# IESO 2024 WRITTEN TEST PART 1

**Test time: 8:00 – 12:00**

**Scores: The answer sheet automatically saved at the end of Written Test Part I will be the only basis for scoring. All questions should have more than one correct answer, unless it is labeled "only one correct answer". When choosing one correct answer, you will receive 1 point; while choosing a wrong answer, you will lose 0.5 point. The score of each question will not be lower than 0.**

## Question1:

The image Figure Q1.1(a) is an internal mold gastropod fossil, showing the internal morphology typical of gastropods (refer to the image of a modern gastropod in Figure Q1.1(b)). What can we learn from the internal mold? (only one correct answer)

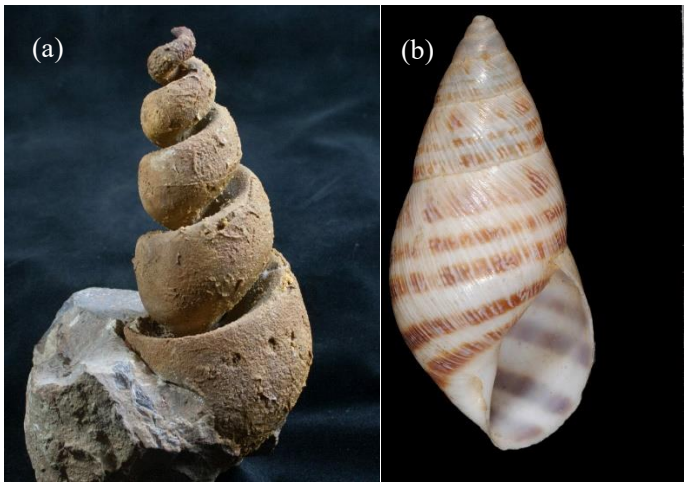



Figure Q1.1

a) Form of the outer surface of the shell
b) Form of the inner surface of the shell
c) The chemical composition of the shell
d) The gut structure of this organism
e) Details of muscle tissue of this organism

## Question2:

Antitropical distribution is a type of disjunct distribution where a species or clade exists at comparable latitudes across the equator but not within the tropics. The distribution of the species/clades can be both polar and temperate zones. Many modern and fossil marine animal groups exhibit antitropical distribution, including mollusks, echinoderms, fishes, insects, and others. What could **NOT** be the reason for an antitropical distribution? (only one correct answer)

a) Animals can migrate through "stepping-stone" islands scattered across the tropical sea from one side to the other
b) Species/clades from both sides may have originated from different ancestors.
c) Animal larvae can migrate, often passively, from one side to the other
d) These species/clades were initially together, but tectonic movements might separate them into two distinct sides

# Climate Change (Questions 3-8)

**Introduction:**

The Carbon Cycle plays a vital role in climate change. Accurate assessment of anthropogenic carbon dioxide ($CO_2$) emissions and its redistribution among the atmosphere, ocean, and terrestrial biosphere is critical to understanding the global carbon cycle and predicting future climate change.

The Keeling Curve, named after scientist Charles David Keeling, illustrates the rise of atmospheric $CO_2$ levels in the past. Established in late 1950s at Mauna Loa Observatory in Hawaii, Keeling's measurements revealed a steady increase in $CO_2$ due to human activities like fossil fuel burning. The curve's upward trend serves as a stark indicator of anthropogenic driver for climate change, urging global action to reduce $CO_2$ emissions and mitigate its climatic effects. Today, the Keeling Curve remains a critical tool in climate science, emphasizing the need for sustainable solutions to address

climate change.

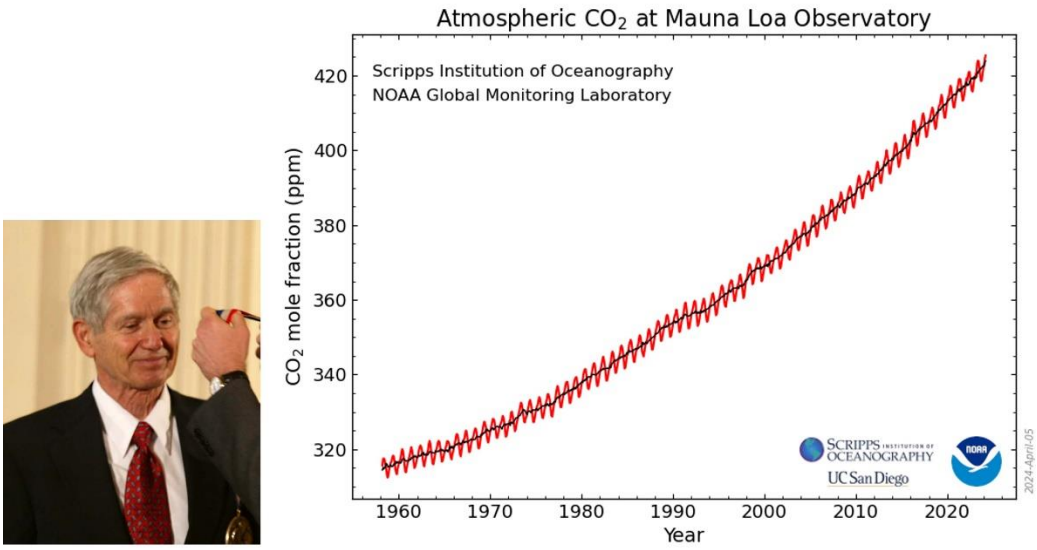



Figure Q3.1 Charles David Keeling and the Keeling Curve

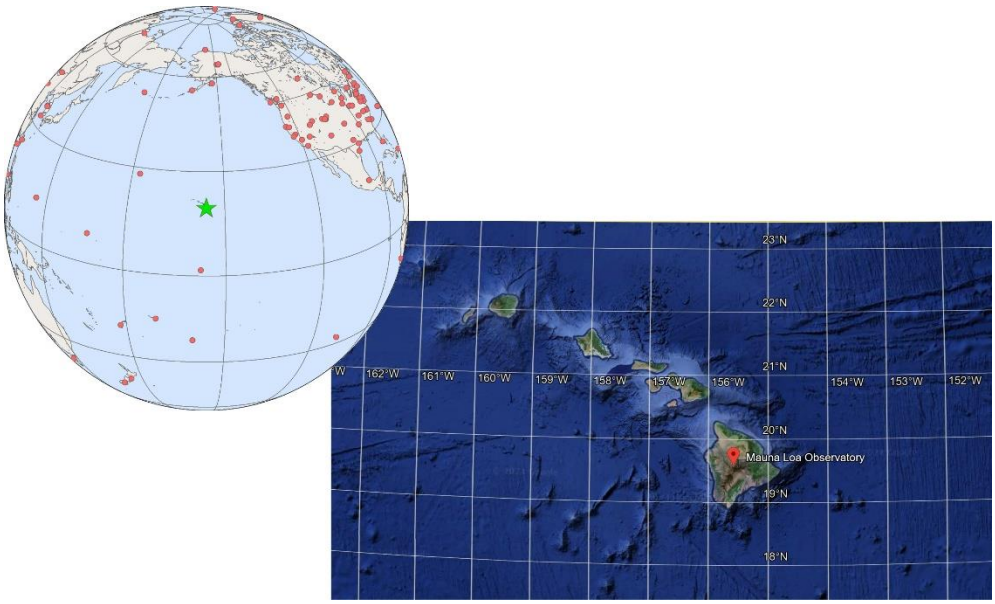



Figure Q3.2 Position of the Mauna Loa Observatory in Hawaii

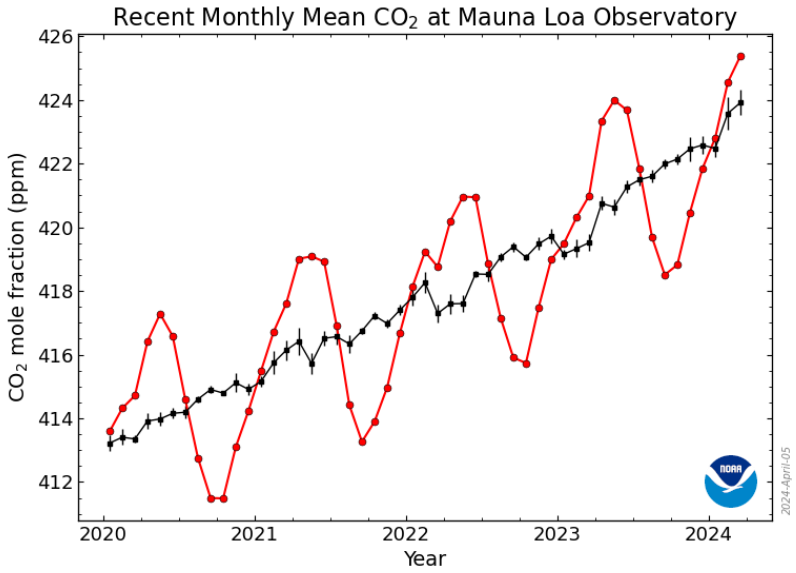



Figure Q3.3 The Keeling Curve, from 2020 to 2024

## Question 3:

Figure Q3.3 shows a zoomed-in version of the Keeling Curve. The **red** line and symbols represent the monthly mean values, centered on the middle of each month. The **black** line and symbols represent the same, after removing the average seasonal cycle. What is the most important driver for the fluctuation of $CO_2$ level within a year? (only one correct answer)

a) Atmospheric circulation

b) Vegetation changes

c) El Niño-Southern Oscillation (ENSO)

d) Human activity

## Question 4:

Fossil fuel $CO_2$ emission generally accounts for 88% of anthropogenic $CO_2$ emissions. The mean annual fossil fuel $CO_2$ emission from 2013-2022 was 35.3 Gt $CO_2$/year. 47% of the anthropogenic $CO_2$ emissions remain in the atmosphere, and the ocean can absorb

10.4 Gt $CO_2$ per year. How much $CO_2$ should the terrestrial ecosystem take up to ensure the global $CO_2$ balance? (only one correct answer)

a) 4.2 Gt $CO_2$/year

b) 6.1 Gt $CO_2$/year

c) 8.5 Gt $CO_2$/year

d) 10.9 Gt $CO_2$/year

## Question 5:

Figure Q5.1 shows the $CO_2$ growth rate (CGR), while Figure Q5.2 illustrates the anomalies of CGR and the global carbon fluxes. Carbon fluxes from different sources are affected by various factors, and therefore have different spatiotemporal characteristics, for example, due to the influence of ENSO, ocean net carbon flux tends to have a cycle of 5-20 years. The different colors in Figure Q5.2 stand for carbon fluxes from different sources including land net flux, ocean net flux, fossil fuel emissions, and land use change emissions. Which color represents the ocean net flux? (only one correct answer)

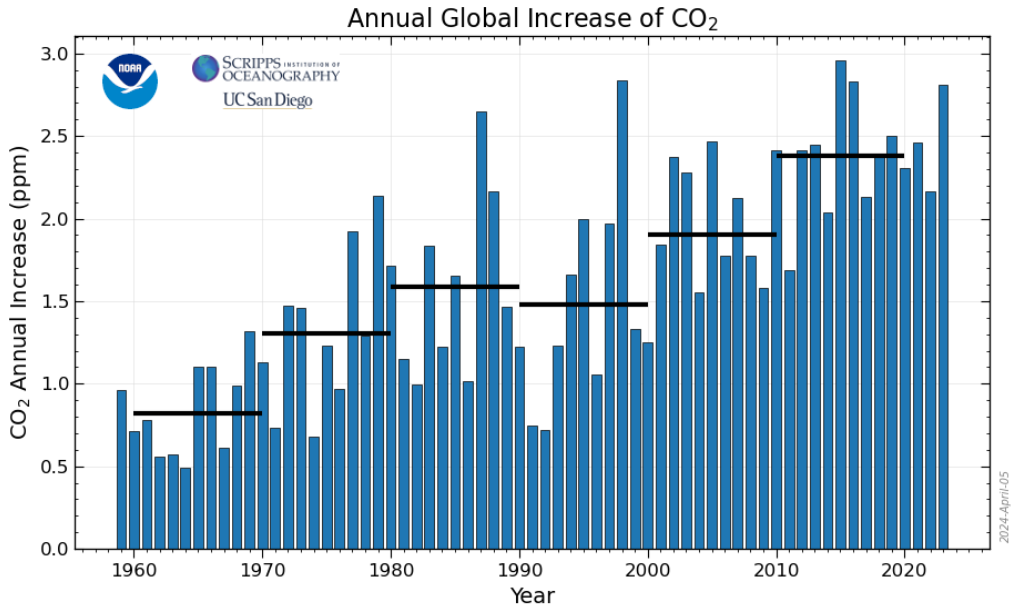



Figure Q5.1 The annual global increases of CO2

1

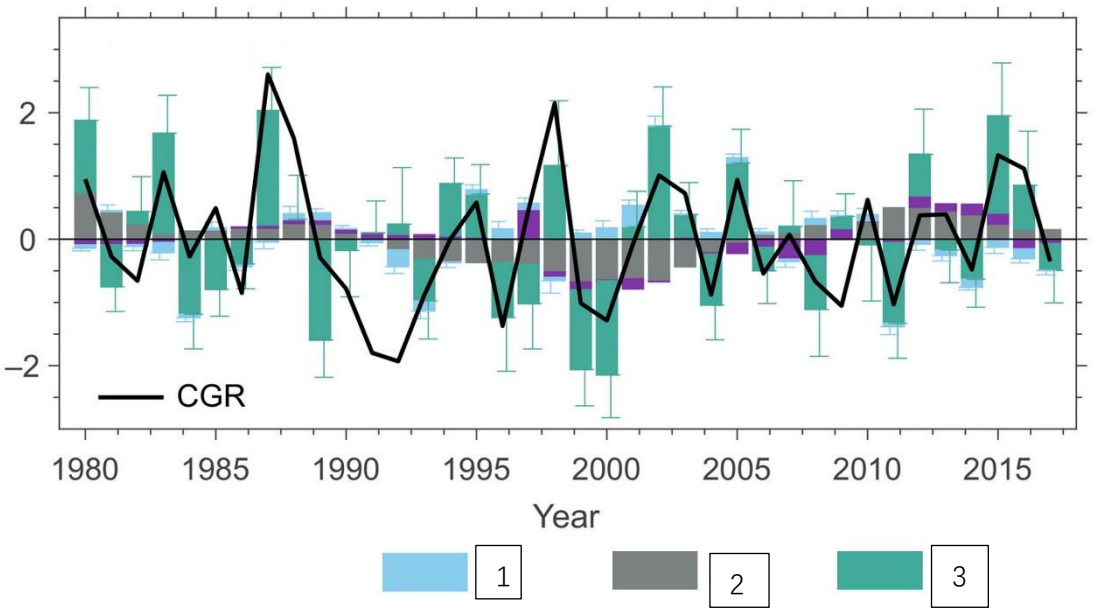



Figure Q5.2 The anomalies of CGR and global carbon fluxes

a) ①

b) ②

c) ③

## Question 6:

Figure Q6.1 shows the relationships between the cumulative amount of $CO_2$ emissions and the rise of global temperature. It is estimated that 2590 Gt $CO_2$ has been emitted by human beings since 1850. In order to limit the temperature increase to 1.5 °C (compared with 1850), what is the maximum amount that could be emitted before we reach this limit? (only one correct answer)

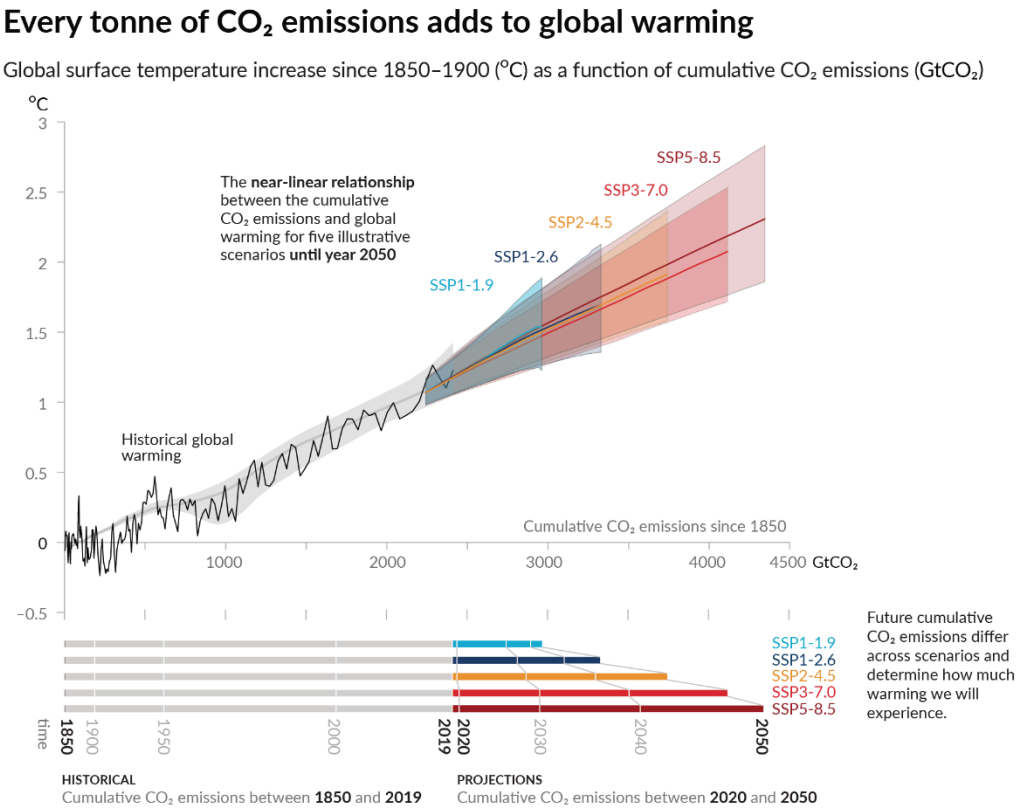



Figure Q6.1 Cumulative carbon emissions and rising global temperature

a) 200 Gt

b) 600 Gt

c) 1000 Gt

d) 1500 Gt

e) 2000 Gt

## Question 7:

Which is(are) the primary form(s) of global ocean carbon sink?

a) Methane emission

b) Carbonate precipitation

c) Organic matter burial

d) Coal deposition

e) Methane clathrate formation in marine sediment

f) Methane clathrate formation in permafrost

## Question 8:

Figure Q8.1 shows the contributions of different geographical factors that may affect the global temperature, which of the following statements is true? (only one correct answer)

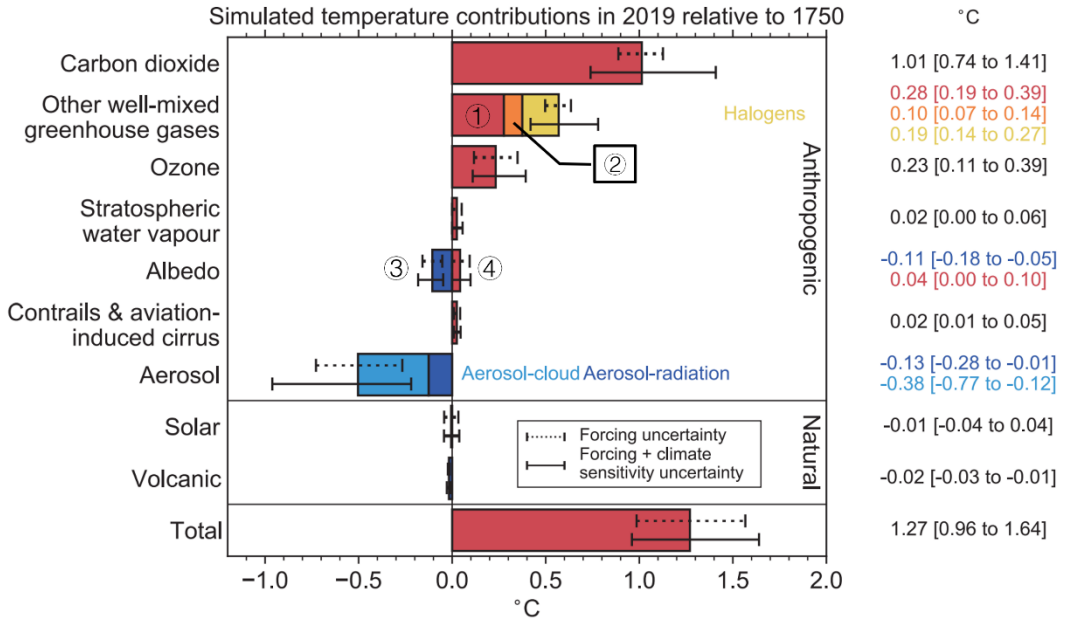



Figure Q8.1

a) The negative effect of aerosols comes from their interactions with clouds and radiation

b) The negative effect of albedo comes from the increase of vegetation on continents

c) The negative effect of albedo comes from the decrease of solar radiation

d) The positive effect of ozone comes from the increase of $O_2$ concentration in the troposphere

# The History of the East Asian Monsoon (Questions 9-15)

**Introduction:**

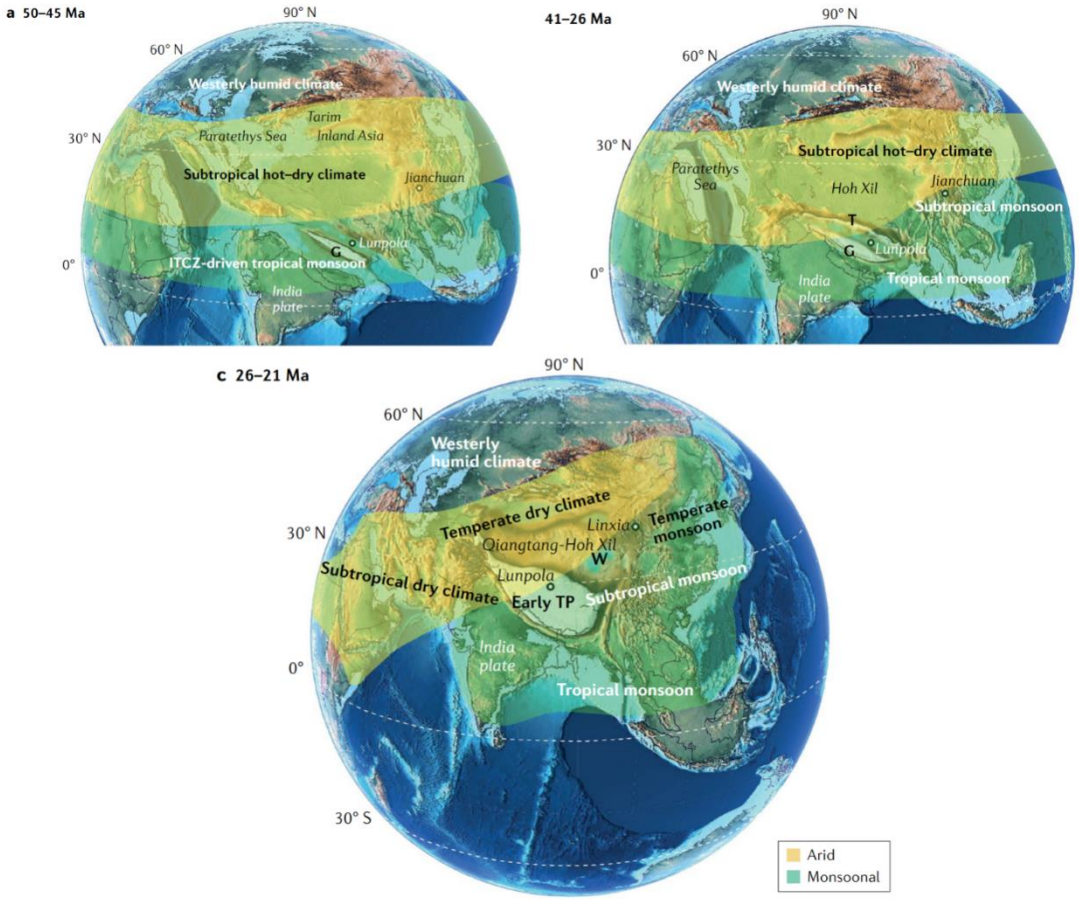



Figure Q9.1

The Asian summer monsoon is the strongest monsoon system on Earth, straddling ~10°–55° N from tropical to warm temperate regions, bringing abundant precipitation on continents. However, the summer monsoon was not always this strong. For example, East Asia was dry more than ~26 million years ago (Ma), while the summer monsoon system expanded northwardly with the northward movement of the Indian plate and uplift of the Tibetan Plateau (TP).

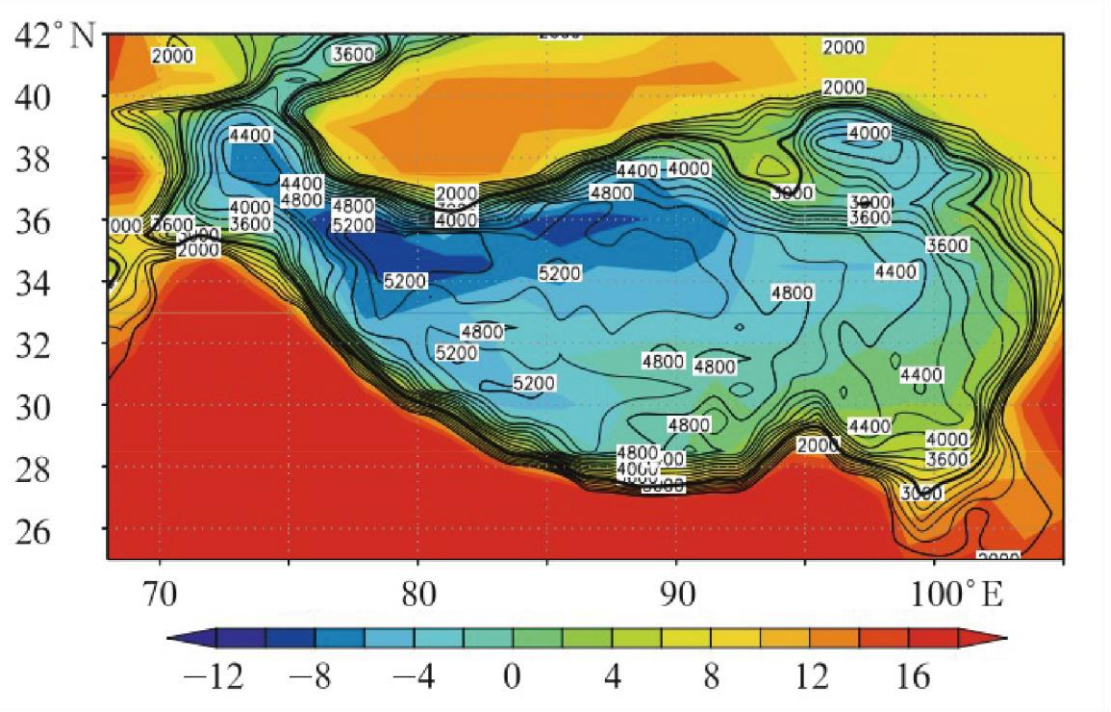



Figure Q9.2

Mean surface temperature (°C; shading) averaged between 1979 and 2010, based on the ERA-Interim dataset. Elevation is indicated by contour lines, with the plateau boundary (3000 m) marked by a thick solid line.

## Question 9:

In the low- to mid-latitude regions, the atmospheric temperature generally decreases with altitude, i.e. a lapse rate of ~6.5 °C/km. Most of the Tibetan Plateau has an average surface elevation of 4000 m. Accordingly, the surface temperature across the Tibetan Plateau would be more than 26 °C lower than at sea level at the same latitude. However, the summer surface temperature of Tibetan Plateau is only ~10 °C lower. This makes the surface air in the Tibetan Plateau much warmer than the surrounding (i.e., regions outside of Tibetan Plateau) air of the same altitude. What is the reason? (only one correct answer)

a) The Tibetan Plateau is tectonically active, so it has a high geothermal heat flux, which heats up the surface as well as the surface air
b) The Tibetan Plateau is too high to obey the lapse rate rule described above (i.e., temperature decreases at a rate of ~6.5 °C/km)
c) The surface temperature of the Tibetan Plateau is controlled by local radiation effects
d) The surface of the Tibetan Plateau is heated by intense cosmic rays because it is closer to the sun

## Question 10:

Through which of the following processes does the Tibetan Plateau influence the Asian monsoon? (only one correct answer)

a) Blocking cold dry air from the northwest
b) Forming tropical climate
c) Forcing the westerly winds to flow around the northern rim of the Tibetan Plateau to form a low-pressure ridge
d) The surface of Tibetan Plateau remains cold in all seasons

## Question 11:

Here is a schematic diagram showing the impact of the Tibetan Plateau heating on atmospheric circulation (Figure Q11.1). Red contours indicate the geopotential height anomaly isolines on 200-hPa and blue contours denote changes in sea level pressure. Contours show the anomalies caused by Tibetan Plateau heating with solid and dashed curves indicating positive and negative anomalies, respectively.

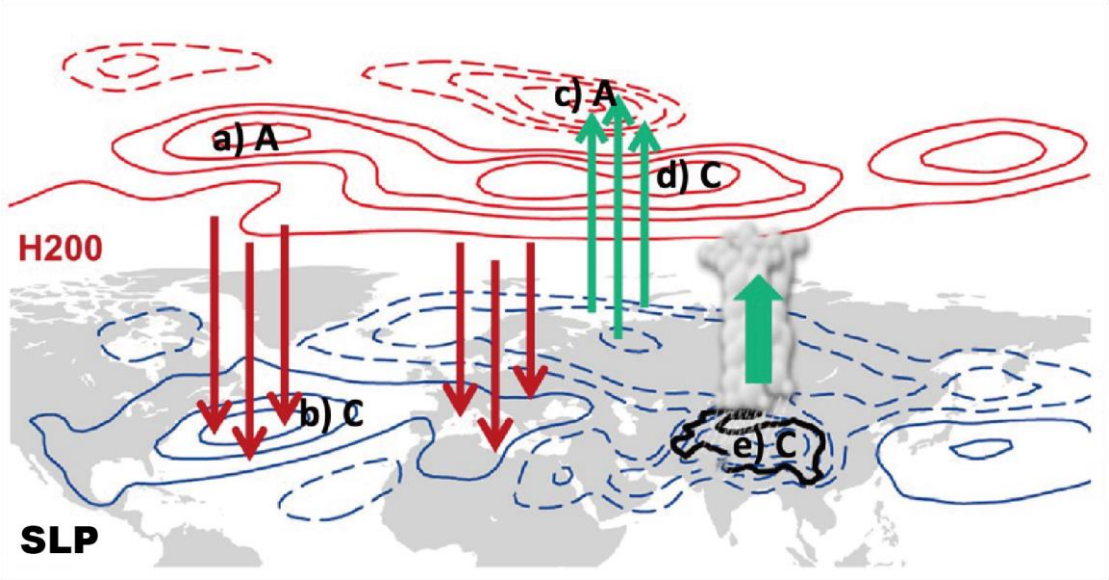



Figure Q11.1

Choose the correct label(s) for Anticyclonic anomalies (or higher pressure in the middle, labeled as "A") and Cyclonic (or lower pressure in the middle, labeled as "C") anomalies on the graph.

a) Anticyclonic anomalies
b) Cyclonic anomalies
c) Anticyclonic anomalies
d) Cyclonic anomalies
e) Cyclonic anomalies

## Question 12:

Studies have shown that during the Cenozoic, large parts of South China were arid. Which of the following descriptions of the uplift of the Tibetan Plateau, the Asian monsoon and aridity is correct? (only one correct answer)

a) South China was dry because it was further from oceans that it is now
b) Uplift of Tibetan Plateau would only enhance the aridity by inhibiting moisture flow
c) Uplift of the Tibetan Plateau has no effect on the aridity

d) The air pressure gradient created by the uplift of the Tibetan Plateau leads to the enhancement of the East Asian Monsoon

## Question 13:

Some chemical compounds at the Earth's surface may be transported to the stratosphere via the Asian Summer Monsoon. In this case, which of the following statements is(are) correct?

a) Molecular oxygen produced by oxygenic photosynthesis may be transported to the stratosphere, which ultimately increase stratospheric ozone levels and protects our planet
b) Sulfate aerosols from air pollution may be transported to the stratosphere, which could cool our planet by reducing incoming solar radiation
c) Chlorine from seawater or air pollution may be transported to the stratosphere, which ultimately destroys the stratospheric ozone layer
d) Water vapor may be transported to the stratosphere, where it is photolyzed into $H_2$ and $O_2$, leading to significant increases in atmospheric $O_2$

## Question 14:

Reconstructing the uplift history of the Tibetan Plateau is crucial for understanding the evolution of the Asian Summer Monsoon. Geochemists usually use geochemical proxies to achieve this goal. Which of the following statements is **NOT** a reasonable approach for reconstructing the uplift history of the Tibetan Plateau? (only one correct answer)

a) Reconstructing the change of temperature over the Tibetan Plateau
b) Reconstructing the change in CFC-11 (chlorofluorocarbon 11) gases
c) Reconstructing the change of precipitation over the Tibetan Plateau
d) Reconstructing the change of ecosystem over the Tibetan Plateau

## Question 15:

What is the implication of a strong Asian summer monsoon for the regions it affects? (only one correct answer)

a) Increased risk of droughts in East Asia
b) Increased rainfall favoring higher primary productivity across continents
c) A decrease in the frequency of tropical storms
d) Higher average temperatures due to increased evaporation and humidity

# The Earth System during a Snowball Earth Event (Questions 16-22)

**Introduction:**

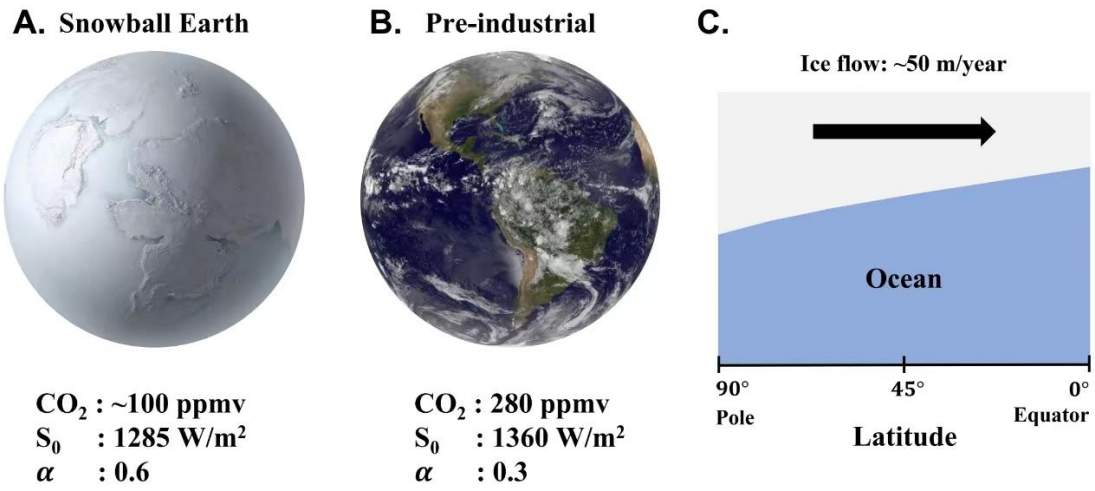



Figure Q16.1 (A) A schematic illustration of snowball Earth; (B) Pre-industrial Earth; (C) Sea ice extent during a snowball Earth event. $CO_2$ denotes the atmospheric $CO_2$ concentration, $S_0$ is the solar constant, and α is planetary albedo (i.e., reflectivity).

Multiple lines of geological evidence indicate that the Earth likely entered a global glaciation (also called Snowball Earth state; see Fig. Q16.1 (A)) twice during the Late

Neoproterozoic (720 – 541 million years ago). In each event, the glaciation lasted for at least a few million years, with the annual mean surface temperature as low as -40 °C near the equator, and -100 °C near the poles. Correspondingly, the atmosphere was dry and the maximum precipitation rate was ~20 cm/year. By comparison, the present annual mean surface temperature near the equator is ~28 °C and the maximum precipitation rate near the equator is ~ 400 cm/year in present day.

## Question 16:

What were the potential cause(s) for Earth to enter a global glaciation during the Late Neoproterozoic?

a) Land was not exposed above sea level, i.e., no continents above sea level.
b) Solar luminosity increased with time. That is, the Sun was not as bright as in the present day.
c) The concentration of atmospheric greenhouse gases was very low.
d) The ocean was shallower and smaller.
e) The Earth was rotating too fast.

## Question 17:

Hint: the thermal conductivity of ice is approximately 2.5 W/(m·K) (slightly dependent on temperature, but not important here). Estimate the rate of heat loss at the bottom of the sea ice during a Snowball Earth event.

During a Snowball Earth event, sea ice was around 1000 m thick, beneath which there was a deep liquid ocean. Why wasn't the whole ocean frozen?

a) The heat capacity of the ocean was sufficient enough to prevent it from freezing completely at the water ice interface (i.e., without liquid water)
b) The latent heat of freezing of seawater is sufficiently high to warm the underlying seawater as ice forms at the surface

c) The geothermal heat flux, which had a value of approximately 0.1 $W/m^2$, was continuously heating the ocean
d) The decay of radioactive elements in the ocean was constantly heating the ocean
e) Meteorites continuously hit the Earth, preventing permanent complete freezing of the ocean

## Question 18:

What are the potential major process(es) that led to the end of the Neoproterozoic Snowball Earth event?

a) Volcanic outgassing
b) Reduced weathering of rocks
c) More clouds in the atmosphere
d) Human activities increasing atmospheric $CO_2$
e) Earthquakes breaking the ice sheets

## Question 19:

Which of the following statements is(are) correct?

a) Modern Earth will enter a global glaciation if the atmospheric $CO_2$ concentration drops below to 100 ppm, so we should encourage greenhouse gas emission to prevent such an event from occurring.
b) The greenhouse effect of atmospheric $CO_2$ increases during a Snowball Earth event because the surface temperature is low; cold bodies absorb heat more easily.
c) The greenhouse effect of atmospheric $CO_2$ decreases during a Snowball Earth event because the surface temperature is low; there is little outgoing longwave radiation for the atmospheric $CO_2$ to block.
d) The greenhouse effect of atmospheric $CO_2$ decreases during a Snowball Earth event because the surface temperature is low; the atmospheric water vapor, which

is a powerful greenhouse gas, increases slowly with surface temperature when the surface temperature is low.

## Question 20:

Hydrogen peroxide ($H_2O_2$) plays a crucial role in shaping the planetary surface redox state. There is a hypothesis that $H_2O_2$ in the anoxic atmosphere could have driven the evolution of oxygen-mediating and -using enzymes paving the way for the emergence and evolution of oxygenic photosynthesis. The atmospheric $O_2$ level of the Late Neoproterozoic is believed to be 1-10% of present atmosphere level. It is known that $H_2O_2$ may be produced in the atmosphere via the following photochemically induced reactions: (*hv*: solar radiation)

$$O_2 + hv \rightarrow O + O(^1D) \text{ (mainly < 242 nm)}$$

$$O_3 + hv \rightarrow O_2 + O(^1D) \text{ (mainly < 320 nm)}$$

$$H_2O + hv \rightarrow OH + H \text{ (mainly <190 nm)}$$

$$NO_2 + hv \rightarrow NO + O(^3P) \text{ (visible light)}$$

$$O(^3P) + O_2 + M \rightarrow O_3$$

$$H_2O + O(^1D) \rightarrow 2OH$$

$$OH + CO \rightarrow CO_2 + H$$

$$H + O_2 + M \rightarrow HO_2 + M$$

$$2OH + M \rightarrow H_2O_2 + M$$

$$2HO_2 \rightarrow H_2O_2 + O_2$$

It is known that $H_2O_2$ can be produced in the atmosphere via photochemical reactions. The freezing point of $H_2O_2$ is -1°C. During a Snowball Earth event, which statements is correct? (only one correct answer)

a) Production of atmospheric $H_2O_2$ was impossible because there was no water vapor during a Snowball Earth event

b) The production rate of atmospheric $H_2O_2$ was extremely slow because only limited sunlight reached Earth's surface

c) $H_2O_2$ in the atmosphere increased with time because with limited water deposition

(i.e., precipitation) atmospheric $H_2O_2$ cannot be deposited on Earth's surface

d) $H_2O_2$ accumulated in the ice because its freezing point is only slightly lower than water

## Question 21:

What would you expect at the end of the Neoproterozoic Snowball Earth events?

a) A high greenhouse gas concentration in the atmosphere
b) Chemical decomposition of $H_2O_2$ stored in the thick ice could act as a source of $O_2$ to be released into the atmosphere
c) A significant increase in atmospheric $O_2$ levels due to chemical decomposition of melt water
d) The melt water would cause a dramatic overturning of the ocean

## Question 22:

Which of the following feedback mechanisms would be expected during a Snowball Earth event? (only one correct answer)

a) Ice reflects more sunlight (positive ice-albedo feedback)
b) Plants on land died, resulting in less $CO_2$ absorption and burial (negative $CO_2$ feedback)
c) Oceans stored less $CO_2$ due to increased sea-ice coverage (negative $CO_2$ feedback)
d) The atmosphere transported more heat from the equator to the poles (negative heat transport feedback)

# The Depositional System (Question 23-30)

**Introduction:**

A complete sedimentary process includes: weathering and erosion of the parent rock, transportation of sediment, and sediment deposition. Among these, sediment transportation is mainly via rivers; sediment deposition mainly occurs in deltas or shallow marine environments. Delta deposition is closely related to carbon burial and the formation of oil and gas reservoirs. similarly carbonate sedimentation, normally occurring in shallow marine environments, is also important for the carbon cycle and petroleum formation.

## Question 23:

Siliciclastic strata deposited after the evolution of land plants contain a proportion of mudrock, that is, on average, 20 times greater than equivalent strata from the preceding 90% of Earth's history.

Two non-exclusive explanations have been proposed to account for this difference, which invoke the possible influences of extant plant life on muddy sediment: (1) plants increased total mud production on continents due to enhanced silicate weathering; and (2) plants promoted the retention of mud on the continents, preventing it from being washed into the marine environment via below-ground stabilization of sediment, above-ground baffles that reduce the velocity of fluids and sediment, and the release of organic by-products that promote flocculation and subsequent deposition.

Recent research focused on the mudrock content of alluvial and tidal landscapes that remained locally unvegetated even after the greening of the continents, namely inclined heterolithic stratification (IHS) that records submerged in-channel bars. The primary result is as follows:

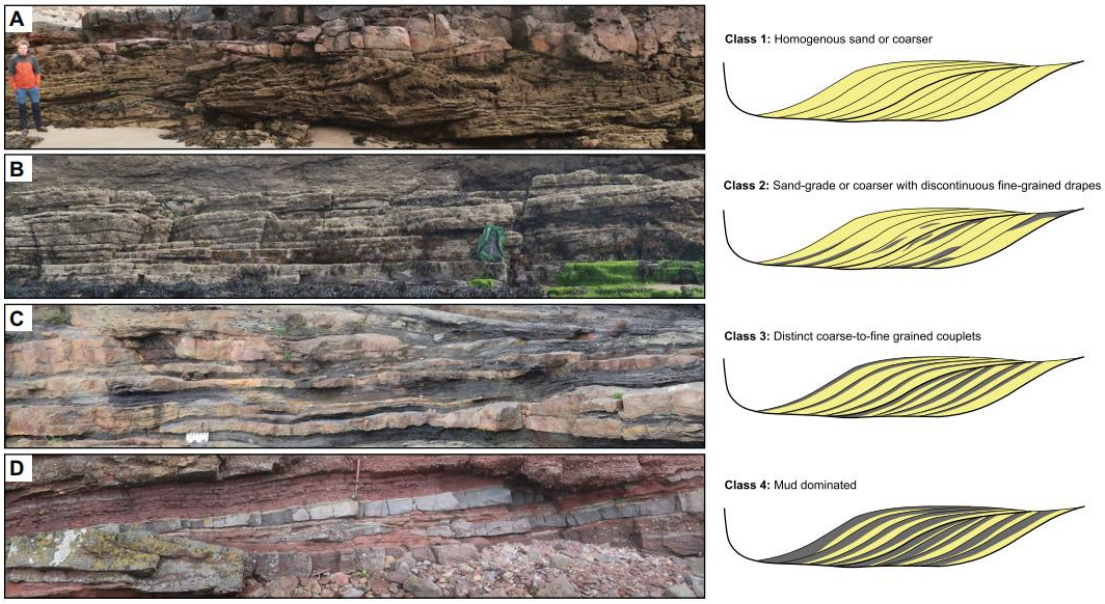



Figure Q23.1: Examples of inclined heterolithic stratification (IHS) (Based on the mud content)

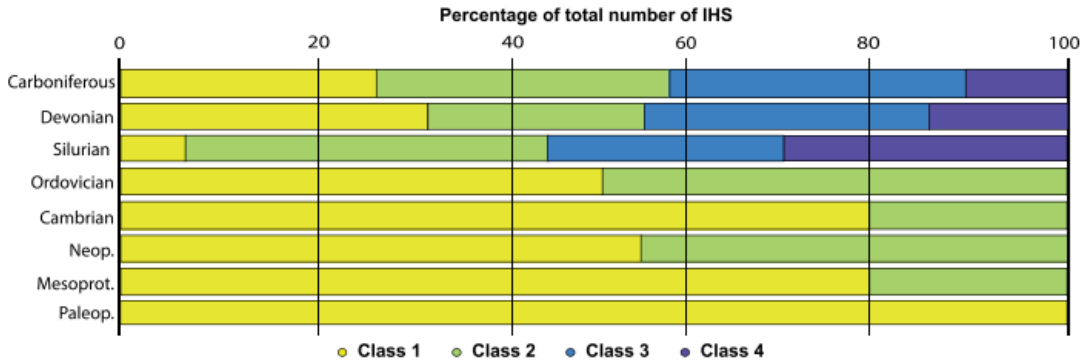



Figure Q23.2: Percentage of total number of IHS reported from the Paleoproterozoic to Carboniferous.

Which of the following statements is **NOT** correct? (only one correct answer)

a) The order of the IHS mud content is: Class 1 < Class 2 < Class 3 < Class 4
b) The alluvial and tidal landscapes in this study are away from biomechanical binding and the baffle effect of plants
c) Precambrian and Cambrian IHS are mostly composed of sandstone, whereas Silurian to Carboniferous show a steady increase in total mudrock content
d) Paleozoic land plant evolution triggered a global increase in the production and supply of fine-grained sediment

## Question 24:

After land plants colonized continents, frequent occurrences of wildfire might have had some impact on the Earth system. Figure Q24.1 shows the Holocene wildfire history in the Changjiang River drainage Basin, while Figure Q24.2 shows the agricultural land use and rice field distribution.

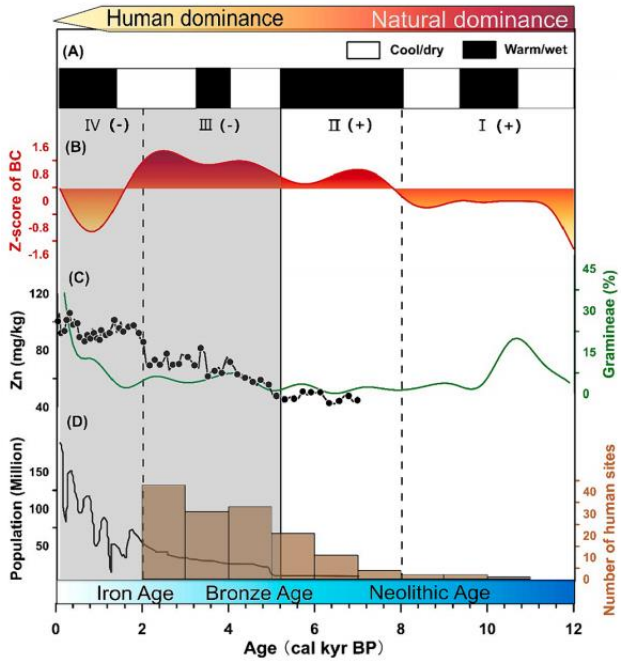



Figure Q24.1: (A) Millennial-scale climate fluctuations. (B) Z-scores of the BC curve are corrected by the smoothed generalized additive model. (C) Sediment Zn concentration in Liangzi Lake, and Gramineae pollen content from Core CM97. (D) Population change (black line) and number of human cultural sites (Brown bars).

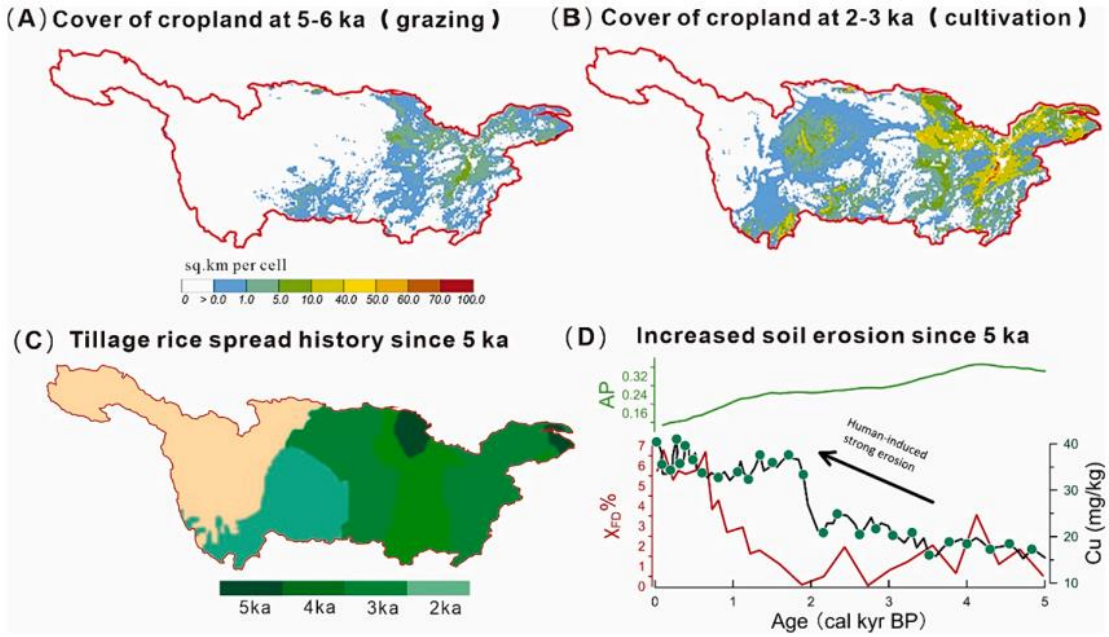



Figure Q24.2: Map of agricultural land use and rice field distribution in the Changjiang River drainage Basin. (A-B) Cover of cropland; (C) Tillage rice spread history; (D) Comparison of frequency-dependent magnetic susceptibility (χFD%, i.e., more magnetic Fe minerals) in the Changjiang Delta sediments of subaqueous and Liangzi lake copper (Cu) content with arboreal pollen (AP) in the Changjiang River Basin.

Which of the following statements is **NOT** correct? (only one correct answer)

a) Human activities have expanded, leading to increased impacts on nature.
b) Human activities caused increased soil erosion.
c) The impacts of human activities increased since 2000 BC.
d) Human migrated from west to east (corresponding to left to right in Figure Q24.2)

## Question 25:

Deltas are primarily formed when rivers carrying large amounts of sediment deposit them rapidly upon meeting the ocean; meanwhile, sea water redistributes the sediments, modifing or destroying of the delta. Therefore, various types of deltas can be produced through interactions between river systems and the ocean. Deltas can be classified into three types, i.e., river-dominated deltas, wave-dominated deltas, and tide-dominated

deltas.

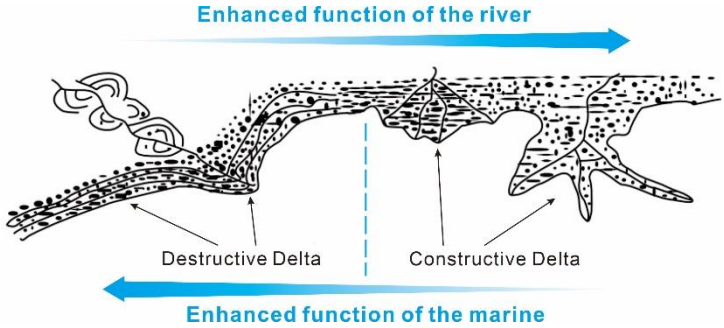



Figure Q25.1: The classification of delta.

Figure Q25.2 displays the topography of modern delta. Which of the following statements is(are) correct?

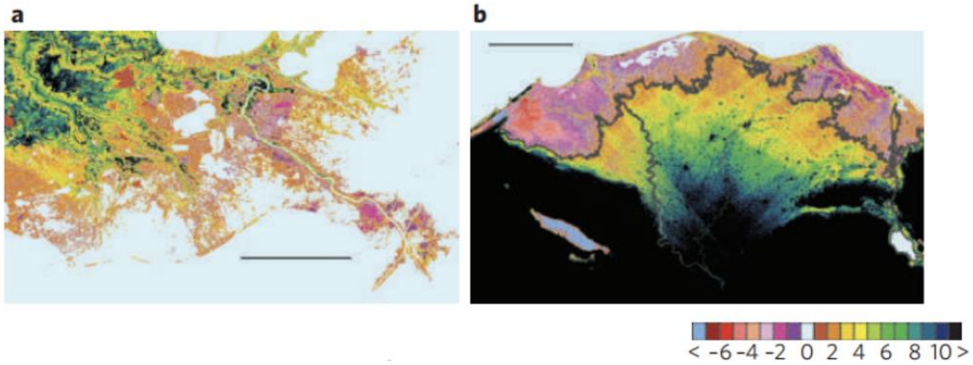



Figure Q25.2: Topography of representative deltas.

a) Delta A is predominantly a constructive delta.
b) Delta A is predominantly a destructive delta.
c) Delta B is predominantly a constructive delta.
d) Delta B is predominantly a destructive delta.

## Question 26:

$58 \pm 17$ Mt/yr of organic matter from the continents is buried in marine sediment each year, representing the second largest sink of atmospheric $CO_2$ after silicate weathering. Thus, it is suggested that terrestrial organic matter burial would regulate climate over geologic timescales ($\geq 10^5$ yr). Deltas and associated shelf deposits hold between 70% and 90% of the global organic carbon burial budget in marine sediments. Figure Q26.1

shows organic carbon (OC) content and composition in the studied delta.

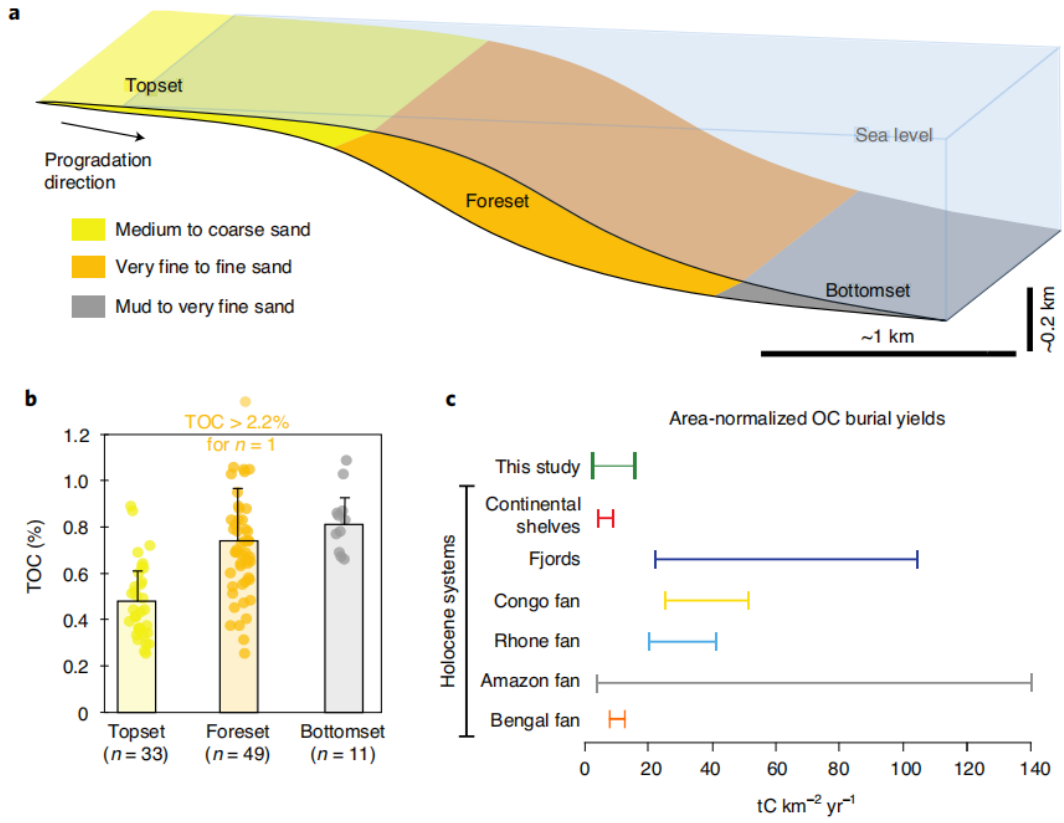



Figure Q26.1: a) Schematic representation of the studied delta. b) Mean total organic carbon (TOC) content for the topset, foreset and bottomset segments. Dots represent the measured TOC on each sample. Vertical bars represent the standard deviation for each segment, n, number of samples used to calculate the mean TOC for each segment, c) Comparison between area-normalized organic carbon burial rate.

Which of the following statements is **NOT** correct? (only one correct answer)

a) The maximum burial of OC per unit occurs at the base of the delta.

b) The maximum burial of OC per unit occurs at the top of the delta.

c) Finer rock particles are more favorable for OC burial.

d) The Amazon delta has the highest global OC burial rate record during the Holocene.

## Question 27:

Present day human activities are modifying delta dynamic, including their ability to migrate toward the ocean (prograde), which can alter the flux of carbon burial. Figure Q27.1 displays the remote sensing images of some modern deltas.

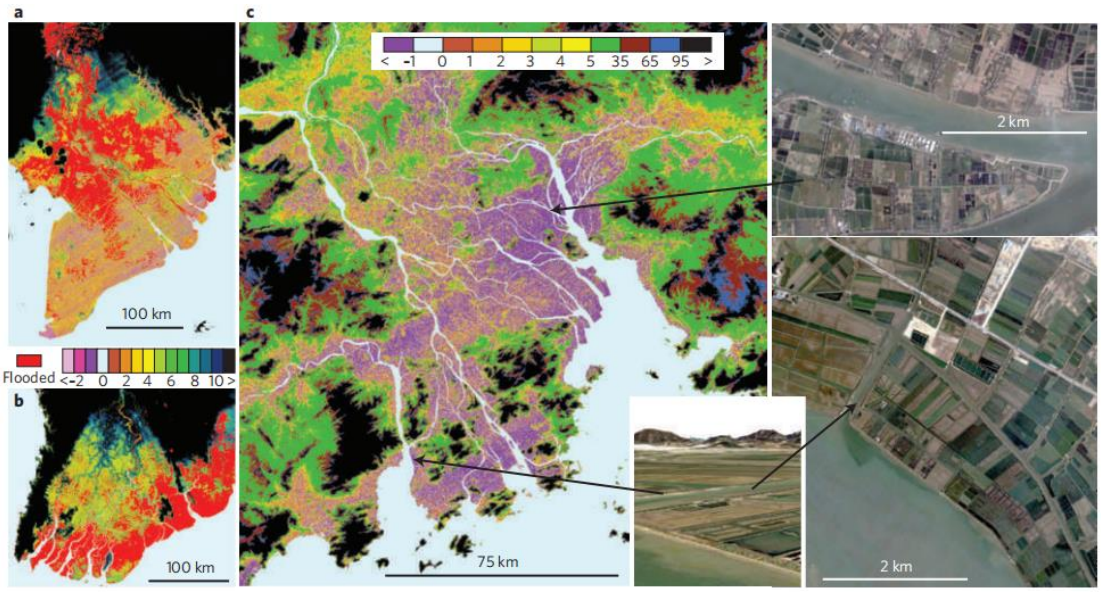



Figure Q27.1: Remote sensing images of deltas. a) Mekong, Vietnam, and b) Irrawaddy, Myanmar. The flooded areas are marked in dark red color. c) The Pearl Delta, China. Areas below sea level are in purple color. The Pearl is protected from storm surges by coastal and channel barriers as seen in associated Digital Globe images.

Which of the following statements is(are) correct?

a) The Mekong River Delta is prone to flooding in high regions
b) The Irrawaddy River Delta is prone to flooding in coastal areas
c) Most parts of the Pearl River Delta are below sea level because of sea level rise due to fossil fuel burning
d) Constructing farmland on deltas is conducive to their expansion
e) Constructing farmland on deltas hinders their expansion

## Question 28:

A study analyzed deposits in the Qaidam Basin, northwestern China, and discovered microbial carbonate (microbialites).

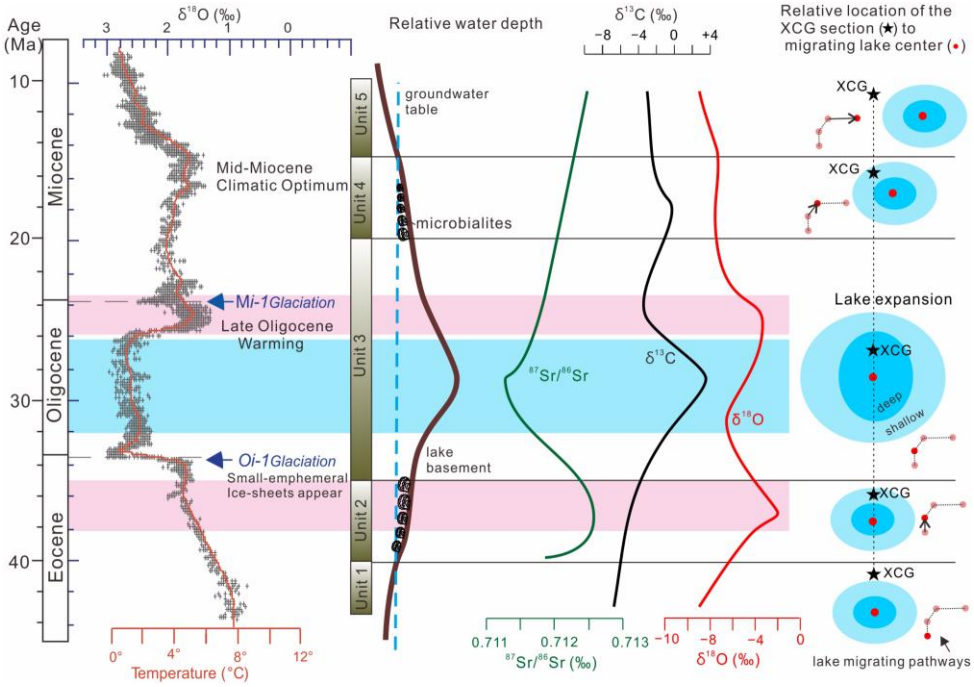



Figure Q28.1: Coupling of global climate fluctuations and tectonically induced lake migration history with the trends of oxygen, carbon, and strontium isotopes and the relative water depth of the Xichagou section. Global temperature variations are shown on the left.

Which of the following statements is **NOT** correct? (only one correct answer)

a) The lower microbial carbonate mainly formed in the Late Eocene

b) The lower microbial carbonate formed as the lake level rose, while the upper microbial carbonate rocks formed as the lake level fell

c) During the lower microbial carbonate deposition, there was a simultaneous positive excursion in $^{87}Sr/^{86}Sr$, indicating a correlation between them

d) Microbial carbonate does not occur in some stratigraphic horizons, possibly due to sampling locations being outside the lake

## Question 29:

Satellite remote sensing data is increasingly being generated and applied to many questions, including carbonate formation in the modern oceans.

Figure Q29.1 presents six relevant global oceanic data sets.

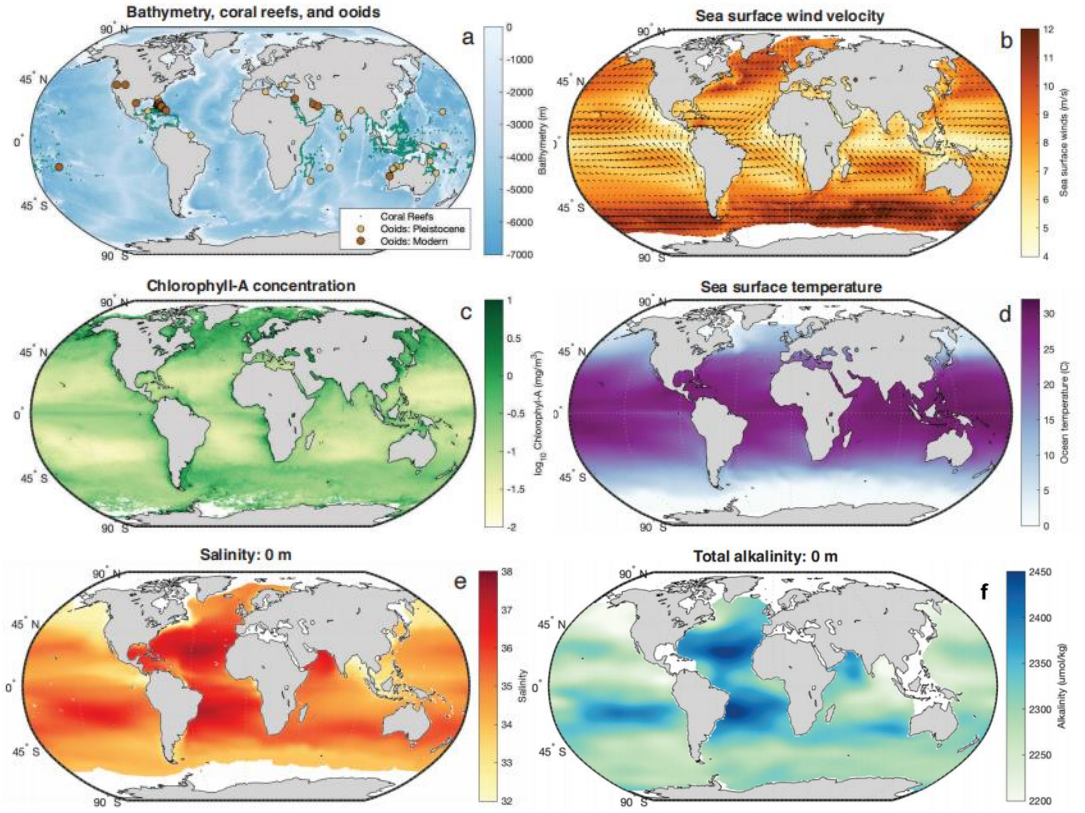



Figure Q29.1: Global map of modern ocean parameters

Which of the following statement(s) is(are) correct?

a) Modern coral reefs are mainly distributed near the equator and coupled with a high-temperature zone
b) Sea surface wind velocity correlates with Chlorophyll-a, indicating that cyanobacteria are only regulated by ocean currents
c) An increase in calcite saturation promotes the formation of carbonate rocks
d) An increase in alkalinity will certainly promote the formation of carbonate rocks
e) High salinity in mid-latitude results from less river water input

**Question 30:**

A recent study summarized the carbonate formation model in the Bahamian carbonate platform.

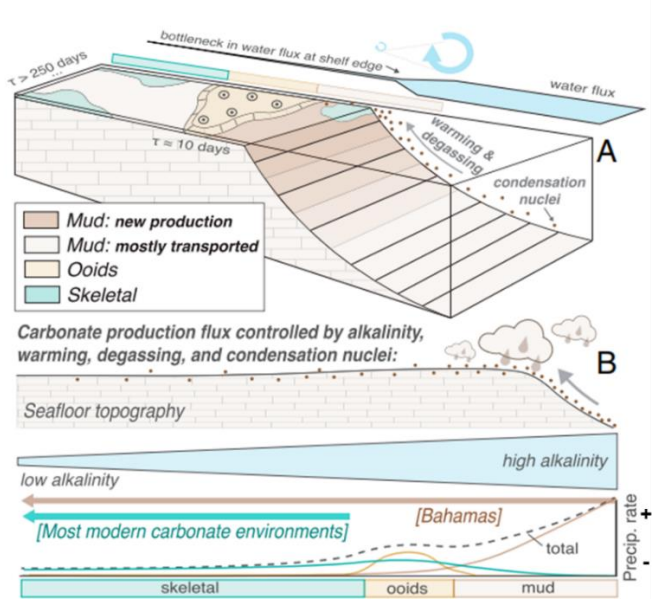



Figure Q30.1: A conceptual model for deposition in a carbonate platform

Which of the following statements is **NOT** correct? (only one correct answer)

a) Carbonate sediment can be produced in the form of skeletal grains, ooids, and lime mud

b) Ooids can be produced on the platform margin, within the platform, and on the outer platform slope

c) Non-skeletal mud production requires the highest alkalinity

d) Ooid production can sustain precipitation from less alkaline waters

e) Skeletal production can persist in the least alkaline waters

## The History of Land Plant Evolution (Questions 31-33)

**Introduction**

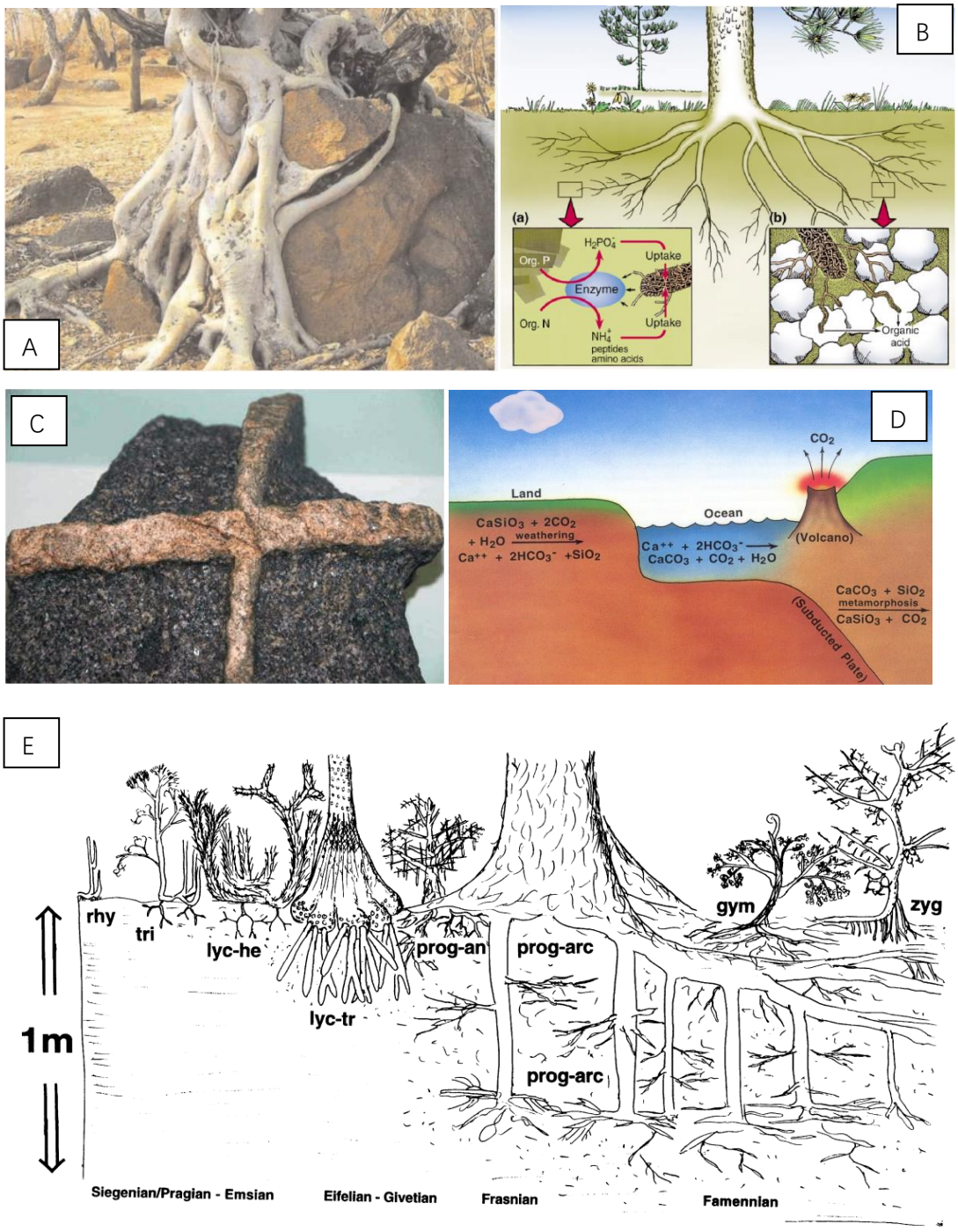



Figure Q31.1

Weathering is an essential step of the geological processes, representing the initial stage of materials (rock chips, minerals, and elements) cycling on Earth, and plays a substantial role in maintaining Earth's habitability. During weathering, the parental rock is broken into small rock chips or minerals or dissolved into soluble ions (Figure Q31.1 A-B). Many factors can affect the weathering intensity, such as temperature, hydrological cycling, and the development of terrestrial organisms. For example, dark

and fine magmatic rocks (also enriched in phosphorus and biological critical trace metals) are generally weathered more quickly than those with light color) and coarse grains (Figure Q31.1 C). The weathering products transported to lakes and oceans by rivers and wind have significant impacts on seawater chemistry, depositional systems, biological evolution, and even the processes in Earth's interior.

Vascular land plants, the primary source of the coal we use, are also a crucial geological force in weathering. Fossil records reveal the plant root system expanded and increased in complexity from the Early to Late Devonian. The Carboniferous period, directly after the Devonian period, is characterized by global coal deposition and expansion of ice caps from the South Pole to mid-latitudes.

**Question 31:**

Plants promote weathering. Which one of the following is **NOT** correct?

a) Plants promote physical breaking of rocks
b) Plants increase the water content in the region covered by the root system
c) Plants release organic acids
d) Plants elevate $CO_2$ content in the soil
e) Plants promote erosion of loose ground

**Question 32**

Which of the lithologies listed below would be the most nutrient rich and significant for promoting plant growth? (only one correct answer)

a) Sandstone
b) Granite
c) Basalt
d) Chert
e) Limestone

**Question 33**

Expansion of vascular land plants occurred in the Late Devonian, followed by glaciation in the Carboniferous. What is(are) the possible reason(s) for the onset of Carboniferous glaciation?

a) Consumption of atmospheric $CO_2$
b) Decreasing Earth surface albedo
c) Increased atmospheric $O_2$ content
d) Enhanced organic carbon burial

## Fossil Fuel Resources (Questions 34-36)

**Introduction**

Oil and gas are valuable hydrocarbon fossil fuels which form as a result of thermal maturation of organic matter. As organic matter is buried to increasing depths, it undergoes thermal evolution via a sequence of steps, progressing from the oil-generation window to the gas-generation window, producing oil and gas respectively. Oil and gas are able to migrate from source reservoir to rock driven by natural buoyancy. These hydrocarbons accumulate under suitable structural or lithological conditions, forming conventional oil–gas reservoirs. In contrast, hydrocarbons can also remain within the source rock or accumulate in layers closer to it, forming continuous oil–gas reservoirs and unconventional shale oil–gas reservoirs (Figure Q34.1).

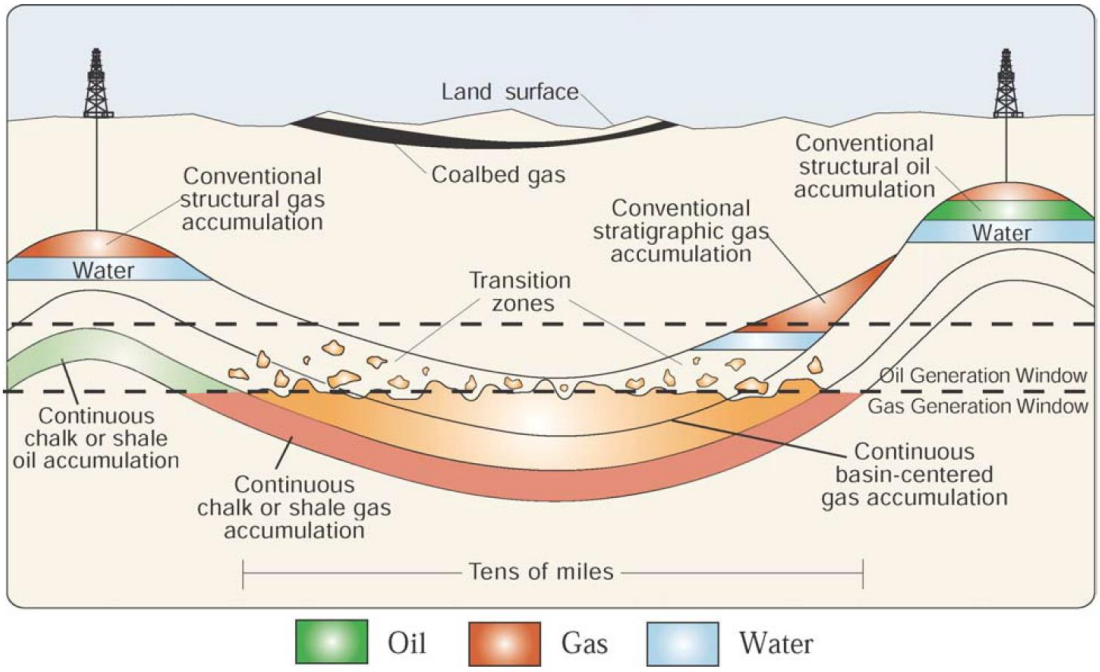



Figure Q34.1: Generalized diagram showing the categories of conventional, continuous, and shale oil and gas accumulations

**Question 34:**

Which of the following statements is the most reasonable description of the key difference between conventional and unconventional oil–gas accumulations? (only one correct answer)

a) The difference is only the location, with conventional hydrocarbon reservoirs being closer to the surface
b) Conventional hydrocarbon reservoirs typically contain ordered distribution of water–oil–gas
c) There are differences in source–reservoir relationships, whereby unconventional hydrocarbon reservoirs are usually integrated with, or closely related to, their source rocks

**Question 35:**

What is the main control on the vertical distribution of oil, water, and gas? (only one

correct answer)

a) Volume
b) Density
c) Pressure
d) Temperature

**Question 36:**

Which of the following descriptions of gas accumulation is correct? (only one correct answer)

a) Gas may accumulate in both conventional and unconventional reservoirs
b) Coal-bed gas is an example of conventional gas accumulation
c) Gas cannot accumulate in transition zones
d) Oil can only accumulate in unconventional reservoirs

## Clean Energy (Questions 37-41)

**Introduction:**

Hydrogen ($H_2$) is a carbon-free fuel, but hydrogen production can be environmentally damaging and expensive. Some researchers consider that vast reserves of cheap and potentially renewable natural hydrogen exist underground. These possible resources constitute so-called "Earth's hydrogen factories", which refer to the geological processes that provide the reaction conditions required for natural $H_2$ formation (Figure Q37.1). After migration and accumulation, the produced $H_2$ can form a commercially exploitable hydrogen reservoir in a suitable geological unit. However, microorganisms or active metal elements might react with $H_2$ in reservoirs. In addition, hydrogen reservoirs must have specific properties to ensure geological preservation, and tectonic processes may cause $H_2$ leakage. These abovementioned processes and characteristics

constitute complex links in the operation of Earth's hydrogen factories.

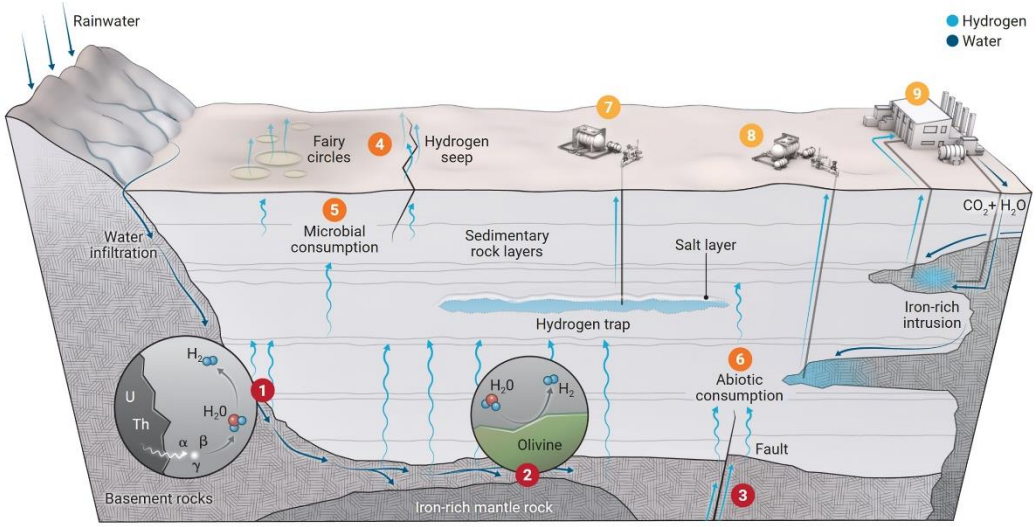



Figure Q37.1 Generalized diagram of Earth's hydrogen factories

## Question 37:

The serpentinization of olivine is an important geological mechanism for $H_2$ generation. Assuming that each gram of olivine can produce a maximum of $2500 \times 10^{-6}$ mol $H_2$ per year, which of the following statement(s) is(are) correct?

a) The time required for 1 gram of olivine to generate 1 ton of hydrogen is 200 million years
b) The time required for 1 gram of olivine to generate 1 ton of hydrogen is 100 million years
c) 20,000 tons of olivine can produce 1 ton of hydrogen per year
d) 10,000 tons of olivine can produce 1 ton of hydrogen per year

## Question 38:

Which statement about the process of $H_2$ formation from $H_2O$ is **NOT** correct? (only one correct answer)

a) $H_2O$ forms $H_2$ through electrolysis

b) Hydrogen ions in $H_2O$ lose electrons

c) Hydrogen ions in $H_2O$ gain electrons

d) $H_2$ generation from $H_2O$ only occurs in some specific conditions

## Question 39:

Which of the following geological processes is(are) conducive to the accumulation of $H_2$?

a) Microbial consumption

b) Abiotic consumption

c) U–Th radioactive decay in basement rock

d) Serpentinization of basalts

e) Hydrolysis of carbonate

f) Carbonate reacting with granitic magma

## Question 40:

Which geological unit(s) can be used for the extraction of $H_2$?

a) Iron-rich mafic intrusions

b) Salt layers

c) Granitoid rocks

d) Quartzite

## Question 41:

What is also produced by U–Th radioactive decay in bedrock that contributes to the formation of $H_2$? (only one correct answer)

a) Electrons

b) Energy

c) Pb ions

d) water

# IESO 2024 WRITTEN TEST PART 2

## Dynamic Earth and its Impacts (Questions 1-21)

### Introduction

Magmas generated within Earth's interior can be both dangerous and beneficial to human beings. On one hand, magmatic rocks provide us with significant quantities of mineral resources. On the other hand, volcanic eruptions may cause disastrous consequences. Thus, it is necessary to understand how magmas are generated and how they may affect us.

**Question 1:**

Melting occurs when the geotherm (red line) intersects with the solidus (green line). The dashed lines indicate the initial conditions. Figure Q1.1 illustrates three possible mechanisms to induce melting: lowering pressure, increasing temperature, and adding volatiles. What is the order of the mechanisms as displayed from left to right in Figure Q1.1? (only one correct answer)

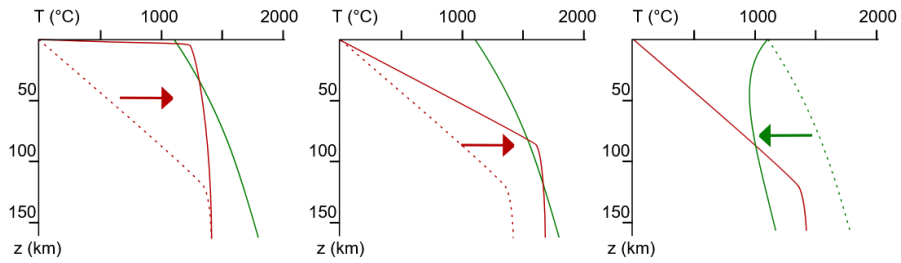



Figure Q1.1

a) increasing temperature; lowering pressure; adding volatiles.

b) lowering pressure; increasing temperature; adding volatiles.

c) adding volatiles; increasing temperature; lowering pressure.

d) lowering pressure; adding volatiles; increasing temperature.

e) increasing temperature; adding volatiles; lowering pressure.

**Question 2:**

Mafic magmas may differentiate into more felsic magmas during their ascent. Figure Q2.1 shows the variation of mineral proportion in magmas of different compositions. Which of the following statements is(are) correct?

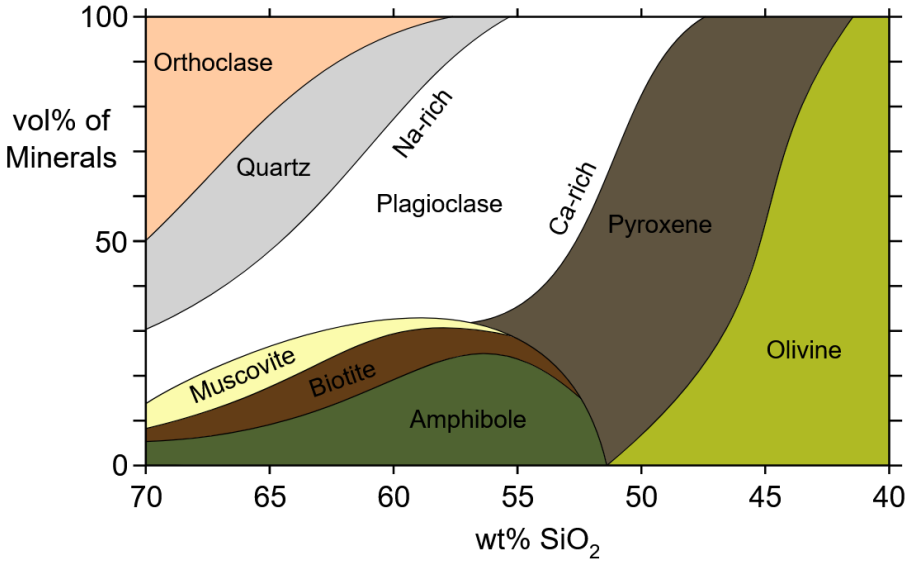



Figure Q2.1

a) A felsic magma is more silica rich than a mafic magma.

b) Plagioclase in a mafic magma is more Ca rich than in a felsic magma.

c) Olivine and amphibole cannot coexist.

d) Olivine is the first mineral that crystallizes from a felsic magma.

e) Biotite crystallizes earlier than muscovite.

f) When a magma with 60 wt% $SiO_2$ crystallizes, orthoclase is the most abundant mineral.

g) The amount of olivine decreases with magma differentiation.

**Question 3**

Large Igneous Provinces (LIPs) are extremely large (continental-scale) accumulations of igneous rocks formed over a relatively short period of geologic time, usually attributed to mantle plume processes. The Emeishan flood basalt, located in southwestern China, is recognized as one of the largest LIPs. The majority of the Emeishan LIP consists of basalt with minor rhyolite. The geodynamic mechanism for forming the Emeishan LIP is still under debate. A recent study proposed the mechanism illustrated in Figure Q3.1. Use what you learnt from Q1 to choose ALL the potential mechanism(s) responsible for generating mafic magma to form the Emeishan LIP.

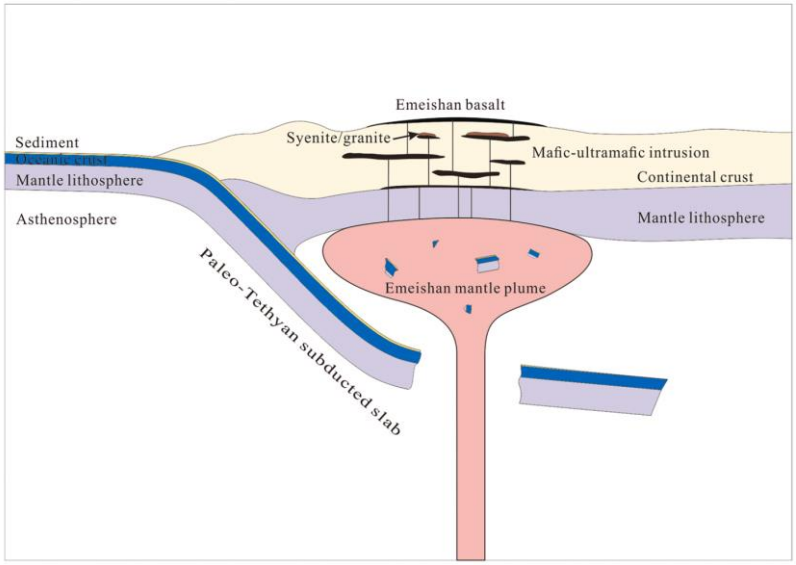



Figure Q3.1

a) Increasing temperature
b) Increasing pressure
c) Decreasing temperature
d) Earthquakes
e) Addition of water and other volatiles

**Question 4:**

Geologists studying a region's plate tectonic activity have observed the following

phenomena: a significant amount of volcanic rocks, layers of volcanic ash, and geothermal springs associated with volcanic activity. In addition, frequent seismic activity with earthquake foci from shallow to deep. Based on these observations, which of the following plate tectonic processes control this area? (only one correct answer)

a) Subduction of oceanic plates e.g. Japan
b) Divergence of oceanic plates, e.g. the mid-ocean ridge in the Indian Ocean
c) Transform faulting of plates
d) Convergence of plates with associated Himalaya mountain building

**Question 5:**

The Emeishan LIP intruded into strata predominantly composed of carbonate, consisting of Ca-carbonate minerals ($CaCO_3$), with polymorphs known as calcite and aragonite. These two minerals can be transformed from one to the other with changes in temperature and pressure. Given that the calcite-aragonite transition phase boundary on a P-T phase diagram exhibits a positive slope, and calcite is more stable under higher pressure, choose ALL the mechanism(s) that POSSIBLY convert aragonite to calcite.

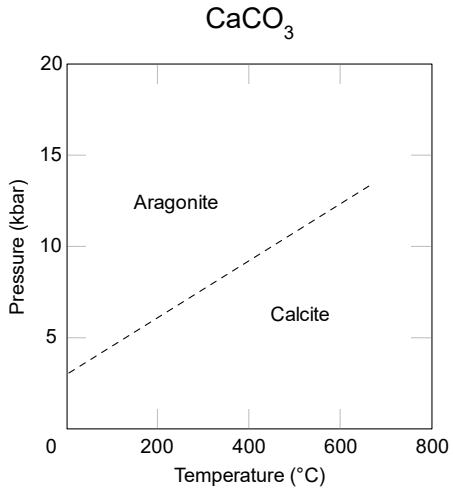



Figure Q5.1 P-T phase diagram of calcite-aragonite

a) Increased temperature

b) Increased pressure
c) Decreased temperature
d) Decreased pressure

**Question 6:**

LIPs may have profound impacts on Earth's surface environment. The Emeishan LIP, which formed at the end of the Permian, resulted in significant crust-mantle material exchange. The explosive and destructive eruptions of the Emeishan LIP released vast quantities of ash and gases, including water vapor and $SO_2$, into the stratosphere. These materials were then carried by atmospheric circulation, spreading around the entire Earth, forming aerosols, which reflect most of the incident sunlight over a relatively short geological period. Choose **ALL** the possible direct consequenc(es) of LIP formation.

a) Short-term global temperature decreases (less than one year)
b) Short-term global temperature increases (less than one year)
c) Long-term global temperature decreases (more than one hundred years)
d) Long-term global temperature increases (more than one hundred years)
e) A mass extinction
f) Acid rain
g) Oceanic overturn
h) Halting thermohaline convection in the ocean

**Question 7:**

In structural geology, crustal deformation and movement are key to understanding geological phenomena. Suppose geologists observe a series of closely-spaced folded rock layers with their axes aligned, accompanied by significant reverse faulting. Based on these observations, which of the following factor(s) or process(es) could have

generated such structural characteristics?

a) Isostatic crustal adjustment leading to local surface uplift.
b) Compressional forces from plate convergence.
c) Localized heating of the crust causing plastic deformation of the rock layers.
d) Regional compression caused by crustal cooling and contraction.

**Question 8:**

We find a large number of meteoritic impact craters on the Moon, but relatively few on the Earth. Why?

a) Earth's atmosphere prevents most meteoroids from reaching the Earth's surface.
b) Due to active tectonics on Earth.
c) Due to an active water cycle on Earth.
d) The Moon has no human activity.
e) The Moon is more attractive to meteorites.
f) The Moon is smaller than Earth.
g) The Moon orbits the Earth

**Question 9:**

The edges of tectonic plates experience frequent geological activity. Therefore, when a person is preparing to build a high-rise house in the Aleutian Islands, stretching from Alaska to easternmost Russia in the North Pacific, he or she needs to consider:

a) Volcanic eruptions
b) Earthquakes
c) Tsunami
d) Tides
e) Drought

**Question 10:**

On January 14, 2022, a severe eruption began at the underwater volcano of Hunga Ha'apai, located 65 kilometers north of Nuku'alofa, the capital of Tonga in the South Pacific island nation north of New Zealand. The large-scale eruption continued for several days. The eruption of the Tongan volcano resulted in the almost complete submergence of the 3 million square meters of Hunga Ha'apai Island. Which of the following statements is(are) correct?

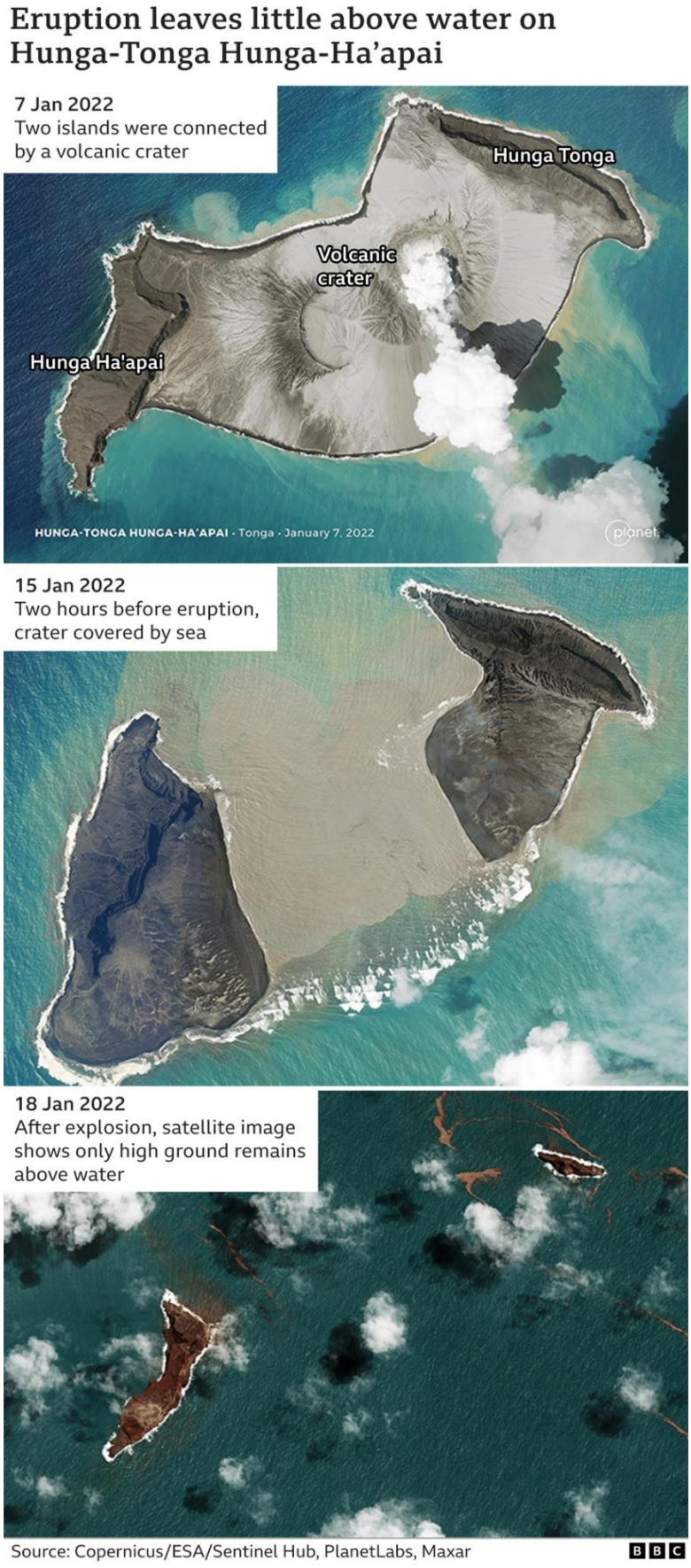

Eruption leaves little above water on Hunga-Tonga Hunga-Ha'apai
7 Jan 2022
Two islands were connected by a volcanic crater
Hunga Tonga
Volcanic crater
Hunga Ha'apai
HUNGA-TONGA HUNGA-HA'APAI · Tonga · January 7, 2022
planet.
15 Jan 2022
Two hours before eruption, crater covered by sea
18 Jan 2022
After explosion, satellite image shows only high ground remains above water
Source: Copernicus/ESA/Sentinel Hub, PlanetLabs, Maxar
BBC

Figure Q10.1

a) Hunga Ha'apai Island formed by volcanic accumulation.
b) Hunga Ha'apai Island is mainly composed of granite.
c) The eruption released high-pressure blasts that dislodged surrounding rocks, causing the island to rise.
d) The eruption caused a caldera collapse due to the magma chamber emptying, causing the island to disappear.
e) Spreading pumice all the way along the Australian east coast.

**Question 11:**

Regarding the potential impact of volcanic eruptions on climate change, which of the following statements are NOT correct?

a) Volcanic ash produced by volcanic eruptions can strongly block solar radiation, causing global cooling.
b) The large amount of sulfur dioxide released during some volcanic eruptions forms sulfuric acid aerosols in the atmosphere, which block solar radiation and cause global cooling.
c) The sulfur dioxide produced by volcanic eruptions can contribute to the greenhouse effect, leading to global warming.
d) Artificially inducing volcanic eruptions can reduce the greenhouse effect.

**Question 12:**

Assuming the elevation of a location is 1500 meters above sea level, and the average elevation of the geoid (geoid is the equipotential surface of the Earth's gravity field) relative to sea level is -300 meters, what is the elevation of the location relative to the geoid? (only one correct answer)

a) 1800 m
b) 1200 m
c) -1200 m

d) -1800 m

**Question 13:**

Studying the history of river incision is useful for clarifying the controlling tectonic or climate effects on river development. The incision rate in a certain area of the Lancang River was studied by dating the river terraces. Figure Q13.1 is a diagram of the terraces with the dating results based on K-feldspar post-infrared infrared stimulated luminescence dating (K-Feldspar pIR-IRSL). (only one correct answer)

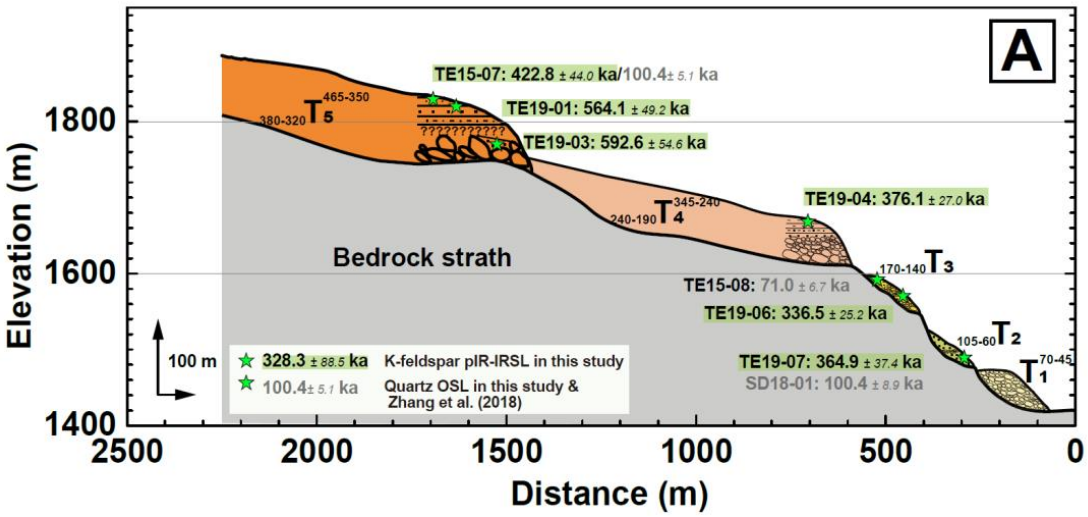



Figure Q13.1

Which of the following descriptions of the incision rate during the Middle Pleistocene is correct?

a) <5.9–2.2 mm/yr.

b) <0.59–0.22 mm/yr.

c) <0.059–0.022 mm/yr.

d) <0.0059–0.0022 mm/yr.

**Question 14:**

Commonly used relative dating methods include the law of superposition, the law of faunal succession and the law of cross-cutting relationships.

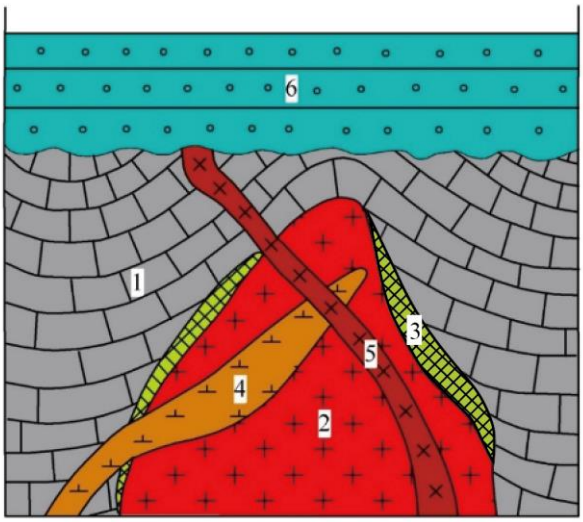



Figure Q14.1. 1: limestone, 2: granite, 3: skarn, 4: diorite, 5: dolerite, and 6: conglomerate.

Which of the following explanation(s) is(are) correct?

a) Limestone is the oldest.

b) Diorite is older than granite.

c) Dolerite is older than conglomerate and diorite.

d) Conglomerate is the youngest.

**Introduction**

Assume tectonic movement on Earth happens on a two-dimensional surface instead of a spherical surface.

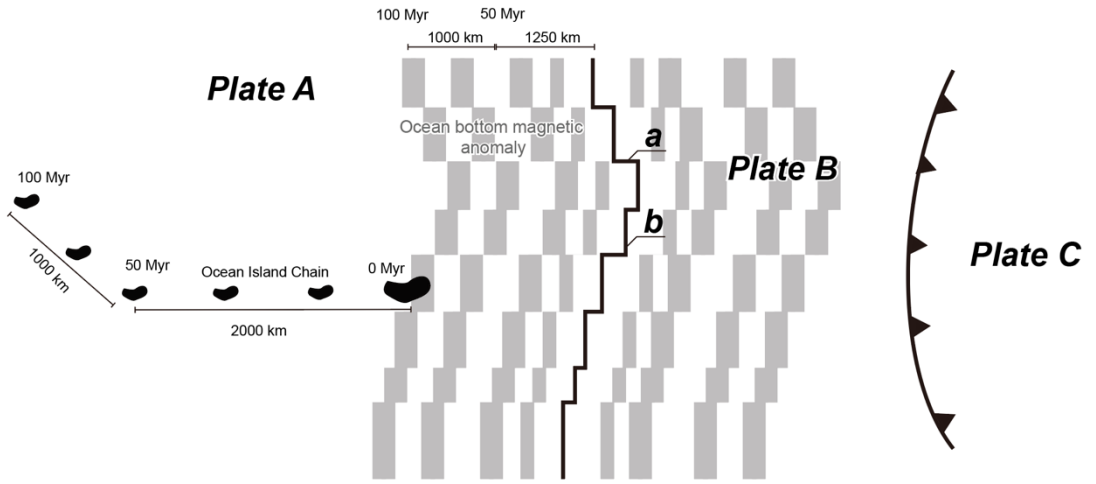



Figure Q15.1 Three plates and an idealized model of tectonic interactions between them.

**Question 15:**

Which plate(s) could be oceanic?

a. Plate A
b. Plate B
c. Plate C
d. None of them

**Question 16:**

Which plate(s) could be continental? (only one correct answer)

a. Plate A
b. Plate B
c. Plate C
d. None of them

**Question 17:**

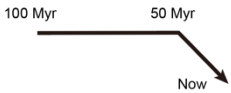
Assuming that the mantle plume is stationary, which could be the movement trace of Plate A? (only one correct answer)

a)


b)


c)


d)




**Question 18:**

A focal mechanism, or "beachball", is a graphic symbol that indicates the type of slip that occurs during an earthquake. The darker-shaded quadrants (compression) of the focal mechanism indicate motion toward those quadrants; the lighter-shaded quadrants (extension) indicate motion away from those quadrants. Which of the following focal mechanisms characterizes Site a? (only one correct answer)

a)

b)

c) 

d) 

**Question 19:**

Which of the following focal mechanisms characterizes Site b? (only one correct ansser)

a) 

b) 

c) 

d) 

**Question 20:**

Which of the following focal mechanisms characterizes high magnitude earthquakes

that occur at the boundary between Plate B and Plate C?

a) 

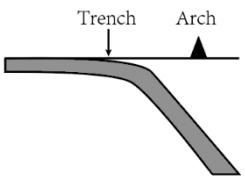
b) 

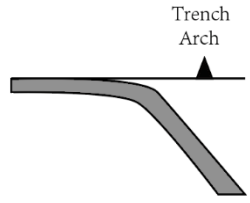
c) 

d) 

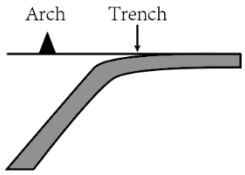
**Question 21:**

Which of the following simple schematic diagrams (the line thickness does not represent the plate thickness) could be the structural profile at the plate junction between Plate B and Plate C? (only one correct answer) Correction: ARCH = ARC in the diagram

a) 


b) 

c)

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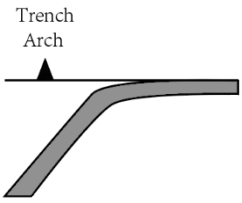



# Element Cycles in the Magmatic System (Questions 22-24)

## Introduction

The father of modern geochemistry, Victor Goldschmidt, classified the elements of the periodic table into several groups, including siderophile (iron-loving), chalcophile (sulfur-loving), lithophile (oxygen-loving) and atmophile elements (Figure Q22.1 and Q22.2). These elements are distributed in different Earth spheres, according to their partition coefficient, which quantifies the distribution of an element between coexisting phases. Outside of Earth's core, the abundances of siderophile and chalcophile elements in the Earth's mantle and crust are relatively low (e.g., 20-30 μg/g Cu). However, these elements may become enriched during multi-stage magmatic-hydrothermal processes that form ore deposits containing abundances sufficient for industrial mining (e.g., 0.2-0.5 wt. % Cu).

Elements with similar geochemical behavior are often strongly coupled (e.g., Cu, Ag and Au). Their associations are mainly a function of how similar their ionic radii and charges are.

High concentrations of certain elements may become ore deposits, which can be mined if their abundances are sufficiently high to be economically viable. However, serious environmental pollutants (e.g., heavy metals, Pb) are another potential product.

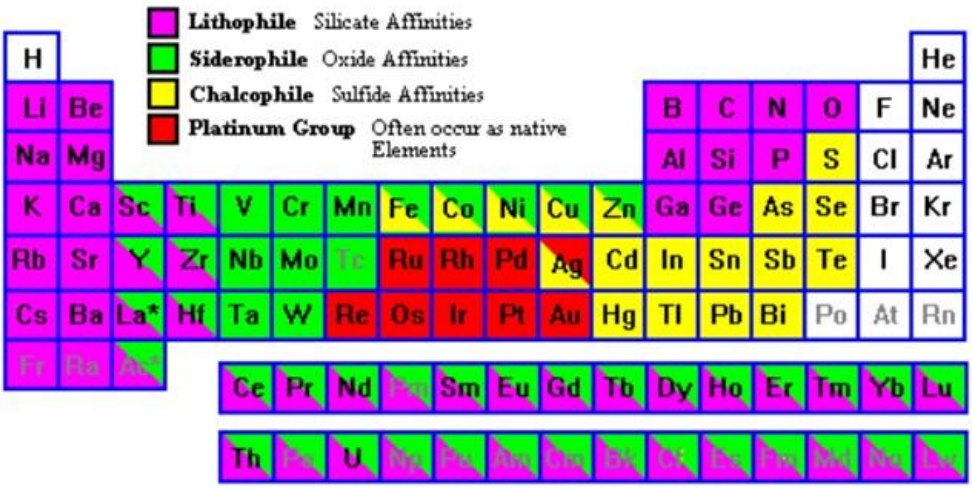



Figure Q22.1

**Question 22:**

Based on Goldschmidt's element classification scheme, which elements become enriched in Earth's core?

a) Ni, Co, Mo, W
b) Al, Ti, Ca, Zr, Th, U
c) Li, Rb, K, Na, Cs
d) Rare Earth Elements
e) Platinum group elements

**Question 23:**

During partial melting, certain elements in the mantle are preferentially transferred to the coexisting partial melts. The partition coefficient is calculated based on the abundance ratio of solid mantle rock to partial melt. If the partition coefficient is less than 1, the element is called an incompatible element, for example, K, U; if the partition

coefficient is larger than 1, the element is compatible, for example, Mg, Fe. Which of following statements is correct? (only one correct answer)

a) Incompatible elements preferentially enter melts during partial melting.

b) Potassium is an incompatible element, thus granite normally has low K content.

c) The Earth's mantle has 20-30 µg/g copper and basalts often contain 80-100 µg/g copper. Copper is thus a compatible element in basaltic melts.

**Question 24:**

Given similar radius and charge, trace metal elements often substitute for the major elements of ore minerals. Such substitution theory is important for understanding element associations in critical metals exploration for advanced industry.

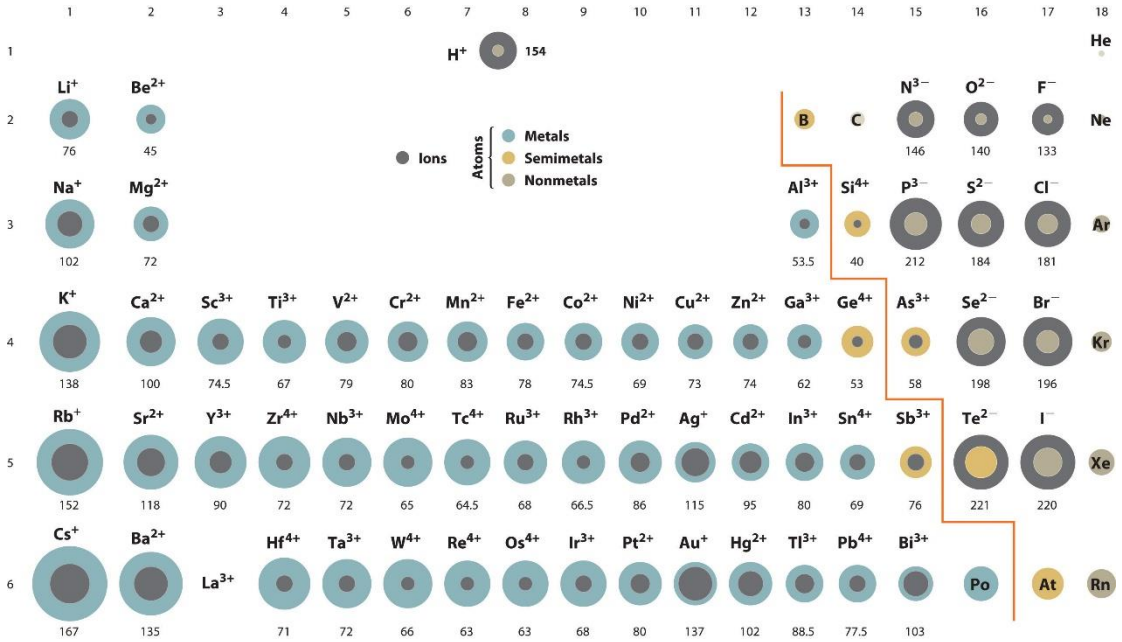



Figure Q22.2

Which of the following statements are correct?

a) Calcium and Sodium tend to substitute for each other.

b) Iron and Manganese tend to substitute for each other.

c) Lead and Titanium have similar geochemical properties, and Lead-rich minerals tend to show high Titanium abundances.

d) Zinc and Cadmium are neighboring elements in the periodic table. Therefore, Cadmium is often enriched in Zinc ore deposits.

## The Sun in the Solar System (Questions 25-30)

**Question 25:**

Total eclipses and annular eclipses are two fascinating types of solar eclipses, photos of which are shown below in Fig Q25.1. In a total eclipse (Figure Q25.1 (a)), the solar photosphere is fully obscured by the moon. In an annular eclipse (Figure Q25.1 (b)), the moon cannot block the edge area of the sun, and the sun appears as a very bright ring. Which of the following statements is(are) correct regarding these two phenomena?

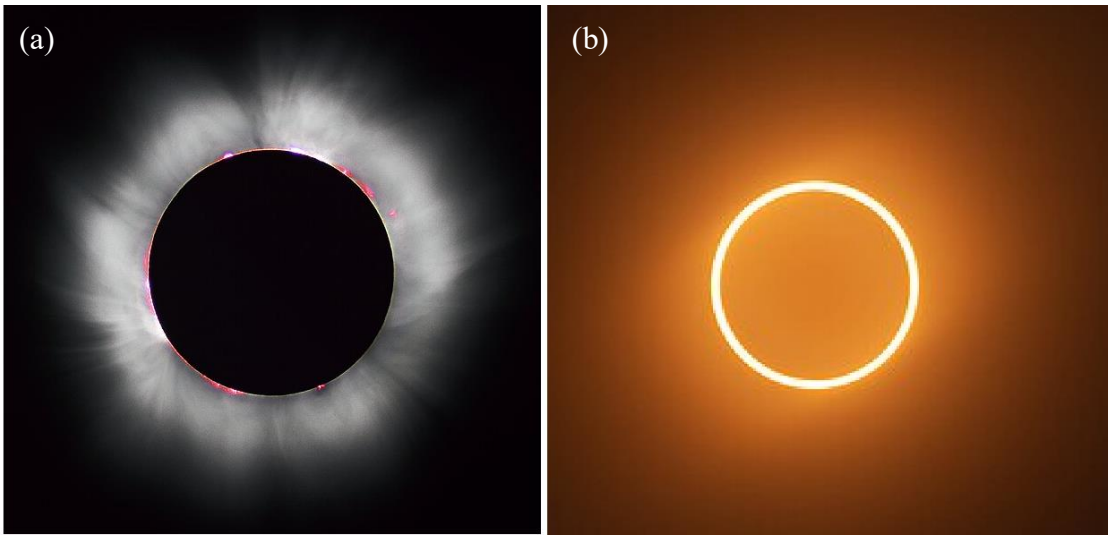



Figure Q25.1

a) Total eclipses are excellent opportunities to observe the solar corona, which is much dimmer than the photosphere.

b) When a total solar eclipse occurs, people in the umbra area of the moon can see this phenomenon. Observers in the penumbra area can only see an annular eclipse.

c) For observers on Earth, the apparent size of the Moon is sometimes larger than and sometimes smaller than the apparent size of the Sun. These two situations correspond to the total eclipse and annular eclipse, respectively.

d) It is known that Earth's orbit is elliptical, and the distance between the sun and the Earth minimizes in January every year. Since the apparent size of the Sun is relatively large in northern hemisphere winter, annular eclipses (but not total eclipses) can only occur in winter months.

**Question 26:**

During a total solar eclipse, people can not only observe the corona but sometimes also the chromosphere (the pink area in Figure Q25.1 (a)), which is located between the corona and the photosphere. It is believed that the temperature of the corona is as high as one million degrees Celsius, much higher than the chromosphere (between 5,000 to 20,000 degrees Celsius) and photosphere (about 6,000 degrees Celsius). Which of the following statements is(are) correct?

a) Since the corona's temperature is greater than the chromosphere and photosphere, energy is transmitted downward from the corona to the chromosphere and the photosphere at lower altitudes.

b) The extremely high temperatures in the corona indicate that most of the coronal matter is ionized and is in a plasma state.

c) The motion of charged particles in the corona is controlled by the Lorentz force due to the existence of the solar magnetic field. This forms the fine coronal structures seen in the photo.

d) The extremely high temperatures in the corona facilitate the collision between hydrogen nuclei (since they can more easily overcome the repelling Coulomb force), which leads to nuclear fusion.

**Question 27:**

According to Wien's displacement law, the wavelength of the peak blackbody radiation is inversely proportional to temperature. In other words, the product of the peak wavelength and the temperature is a constant (Wien's displacement constant, approximately 2.9 mm · K). In the visible light band, the relationship between the wavelength of the electromagnetic waves and the corresponding color is shown in Figure Q27.1.

The average temperature of the solar photosphere is 5780 K. What color corresponds to the wavelength at the peak solar photospheric radiation? (Only one correct answer)

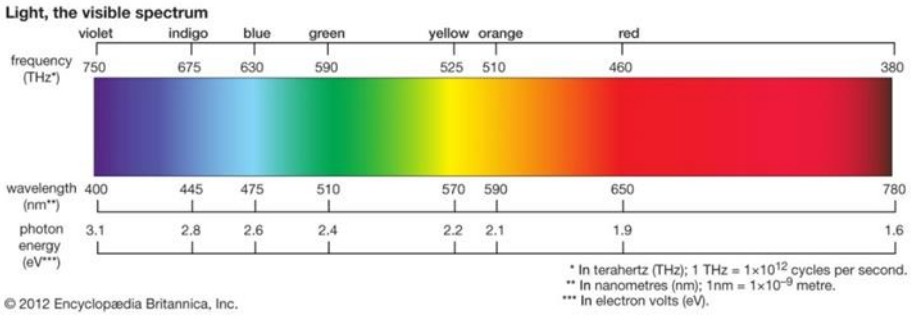



Figure Q27.1

a) Violet

b) Blue

c) Green

d) Yellow

e) Orange

f) Red

**Question 28:**

Sunspots are located in the photosphere, but their temperatures are about 2000 K lower than the average temperature of the photosphere. What color corresponds to the wavelength of the peak sunspot radiation? (Only one correct answer)

a) Violet

b) Blue

c) Green

d) Yellow

e) Orange

f) Red

**Question 29:**

Which of the following statements about solar radiation is(are) correct?

a) The color of solar radiation is determined by the wavelength of the peak photospheric radiation.

b) The color of solar radiation depends not only on the wavelength of the peak photospheric radiation. Since the chromosphere and the corona also contribute a considerable part of the solar radiation, their wavelength at peak radiation also directly determines the color.

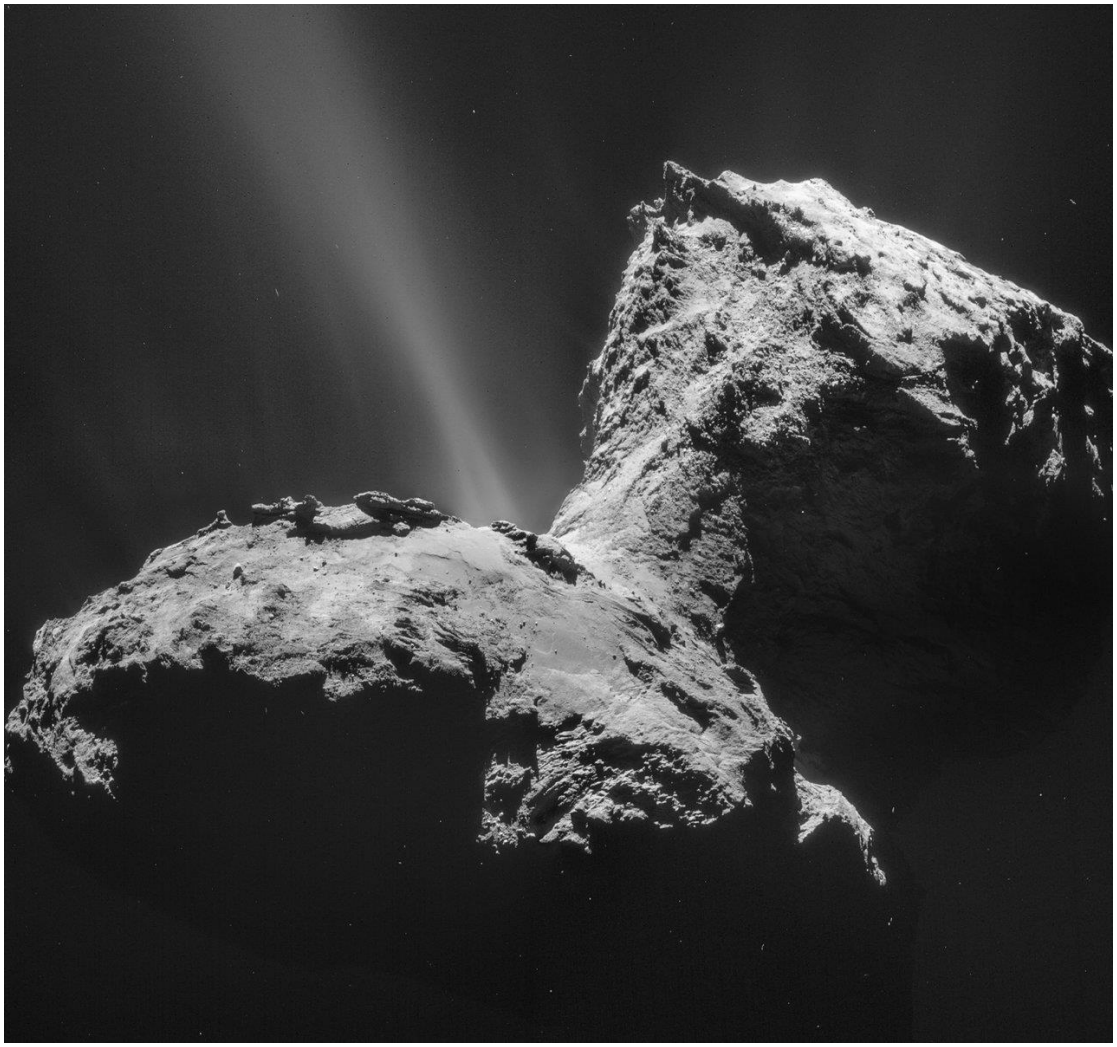
c) The color of solar radiation depends not only on the wavelength of the peak photospheric radiation. Since photospheric radiation covers a wide range of wavelengths, solar radiation is actually a superposition of electromagnetic waves covering a wide range of wavelengths.

d) Since the power of blackbody radiation is proportional to the fourth power of temperature, sunspot radiation is much weaker than the average photospheric radiation. This fact also explains why sunspots are much darker than the surrounding area.

**Question 30:**

The photo below (Fig Q30.1)was taken by the Rosetta spacecraft when it was close to the nucleus of comet Churyumov-Gerasimenko. This picture clearly shows the ejection

of cometary material from the nucleus into space. Which of the following statements is **NOT** correct? (only one answer)



FigureQ30.1

a) Solar radiation enhances the temperature on the sun-facing side of the nucleus, which facilitates sublimation and eruption of materials from the sunlit surface.

b) The eruption jets from the nucleus form comet tails, which is roughly oriented from the comet nucleus towards the sun.

c) When a comet is far away from the sun, the nucleus temperature is so low that the material can hardly erupt to space. Therefore, comet tails hardly appear.

d) Jets on the sunward side of the nucleus exert a thrust on the nucleus, which leads to gradual changes in the orbital parameters of the comet nucleus.

# Planetary Bodies in the Solar System and Beyond (Questions 31-45)

## Introduction

Under the high-temperature conditions of the early Solar System, besides the common gaseous elements (such as C-H-O-N-S), many metallic elements (such as Al-Ca-Si-Mg-Fe-Ni-Na, etc.) could also exist in gaseous form. In the field of early Solar System research, there is a classic theoretical model that posits a gas cloud with the average composition of the Solar System gradually cools, accompanied by equilibrium mineral condensation and reactions. This process can effectively explain the mineral compositions and chemical characteristics observed in primitive chondritic meteorites (Figure Q31.1). The term "equilibrium mineral condensation and reactions" refers to the state where the solid phase (mineral phase) condensed in the system is always in equilibrium with the gas cloud. Assume the mass percentages of metallic elements in the initial gas cloud (excluding H and He) are Na (0.51%), Mg (9.65%), Al (0.860%), Si (10.65%), Ca (0.925%), and Fe (18.1%).

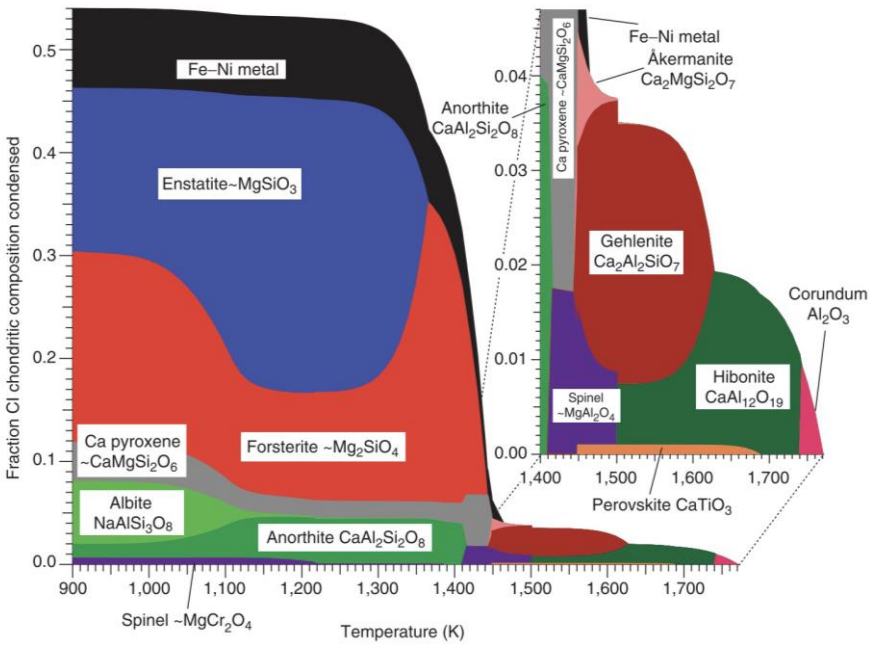



Figure Q31.1 The main equilibrium mineral condensation and reaction sequence

accompanying the cooling process of a gas cloud with the average composition of the Solar System.

**Note:** The vertical axis shows the mass fraction of condensed mineral phases in the system (excluding H and He), while the non-mineral phase portion of the system is in gaseous form.

**Question 31:**

Based on Figure Q31.1, at 1250 K, what is the mass percentage of Na in the gas cloud (excluding H and He)? (only one correct answer)

a) 0.51%
b) 0.75%
c) 1.09%
d) 1.53%
e) 2.01%

**Question 32:**

According to Figure Q31.1, how does the Mg/Si ratio in the gas cloud change from 1450 K to 1200 K? (Only one correct answer)

a) It increases
b) It decreases
c) It does not change
d) It decreases then increases
e) It increases then decreases

**Question 33:**

Carbonaceous chondrites often contain refractory inclusions. Assuming that a particular refractory inclusion forms within the temperature range of 1400-1600 K, which of the following mineral(s) could it contain?

a) Albite
b) Forsterite
c) Spinel
d) Corundum
e) Gehlenite

## Introduction

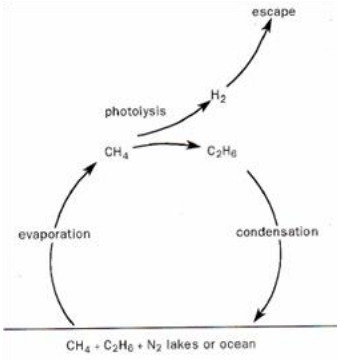
Titan, Saturn's largest moon, has an average radius of approximately 2575 km. It possesses a dense atmosphere primarily composed of nitrogen and methane (with methane proportion varying from 1.4% to 5% with altitude). The surface atmospheric pressure (P) is $1.5\times 10^5$ Pa [1 Pa = 1 kg/(m·s$^2$)], with a surface temperature of 94 K and a gravity (g) of 1.4 m/s$^2$.

**Question 34:**

The mass of a vertical air column on Titan (Mc: the mass of the vertical air column extending upwards to the upper atmosphere per unit area, Mc = P/g) is? (Only one correct answer)

a) 1,000 kg
b) 10,000 kg
c) 100,000 kg
d) 1,000,000 kg

Introduction (Q35-Q36): Methane in Titan's atmosphere undergoes photolysis by solar radiation, generating heavier ethane and other organic compounds.




**Question 35:**

The loss rate of methane is approximately $1.3 \times 10^{10}$ molecules $cm^{-2}$ $s^{-1}$ ($3.46 \times 10^{-16}$ kg $cm^{-2}$ $s^{-1}$), if no other mechanism provides methane to the atmosphere, approximately how long will it take for methane in Titan's atmosphere to be completely depleted? (Only one correct answer)

a) 1-10 million years

b) 10-100 million years

c) 100-1000 million years

d) Greater than 1 billion years

**Question 36:**

If half of the lost methane is converted into liquid ethane and accumulates on Titan's surface, and such a process has occurred over the past 4 billion years, how deep is the ethane ocean on Titan's surface now? (Under the temperature and pressure conditions on Titan's surface, the density of liquid ethane is 650 $kg/m^3$.) (only one correct answer.)

a) 0.1-1 meter

b) 1-10 meters

c) 10-100 meters

d) 100-1000 meters

## Introduction

Earth possesses a natural satellite, the Moon, which is 1% of its own mass. Chemically, the Moon is poor in iron and volatile substances compared to Earth; however, it has isotopic ratios strikingly similar to Earth's. Based on Earth-Moon laser ranging experiments, it is estimated that the current distance between Earth and the Moon is about 60 Earth radii, with the Moon receding from Earth at a rate of approximately 3.8 cm per year.

Traditional planet-moon theories struggle to account for the Moon's aforementioned characteristics. Consequently, four hypotheses have been proposed regarding the Moon's origin: capture, double planet, fission, and giant impact hypotheses. The first three are either contradictory to celestial mechanics or inconsistent with the current chemical characteristics of Earth and the Moon. The giant impact hypothesis is currently the prevailing view on the origin of the Moon. According to this hypothesis, the Moon was formed from the debris accreted after a Mars-sized body, Theia, collided with the primordial Earth, Gaia. Specifically, after the violent collision between Theia and the primordial Earth, the ejected mantle materials from both bodies, in the form of molten and gaseous matter, were propelled into space, forming a cloud of refractory, low-volatility dust. Within this cloud, dust outside the Roche limit began to coalesce and accrete through collisions, leading to the formation of the Moon over approximately 100 years. The dust within the Roche limit eventually fell back to Earth, while the majority of Theia's metallic core sank into Earth's core.

Note: The Roche limit describes the critical distance at which a celestial body can maintain its integrity, that is, the distance at which the body's own gravitational attraction is equal to the tidal forces exerted on it by another celestial body.

The formula for calculating the Roche limit for a rigid body for the Earth Moon system is:

$$d \approx 1.26 \cdot R_{\oplus} \left(\frac{\rho_{\oplus}}{\rho_{\mathbb{C}}}\right)^{1/3} \approx 1.5 \cdot R_{\oplus}$$

The first-order approximation formula for the tidal forces exerted on the Earth by the Moon is as follows:

$$F_{tidal} = 2 \cdot \frac{G \cdot M_{\oplus} \cdot M_{\mathbb{C}} \cdot R_{\oplus}}{d^3}$$

ρ, R, and M are the density, radius, and mass of the Earth (⊕) and Moon (☾), respectively; G is the gravitational constant: $6.67 \times 10^{-11}$ $m^3 \cdot kg \cdot s^{-2}$.

**Question 37:**

Which of the following facts is(are) consistent with the Giant Impact Hypothesis for the formation of the Moon?

a) The Moon is depleted in volatile elements relative to Earth.
b) The Moon has a smaller iron core than the Earth.
c) The Moon and Earth's rocks have highly similar compositions of oxygen isotopes.
d) The majority of the Moon's material is inherited from Theia.
e) Studies of lunar volcanic glass beads, olivine inclusions, and anorthosite have all found evidence of water on the Moon.
f) Earth's spin axis has an inclination of about 23.5 degrees.
g) The lunar surface has a vast number of impact craters.

**Question 38:**

How many times greater was the tidal force exerted on the Earth by the Moon just after its formation compared to today? (Only one correct answer)

a) 64000 times
b) 32000 times
c) 16000 times

d) 8000 times

**Question 39:**

Just after the formation of the Moon, how long did it take to complete one orbit around the Earth? (Only one correct answer)

a) ~ 3 hours
b) ~ 3 days
c) ~ 8 hours
d) ~ 8 days

**Question 40:**

Today, the apparent diameter of the Moon is about 0.5 degrees. What was the approximate apparent diameter of the Moon as seen from Earth's surface 4.5 billion years ago? (Only one correct answer)

a) 40 degrees
b) 30 degrees
c) 20 degrees
d) 10 degrees

## Introduction

Mars is the fourth planet from the Sun and has been a popular target for deep-space exploration in recent years. The fundamental parameters of Mars are as follows: average radius: ~3400 km (about 0.53 times that of Earth); axial tilt: 25.19 degrees; orbital period: 687 Earth days; rotation period: 24.6 hours; volume: $1.63\times10^{11}$ $km^3$ (about 0.15 times that of Earth); mass: $6.42 \times 10^{23}$ kg (about 0.11 times that of Earth); average density: 3.93 $g/cm^3$; surface gravity: 3.7 $m/s^2$ (about 0.38 times that of Earth).

The Martian atmosphere is primarily composed of carbon dioxide, with an atmospheric pressure of about 600 pascals (compared to Earth's). The surface of Mars is varied, including plains, volcanoes, canyons, and polar ice caps. Mars has two moons—Phobos and Deimos. Phobos has an average density of 1.9 g/cm$^3$ and orbits at a distance of 9,236 km, while Deimos has an average density of 1.5 g/cm$^3$ and orbits at a distance of 23,458 km.

**Question 41:**

The tallest mountain on Mars is Olympus Mons, which is approximately 600 kilometers wide and 21.9 kilometers tall, equivalent to three times the height of Earth's Mount Everest (about 8848 meters). What could be the reason(s) for Olympus Mons being the tallest peak in the solar system?

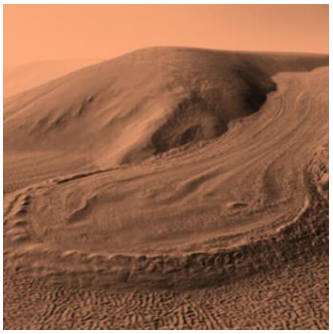
a) Mars has only about 38% of Earth's gravity, allowing for greater potential peak height compared to Earth.
b) Without plate tectonics, magma can continually build up in one place on Mars, increasing the mountain's height.
c) Mars experiences more frequent volcanic activity than Earth, contributing to taller mountains.
d) Mars lacks the geological erosion processes from wind and water that would otherwise wear down a mountain's mass.
e) The volcanic nature of Olympus Mons provides a more stable base than the tectonic plate uplift that formed Mount Everest.

**Question 42:**

Currently, due to the arid, cold, and low-pressure climatic conditions on Mars, no stable liquid water exists on the surface. However, water can still be present on Mars in various forms: as polar ice caps at both poles; as water vapor in the atmosphere; as highly

concentrated brines underground or beneath ice layers; and within mineral crystals, such as clays, sulfates, carbonates, etc. Exploration has discovered traces suggesting that a significant amount of liquid water once existed on the Martian surface. Which of the following pictures could serve as evidence of past liquid water?

A



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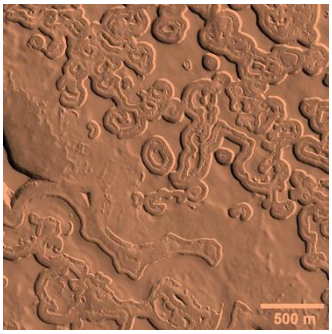


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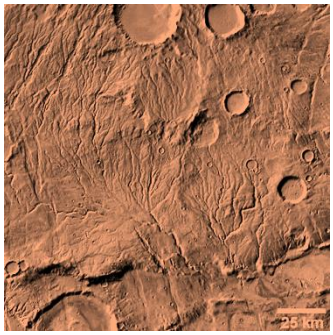

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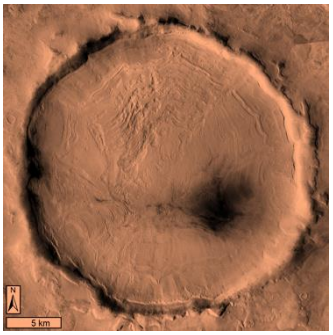


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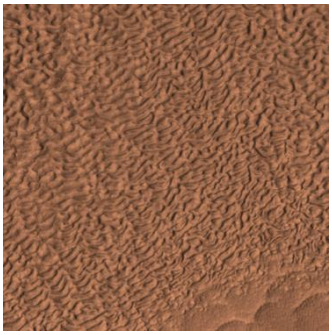

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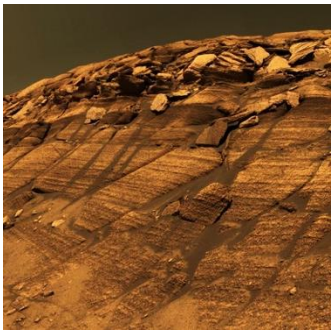

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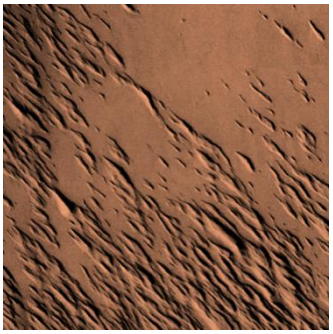

H

**Question 43:**

Research indicates that hydrogen (with an atomic mass of $1.674\times10^{-27}$ kg) on Mars is escaping at a rate of ~ $2\times10^{26}$ atoms/s, oxygen is escaping at ~ $5.05\times10^{25}$ atoms/s, and carbon is escaping at ~ $5\times10^{23}$ atoms/s. Without considering historical variations, over the past 4.5 billion years of evolutionary history, what depth of the global equivalent layer of water has been lost to space? (only one correct answer)

a) ~ 1.5 meters

b) ~ 3 meters

c) ~ 50 meters

d) ~ 500 meters

**Question 44:**

Phobos, one of Mars' moons, is very close to Mars and gradually moving towards the planet due to its tidal forces. Phobos has an average density of 1.9 g/cm$^3$ and orbits at a distance of 9,236 km, while Deimos has an average density of 1.5 g/cm$^3$ and orbits at a distance of 23,458 km.

Note: The formula for calculating the Roche limit assuming a rigid body for Mars (M) and the Martian Moon (ℂ) system is:

$$d\approx1.26\cdot R_M\left(\frac{\rho_M}{\rho_{\mathbb{C}}}\right)^{1/3}$$

At approximately what distance from Mars' surface will Phobos be torn apart by Martian gravity?

a) 5400 km

b) 200 km

c) 500 km

d) 2000 km

**Introduction**

In recent years, astronomers have successfully observed thousands of exoplanets using various methods, greatly expanding our knowledge of planetary systems in the universe. The main observational techniques include: radial velocity method, transit method, microlensing, direct imaging, and astrometry. Among these, the radial velocity method (which measures the mass and orbital parameters of a planet by observing the Doppler frequency shift in the star's spectrum, suitable for detecting large-mass planets close to the star) and the transit method (by observing changes in brightness, the size and orbital period of the planet can be deduced, suitable for detecting planets close to the star) are the two most commonly used methods.

**Question 45:**

When a planet passes in front of the stellar disk, it blocks out a portion of the starlight, causing a periodic slight dimming of the star's brightness. Some exoplanets' information could be obtained by observing the associated light curve of the host star during the transits. Scientists have extracted three light variation signals, a, b, and c, from the observations of a particular star over a period of time, as shown in the following figure, which of the following statements is **NOT** correct? (only one answer)

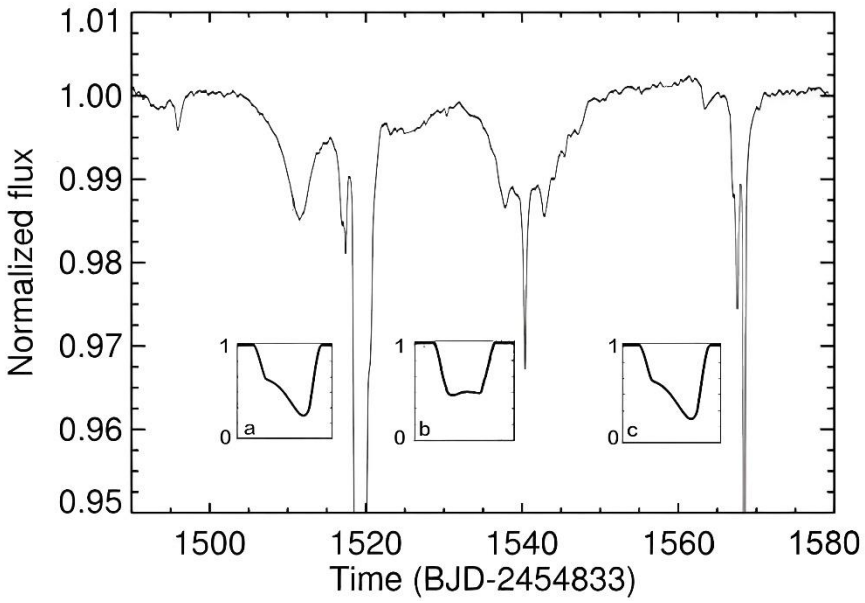


Figure Q45.1 Observations of a star over days. BJD=Barycentric Julian Days. The subset figures a, b and c are condensed diagrams of the peaks. Each subset have the same time period for the X-axis.

a) There is at least a two-planet system present, signals a and c may be produced by the same planet.

b) Planet b has a larger volume relative to the host star compared to the planets a and c.

c) One of the planets has an orbital period of approximately 50 days.

d) Planetary atmospheric characteristics can be obtained by measuring the light curve at the beginning or end of transits.