USESO 2024

National Open Exam

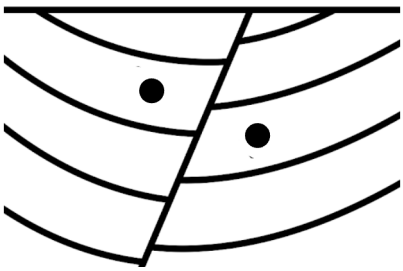
Section I

KEY

Instructions:

- Section I consists of 30 multiple choice questions. Each question is worth 2 points.
- Questions are **not** ordered by difficulty.
- Print your **USESO Student ID** on the ZipGrade answer sheet and the cover of this test.
- Bubble your answers clearly on the ZipGrade answer sheet. Pencil or pen is fine; if you use pencil, push down as you write to make the scan easier to read.
- You have **2 hours** to complete both sections in any order, and you may flip back and forth between sections.

1. Shown below is a sketch of a geologic cross-section. The dots indicate two fossils located in the same rock unit.



Identify the type of fold and fault, respectively, present in the cross-section above.

A. Anticline, normal fault
B. Anticline, reverse fault
C. Syncline, normal fault
D. Syncline, reverse fault

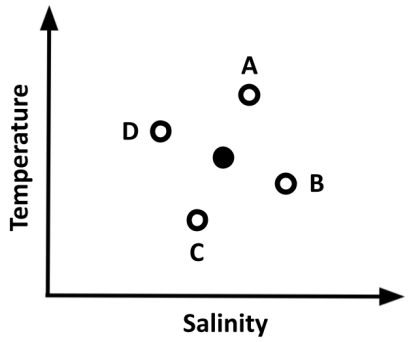
Solution: A syncline is a fold with younger layers at the center and is usually concave up. In this fold, the layers in the center are further up and younger by the principle of superposition. The fault results in uplift of the hanging wall (left) relative to the footwall (right), so it must be a reverse fault.

2. Which of the following is most likely true regarding the flow of groundwater?

A. Groundwater flows away from streams in desert environments
B. Groundwater flows parallel to lines of equal pressure beneath Earth's surface
C. Groundwater flows faster through silt compared to sand
D. The presence of karst topography decreases groundwater flow rates

Solution: Desert environments generally correspond to low water tables due to high evaporation rates, so surface water would flow into the ground and away from the stream - A is true. Because groundwater moves from high to low pressure, it tends to flow perpendicular to lines of equal pressure - B is false. Silt grains are smaller than sand grains, and sediments with smaller grains are typically less permeable - C is false. The dissolution of limestone in karst topography creates openings for groundwater to flow through, increasing flow rates - D is false.

3. Consider the following temperature-salinity (T-S) diagram. Each labeled point represents a possible combination of temperature and salinity conditions.



If the solid black point represents conditions measured at the surface of a subtropical water column, which of the labeled points most likely represents the conditions at the bottom of the water column?

A. A B. B **C. C** D. D

Solution: In subtropical regions, surface water is warm and has very high salinity due to high evaporation and a lack of precipitation. Below the thermocline, deep water is typically much colder due to a lack of sunlight and has high salinity, although not as high as at the surface. Thus, deep water in a subtropical water column has a much lower temperature and slightly lower salinity.

4. Io is a moon of Jupiter subjected to immense tidal forces due to its interactions with nearby moons Europa and Ganymede. Which of the following is/are true of Io?

I) Io's surface displays extensive evidence of impact cratering

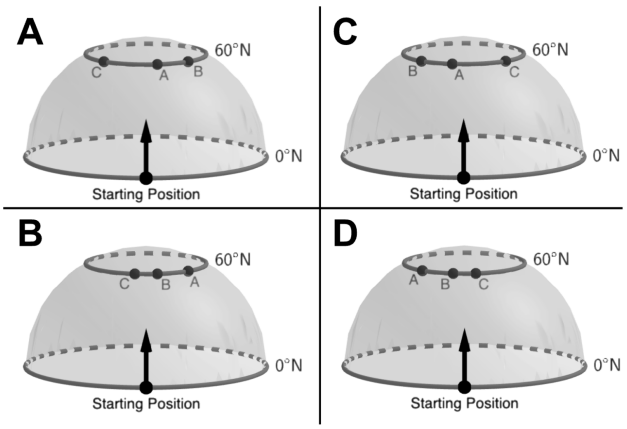
II) Io's atmosphere is predominantly composed of CH_4 gas

A. I only B. II only C. I and II **D. None**

Solution: The immense tidal forces exerted on Io have led to the moon's designation as the most volcanically active object in the solar system. Io's exterior is constantly resurfaced by volcanism, so impact craters are rarely preserved – I is false. Io's tenuous atmosphere is produced by outgassing from volcanic activity and is composed mainly of SO_2 – II is false.

5. Paige the pilot explores three planets identical to Earth except with different directions of rotation (when viewed from above the North Pole) and day lengths as shown in the table below.

Planet	Direction of Rotation	Day Length
A	Clockwise	12 hours
B	Clockwise	36 hours
C	Counterclockwise	36 hours



Paige begins flying at each planet's equator and travels northward until she reaches 60°N latitude. Which of the above configurations best approximates her final location on each of the three planets?

A. A B. B C. C **D. D**

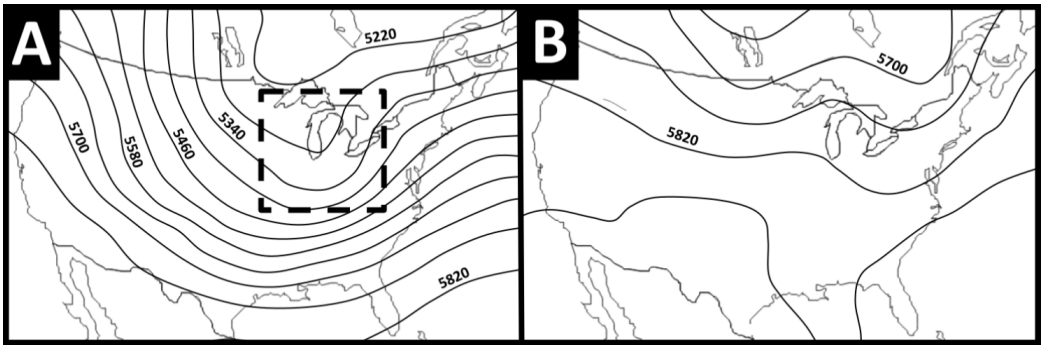
Solution: When an object travels polewards, the Coriolis effect induces deflection in the same direction as the rotation of the planet due to the conservation of angular momentum. Counterclockwise rotation represents left-to-right movement, so planet C would cause a rightward deflection while planets A and B would cause a leftward deflection. This deflection is magnified when rotational velocity is increased and day length is decreased, so planet A would have the greatest deflection.

6. A rising magma plume enters a section of continental crust. Which of the following minerals would be the first to crystallize from the magma?

A. Biotite **B. Olivine** C. Pyroxene D. Quartz

Solution: Minerals are removed from magma by fractional crystallization in the order determined by Bowen's reaction series. Since olivine has the highest crystallization temperature of the minerals in the series, it would be removed first.

7. Shown below are two atmospheric maps of the contiguous United States. The wavy black lines represent height contours at 500 mb.



Which of the following statements is/are true regarding these diagrams?

I) On Map A, a surface high-pressure zone can be found in the boxed region

II) Map A is more typical of summer conditions while Map B is more typical of winter conditions

A. I only B. II only C. I and II **D. None**

Solution: 500 mb atmospheric maps mark the elevation at which air pressure reaches 500 mb. Since upper-level divergence is occurring in the boxed region, air is likely rising, indicating the presence of a surface low-pressure zone - I is false. Map A has a stronger gradient and lower 500 mb heights than Map B, indicating the presence of higher-density cold winter air - II is false.

8. The concentrations of iron oxide and aluminum in tropical soil horizons are heavily influenced by leaching. Which of the following correctly lists the A, B, and E horizons in order of lowest to highest iron oxide and aluminum concentrations?

A. A, B, E B. B, A, E C. E, B, A **D. E, A, B**

Solution: Leaching typically removes iron oxide and aluminum from the E horizon and, to a lesser extent, the A horizon. This causes them to accumulate in the lower B horizon. Thus, the E horizon would have the lowest concentrations of iron oxide and aluminum while the B horizon would have the highest concentrations.

9. Light produced by nuclear fusion in the Sun's core powers almost all biological processes on Earth. However, this light does not follow a smooth path as it escapes the Sun. Which of the following solar layers is/are almost entirely transparent to visible light?

I) Radiative zone

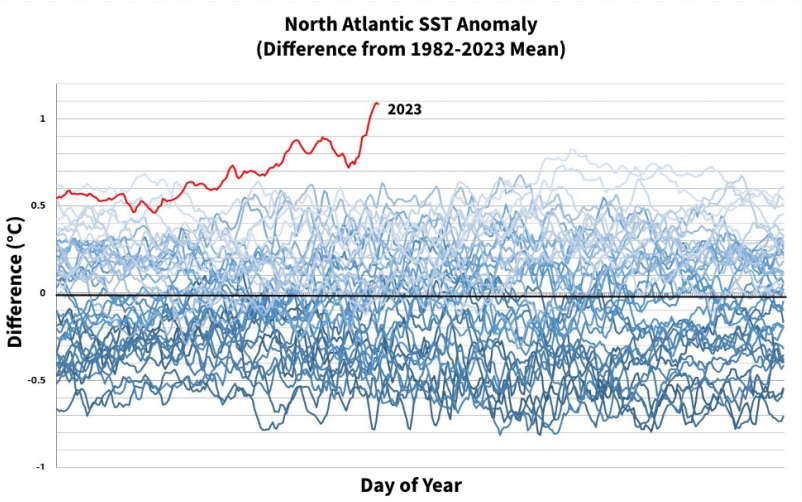
II) Photosphere

III) Chromosphere

A. I only B. II only **C. I and III** D. II and III E. I, II, and III

Solution: Radiation is the primary heat transfer mechanism in the radiative zone, meaning the layer must be transparent to visible light - I is true. The photosphere is defined as the outermost opaque layer of the Sun and is the part of the Sun that is visible to us - II is false. The chromosphere lies just outside the photosphere and is too thin to absorb an appreciable amount of light - III is true.

10. The graph below records a remarkable 2023 anomaly in Atlantic sea surface temperature (SST), a phenomenon which has caught widespread media attention in regards to global warming: *"The Atlantic is running a fever!"*



This anomaly could stem from a 2020 policy enacted by the International Maritime Organization (IMO) that impacted marine fuel sulfur content and SO_x emissions. Which of the following mechanisms best explains the Atlantic SST anomaly as an effect of this policy?

A. Sulfate aerosols maintain acidity of rain, which controls phytoplankton growth. Reduced SO_x emissions increased surface algae biomass, lowering ocean albedo and increasing mean SST.

B. Reduced SO_x emissions reduced aerosols and cloud condensation nuclei, decreasing cloud cover and solar reflectivity, increasing absorption of sunlight by the ocean and mean SST.

C. Greater deposition of sulfate aerosols darkened Arctic sea ice, decreasing polar albedo and increasing absorption of solar radiation, increasing mean SST.

D. Greater SO_x emissions enhanced the greenhouse effect by forming sulfuric acid aerosols that trap infrared radiation, increasing mean SST.

Solution: Phytoplankton growth has a cooling effect due to carbon uptake, while its effect on albedo is minimal – A is false. Sulfate aerosols largely impact lower latitudes with more shipping activity, while Arctic ice darkening is due to black carbon and dust – C is false. Sulfate compounds like H_2SO_4 do not efficiently absorb infrared radiation at Earth's emission wavelength and generally cause net cooling by increasing cloud cover – D is false. B explains the effects most accurately: the IMO policy reduced sulfur fuel content, indirectly decreasing the presence of high-albedo ship trails and contributing to this warming.

11. Gwen the geologist measures temperature profiles of the crust in three regions and finds geothermal gradients of 20°C/km, 30°C/km, and 40°C/km. Which of the following tectonic environments most likely correspond to these three profiles, respectively?

A. Continental hotspot, subduction zone, mid-ocean ridge

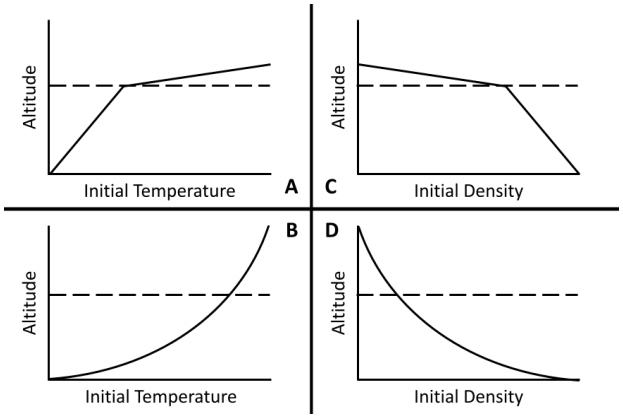
B. Mid-ocean ridge, continental hotspot, subduction zone

C. Mid-ocean ridge, subduction zone, continental hotspot

D. Subduction zone, continental hotspot, mid-ocean ridge

Solution: Subduction zones typically exhibit depressed geotherms because they involve cold crust sinking deeper than normal, so temperature increases slowly. Hotspots and mid-ocean ridges both have elevated geotherms due to the presence of magma from the mantle, but mid-ocean ridges typically have the most elevated geotherms because their unusually thin crust allows hot mantle to push up near the surface. Thus, subduction zones have the lowest geothermal gradients, followed by hotspots, followed by mid-ocean ridges.

12. Mike the meteorologist creates and releases two sets of balloons into the atmosphere. The first set contains air heated to different temperatures, while the second set contains gases of different densities at room temperature. Mike then graphs the height each balloon reached compared to the variable he changed, with the tropopause shown as a dashed line. Which of the following pairs of graphs most accurately represents his findings?



A. A and C **B. A and D** C. B and C D. B and D

Solution: These balloons represent air parcels as they travel through the air. A balloon with a higher temperature would rise because it is less dense than the surrounding air, but it would gradually cool as it rises until it reaches the same temperature as the environment. Once it reaches the tropopause, the environmental temperature would rise and the balloon would no longer be warmer than its surroundings, preventing it from rising further. Density is not affected by this, however, because atmospheric density decreases monotonically as altitude increases. A balloon that is less dense than the atmosphere would rise until it has the same density as its surroundings, so it would not be bounded by the tropopause.

13. A gyre consists of ocean currents circulating around a central region. Which of the following best describes the motion of water at the center of the gyre in the subtropical South Atlantic?

A. Upwelling due to convergence of water at the center of the gyre

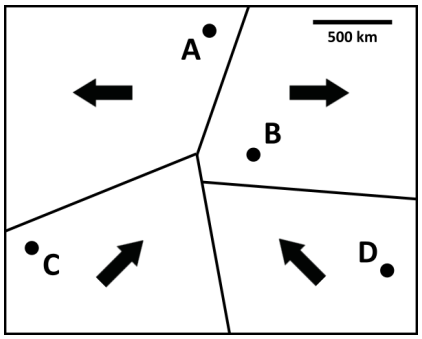
B. Upwelling due to divergence of water at the center of the gyre

C. Downwelling due to convergence of water at the center of the gyre

D. Downwelling due to divergence of water at the center of the gyre

Solution: Ekman transport moves water towards the center of subtropical gyres as the Coriolis effect deflects water from circulating currents (to the left in the Southern Hemisphere, to the right in the Northern Hemisphere). This convergence of water at the surface displaces water downwards via a process called Ekman pumping.

14. The following map displays four oceanic tectonic plates and their boundaries, with arrows showing each plate's direction of motion. At which of the four labeled points on the map would an island arc most likely be present?



A. A **B. B** C. C D. D

Solution: Island arcs primarily form from magma at subduction zones on the opposite side of the subducting plate. Point B is the only point where this occurs; here, the two bottom plates would each subduct and melt, producing magma that would rise to the surface.

15. Mass movements tend to occur more frequently on slopes that have been destabilized. Which of the following would likely increase the probability of a mass movement occurring?

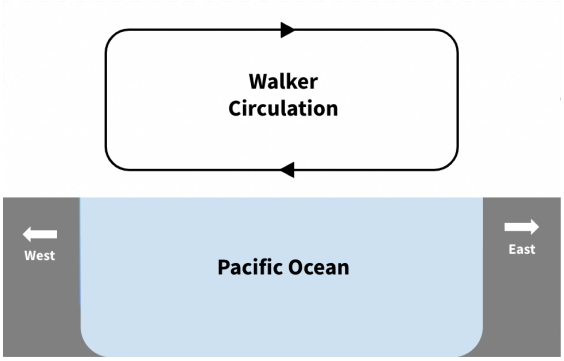
I) Presence of a stream near the bottom of the slope

II) Presence of an internal schist bed with planes dipping perpendicular to the slope

A. I only B. II only C. I and II D. None

Solution: Downcutting and erosion by a stream at the bottom of a slope would steepen and destabilize the slope, making mass movement more likely - I is true. The presence of foliated schist dipping perpendicular to slope direction would likely have minimal effect on the probability of mass movement as the planes of weakness would not align with slope direction - II is false.

16. El Niño is a recurring climate phenomenon that alters the circulation pattern of air over the Pacific Ocean. This pattern is known as the Walker Circulation and is shown below.



Which of the following best characterizes the effect of El Niño on the strength of the Indian Summer Monsoon, a large-scale climate event that brings heavy rains to the Indian subcontinent between June and September?

A. Strengthens, because the Walker circulation is strengthened

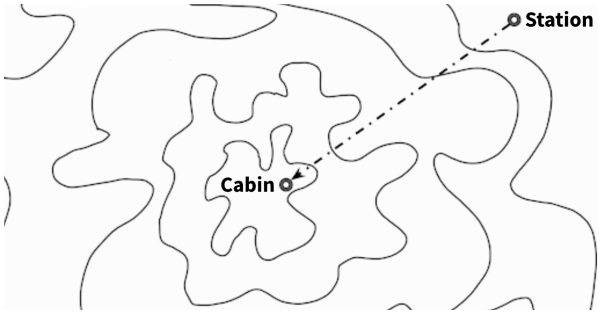
B. Strengthens, because the Walker circulation is weakened

C. Weakens, because the Walker circulation is strengthened

D. Weakens, because the Walker circulation is weakened

Solution: El Niño events correspond with weakening trade winds in the equatorial Pacific as pressure falls over the Eastern Pacific and rises over the Western Pacific. This would weaken the Pacific Walker circulation and result in anomalous sinking of air in the Western Pacific, suppressing rainfall and weakening the Indian Summer Monsoon.

17. Gerry the geologist stumbles upon a rare exposed gabbro pluton surrounded by a region of metamorphic rock. After setting up a station on the unaltered shale and mudstone around the pluton, he notices that his friend Sherry has built a cabin on top of the pluton. Gerry maps out the region and his path to Sherry's cabin as shown below.



Given that the region had uniform composition before the pluton intruded, which of the following sequences would Gerry most likely find as he walks toward Sherry's cabin?

A. Shale, phyllite, greenschist, blueschist

B. Shale, slate, greenschist, gneiss

C. Shale, slate, phyllite, greenschist

D. Shale, zeolite, hornfels, sanidinite

Solution: This scenario represents an occurrence of contact metamorphism as rocks bordering hot magma are altered in relatively low-pressure conditions. Choices A, B, and C may be eliminated by noting the presence of schists, highly foliated metamorphic rocks that occur as products of regional metamorphism. However, zeolites, hornfels, and sanidinite are all formed in relatively low-pressure metamorphic environments, typically due to contact metamorphism surrounding bodies of magma.

18. Comet Hale–Bopp reached its perihelion in April 1997, becoming visible to the naked eye for 18 months. In the year 4385 CE, Hale–Bopp is expected to reach its perihelion once again. Which of the following statements about Hale-Bopp is most likely true?

A. Comet Hale–Bopp is approximately confined to the ecliptic plane

B. Comet Hale–Bopp was set into motion by a passing star

C. Comet Hale–Bopp has a hyperbolic orbit

D. Comet Hale–Bopp will be nearly depleted of volatiles by 4385 CE

Solution: Long-period comets like Comet Hale-Bopp generally originate from the Oort Cloud, which is not confined to the ecliptic - A is false. As Hale-Bopp will make a second passing, it must have an elliptical orbit - C is false. In addition to being able to survive several passings, long-period comets usually break up before they are depleted of volatiles - D is false. Most long-period comets in the Oort Cloud are set into motion by passing stars; although the specific trigger for Hale-Bopp's motion is currently indeterminable, B is likely true.

19. Which of the following statements accurately describe(s) radiation in the Earth system?

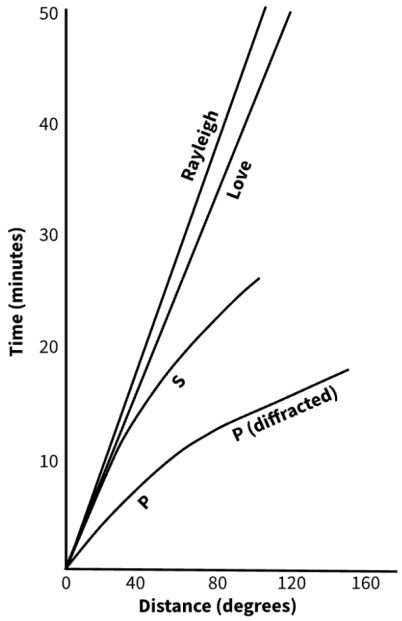
I) Greenhouse gases increase surface temperatures mainly by reducing the amount of shortwave radiation emitted to space

II) An increase in the global mean surface temperature results in more longwave radiation being emitted from Earth's surface

A. I only **B. II only** C. I and II D. None

Solution: Although Earth receives shortwave radiation from the Sun, Earth emits lower-energy longwave radiation because it is much cooler than the Sun. Greenhouse gases primarily affect the longwave radiation emitted to space, not shortwave - I is false. By the Stefan-Boltzmann law, objects with higher temperatures emit greater amounts of radiation - II is true. (This describes an important feedback in Earth's climate called Planck feedback.)

20. The diagram below shows travel time curves for selected types of seismic waves released during an earthquake. Distance is measured from the epicenter and time is measured from the onset of the earthquake.



Which of the following is true regarding these seismic waves?

A. P waves speed up over time due to increasing mantle rigidity with depth

B. S waves slow down over time due to mineral phase transitions in the mantle

C. Both P and S waves cannot propagate through the outer core

D. Surface waves have the longest travel times due to their elliptical paths through the mantle

Solution: S wave velocity is shown to increase over time - B is false. P waves can propagate through the outer core because compressional waves can travel through liquids - C is false. Surface waves by definition do not travel through the mantle - D is false. P waves travel faster through the mantle because rock is more rigid at high pressures within the planet, and the formula for P wave velocity is proportional to the square root of rigidity - A is true.

21. An exoplanet is observed transiting a Sun-like star every 3.54 days, dimming the star by about 1% each time it passes in front. Given that the change in brightness during transit can be approximated as $(\frac{R_p}{R_s})^2$, where R_p represents the exoplanet's radius and R_s represents the star's radius, which of the following statements is/are likely true?

I) The exoplanet contains large amounts of water, methane, and ammonia ices

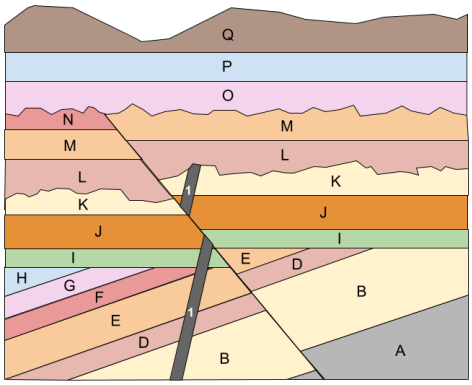
II) The exoplanet has a rotational period of 3.54 days

III) The exoplanet migrated inward after its initial formation

A. I only B. III only C. I and II **D. II and III** E. I, II, and III

Solution: The observed exoplanet is likely a hot Jupiter due to its short orbital period and large radius. Water, methane, and ammonia are common in ice giants but rare in Jupiter-like planets - I is false. Hot Jupiters are typically tidally locked, meaning their rotational periods equal their orbital periods - II is true. Since large gas giants cannot originate close to their host stars, they typically form further out and then migrate inward - III is true.

22. Roger the rock hound collects samples from the rock layers shown below to be radiometrically dated. After processing the samples, he obtains the data in the table to the right.



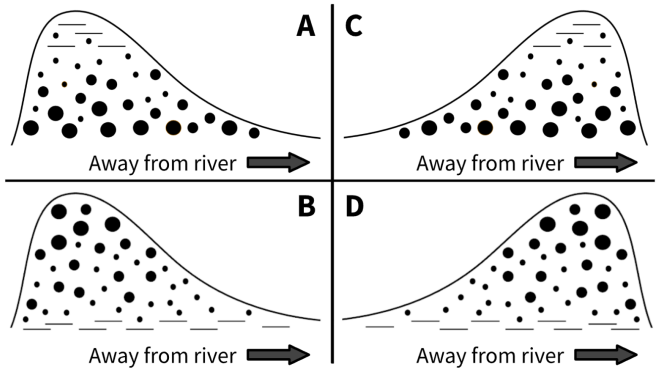
Structure	Approximate Age of Formation
A	5.5×10^8 years ago
I	3.1×10^8 years ago
K	2.7×10^8 years ago
N	2.0×10^8 years ago
O	1.1×10^8 years ago

How many millions of years ago (mya) could Structure 1 have formed?

A. 400 mya B. 300 mya **C. 250 mya** D. 150 mya

Solution: Because the exact age of Structure 1 was not determined, it must be bounded by the ages of surrounding layers. Structure 1 must be younger than Layer K and older than Layer L according to the law of cross-cutting relationships. Since layer N is younger than layer L according to the law of superposition, Structure 1 must have formed between the ages of Layer K and Layer N, or between 270 and 200 mya.

23. A meandering river repeatedly overflows, leading to the formation of natural levees along its banks. Which of the following cross-sectional views of the resulting levees, with dots representing individual sediment grains, is most accurate?



A. A **B. B** C. C D. D

Solution: Natural levees have gentler slopes farther from the river channel because energy is lost away from the river. Coarser sediments are deposited near the channel edges, and gradual progradation of the levee results in coarser sediments being located higher up (see Hudson 2007). Finer material also travels farther from the stream because it can be carried by lower-energy flows during flooding. The diagram consistent with all of these observations is B.

24. Estuaries are water bodies most commonly found in regions where rivers and oceans meet. Which of the following statements is/are true regarding estuaries?

I) Well-mixed estuaries have nearly vertical isohalines, lines connecting points of equal salinity

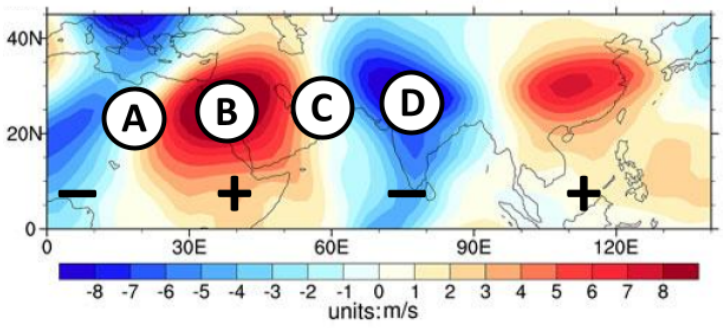
II) The onset of dry offshore winds reduces the salinity gradient of highly stratified estuaries

III) Internal waves are more prevalent in well-mixed estuaries compared to highly stratified estuaries

A. I only B. III only **C. I and II** D. II and III E. None

Solution: Salinity remains relatively constant with depth in well-mixed estuaries because freshwater and saltwater will be blended together uniformly – I is true. The onset of dry offshore winds increases the evaporation rate and thus surface salinity. As highly stratified estuaries exhibit more saline bottom waters and fresher surface waters, increasing surface salinity reduces the salinity gradient – II is true. Internal waves form at density boundaries, which would be more prevalent in highly stratified estuaries – III is false.

25. Shown below is a map of average meridional wind speed at a pressure of 250 mb (v250). Positive v250 corresponds to northward winds and negative v250 to southward winds. The sign of each shaded region is indicated on the map.

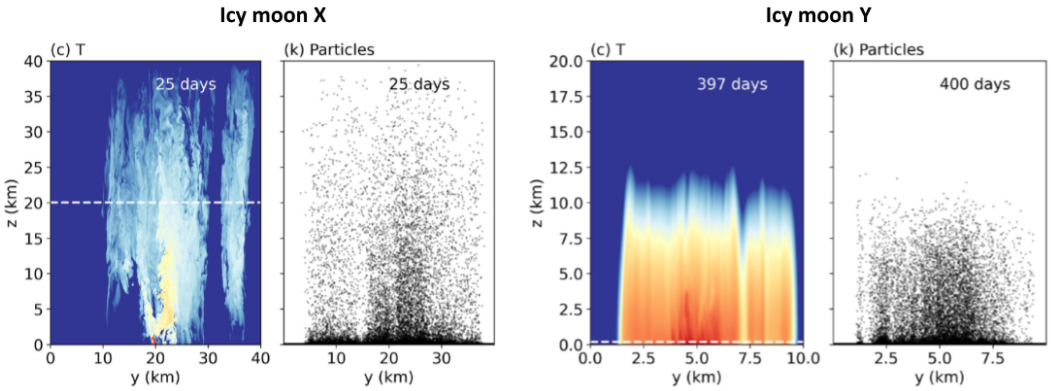


Based on these wind patterns, at which of the labeled regions would an upper-level ridge most likely be present?

A. A B. B **C. C** D. D

Solution: Upper-level ridges are situated in "bulges" of the jet stream, whereas troughs are situated in "dips." These "bulges" force the jet stream north, so winds would travel north as they enter the bulge to the west and south as they exit the bulge to the east. Thus, region C, the area between the strongest northward and southward winds, corresponds to a ridge.

26. Shown below are simulated hydrothermal vent plumes in subsurface oceans of two icy moons. The plumes both originated from point heat sources on the ocean floor and diffused into the surrounding ambient water, but they display very different shapes. Which of the following statements is/are likely true of the two moons?



(Note: Buoyancy force on the plume can be modeled as $b \approx \frac{g(\rho_{\text{ambient}} - \rho_{\text{plume}})}{\rho_0}$, where g is acceleration due to gravity and ρ_{ambient}, ρ_{plume}, and ρ_0 are the density of the ambient, plume, and reference water, respectively.)

I) Icy moon X has stronger gravity than icy moon Y

II) Icy moon X has a weaker heat source than icy moon Y

A. I only B. II only C. I and II D. None

Solution: Since the buoyancy force b is proportional to g, a stronger gravitational force would create a stronger buoyancy force. This is because the surrounding water is pulled down more by gravity while the less dense plume water is forced upward - I is true. A weaker heat source, however, would create cooler plume water that is less dense and rises less, which is not what is observed on icy moon X - II is false. Accordingly, icy moon X is Europa and icy moon Y is Enceladus; Europa has stronger gravity and more internal heat than Enceladus. See Bire et al. (2023) for more information.

27. Which of the following sets of conditions would be most favorable for the formation of a nighttime radiation fog?

A. Slight breeze and clear sky

B. Slight breeze and cloudy sky

C. Strong breeze and clear sky

D. Strong breeze and cloudy sky

Solution: Nighttime radiation fogs are typically formed in association with temperature inversions as surface layers of stable, cold air drop below dew point and condense. A strong breeze would mix air layers and bring warmer air aloft to the surface, inhibiting fog formation. Cloudy skies correspond to increased absorption of outgoing longwave radiation and would thus disrupt the cooling of surface air layers, inhibiting fog formation.

28. Eustatic sea level change is largely driven by freezing and thawing in polar regions. Rank the following ice masses in increasing order of effect on instantaneous, local sea level change if 10,000 km^3 of ice was melted from each mass.

I) Greenland Ice Sheet

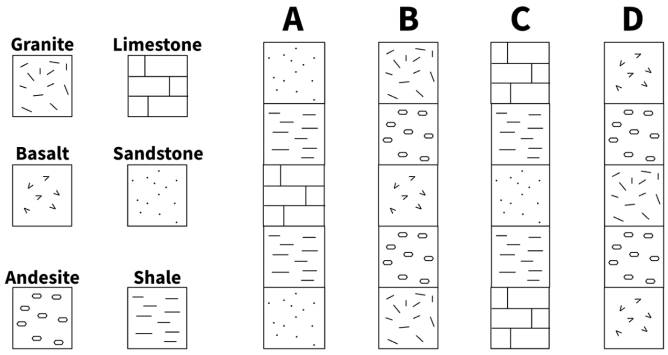
II) Ross Ice Shelf

III) North Atlantic sea ice

A. I, II, III B. II, I, III C. II, III, I **D. III, II, I**

Solution: While each of these processes would contribute to sea level rise, the largest effect would be produced by the melting of part of the Greenland Ice Sheet as it is located on land and displaces relatively less seawater per unit volume of ice. The Ross Ice Shelf would have the second largest effect because the shelf is partially submerged and partially grounded. North Atlantic sea ice is not grounded at all, meaning it displaces the most seawater per unit volume of ice and its melting would have a relatively small effect on sea level. Compensating factors such as isostatic rebound would not trigger instantaneously.

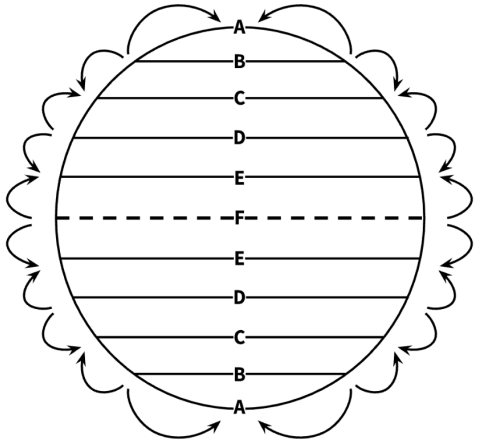
29. Diana knows that, beginning one million years ago at a particular section of tectonically inactive coastline, the sea level fell from its initial position and then rose back up. If Diana dug to rocks formed around one million years ago, which of the following sequences would she most likely find? Assume that layers on top are younger.



A. A B. B **C. C** D. D

Solution: The depositional energy of an environment generally decreases as water levels rise, resulting in a transition to finer-grained and bioclastic sedimentary rock. The opposite occurs as water levels fall. If sea levels fell and then rose, a sequence of bioclastic, then coarse-grained, then bioclastic rock would be expected. This corresponds with the limestone, shale, sandstone, shale, limestone sequence depicted in C.

30. A new planet, similar to Earth and possessing both liquid water and an atmosphere, is discovered. However, it is found to have five instead of three atmospheric circulation cells as shown below.



At which regions on this planet would arid climates most likely be present?

A. A, B, and C B. D, E, and F **C. A, C, and E** D. B, D, and F

Solution: Arid conditions are found at the descending branches of global atmospheric convection cells. In the above image, air rises at latitudes B, D, and F and descends at latitudes A, C, and E, losing humidity along the way due to precipitation. Descending air is relatively dry and warm due to adiabatic heating, leading to the development of arid climates.

END OF SECTION I