USESO 2025

Training Camp Exam

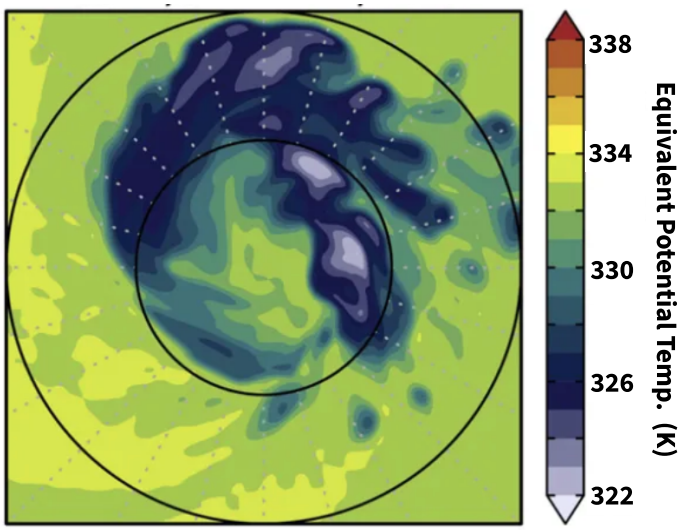
Multiple Choice

KEY

Instructions:

- Section I consists of 30 questions that assess geoscience knowledge in the form of multiple-choice questions. Each question is worth 2 points.
- You have 1 hour and 15 minutes to complete this section.
- Any type of calculator is allowed.
- Participating in this exam is agreement to our Academic Integrity Policy.

1. The following figure depicts the equivalent potential temperature (EPT) of a region on an isobaric surface; the black circles represent radii at every 50 kilometers. EPT is defined as the temperature that an air parcel would reach if all the water vapor it contained condensed and released the corresponding latent heat.



Which of the following statements is/are true regarding this region?

I) The region is located in the Northern Hemisphere and contains a surface low

II) EPT likely decreases with height in the region

A. I only

B. II only

C. I and II

D. None

Solution: A lower EPT implies a lower absolute humidity because less potential condensation is able to release heat. The green center of the region has a higher EPT than its bluer surroundings, implying it likely has a higher absolute humidity and temperature; this corresponds to a less dense low-pressure zone. The low-pressure system appears to spiral inward in a counterclockwise fashion, indicating that it is located in the Northern Hemisphere – I is true. Low-pressure environments are characteristically unstable. An EPT that decreases with height implies that colder, drier air overlies warmer, more humid, and less dense air, resulting in an unstable environment – II is true.

2. In an area thought to have once been at the ocean floor, scientists find a bed of calcareous sediment overlain by siliceous sediments. Which of the following past environmental changes would **least** likely account for this change in deposited material?

A. Sinking of the seafloor over time

B. Increase in subsurface ocean temperature over time

C. Increase in ocean acidity over time

D. Movement of the seafloor towards an area of coastal upwelling over time

Solution: This shift in sediment deposition typically occurs when a region goes from above to below the carbonate compensation depth (CCD). Below the CCD, carbonate minerals dissolve before reaching the seafloor, but new deposition protects existing sediments from dissolution. A decrease in seafloor elevation could bring a seafloor segment below the CCD - A is not the best choice. An increase in ocean acidity could increase the CCD height above a seafloor segment - C is not the best choice. Movement of the seafloor would not necessarily change its height, but the organisms that produce siliceous ooze (typically diatoms and radiolarians) thrive in regions of upwelling, which would shift the type of sediment deposited - D is not the best choice. An increase in ocean temperature would reduce calcareous ooze solubility and make it more likely to deposit, not less - B is the best choice.

3. During the early Pliocene, low mean sea levels resulted in the closing of the Indonesian Gateway, preventing equatorial water flow between the Pacific and Indian Oceans. A recent study used paleoclimate proxies to characterize P-E, or precipitation minus evaporation, across the Pacific Ocean during the early Pliocene. Which of the following correctly describes how the closing of the Indonesian Gateway would likely affect Pacific P-E?

   A. Higher P-E at the equator, higher P-E at mid-latitudes

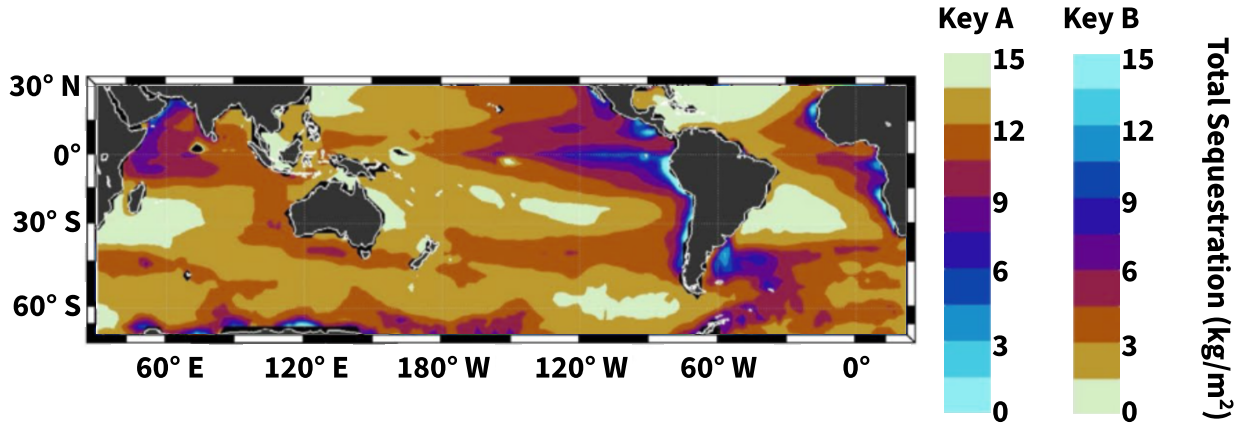
   B. Higher P-E at the equator, lower P-E at mid-latitudes

   C. Lower P-E at the equator, higher P-E at mid-latitudes

   D. Lower P-E at the equator, lower P-E at mid-latitudes

Solution: The closing of the Indonesian Gateway prevents equatorial water from leaving the Pacific, resulting in increased sea surface temperatures in the equatorial Pacific. This leads to increased equatorial evaporation and thus lower P-E at the equator. Since total precipitation approximately equals evaporation, global P-E must be very close to zero; lower P-E at the equator would thus be compensated by higher P-E at mid-latitudes.

4. The ocean carbon pump transfers carbon from the atmosphere and ocean surface to the deep ocean. The figure below depicts a model of the spatial distribution of the amount of carbon sequestered by this pump per year.



Given that one of Key A or Key B is correct, which of the following is true regarding this figure?

A. Key A is correct; downwelling at the center of subtropical gyres transports large amounts of CO2 into the deep ocean

B. Key A is correct; upwelling at the center of subtropical gyres increases productivity of biological organisms

C. Key B is correct; downwelling at the center of subtropical gyres decreases the productivity of biological organisms

D. Key B is correct; upwelling at the center of subtropical gyres brings CO2 in the deep ocean back to the surface

Solution: Ekman transport piles up water at the center of subtropical gyres due to the Coriolis force. This results in downwelling at the center of subtropical gyres, which decreases the productivity of organisms such as algae at the ocean surface by removing nutrients. These organisms can no longer sequester carbon dioxide through photosynthesis – C is the correct choice. Note that downwelling does not directly transport large amounts of atmospheric CO_2 into the deep ocean.

5. At a given point, two weather models, A and B, predict the same geopotential heights for the 1000 and 500 hPa pressure levels. However, they predict different temperature **anomalies** (relative to the climatological average within each pressure level), as shown in the table below.

	1000 hPa	**500 hPa**
A	+3 °C	+1 °C
B	+3 °C	+5 °C

Which of the following about the 1000-500 hPa layer **must** be true given the information above?

I) A predicts a less stable atmosphere than B

II) A predicts a conditionally unstable atmosphere

III) B predicts an atmospheric inversion

A. None

B. I only

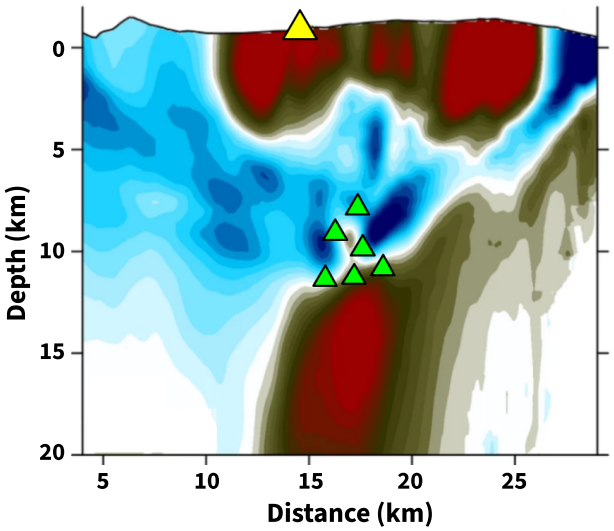
C. III only

D. I and II

E. I and III

Solution: The stability of the atmosphere is related to the lapse rate; higher lapse rates indicate less stability. The 1000-500 hPa lapse rate is the (negative) change in temperature per change in height. Since the geopotential heights (and thus the height difference) is the same in A and B, and the ground temperature is the same in both, but A predicts a relatively cooler temperature at 500 hPa, the lapse rate is higher in A than in B. A is therefore less stable - I must be true. Conditional instability occurs when the lapse rate is greater than the moist adiabatic lapse rate but less than the dry adiabatic lapse rate. No information is given about the moist adiabatic lapse rate - II cannot be concluded. While the temperature anomaly at a higher altitude (500 hPa) is greater than that of the 1000 hPa level, this does not mean that the temperature increases with height anywhere, only that the lapse rate is less than usual - III cannot be concluded.

6. The image below represents a two-dimensional cross section of v_s/v_p (the ratio of S wave velocity to P wave velocity) under La Palma, an island where a lengthy volcanic eruption occurred in 2021. The yellow triangle represents the location of the eruption, while the smaller green triangles represent locations of major earthquakes that occurred during the eruption.



Which of the following statements is/are true of the image and the geology of the region?

I) In the image, red represents an unusually high v_s/v_p ratio

II) The eruption was primarily fed by magma from less than 5 kilometers beneath the surface

A. I only

B. II only

C. I and II

D. None

Solution: Magma is typically found immediately beneath a volcano. This suggests that regions with more magma are depicted as red, and that magma is present both immediately below the surface and at a depth of 10-20 kilometers. Since S waves do not travel through liquid, they will be uniquely slow through magma and v_s/v_p should be lower than usual - I is false. The presence of earthquakes at a depth of 10 kilometers indicates compression in this region, which would be caused by the emptying of the lower magma chamber as it feeds the surface volcano - II is false.

7. A total solar eclipse occurs during July. Assuming that the Sun, Moon and Earth are collinear during the height of the eclipse and using the table of values provided below, which of the following is closest to the maximum radius of the resulting umbra?

Radius of the Sun	$6.96 \cdot 10^5$km
Radius of Earth	6370 km
Radius of the Moon	1740 km
Perihelion of Earth	$1.47 \cdot 10^8$km
Aphelion of Earth	$1.52 \cdot 10^8$km
Perigee of Moon	$3.62 \cdot 10^5$km
Apogee of Moon	$4.05 \cdot 10^5$km

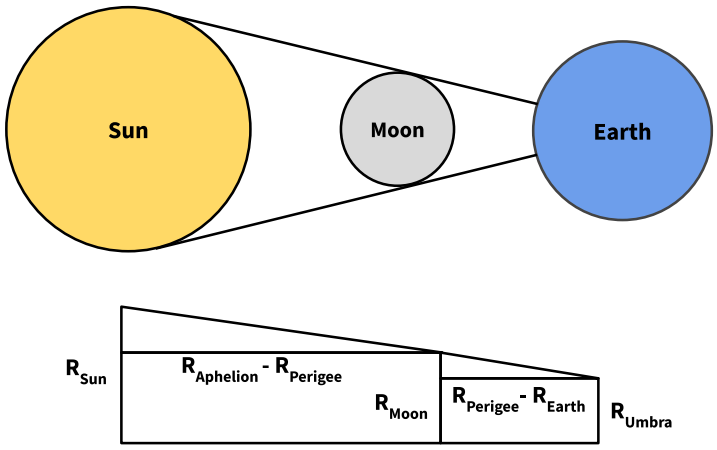
A. 28 km

B. 56 km

C. 84 km

D. 112 km

Solution: The Earth is at aphelion during July. With this information, we can draw the diagram below to represent the situation:



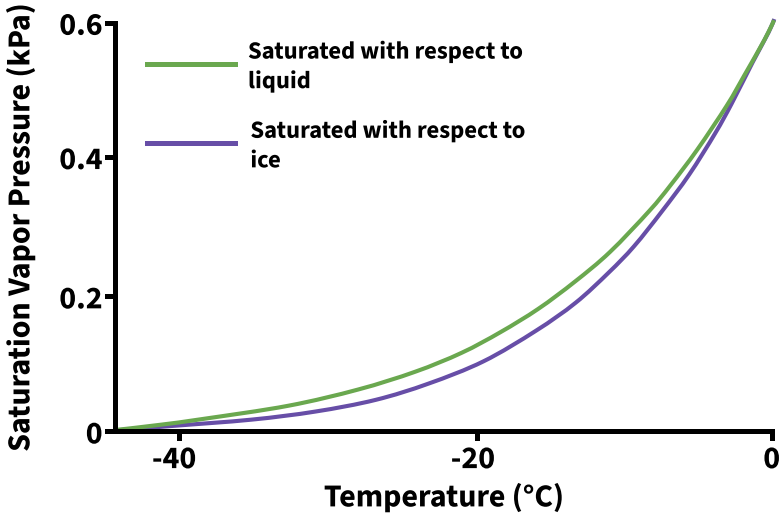
We can derive an equation to find the answer using ratios between similar triangles:

$$\frac{R_{\text{Sun}} - R_{\text{Moon}}}{R_{\text{Aphelion}} - R_{\text{Perigee}}} = \frac{R_{\text{Moon}} - R_{\text{Umbra}}}{R_{\text{Perigee}} - R_{\text{Earth}}}$$

$$R_{\text{Umbra}} = R_{\text{Moon}} - \frac{(R_{\text{Sun}} - R_{\text{Moon}})(R_{\text{Perigee}} - R_{\text{Earth}})}{R_{\text{Aphelion}} - R_{\text{Perigee}}}$$

Plugging in the above values gives us $R_{\text{Umbra}} = \boxed{112 \text{ km}}$

8. The graph below plots saturation vapor pressure as a function of temperature.



Which of the following best explains how the difference between the two curves contributes to precipitation formation in clouds that contain both liquid water droplets and ice crystals?

A. Supercooled droplets grow quickly because water vapor deposits preferentially on liquid water

B. Ice crystals grow at the expense of surrounding water droplets because water vapor condenses preferentially on ice

C. Precipitation rarely forms in mixed-phase clouds because it is difficult for air to become saturated with respect to both liquid water and ice

D. Ice crystals do not grow until all water droplets freeze because the saturation vapor pressure of ice is lower than that of liquid water

Solution: At the same temperature, air that is saturated with respect to ice may not be saturated with respect to liquid, implying that it is easier for molecules to escape near the surface of a water droplet compared to an ice crystal. As a result, water vapor molecules tend to diffuse toward ice crystals, which grow larger at the expense of the dissipating water vapor molecules in what is known as the Bergeron process.

9. Clastic dikes are discordant structures similar to igneous dikes but filled with sediment rather than igneous rock. Clastic dikes found in Badlands National Park extend up to 30 meters deep and run for a quarter of a mile at many different strikes and dips, criss-crossing at random intervals. Identify all of the following possible formation mechanisms that could explain the formation of these structures.

I) Large mud cracks formed and then filled with clastic material.

II) Large-scale extensional tectonics resulted in stretching and fracturing of crustal rock.

III) Liquefaction during seismic activity injected sediment into the resulting fractures.

A. I only

B. III only

C. I and II

D. I and III

E. II and III

Solution: It is not feasible for mud cracks to be over 30 meters deep, and mud cracks would also form regularly spaced, roughly polygonal cracking patterns – I is not a possible mechanism. Large-scale extensional tectonics would create near parallel jointing, not the criss-crossing at random intervals observed in Badlands National Park – II is not a possible mechanism. Liquefaction often results in increased pore water pressure, resulting in material pushing deep into fractures and producing long features. This pressure is also isotropic and does not have a preferred direction of growth, explaining the varying strikes and dips – III is a possible mechanism.

10. The Sun has gradually been getting brighter over time—when the Solar System formed, it was only about 70 percent as bright as it is today. Scientists hypothesize that Mars formerly had liquid water, but it is unclear how a dimmer Sun could sustain high enough temperatures to do so. One model suggests that this was possible due to processes related to hydrogen release in the atmosphere of Mars, which occurs due to the oxidation of iron with equation $2\,FeO + H_2O \longrightarrow Fe_2O_3 + H_2$. Which of the following statements is/are true regarding the effect of this process on the Martian surface and atmosphere?

I) The rate of H_2 outgassing has increased over time

II) The Martian equator likely has a higher Fe_2O_3/FeO ratio than the poles

A. I only

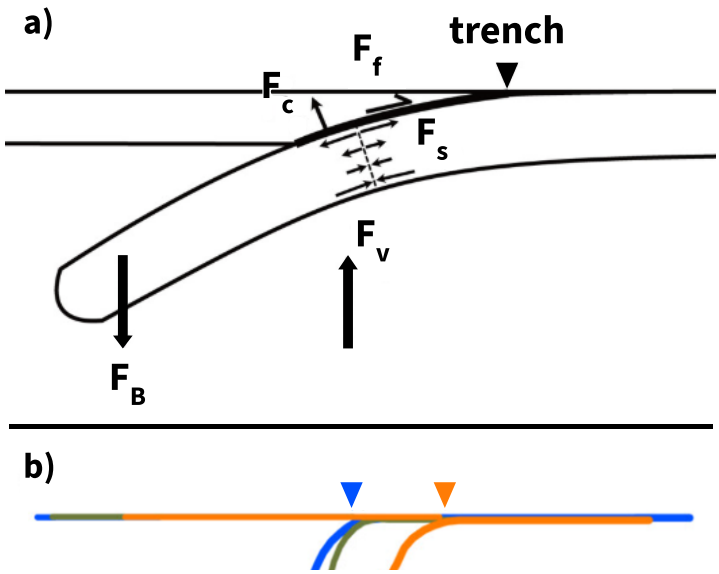
B. II only

C. I and II

D. None

Solution: The equation for oxidation suggests that water is necessary for H_2 outgassing to occur. As the Sun became brighter and the Martian ocean evaporated, water was no longer available for oxidation, preventing H_2 outgassing - I is false. The Martian equator has suitable conditions for oxidation, with a water-air boundary (roughly along the border of the former Martian ocean) and warm temperatures that favor chemical activity - II is true.

11. Some geologists have created a model of a subduction zone in which there is no mantle flow. As shown in panel (a) of the figure, some forces relevant to this simplified model include the slab pull force (F_B), slab bending force (F_s), the viscous force due to the mantle (F_v), friction (F_f), and the compressive force (F_c).



The model predicts that the trench associated with the subducting plate moves while the subduction progresses, as shown in panel b). Which of the following choices correctly gives both the direction and the dominant driving force of this movement?

A. Blue → Green → Orange, F_f

B. Blue → Green → Orange, F_s

C. Blue → Green → Orange, F_B

D. Orange → Green → Blue, F_v

E. Orange → Green → Blue, F_c

Solution: In this model, the subducting plate sinks primarily due to the slab pull force (F_B) because it is colder and more dense. As the plate travels downward, it encounters resistance from the mantle (F_v) that orients the slab at an angle and influences the location of the trench. Continued subduction leads to a hinging motion at the trench, driven by F_B, that pulls more and more of the subducting plate down and therefore "rolls back" the trench.

12. In the Southern Ocean, coastal polynyas are areas of open water in which sea ice forms. Outside these sites, the growth of sea ice in most of the ice-covered region is restricted by a feedback involving brine rejection which results in heat mixing upwards. Which of the following statements best explains why coastal polynyas are often sites of deepwater formation while other ice-covered regions are not?

A. Sea ice formed in coastal polynyas is typically thicker than sea ice formed elsewhere

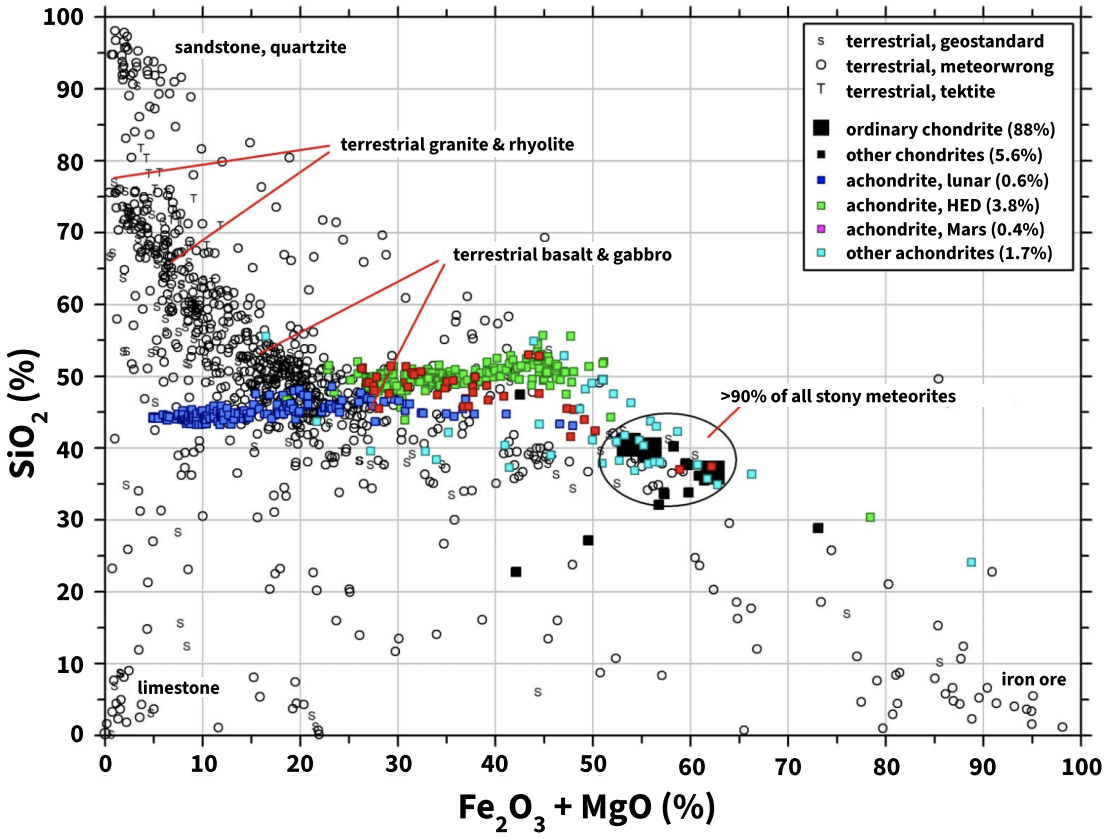
B. In coastal polynyas, most heat is conducted directly from the ocean to the atmosphere

C. The salinity of sea ice formed in coastal polynyas is relatively low, so brine rejection is stronger

D. Isopycnals are nearly horizontal at coastal polynyas, while nearly vertical in the sea ice zone

Solution: Brine rejection from sea ice growth enhances vertical mixing, resulting in relatively warmer water rising from below. In much of the sea ice zone, this feedback limits the continued basal (downward) growth of sea ice. However, in coastal polynyas, the ice is advected away and is effectively removed from the feedback loop. The heat from the warmer water is able to escape directly to the atmosphere, which cools the ocean in addition to promoting further ice growth - B is the correct choice.

13. The figure below shows the SiO_2 and Fe_2O_3 + MgO composition of a number of meteorite finds as well as a number of terrestrial or man-made samples (meteorwrongs).



Based on the diagram, which of the following conclusions may be made?

I) The vast majority of meteorites come from undifferentiated bodies.

II) Glass formed as a consequence of meteorite strikes usually shares a similar composition to the meteorite itself.

A. I only

B. II only

C. I and II

D. None

Solution: The diagram indicates that the vast majority of meteorites are chondrites, which are composed of characteristic chondrules (round grains) that imply they are undifferentiated. Additionally, most meteorites are relatively small and thus lack the internal heat required for differentiation - I is true. Tektites are glass objects that form due to meteorite strikes and are shown in the diagram to have significantly more silica than any meteorites – II is false.

14. Which of the following entries of the table best describes the components and the formation environment of the bedform depicted below?

Entry	Dark Component	Light Component	Formation Environment
A	Basalt	Ash deposit	Volcano flank
B	Mud	Sand	Intertidal zone
C	Clay	Silt	Glacial lake
D	Blueschist	Quartzite	Region of tectonic extension

A. Entry A

B. Entry B

C. Entry C

D. Entry D

Solution: Alternating layers of lava flow and volcanic ash are generally continuous and uniform in thickness across a layer. Similarly, glacial lake varve deposits tend to have flat, uniform layers. However, the depicted layers are hummocky and discontinuous – entries A and C are incorrect. Extensional environments typically create horizontally symmetrical boudinages that look like chained sausage links, and the surrounding layers typically conform to that shape. This is not displayed by the light component shown, and the layers also do not look igneous or metamorphic – D is incorrect. Thus, the depicted formation represents alternating deposits of mud and sand within the intertidal zone as a result of varying water levels (i.e., lenticular bedding).

15. Venus has an orbital eccentricity of 0.21, the largest out of any planet in the Solar System. This results in Venus receiving more light from the Sun when at perihelion. In which of the following ranges does the ratio of the amount of light Venus receives at perihelion to aphelion lie?

A. Between 1.0 and 1.4

B. Between 1.4 and 1.8

C. Between 1.8 and 2.2

D. Between 2.2 and 2.6

E. Greater than 2.6

Solution: Let a be the length of Venus' semi-major axis. Given that Venus' orbital eccentricity is 0.21, its aphelion must be $1.21a$ away from the Sun and its perihelion must be $0.79a$ away from the Sun. The light Venus receives from the Sun is proportional to the inverse of its distance squared. Thus, $(\frac{1.21a}{0.79a})^2 = \boxed{2.34}$.

16. Planetary equilibrium temperatures are critical for determining the potential habitability of a planet. If Earth's emissivity decreased from 0.95 to 0.9, its new albedo would need to lie in which of the following ranges to maintain a stable equilibrium temperature? Assume that Earth's current albedo is 0.3.

A. Between 0.26 and 0.28

B. Between 0.28 and 0.30

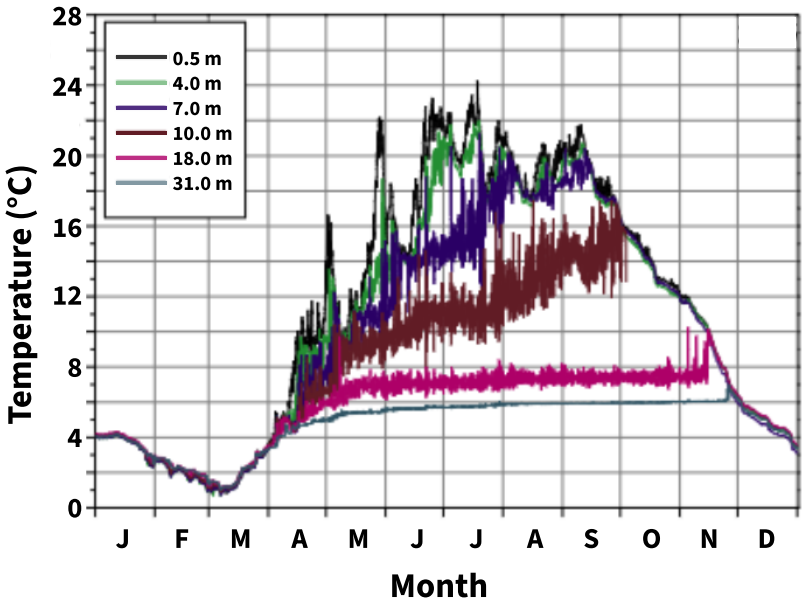
C. Between 0.30 and 0.32

D. Between 0.32 and 0.34

E. Between 0.34 and 0.36

Solution: For Earth to maintain the same equilibrium temperature, its overall energy balance must remain the same. Consequently, the ratio of emissivity (e) to one minus the albedo ($1 - a$) must be constant; e is a measure of how well Earth emits heat and $1 - a$ is a measure of how much energy is absorbed by Earth. Thus, $\frac{1-a_1}{e_1} = \frac{1-a_2}{e_2}$. Solving, $\frac{0.7}{0.95} = \frac{1-a_2}{0.9} \implies a_2 = \boxed{0.336}$.

17. A hydrologist produces the figure below by sampling water at different depths and at different times of year at a lake in Germany. (Note that in areas where some lines appear to disappear, the different lines have simply converged.)



Which of the following accurately gives the lake's mixing regime and the depth of the lake's thermocline between August and September?

A. Amicitic, 0.5-7 meters deep

B. Dimictic, 0.5-7 meters deep

C. Dimictic, 7-10 meters deep

D. Monomictic, 0.5-7 meters deep

E. Monomictic, 7-10 meters deep

Solution: Thermal stratification occurs when a warmer, less dense layer of water overlies a colder, denser layer. It is apparent from the plot that the lake becomes approximately isothermal for a period between December and March. This allows for mixing in the lake during this singular period – the lake is monomictic. Looking at the months of August and September, the temperature profiles from 0.5-7 meters deep are approximately the same. This indicates the presence of a well mixed, isothermal top layer (epilimnion). A significant temperature change occurs between 7 and 10 meters deep – this is likely where the thermocline lies.

18. Although often assumed to be constant for a given location, the moist adiabatic lapse rate (MALR) actually varies with height, primarily due to the effects of latent heat release on rising air. Which of the following accurately describes the relationship between MALR and atmospheric pressure and temperature, respectively?

A. Direct, direct

B. Direct, inverse

C. Inverse, direct

D. Inverse, inverse

Solution: The saturation vapor pressure of water depends almost entirely on temperature. Therefore, if the atmospheric pressure is increased while holding temperature constant, the saturation vapor pressure remains the same and the water vapor content is effectively diluted due to the increased number of other gas molecules. An effective reduction in water vapor content brings the MALR closer to the value of the dry adiabatic lapse rate (i.e. increases the MALR). At a higher temperature given constant pressure, the saturation vapor pressure of water would increase, leading to more water in vapor phase and more condensation. This increases the effect of latent heat release during uplift and decreases the MALR.

19. A soil located in which of the following environments would likely be most susceptible to liquefaction during a major earthquake?

    A. Above a former desert lake bed

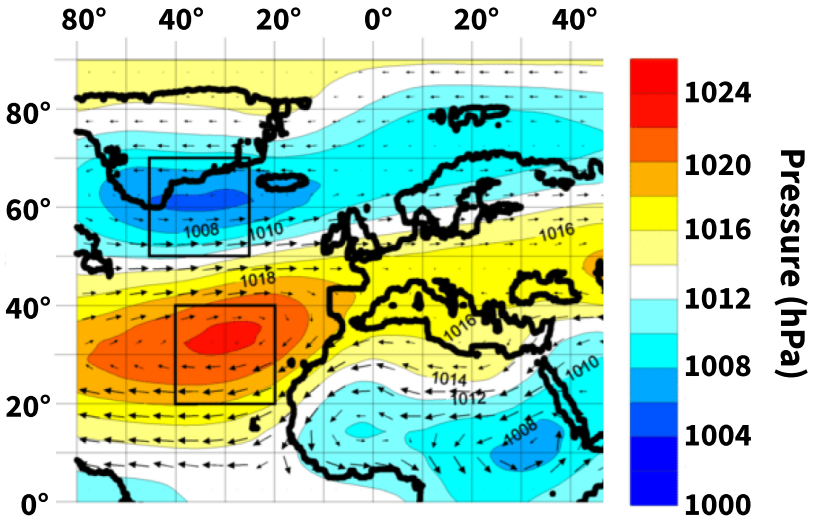
    B. Above a region of karst topography

    C. In the outwash plain of a valley glacier

    D. On the edge of a meandering river

Solution: Liquefaction is most likely in regions with granular soils, low drainage, and high water saturation levels. This is commonly found near meandering rivers, as these are regions of high saturation and with well-sorted sandy or silty soil. Liquefaction is less likely to occur in a desert, which has little water to provide saturation; in karst topography, which has excellent drainage that prevents water buildup; or in glacial sediments, which are unsorted and thus have very low porosity.

20. The North Atlantic Oscillation (NAO) is a phenomenon involving the oscillation in pressure between the Icelandic Low and the Azores High, shown in the map below in the top left and bottom left, respectively. The NAO is defined according to the difference in air pressure between these two pressure centers, i.e. a positive NAO corresponds to higher variation in pressure between the centers.



Meteorologists have found that large CO_2 forcing is likely to make the NAO consistently more positive. Identify all of the following climate conditions that would likely be a result of more positive average NAO conditions.

I) Stronger westerlies over the Atlantic

II) Colder winters in western Europe

A. I only

B. II only

C. I and II

D. None

Solution: Atlantic westerlies are created by the pressure difference between the Icelandic Low and Azores High, so a positive NAO would increase wind speed – I is true. This increased wind speed would cause western Europe to have more mild marine air and less cold continental air, causing winters to be milder – II is false.

21. A major runoff event causes an influx of nutrients into the Gulf of Mexico, causing a large but short-lived algal bloom. Which of the following best describes how this event would affect the water's dissolved oxygen content at the surface and at a depth of 500 meters, respectively?

A. Increase, then decrease; uniformly increase

B. Increase, then decrease; uniformly decrease

C. Decrease, then increase; uniformly increase

D. Decrease, then increase; uniformly decrease

Solution: In the ocean, dissolved oxygen concentration is increased by photosynthesis and decreased by decomposition. An influx of nutrients commonly produces an initial algal bloom (which leads to a lot of photosynthesis); the algal bloom then dies off and decomposes. Thus, the surface is initially dominated by photosynthesis, increasing dissolved oxygen, but more decomposition occurs over time to decrease dissolved oxygen. In the lower ocean, minimal photosynthesis can occur, so it primarily experiences the effect of increased decomposition and decreased dissolved oxygen.

22. Radiation fog forms when Earth's surface cools radiatively and the surrounding air condenses. This type of fog is most likely to form when a relatively _____ layer of _____ air underlies a layer of _____ air.

A. Shallow; moist; drier

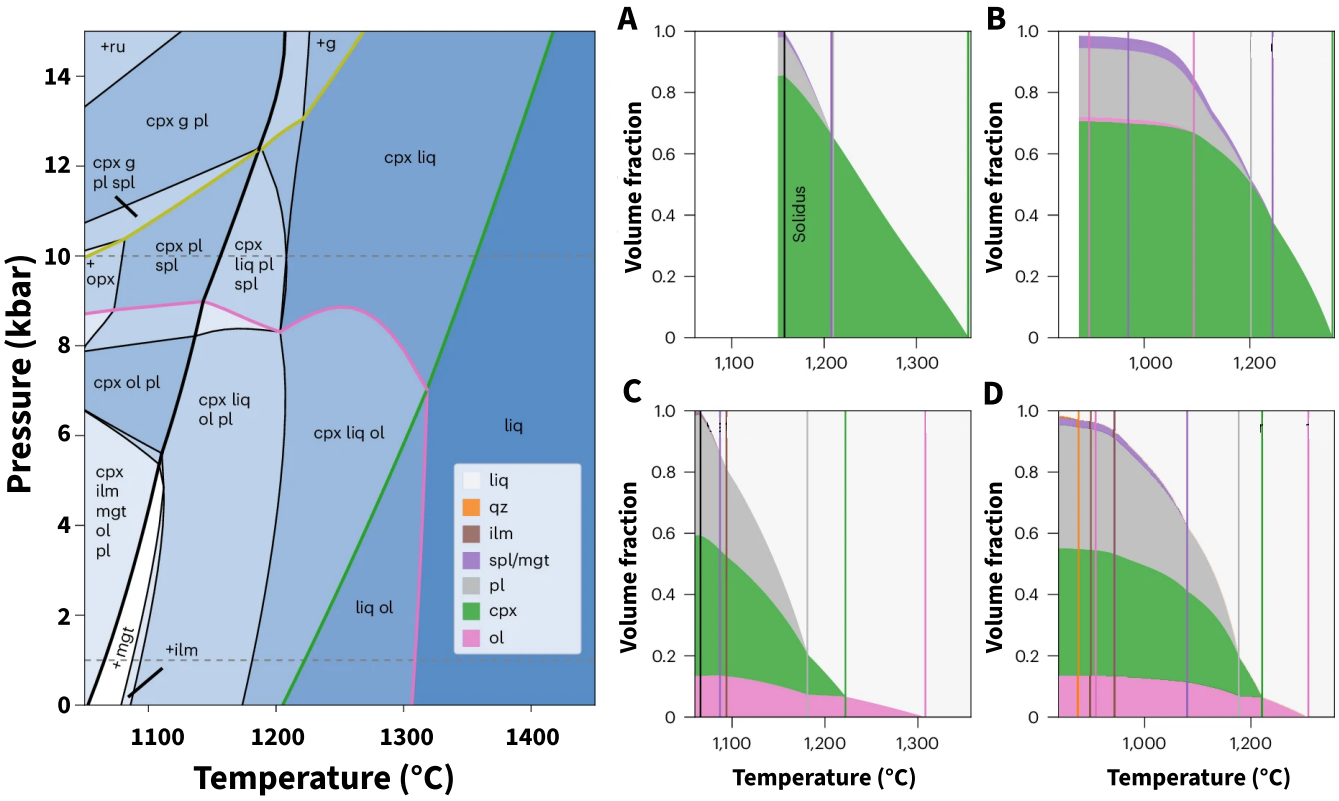
B. Shallow; dry; moister

C. Deep, moist, drier

D. Deep, dry, moister

Solution: Air close to Earth's surface cools most during the formation of radiation fog. Condensation in this lower layer is therefore what drives the production of fog, so the layer should be relatively moist. Condensation of water vapor also releases latent heat that inhibits cooling and further condensation. Thus, the presence of a relatively deep moist layer near the surface would tend to prevent radiation fog formation.

23. The figure below depicts the results of four simulations of the evolution of a mafic magma alongside a phase diagram for this magma. Which of the simulations represents fractional crystallization at a pressure of 10 kbar?



A. Figure A

B. Figure B

C. Figure C

D. Figure D

Solution: Move from higher to lower temperatures (i.e. right to left) on the gray dashed line at 10 kbar in the phase diagram. We expect to see cpx (clinopyroxene) precipitate first from solution as temperature decreases. This is observed in A and B, where the dark green corresponding to cpx juts out into the region of highest temperature. If we look carefully at A, we can see that pl (plagioclase) and spl (spinel) are evolved right at the phase transition line for the initial magma, which we would not expect for fractional crystallization. Thus, the correct answer is B.

24. A geologist is analyzing two basalt samples titled "Sample A" and "Sample B." They determine that Sample A is relatively depleted in alkali metals such as potassium. Meanwhile, Sample B is relatively enriched in alkali metals. The geologist knows that one sample is derived from a continental mantle plume while the other was found near an oceanic rift. Given only this information, which of the following choices most likely describes the origin of Sample A?

A. Sample A was derived from magma associated with a continental mantle plume, which led to more complete melting.

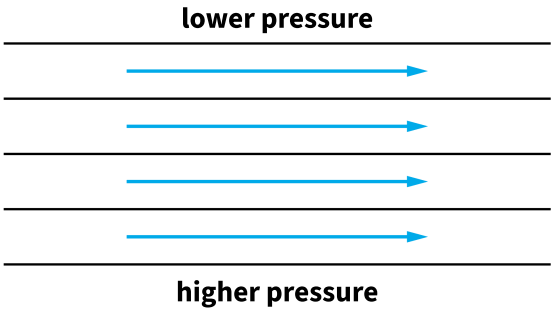
B. Sample A was derived from magma associated with a continental mantle plume, which led to less complete melting.

C. Sample A was derived from magma associated with melting at an oceanic rift, which led to more complete melting.

D. Sample A was derived from magma associated with melting at an oceanic rift, which led to less complete melting.

Solution: Sample A is depleted in alkali metals, which tend to be incompatible in igneous contexts. For instance, potassium has a large ionic radius that makes it difficult to fit in the lattice structure of a solidified rock. Being depleted in incompatible elements indicates that more complete melting occurred, as this allows compatible elements that would preferentially stay in the lattice structure to exit and "dilute" the concentration of incompatible elements that preferentially escape into the melt – choices B and D are incorrect. Despite being hotter, mantle plumes originate at depths where increased pressure increases the temperature of the solidus. Meanwhile, material at oceanic rifts experiences a relatively rapid decrease in pressure as it is lifted to the surface, resulting in more complete (decompression) melting. Thus, choice A is incorrect and choice C best describes the origin of Sample A.

25. A planet rotates at angular velocity Ω. A uniform pressure gradient leads to geostrophic flow as shown in the figure below, in which the black contours represent isobars and the blue arrows represent velocity vectors for the resulting geostrophic wind.



The planet then begins to rotate at 2Ω. After it has reached equilibrium, which of the following changes alone, if any, would be necessary to maintain the same magnitude and direction of the geostrophic winds?

A. Increasing the pressure gradient

B. Decreasing the pressure gradient

C. Inverting the pressure gradient direction

D. Introducing a compensating friction

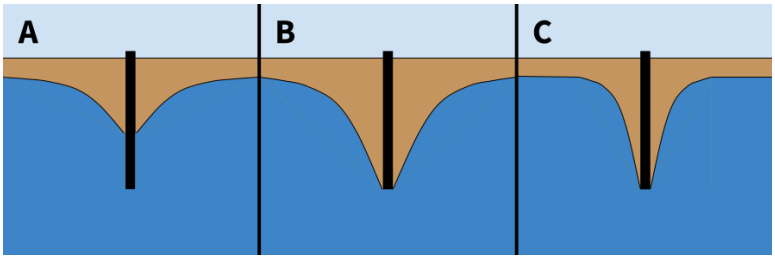
E. No change

Solution: The doubling of the rotation rate leads to a doubling of the Coriolis force. Knowing that geostrophic flows balance the pressure gradient force (PGF) and the Coriolis force, we expect that to maintain the same geostrophic wind velocity, the pressure gradient force must be doubled as well. Heuristically, it is useful to think of a parcel initially at rest that is accelerated by the PGF. The parcel is turned by the Coriolis force until balance is achieved. With a greater Coriolis force but same PGF as the Ω situation, the parcel would be turned more quickly, gaining only half of the speed before the forces balance.

26. The rate of groundwater flow Q is given by Darcy's law:

$$Q = -\frac{k}{\mu}\nabla P$$

where k is the permeability of the material, μ is the viscosity of the fluid, and ∇P is the pressure gradient (equal to the change in pressure over a given distance).



The figure above shows three wells surrounded by cones of depression, regions where overpumping of groundwater has occurred. Which of the following statements correctly describe the environments of wells A, B, and C?

I) Well A is pumping less water than well B

II) The ground surrounding well B has a higher permeability than the ground surrounding well C

A. I only

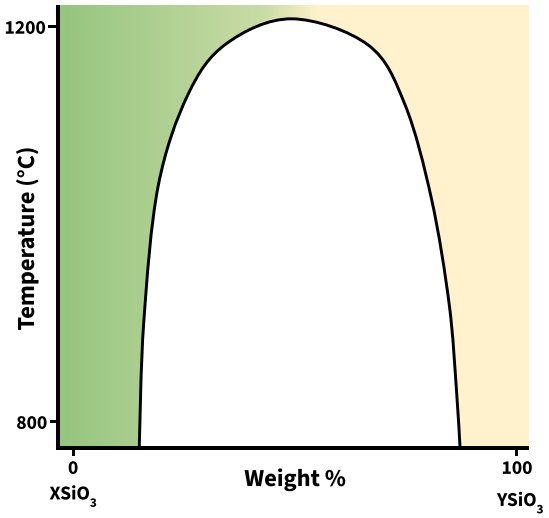
B. II only

C. I and II

D. None

Solution: When a well changes the amount of water it pumps, the cone of depression generally moves up or down accordingly. Since the cone of depression around well A is the same width as around well B but less deep, it is likely pumping less water - I is true. Since the cone of depression around Well C is more localized, it is likely harder for groundwater to replace the water removed by the well, indicating lower permeability - II is true.

27. Show below is a temperature-composition diagram of a hypothetical solid solution series between endmembers $XSiO_3$ and $YSiO_3$, where X represents an ion with charge 2^+ and ionic radius 0.91 Å and Y represents an ion with charge 2^+ and ionic radius 0.73 Å.



Assume that the ionic radii of Y was instead 0.83 Å. Which of the following correctly describes the relative width of the miscibility gap and the probability of finding exsolution textures in minerals crystallized from magma of this altered solid solution?

A. No change, greater

B. Smaller, greater

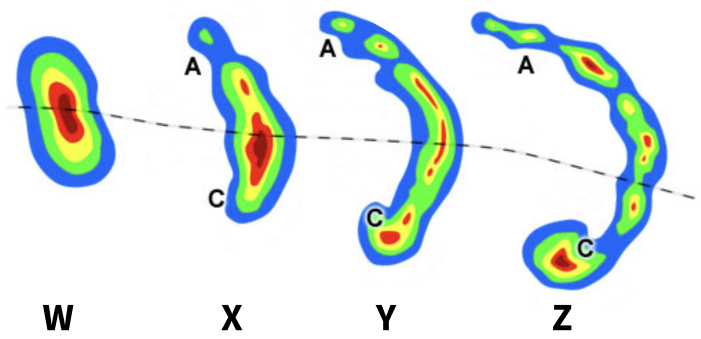
C. Smaller, smaller

D. Greater, greater

E. Greater, smaller

Solution: If the sizes of the cations become more similar, the cations are more readily exchangeable in a solid solution series. This decreases the width of the miscibility gap where the exchange is too unfavorable to occur easily. Exsolution textures form when a homogenous mixture separates into two different minerals due to the thermodynamic unfavorability of a mineral formed directly from the homogenous mixture. They form in the range of miscibility gap compositions, so decreasing the width of the miscibility gap decreases the probability of finding exsolution textures.

28. Certain arrangements of thunderstorms can produce a radar signature called a bow echo, which can morph into a comma echo over time. The figure below depicts a complex of thunderstorms (W) evolving into a bow echo (X and Y) and then into a comma echo (Z). The red shading indicates where the storm is most intense.



Which of the following accurately describes the evolution of the bow echo and the hemisphere in which the storm occurred?

A. Cyclonic winds at A are weakened while anticyclonic winds at C are strengthened; Northern Hemisphere

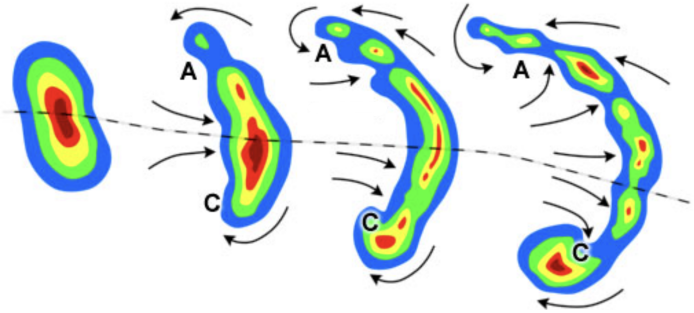
B. Anticyclonic winds at A are weakened while cyclonic winds at C are strengthened; Northern Hemisphere

C. Cyclonic winds at A are weakened while anticyclonic winds at C are strengthened; Southern Hemisphere

D. Anticyclonic winds at A are weakened while cyclonic winds at C are strengthened; Southern Hemisphere

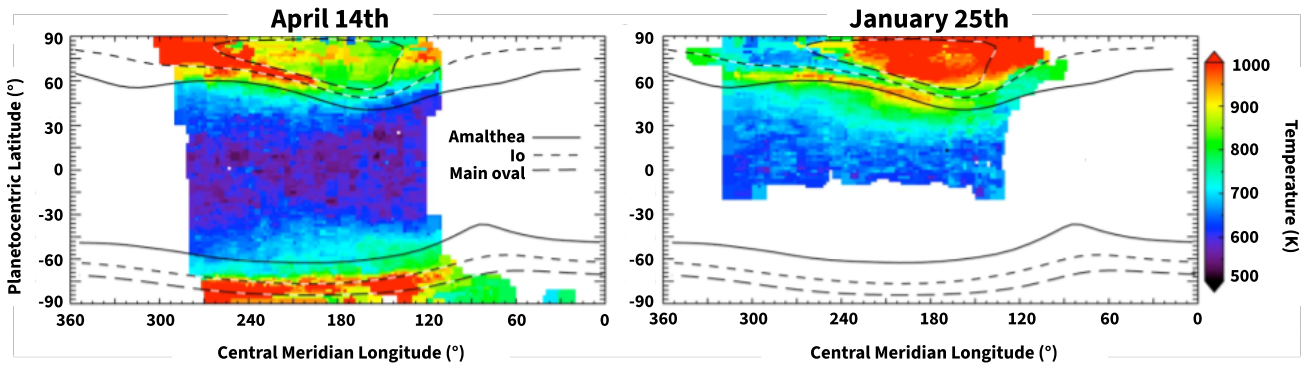
Solution: Observe from the figure that the comma echo develops because winds at A weaken while winds at C strengthen, resulting in a characteristic asymmetrical shape. It is evident from panel Y that the storm is most intense around C, and thus the area around C corresponds to a low pressure, cyclonic region – A and C are incorrect.

Now, draw arrows to indicate the wind direction around the echoes (shown in the figure below).



Recall that in the Southern Hemisphere, winds around a low circulate clockwise. Indeed, we see that winds around C circulate clockwise, and that the overall shape of the comma is spiraled in a clockwise direction – D is correct.

29. Auroral heating on Jupiter plays an important role in the circulation of the planet's thermosphere. The figure below depicts the global distribution of Jupiter's upper atmosphere temperature on two dates; long-dashed lines show the main region of the aurora while short-dashed lines and solid lines show the magnetic influence of the moons Io and Amalthea, respectively.



Astronomers determine that the solar wind pressure was dramatically higher during the January 25th observations compared to the April 14th observations. Which of the following conclusions could be reasonably drawn from the data presented?

A. The higher solar wind pressure on January 25th excited charged particles in Jupiter's atmosphere, creating warming at the equator

B. The higher solar wind pressure on January 25th caused a significant decrease in plasma emitted by Io, resulting in an increase in auroral heating

C. The higher solar wind pressure on January 25th caused an equatorward migration of Amalthea's magnetic footprint, resulting in a decrease in propagation of auroral heating throughout Jupiter's thermosphere

D. The higher solar wind pressure on January 25th compressed Jupiter's magnetic field, resulting in an equatorward propagation of auroral heating

Solution: During the April 14th observations, auroral heat was not contained within the main auroral oval, as evidenced by the higher temperatures immediately outside the oval – A is incorrect. Jupiter's permanent polar aurorae are caused as ions emitted by Io are accelerated through Jupiter's magnetic field. A decrease in plasma created by Io would therefore decrease auroral heating – B is incorrect. Amalthea's magnetic footprint did not migrate, and auroral heat propagation was increased, as evidenced by the higher temperatures at lower latitudes – C is incorrect. The only choice that correctly identifies that auroral heat was propagated equatorward following the increase in solar wind pressure is D.

30. The meandering channel of a slightly-stratified estuary has both a primary flow downstream as well as a secondary circulation that involves cross-channel flow in a helical pattern. A hydrologist determines that the secondary circulation developed due to centrifugal forces pushing the water surface toward the outer banks of meanders. Given this information, which of the following is/are true regarding the isohaline profiles of the estuary channel?

I) Isohalines in the longitudinal profile of the estuary channel are oriented near-horizontal

II) Isohalines in the cross-sectional profile of a meander decrease in salinity toward the outer bank

A. I only

B. II only

C. I and II

D. None

Solution: Cross-channel flow results in turbulence that enhances vertical mixing, resulting in near-vertical isohalines in the longitudinal profile – I is correct. Given that the water surface near the outer bank of the meander is elevated, the centrifugal force at the water surface is directed from the inner to outer bank. To complete the helical motion, the pressure gradient force directs water from the outer to inner bank at depth. Less saline surface water is therefore transported toward the outer bank and downward while more saline deep water is transported toward the inner bank and upward. Water near the outer bank becomes less saline while water near the inner bank becomes more saline – II is correct.

END OF MULTIPLE CHOICE