isua supracrustal belt stromatolite (strom). b) Field sketch of image in a).

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.

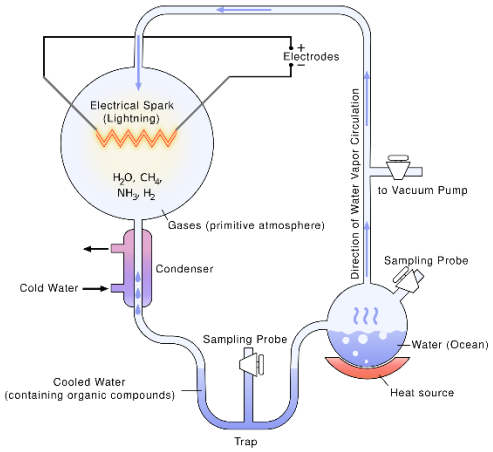


Figure D-2 Schematic diagram of the Miller-Urey experiment

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).

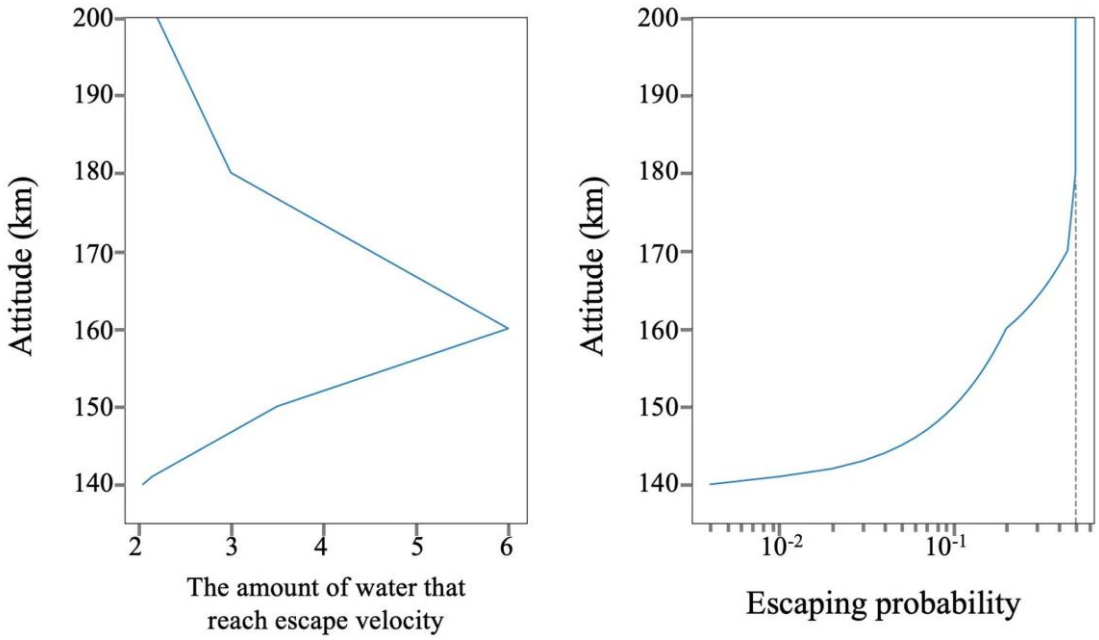


Figure E-1

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

The 18th International Earth Science Olympiad

Individual Theoretical Test Part 2

ID Number:

Answer Sheet (Do Not Detach)

45	46	47	48	49
50	51	52	53	54
55	56	57	58	59
60	61	62	63	64
65	66	67	68	69
70	71	72	73	74
75	76	77	78	79
80	81	82	83	84

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 2 is **150 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 G: Rocks and the earth systems

Question 45:

An ophiolite complex in a mountain belt has been studied by a group of geologists. The sequence includes (from bottom to top): serpentinized peridotite, layered gabbro, a dense zone of vertical mafic dikes, massive and pillow basalts, and radiolarian chert. The complex is tectonically emplaced onto continental crust. Nearby, metamorphosed sediments and blueschist-facies rocks are also observed.

Based on the full rock sequence described above, what can be reasonably inferred about the tectonic history of this region? (multiple correct answers)

A. The area once experienced active seafloor spreading.
B. The sequence likely formed in a subduction zone environment.
C. The ophiolite was uplifted through continental rifting.
D. The oceanic crust was thrust onto the continent during plate convergence.
E. The sequence formed terrestrially and subsequently submerged beneath the ocean.

Question 46:

Geochemical analysis of the ultramafic rocks at the base of an ophiolite suite reveals two important features:

- A high magnesium-to-iron (Mg/Fe) ratio, meaning there is more magnesium relative to iron than in typical mantle rocks.
- Very low concentrations of incompatible elements, such as potassium (K), barium (Ba), and cerium (Ce).

Note:

- During partial melting of the mantle, incompatible elements tend to enter the melt rather than stay in the solid phase.
- Iron (Fe) is more incompatible than magnesium (Mg).

Based on this information, which of the following interpretations is most reasonable? (multiple correct answers)

A. The rocks represent primitive mantle material that has not undergone melting.
B. The rocks were formed from a magma enriched in incompatible elements.
C. The rocks are residues left behind after partial melting of the upper mantle.

D. The rocks are likely associated with the formation of new oceanic crust at a mid-ocean ridge.

Question 47:

Suppose a fossil assemblage from the radiolarian chert layer at the top of the ophiolite is dated to ~160 million years ago (Jurassic).

What geological conclusion is most strongly supported by this data? (multiple correct answers)

A. The ophiolite was formed in or before the Jurassic at a mid-ocean ridge.
B. The entire ophiolite complex was emplaced onto the continent during the Jurassic.
C. The ocean floor above the ophiolite was still active until the end of the Jurassic.
D. The age of radiolarians gives the most recent time of ophiolite formation and not necessarily its emplacement.

Question 48:

Pillow basalts are commonly found at the top of well-preserved ophiolite sequences. These bulbous, rounded volcanic rocks form when magma erupts underwater and cools rapidly. In many pillow basalts, scientists also find evidence of hydrothermal alteration, including the presence of secondary minerals like chlorite and epidote, as well as chemical changes such as increased water content and mobility of certain elements.

Which of the following statements best explain the role of water-rock interaction during and after the formation of pillow basalts? (multiple correct answers)

A. Rapid cooling by seawater causes the outer surface of the lava to solidify, creating the round “pillow” shape.
B. Cold seawater infiltrates hot volcanic rocks, leading to chemical alteration and the formation of new minerals.
C. Water–rock interaction is only possible if the basalts are exposed to the atmosphere, not underwater.
D. Pillow basalts are typically formed in deep continental basins where groundwater replaces seawater.

Section H: The rock telling the story

You are analyzing a wind-blown sedimentary profile exposed in a region of northern China, near the Loess Plateau, an area known for its significant deposits of loess and sand dunes. Loess is a fine-grained, wind-blown deposit.

The profile contains several layers, each reflecting different periods of windy and moisture conditions. Your goal is to use the information in the profile to reconstruct the paleoclimate and environmental conditions at the time of deposition.

Question 49:

You are analyzing the lowermost layer of the wind-blown sediment profile. This layer consists of well-sorted, fine-grained sand with cross-bedding and well-rounded grains, indicating long-distance transportation. Overlying this layer is a thin loess layer containing fine particles, including silt and clay.

What does this suggest about the environmental conditions during the time of deposition? (single correct answer)

A. The region experienced strong winds with dry conditions during the deposition of sand, followed by a change in conditions that allowed for the deposition of loess
B. The region was humid with consistent rainfall, leading to the deposition of both sand and loess
C. The region was subject to tectonic instability, which caused both wind erosion and deposition of finer particles
D. The region was constantly cold with little to no moisture, which prevented the formation of loess

Question 50:

A middle layer in the profile consists of fine silt, with some layers showing calcareous cementation and evidence of bioturbation (plant root traces).

What can be inferred about the past environmental conditions? (single correct answer)

A. The region was consistently humid with frequent rainfall and plant growth.
B. The region was semi-arid, with periodic wet conditions allowing for soil formation and biological activity.
C. The region had stable, dry conditions, allowing only wind-driven deposition of fine particles.
D. The region was subject to frequent glaciation, which prevented the establishment of vegetation.

Question 51:

In the upper part of the profile, you find a transition from fine loess to coarse sand with well-developed cross-bedding. The grain size becomes more heterogeneous with occasional gravel layers.

What does this change suggest about the climate conditions at the time of deposition? (single correct answer)

A. The region transitioned from a humid environment to a more arid one, with decreased wind strength and coarser sediment deposition

B. The region became more humid, with frequent rainfalls leading to coarse sand deposition
C. The region was subject to tectonic uplift, which caused the coarsening of the sediments
D. The region experienced intense seasonal variations, with alternating periods of wet and dry conditions that caused grain size fluctuations

Question 52:

Further up in the profile, you find evidence of biological activity in the form of microfossils and plant root traces. This suggests a change in the environmental conditions.
Which of the following is the most plausible interpretation of these observations? (single correct answer)

A. The region transitioned to a more humid environment, where vegetation could establish and biological activity could occur
B. The region remained arid, but biological activity was still present during rare wet events
C. The region was cold and dry, preventing the establishment of vegetation but allowing for the preservation of microfossils
D. The region was subject to frequent disturbances, such as volcanic eruptions, which allowed plant roots to grow temporarily

Question 53:

Based on your analysis of the entire sediment profile, what can you deduce about the paleoclimate of the region during the time of deposition? (single correct answer)

A. The region experienced constant dry conditions, with little seasonal variation, and mostly wind-blown sand deposition
B. The region underwent alternating wet and dry conditions, with seasonal changes in wind strength and moisture availability
C. The region had a stable humid climate, with consistent rainfall and little wind influence
D. The region was characterized by intense seasonal flooding, which prevented the formation of wind-blown sediments

Section I: The hydrosphere and the earth systems

Students are recommended to read the following questions on the next page for the section FIRST, and then return to this information.

Figure I-1 describes eight landscapes of China marked A-H. China spans nearly 5,000 kilometers from west to east and hosts one of the most complex and varied physical geographies on Earth. Its landscape is characterized by a dramatic west-to-east elevation gradient. Towering mountain ranges and high plateaus dominate the western regions, while the terrain steps downward through basins and river valleys into low-lying plains and coastal zones in the east. This topographic structure—often described as "three steps"—is the result of long-term tectonic uplift, erosion, and sedimentary processes.

The westernmost regions consist of high-altitude deserts and enclosed basins (Regions A and B). These areas experience extremely dry conditions, with minimal rainfall and strong winds that shape sand dunes and deposit fine dust. Some of the basins in this zone have no outlet to the ocean; water collects temporarily and evaporates, often leaving behind salt flats or saline lakes.

To the south lies a vast highland plateau (Region C), the highest and largest of its kind on Earth. Its glaciers and snowfields give rise to many of Asia’s great rivers, including the Yangtze, Yellow, Mekong, and Yarlung Tsangpo. These rivers carve deep valleys into the plateau and carry sediment eastward through lower elevation regions. In some of these valleys (Region F), rapid erosion and tectonic uplift combine to produce rugged terrain and chaotic sedimentation patterns.

Moving eastward, a large mid-latitude plateau contains some of the thickest known deposits of wind-blown dust (Region D). This region, influenced by strong winter monsoons, accumulated loess sediments over thousands of years. Farther east, vast alluvial plains and deltas (Regions E and G) have developed at the mouths of major river systems, where sediment is deposited as river velocity decreases upon reaching the coast. These areas are shaped by fluvial, tidal, and wave-driven processes.

In the south and southeast, a subtropical to tropical climate prevails. Here, heavy summer rainfall, warm temperature, and marine influences produce diverse environments, including lowland river valleys, humid coastal plains, and shallow reef-fringed island systems (Region H). In some offshore zones, biological activity such as coral growth contributes directly to sediment formation in the form of carbonate reefs and lagoons.

Throughout these regions, sedimentation patterns are controlled by interactions among the Earth's spheres: atmospheric circulation, water flow, tectonic processes, and biological productivity. By analyzing the topographic map and applying your understanding of Earth system science, you will identify how different environments correspond to specific types of sedimentary processes.

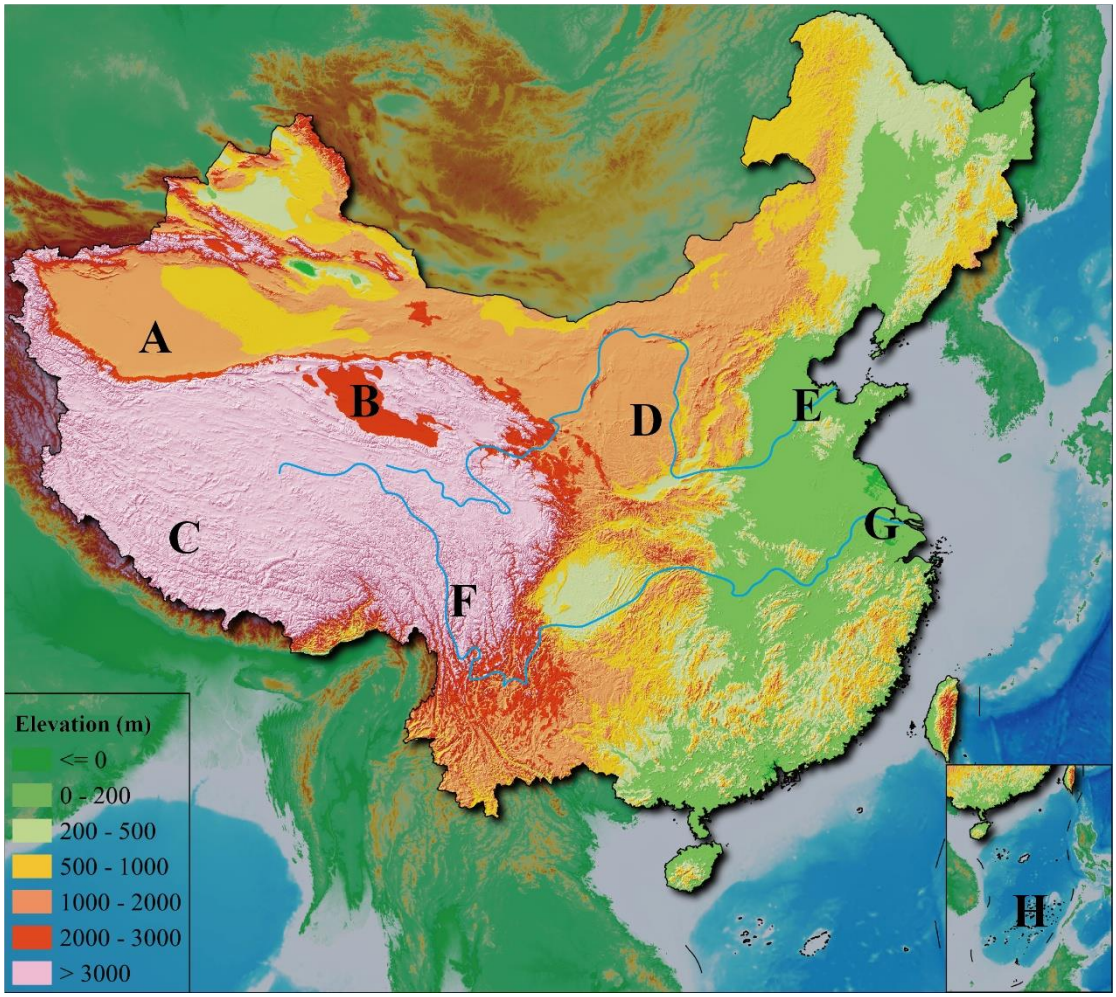


Figure I-1. Topographic Map of China

Question 54:
Which locations on the map show sedimentation patterns that are primarily influenced by interactions between the atmosphere and the lithosphere? (multiple correct answers)
Refer to the labeled map for options A–H.

Question 55:
Which location on the map shows sedimentation that is primarily controlled by the interaction of the hydrosphere, biosphere, and lithosphere? (single correct answer)
Refer to the labeled map for options A–H.

Question 56:
Which of the following locations on the map illustrate sedimentation primarily driven by direct physical interactions between the hydrosphere and the lithosphere — such as fluvial erosion, transport, and deposition — without major contributions from atmospheric or biological processes? (multiple correct answers)
Refer to the labeled map for options A–H.

Question 57:

Sorting describes the distribution of grain sizes in sedimentary deposits. The degree of sorting reflects the energy and consistency of the transport processes.
In which of the following depositional environments are very poorly-sorted sediments most likely to be found? (multiple correct answers)
Refer to the labeled map for options A–H.

Question 58:
Terrigenous saltwater lakes are typically formed under specific environmental conditions.
Based on the map and your understanding of regional geography, which of the following locations are likely to host terrigenous saltwater lakes? (multiple correct answers)
Refer to the labeled map for options A–H.

Question 59:
Lagoons are shallow coastal water bodies partially separated from the open sea, often influenced by both seawater and freshwater input.
Based on your understanding and the map, which location is most likely to support brackish lagoon environments rather than freshwater systems? (single correct answer)
Refer to the labeled map for options A–H.

Question 60:
Karst landscapes are formed by the chemical interaction between water and soluble rocks.
Which of the following bedrock types is most likely to develop karstic features through this process? (single correct answer)

A. Marl
B. Dolomite
C. Schist
D. Granite

Question 61:
Which of the earth systems are interrelated (directly and indirectly) to form karstic landscape? (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 62:
At a site along the middle reaches of the Yellow River, a meandering river segment shows highly curved bends, low gradient, and fine-grained floodplain deposits. This region is characterized by seasonal variation in discharge and clear erosion–deposition patterns.
Which of the following statements about river sinuosity is correct? (single correct answer)

A. River sinuosity refers to the degree of bending in a river, typically expressed as the ratio

of channel length to valley length.

B. Higher sinuosity indicates faster flow velocity.

C. River sinuosity is independent of erosional processes.

D. River sinuosity is solely influenced by topography, not discharge.

Question 63:

In a mountain valley of the eastern Tibetan Plateau, geologists have identified multiple levels of river terraces along the valley sides. These terraces lie above the modern floodplain and show clear stratigraphic separation, with some surfaces capped by loess.

Which of the following statements about river terraces is **not** correct? (single correct answer)

A. River terraces are step-like landforms resulting from fluvial deposition and incision.

B. River terraces can reflect tectonic uplift or climatic change.

C. The formation of river terraces is unrelated to fluvial deposition.

D. A greater number of terrace levels indicates more tectonic uplift events.

Question 64:

Near the First Bend of the Yangtze River, field observations show well-developed point bars on the inner curves of the meander bends, and lateral bars forming along the straight channel segments downstream. Both are visible at low flow stages.

Which of the following statements about fluvial bars is **not** correct? (single correct answer)

A. Both point bars and lateral bars are formed by fluvial deposition.

B. Point bars are located on the inner side of meander bends, whereas lateral bars are found along the channel margins.

C. The grain size of sediments in point bars and lateral bars is identical.

D. The formation of point bars and lateral bars is influenced by river discharge and flow velocity.

Question 65:

Satellite imagery of a lowland river in eastern China reveals curved sandbar structures and shallow point bar growth. Field students are tasked with using geomorphic indicators to determine the direction of water flow in this area.

Which of the following landforms can help indicate river flow direction? (multiple correct answers)

A. Point bars

B. Lateral bars

C. River terraces

D. Floodplains

Question 66:

Across China's diverse terrain, rivers display a wide range of channel patterns. In the central plains, some rivers develop highly sinuous single channels with broad floodplains. In mountainous regions such as the Tianshan or Hengduan Ranges, others form wide, shallow channels that constantly shift due to unstable flow conditions. In certain vegetated lowlands, rivers split into multiple fixed branches separated by muddy islands and levees. These

differences reflect complex interactions among slope, sediment load, discharge variability, and vegetation, shaped by the combined influence of the hydrosphere, lithosphere, and biosphere.

Such channel forms are commonly classified as:

Meandering rivers*: single, curved channels in low-gradient areas.*

Braided rivers*: networks of shifting shallow channels in high-energy environments.*

Anastomosing rivers*: multiple, vegetated channels with long-term stability.*

Which of the following statements about meandering, braided, and anastomosing rivers are correct? (multiple correct answers)

A. Meandering rivers typically develop in areas with gentle slopes and fine sediments.
B. Braided rivers are typically associated with coarse sediment load and large fluctuations in flow, leading to frequent channel rearrangement.
C. Anastomosing rivers are transitional between meandering and braided rivers, with stable channels and minimal branching.
D. The formation of meandering and braided rivers is independent of river discharge and solely controlled by topography.

Section J: The groundwater and the earth systems

Geogenic groundwater contaminants (GGCs) include arsenic (As), fluorine (F), selenium (Se) and uranium (U). The global distribution of GGCs is controlled by basin geology and tectonics, with GGC enrichment in both orogenic systems and cratonic basement rocks (Fig. J-1). This regional distribution is broadly influenced by climate, geomorphology and hydrogeochemical evolution along groundwater flow paths. Volcanic eruptions along volcanic arcs can deposit rhyolitic glass, volcanic ash and metastable, high-temperature minerals that undergo chemical weathering in rapidly (on geological timescales) uplifted mountain chains to become the source of allochthonous sedimentary detritus.

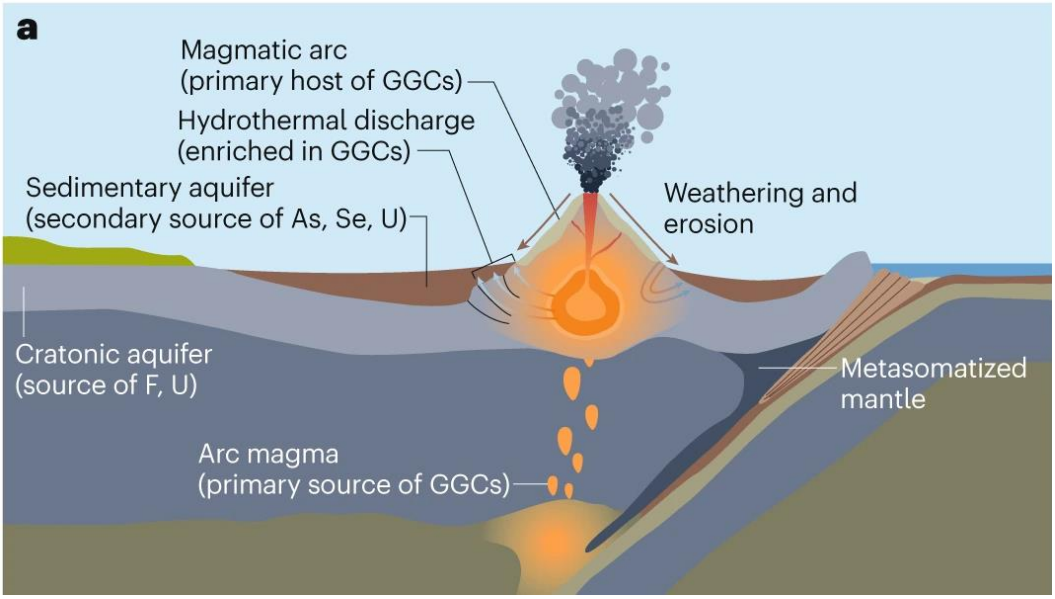


Figure J-1 Not to scale.

Question 67:

Based on the distribution of geological units in Fig. J-1, which of the following pollutant migration pathways best represents the complete geochemical cycle of GGCs? (single correct answer)

A. Magma → hydrothermal activity → sedimentary aquifer
B. Craton basement → weathering → hydrothermal system
C. Metasomatized mantle → sedimentary aquifer → surface runoff
D. Volcanic ash deposits → erosion → deposition

Question 68:

Fig. J-2 shows the global water fluxes (×1000 km^3 per year) in brackets and water storage (×1000 km^3). The upward arrows show annual evaporation from the ocean and terrestrial evapotranspiration. Global groundwater withdrawal is set at 1000 km^3 per year. (Antarctica was not included in the terrestrial water balance.)

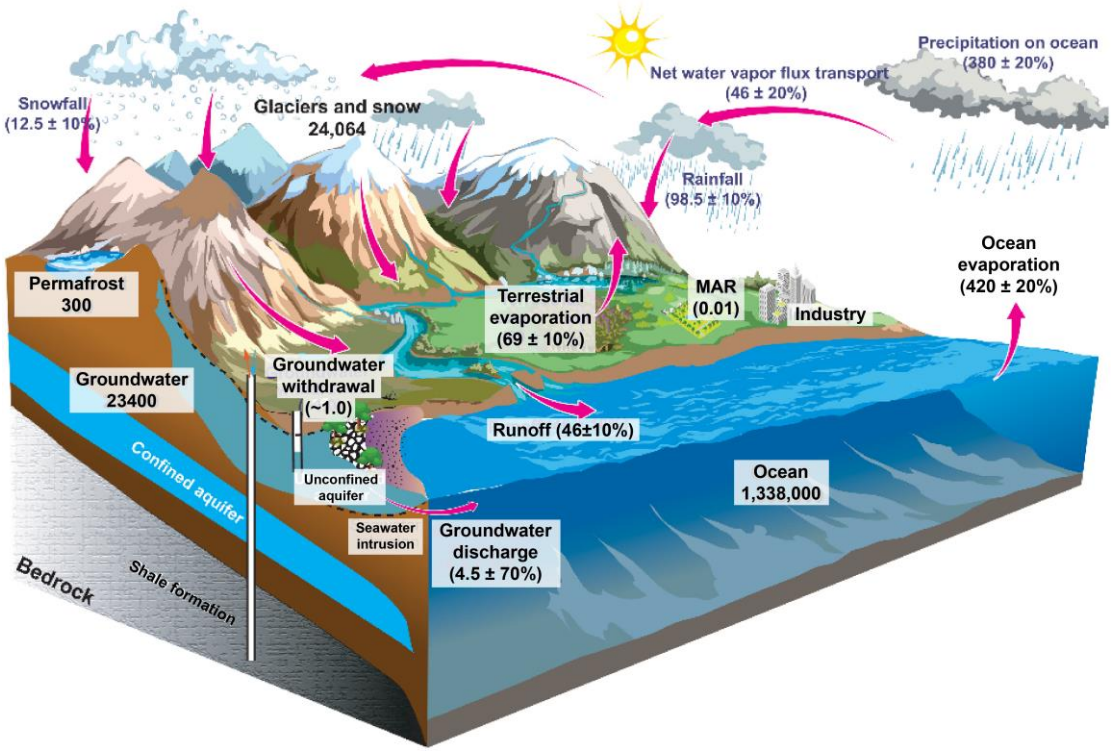


Figure J-2 Diagram showing water fluxes (×1000 km^3 per year; given in parentheses or brackets) and water storage (×1000 km^3) in the different earth systems.

Based on the global water cycle shown in Fig. J-2, calculate the annual water balance of the oceans using the given average annual water volume (unit: 10^3 km^3/year), and select the closest net change and its direction from the options given below. (single correct answer)

A. Gains approximately 10 × 10^3 km^3 of water annually.
B. Gains approximately 20 × 10^3 km^3 of water annually.
C. Loses approximately 20 × 10^3 km^3 of water annually.
D. Loses approximately 35 × 10^3 km^3 of water annually.
E. Maintains a dynamic balance and experiences no net change in water volume annually.
F. Gains approximately 40 × 10^3 km^3 of water annually.

Question 69:

Coastal areas often undergo land reclamation and urbanization. Land reclamation can change groundwater levels and the position of the saltwater-freshwater interface. Urbanization, especially high-rise building construction, involves dewatering and building deep foundations, which affect groundwater flow (Fig. J-3).

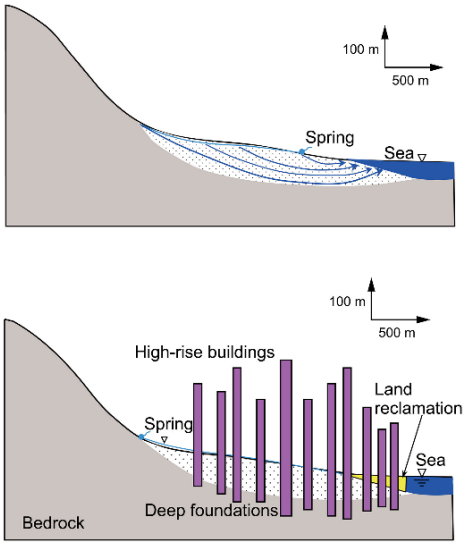


Figure J-3

During urbanization in coastal areas, what is the impact of deep foundations (for high-rise buildings) on groundwater flow? (single correct answer)

A. Promotes horizontal groundwater flow
B. Does not affect groundwater flow
C. Raises the groundwater level
D. Accelerates groundwater flow velocity on average
E. Causes groundwater to flow toward the sea

Section K: The Carbon Cycle and the Earth Systems

Chemical weathering changes the composition of rocks, often transforming them when water interacts with minerals to create various chemical reactions. Chemical weathering is a gradual and ongoing process as the mineralogy of the rock adjusts to the near-surface environment. It changes the mineralogy of the rocks over time that makes them to wear away, dissolve, or disintegrate. The end result is the formation of new materials that contribute to the creation of pores and fissures in the rocks which, in turn, accelerate disintegration. Chemical weathering involves various processes.

Question 70:

Chemical weathering not only contributes to landscape formation but also plays a key role in the material cycles among Earth's subsystems.

Which of the following processes is most effective in removing carbon dioxide from the atmosphere and thereby reducing atmospheric CO_2 levels? (single correct answer)

A. Carbonate weathering
B. Silicate weathering
C. Sulfide oxidation
D. Evaporite dissolution

Question 71:

Which reaction of olivine (Mg_2SiO_4) weathering contributes more to CO_2 sequestration? (single correct answer)

A. $Mg2SiO4 + 4CO2 + 4H2O \rightarrow 2Mg2+ + 4HCO3^- + H4SiO4$
B. $Mg2SiO4 + 2H2O \rightarrow 2Mg(OH)\ 2 + SiO2$
C. $Mg2SiO4 + O2 \rightarrow 2MgO + SiO2 + CO2$
D. $Mg2SiO4 + 2CO2 \rightarrow 2MgCO3 + SiO2$

Question 72:

To mitigate the rising concentration of atmospheric carbon dioxide, Enhanced Rock Weathering (ERW) has been proposed as a carbon removal strategy. It helps address climate change by capturing CO_2 from the atmosphere and storing it in solid mineral forms. One widely used approach involves the application of crushed basalt.

The underlying principle is: (single correct answer)

A. Increasing the availability of calcium and magnesium ions
B. Increasing the availability of sodium and potassium ions
C. Increasing the availability of iron and aluminum oxides
D. Increasing the availability of sulfate and nitrate ions

Question 73:

In the ERW (Enhanced Rock Weathering) process, what factors may enhance the rate of this process? (single correct answer)

A. Increased temperature
B. Increased grain size of crushed rock
C. Decreased precipitation

D. Decreased runoff

Question 74:
Which of the following is **not** a possible consequence of scaling up enhanced weathering for carbon removal? (single correct answer)
A. Limited global reserves of suitable rocks
B. Energy costs of mining and grinding rocks
C. Competition with agricultural land use
D. A possible mass extinction

Question 75:
Due to the ocean's absorption of large amounts of anthropogenic carbon dioxide, significant ocean acidification has occurred since the Industrial Revolution.
How might enhanced weathering indirectly mitigate ocean acidification? (multiple correct answers)
A. By reducing atmospheric CO2 concentrations
B. By releasing cations (e.g., Ca2+, Mg2+) into rivers
C. By increasing oceanic dissolved oxygen levels
D. By adsorbing carbonate ions from seawater

Question 76:
How do human activities disrupt geological-scale carbon cycling? (single correct answer)
A. Mining carbonate rocks for construction reduces the long-term capacity of weathering as a carbon sink
B. Burning fossil fuels releases ancient carbon faster than it can be reabsorbed by weathering processes
C. Acid rain enhances limestone dissolution, temporarily accelerating carbon sequestration
D. Agricultural expansion increases soil erosion, promoting the burial of organic carbon

Question 77:
Changes in various components of the global carbon cycle can shift the Earth's climate system away from its steady state. Because different carbon sources have distinct carbon isotope signatures, marine carbon isotopes can partially record global carbon cycle changes in Earth's history. Note:

$$\delta^{13}C = \left[\frac{\left(\frac{^{13}C}{^{12}C}\right)_{sample}}{\left(\frac{^{13}C}{^{12}C}\right)_{standard}} - 1 \right] \times 1000‰$$

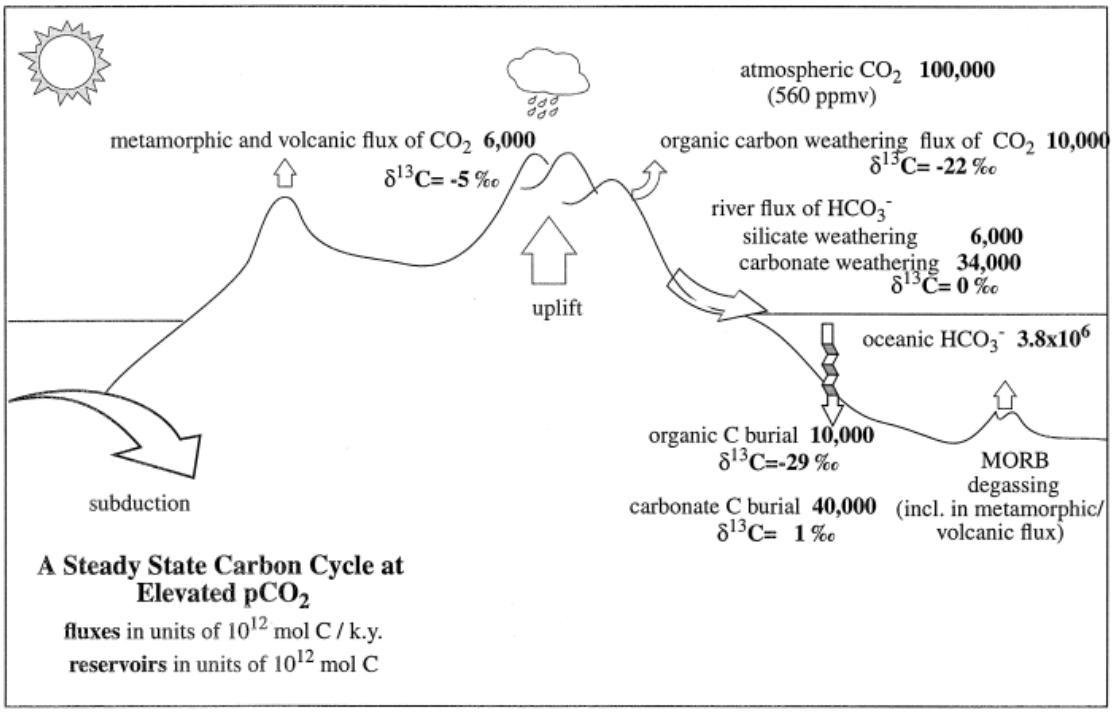


Figure K-1$\delta^{13}C$ values associated with different carbon sources. k.y. = thousand years

Which of the following factors could explain negative excursions in marine $\delta^{13}C$ during Earth's history? (multiple correct answers)

A. Large-scale volcanic activity releases ^{13}C-depleted magmatic CO_2
B. Methane hydrate dissociation emits extremely light carbon
C. Expansion of terrestrial vegetation increases soil organic carbon burial
D. Glacial retreat enhances silicate weathering, delivering ^{13}C-enriched material
E. Ocean warming suppresses the biological pump, reducing organic carbon burial

Section L: Carbon cycle in the ocean

The ocean is the Earth's largest active carbon reservoir, regulating atmospheric CO_2 levels through air-sea gas exchange. The CO_2 flux between the ocean and atmosphere depends primarily on seawater temperature (via solubility) and biological processes. Meanwhile, the total dissolved inorganic carbon (DIC) in seawater is governed mainly by physical processes, including ocean circulation and the hydrological cycle. Because the concentration of CO_2 in the atmosphere has increased through human-made CO_2 emissions, the ocean has taken up an increasing amount of CO_2 (about 25% of the emissions).

Marine phytoplankton consume CO_2 through photosynthesis, driving a mechanism known as the *biological pump*. This process facilitates the ocean's absorption of over 10^{11} kg of carbon from the atmosphere daily. However, this carbon does not directly reach the deep ocean. Instead, it fuels metabolic activities of consumers and decomposers in surface waters, while particulate organic carbon undergoes gradual sinking before long-term sequestration in the deep sea. The biological carbon pump annually supplies $5\text{-}10 \times 10^{12}$ kg of carbon to the oceans, driving long-term sequestration and providing energy for deep-sea ecosystems.

Question 78:

Fig. L-1 illustrates the process of the biological pump.

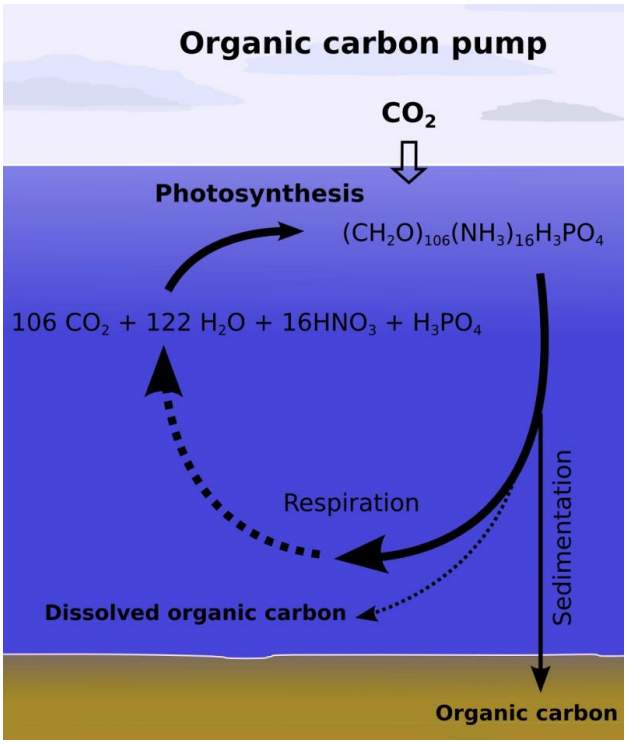


Figure L-1

Regarding the fundamental processes of the marine biological pump, which of the following statements is **not** correct? (single correct answer)

A. Photosynthesis by phytoplankton converts dissolved inorganic carbon (DIC) into particulate organic carbon (POC).

B. The biological pump's carbon export efficiency depends on the sinking rate of POC from the euphotic zone to the deep ocean.

C. Remineralization in the mesopelagic zone (200-1,000 m) reduces the carbon flux reaching the deep ocean. (Remineralization refers to the microbial breakdown of sinking particulate organic carbon (POC) back into dissolved inorganic carbon (DIC) as it descends.)

D. Deep sea sediments permanently sequester biologically exported carbon and no longer participate in the carbon cycle.

Question 79:

Which of the following factors would enhance the efficiency of the biological pump in a given region (i.e., increase the export of carbon to the deep ocean)? (multiple correct answers)

A. Strong upwelling (e.g., off the coast of Peru)

B. Strong stratification in the surface ocean

C. Favorable conditions for the formation of rapidly sinking large particles (e.g., fecal pellets)

D. Extremely high surface temperatures

Question 80:

Fig. L-2 presents global patterns of ocean productivity (as indicated by chlorophyll concentration, Chl), sea surface temperature (SST), surface nitrate concentration (N), and surface phosphate concentration (P).

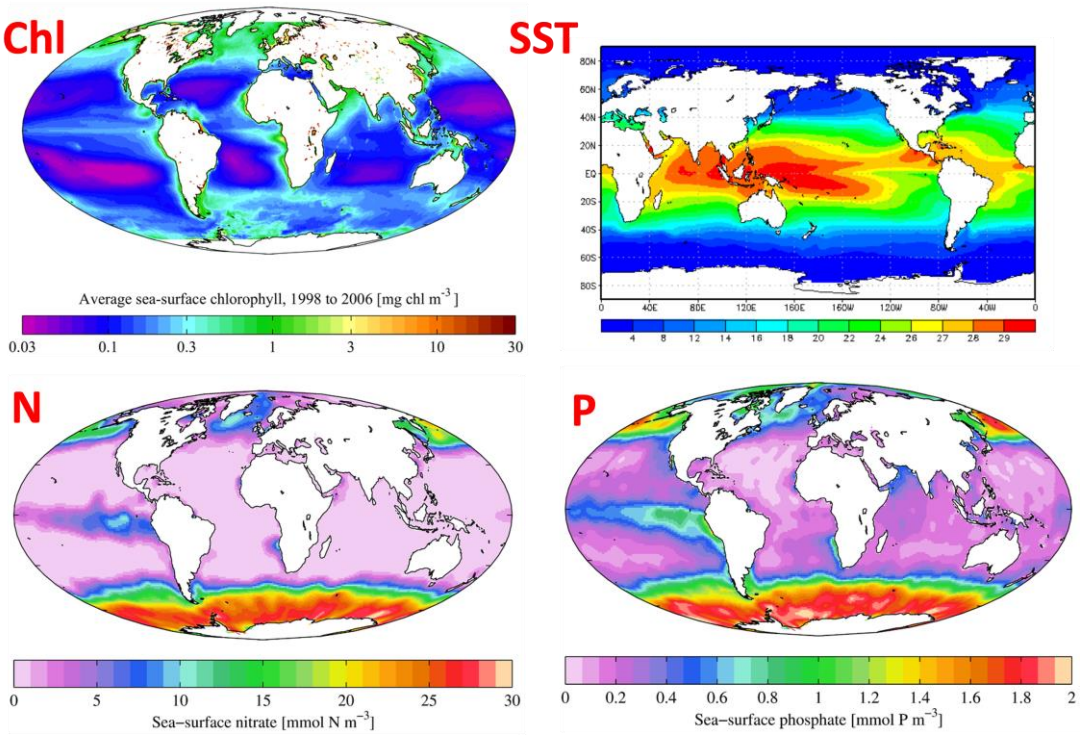


Figure L-2

In the subtropical open ocean regions (typically between 20° and 40° latitude in both hemispheres), the efficiency of the biological pump is generally low. What are the likely reasons for this? (multiple correct answers)

A. Surface nutrients (nitrogen and phosphorus) are extremely scarce, limiting phytoplankton growth (oligotrophic conditions).

B. Sea surface temperatures are too low, inhibiting photosynthesis.
C. The deep euphotic zone allows sinking particles more time to be decomposed before reaching the deep ocean.
D. These regions lack deep oceans and cannot store carbon.

Question 81:
The biological pump is a process whereby CO_2 in the upper ocean is fixed by primary producers and transported to the deep ocean as sinking biogenic particles (particulate organic matter, POM) or as dissolved organic matter (DOM).

How might climate change (e.g., global warming) affect the efficiency of the ocean biological pump? (multiple correct answers)
A. Enhanced ocean stratification reduces nutrient upwelling, potentially lowering productivity in some regions.
B. Ocean acidification promotes phytoplankton calcification, increasing carbon export.
C. Shifts in phytoplankton community composition (e.g., more small-sized algae) may reduce sinking efficiency.
D. Accelerated deep ocean currents enhance carbon release from sediments.
E. Increased glacial meltwater delivers more nutrients, improving the efficiency of the global biological pump.

Question 82:
Which of the following physical factors does **not** control the global pattern of biological pump efficiency? (single correct answer)
A. Wind-driven upwelling that transports deep nutrients to the surface
B. Stratification strength, which regulates nutrient diffusion into the euphotic zone
C. Infrared radiation directly enhances the degradation of particulate organic matter (POM)
D. Ocean circulation patterns that influence nutrient residence time.

Question 83:
Previous studies have shown that the organic matter produced by marine phytoplankton has a statistically consistent atomic C:N:P ratio, known as the Redfield ratio (C:N:P = 106:16:1). If the annual flux of sinking organic phosphorus in a certain region is 0.5 mol $m^{-2} \cdot yr^{-1}$, which of the following statements correctly describe the associated organic matter fluxes? (multiple correct answers)
A. The organic carbon flux is approximately 53 mol $m^{-2} \cdot yr^{-1}$
B. The organic nitrogen flux is 16 mol $m^{-2} \cdot yr^{-1}$
C. For every 1 mol of phosphorus exported, 6.6 mol of CO_2 is consumed
D. If the measured nitrogen flux is 9 mol $m^{-2} \cdot yr^{-1}$, the sinking particles are nitrogen-enriched

Question 84:

Direct injection of CO_2 into the ocean is a potentially effective carbon sequestration strategy. Sequestration would be accomplished by injecting CO_2 stripped from the flue gases of fuel-burning power plants into the bottom waters (~3000 m) of the deep-sea, where the circulation time of the world ocean would prevent CO_2 out-gassing to the atmosphere for centuries, thereby mitigating the peak atmospheric CO_2 levels expected during the next 200-300 years.

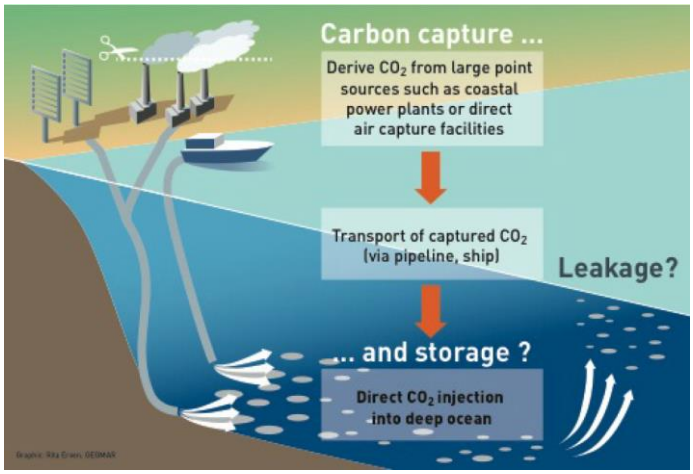


Figure L-3 Schematic diagram of direct CO_2 injections into the deep ocean

Which effect is anticipated to arise as a result of elevated CO_2 concentrations in the deep ocean on marine organisms? (single correct answer)

A. change in deep-sea pH
B. interference with consumers' feeding patterns
C. erode calcareous components of marine organisms
D. ecosystems with enhanced biological activity are likely to form