



USESO 2026

Training Camp Exam

Section I

KEY

Instructions:

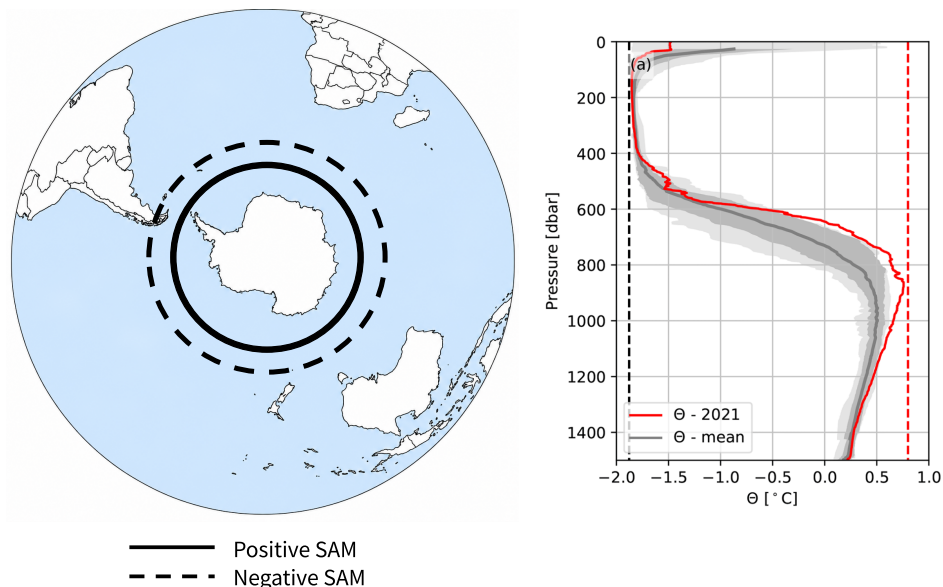
- Section I consists of 30 multiple choice questions. Each question is worth 2 points.
- Print your **USESO Student ID** on the ZipGrade answer sheet and bubble your answers clearly.
- You have **1 hour and 15 minutes** to complete this section.
- Any type of calculator is allowed.
- Participating in this exam is agreement to our Academic Integrity Policy.

1. The Bob River enters the Omjoe Ocean to produce a delta that is steadily growing outwards. A few thousand years later, the Bob River dries up, and the delta slowly recedes due to sea level rise. Which of the following best describes the trend in grain size for a column of the delta's sediments, from bottom to top?

- A. Always increasing
- B. Always decreasing
- C. Increasing, then decreasing
- D. Decreasing, then increasing

Solution: A prograding delta builds outwards through multiple sequences of sediment depositions, so coarser sediments lay on top of finer ones to produce a reverse grading. When deposition stops and sea level rises, increasingly fine sediments are deposited on the delta as water depth increases, producing a normal grading.

2. The Southern Annular Mode (SAM) is a pattern of atmospheric variability in which, due to changes in atmospheric pressure above Antarctica, the Southern Westerly Winds move north or south. The figure below shows the difference in westerly wind position during the different phases of the SAM, as well as a typical potential temperature gradient with depth for the Southern Ocean. Potential temperature is the temperature a parcel of water would reach if brought to a reference pressure adiabatically.



Climate change has been predicted to cause stronger and more frequent positive phases of SAM. Which of the following are true?

- I) This would cause the Antarctic Circumpolar Current to strengthen.
- II) This would increase the melting of the Antarctic ice sheet.

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

Solution: More positive SAM phases would cause a contraction of the westerly wind belt, aligning it further with the Drake Passage and the belt of water around Antarctica. This would increase the wind stress that the winds exert on the surface of the ocean, strengthening the ACC - I is true. The Coriolis effect pushes surface waters away from Antarctica more strongly due the increased effect of wind on coastal Antarctic waters. This results in upwelling bringing deeper water towards the surface. As seen in the figure, deeper waters in the Southern Ocean tend to be warmer than those at the surface. Upwelling would therefore cause an increase in SST and a corresponding increase in melting of the ice sheet - II is also true.

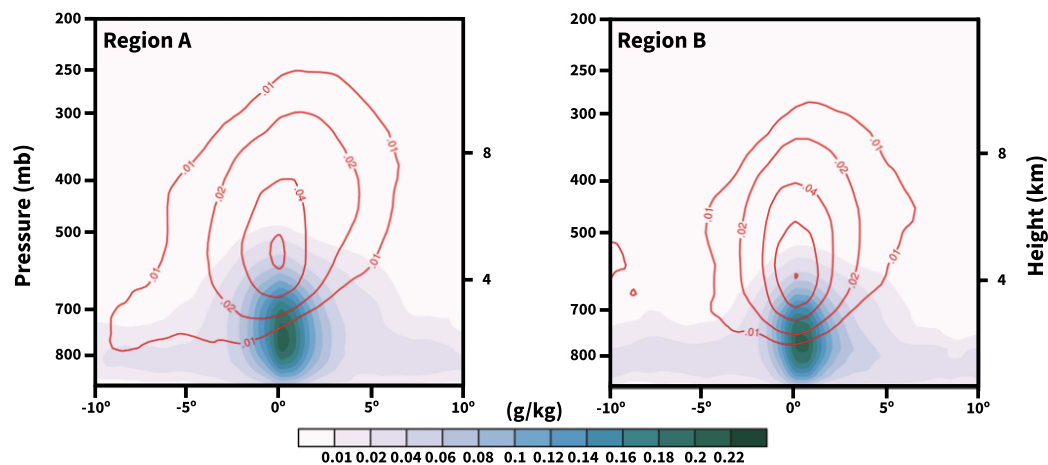
3. The South American low-level jets (SALLJs) are high-speed winds traveling 1000–3000 feet off the planet's surface, typically occurring at night. They are caused by two factors: the jets are separated from surface friction, and, due to the elevation disparity between the Andes and eastern South America, the misalignment of isobaric and constant height surfaces drives movement. Identify all of the following statements that are true.

- I) SALLJs are more common on nights with extensive stratus cloud cover than on those without.
- II) SALLJs are a source of moisture for precipitation.
- III) SALLJs would be purely zonal if their flow were at the equator.

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

Solution: Convective mixing increases lower atmospheric turbulence, meaning stratified air is more favorable for SALLJs. Cloud cover prevents radiative surface cooling at night to stratify the air, which causes SALLJs to experience more surface friction - I is false. Cold air over the Andes and warm air over eastern South America causes a higher pressure over the plains. The PGF thus points westward, creating north to south SALLJs due to the Coriolis effect. This brings moisture from the Atlantic over South America - II is true. Because they are turned meridionally by the Coriolis force, the winds would be zonal without it - III is true.

4. The figure below shows vertical cross-sections of liquid water content (blue/pink shading) and ice water content (red contours) in two low-pressure systems in the Northern Hemisphere. The x-axis represents the degrees of longitude from the location of interest.



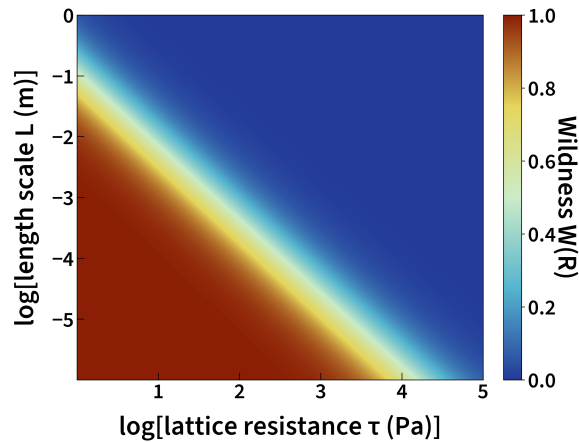
Which of the following statements are true regarding the figure?

- I) Region A has more significant cloud development than region B.
- II) The low-pressure system in region A is likely to strengthen more rapidly than the one in region B.

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

Solution: The ice and liquid contours in region A extend deeper into the mid-troposphere than those in region B. The greater region of condensed liquid water and crystallized ice indicates a greater extent of cloud formation - I is true. In region A, the larger ice clouds indicate a greater degree of ice formation, which would release latent heat into the air parcel. This heat would increase the buoyancy of the air parcel, inducing further rising. As this positive feedback loop would be less pronounced in region B with shallower ice clouds - II is true.

5. Below is a diagram showing the wildness of plasticity, which is the amount of dislocation that happens in bursts of high strain rate rather than gradual plastic flow.

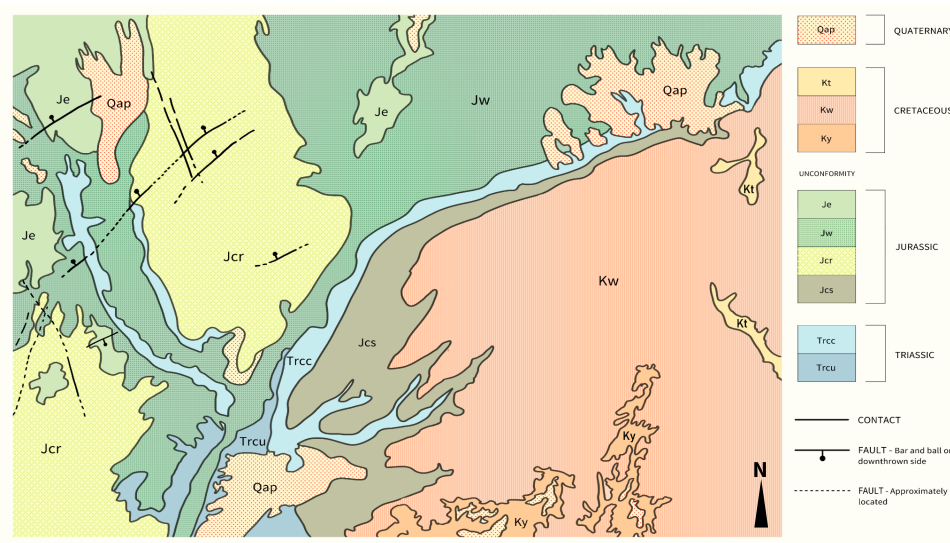


The lattice resistance τ is a parameter that describes the resistance of a crystal lattice to the movement of dislocations, and L is the length of the system along the axis of dislocation. Based on this, which of the following best explains how these parameters influence the strengths of deep earthquakes?

- A. The lower lithosphere has a lower lattice resistance than the upper asthenosphere, which results in stronger earthquakes
- B. The lower lithosphere has a smaller length scale than the upper asthenosphere, which results in stronger earthquakes
- C. The upper asthenosphere has a lower lattice resistance than the lower lithosphere, which results in stronger earthquakes**
- D. The upper asthenosphere has a larger length scale than the lower lithosphere, which results in stronger earthquakes

Solution: The asthenosphere exhibits more plastic flow than the lithosphere. At the atomic scale, one of the primary mechanisms for plastic flow is lattice dislocations, implying low lattice resistance. Thus the upper asthenosphere should have a lower lattice resistance. Since a low lattice resistance is associated with high wildness (aka large bursts of strain release), the upper asthenosphere would have stronger earthquakes.

6. The geologic map pictured below shows an area of untilted strata. Which of the following statements about the area are most likely true?

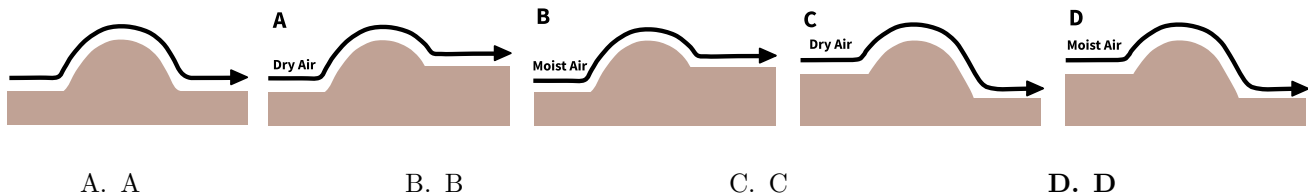


- I) A river once flowed from the southwest towards the northeast.
 II) This area exhibits horst and graben topography.
 III) The area is useful for studying the Jurassic-Cretaceous transition boundary.

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

Solution: The southwest displays older rocks indicating higher degrees of down cutting. Thus, the river likely flowed toward the southwest - I is false. Faults dip in the same direction, preventing the development of explicit horsts and grabens - II is false. As there is an unconformity between the J and K rock units, studying the transition boundary would be difficult - III is false.

7. The diagram on the left shows the idealized path of an air parcel as it flows over a mountain, losing all moisture in the process. The next four figures show the same basic scenario, but with some changes in the mountain's topography and the air humidity. Assuming temperature is constant on either side of the mountain before the onset of the wind, in which scenario would the air parcel experience the largest increase in temperature?



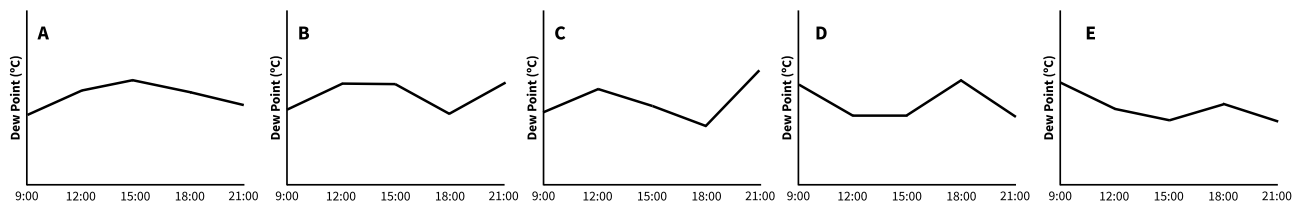
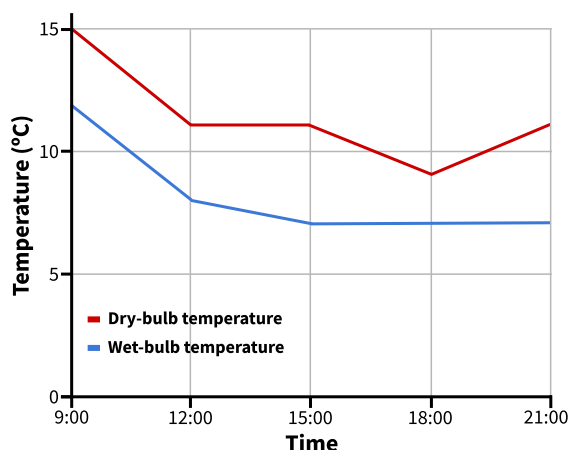
Solution: As an unsaturated air parcel rises, it cools along its dry adiabatic lapse rate (DALR) until it becomes saturated, then it proceeds to follow the moist adiabatic lapse rate (MALR). Upon sinking, the parcels all follow dry adiabatic heating, as heating results in the parcels becoming unsaturated. Due to the latent heat of condensation, the MALR is less than the DALR.

Scenario D presents us with the largest warming, due to the small decrease in temperature on ascent while following the MALR and the large increase in temperature during descent.

8. A firestorm is a self-sustaining convective storm driven by massive fire events, producing clouds known as pyrocumulonimbus clouds. Which of the following statements is **least** accurate regarding firestorms?
- A. Their formation is favored by dry surface air and moist upper-level air
 - B. Their strong downbursts can spawn secondary fires away from the storm front
 - C. They are more likely to form in densely vegetated regions
 - D. As the system develops vertically due to updrafts, the rotational speed of the central vortex decreases**

Solution: Dry surface conditions are favorable for large scale fire formation, but moisture is also required for cloud development. A describes a situation that satisfies both requirements – A is true. The dry downbursts spread laterally upon reaching the surface, spreading to produce new fires – B is true. Vegetation serves as fuel for the fire to burn as well as a source of moisture – C is true. As the system grows vertically, the vortex narrows and speeds up in order to conserve angular momentum – D is false.

9. Kat measures the dry-bulb and wet-bulb temperatures in 3-hour intervals over a day and obtains the below data. Which of the following graphs most accurately describes the dew point fluctuation throughout the day?



A. A

B. B

C. C

D. D

E. E

Solution: Dew point roughly tracks the difference between dry-bulb and wet-bulb temperature. When the difference is small, the dew point should be close to the two temperatures. When the difference is large, the dewpoint should be somewhat depressed. Given the bulb temperatures, we expect a dip from 12:00 to 15:00, a bump at 18:00 relative to the 15:00 measurements, then a return to 15:00 dew point at 21:00. E matches this best.

10. Phobos orbits Mars counterclockwise (as viewed from Mars' north celestial pole) with a sidereal orbital period of 0.319 days. Mars rotates counterclockwise with a sidereal day of 1.026 days. An observer is stationed at the Martian equator to log the motion of Phobos. Neglecting Mars' axial tilt, which of the following statements are true?

- I) From the observer's perspective, the synodic period of Phobos is 0.463 days.
- II) The observer would see Phobos rise in the east and set in the west.
- III) Over the course of a single Martian sol, the observer would witness Phobos complete more than one full cycle of phases.

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

Solution: Since Phobos orbits in the same direction as Mars' rotation, the synodic period of Phobos equals $\frac{1}{(1 \text{ rev}/0.319 \text{ days}) - (1 \text{ rot}/1.026 \text{ days})} = 0.463 \text{ days/rev}$ – I is true. Because Phobos' orbital period is shorter than Mars' rotational period, the observer would see it move in the opposite direction compared to most celestial bodies (rising in the east), so it actually rises in the west and sets in the east – II is false. Over a Martian sol, Phobos goes through its phases roughly $1.026/0.463 = 2.2$ times, which is more than once – III is true.

11. Ice streams are regions of ice sheets with increased ice velocities. Understanding the processes controlling ice streams is critical for evaluating the stabilization of ice sheets. The lateral margin growth of ice streams happens through the following process:

- Ice moves faster within a region due to topographic or geologic features.
- Increased shear stresses between the faster ice stream and the slower neighboring ice lead to weakening and warming ice.
- Subsurface sediment mobilization increases, propagating higher ice velocities.

Which of the following options accurately pairs a change made to the lateral ice stream margin with the impact on the magnitude of the ice stream velocity it would have?

- A. Increased water drainage at the boundaries, increase
- B. Increased bed sediment stiffening, increase
- C. Shear thinning of the ice, decrease
- D. Transition from channelized to sheet subsurface water flow, decrease**

Solution: Less water in the subglacial sediment would lead to stiffer, stronger subglacial sediment that would decrease flow rates - A is false. Stiffer subglacial sediment would lead to slower flow, as subglacial sediment mobilization would decrease - B is false. Shear thinning of the ice would result in weaker, warmer ice, increasing stream velocities - C is false. Sheet subsurface water flow acts as a better lubricant than channelized flow allowing for faster flow rates - D is true.

12. The table below shows the magnetic field strengths of several bodies as well as the predicted field strength of Triton based on a recently published model. Assuming the model is correct, which of the following is the likely cause of the magnetic field?

Body	Radius (km)	Distance from Sun (AU)	Field Strength (nT)
Venus	6050	0.73	10
Europa	1560	5.5	100
Mercury	2440	0.46	300
Triton (Predicted)	1350	30	1000
Earth	6700	1	25000

- A. Induced magnetic field in subsurface oceans
 B. Internal dynamo from subsurface saltwater ocean
 C. Induced magnetic field in its liquid outer core
 D. Internal dynamo in its liquid outer core

Solution: Induced magnetic fields tend to be much weaker than internal dynamos. Europa's magnetic field is induced from Jupiter's magnetic field acting on its subsurface ocean. A similar effect from Neptune would likely be weaker as Neptune has a weaker magnetic field, so A and C can be eliminated.

A strong internal dynamo in the subsurface saltwater ocean required to produce the expected field strength would require high amounts of heating from the seafloor. In such a situation, it is highly unlikely that there would not be a stronger dynamo in a liquid outer core. Thus the answer is D.

13. Komatiites are a rare type of rock formed by very high-temperature magmas that erupted during the Archean Eon. Which of the following statements would you expect to be true of komatiites?

- I) Present-day komatiite finds are more often in paleo-lava tube or paleo-lava pool settings rather than paleo-surface flow settings.
 II) Present-day komatiites are uniformly distributed amongst tectonic settings.
 III) Komatiite formation was primarily due to the heat generated by ^{87}Rb , a radioactive isotope with a 50 billion-year half-life.

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

Solution: Due to the high formation temperatures of komatiites, it can be inferred that komatiitic magmas have low viscosities. Thus, surface flows are thin and are more likely to be eroded compared to lava tube or lava pool komatiites - I is true. Since komatiites formed during the Archean, they are most likely to be preserved in areas with little tectonic activity, such as continental cratons - II is false. Komatiite formation requires high planetary internal heat and was partially caused by radioactive heating in the Archean. However, Rb is very rare and has a long half life, meaning it did not produce significant heat during the Archean - III is false.

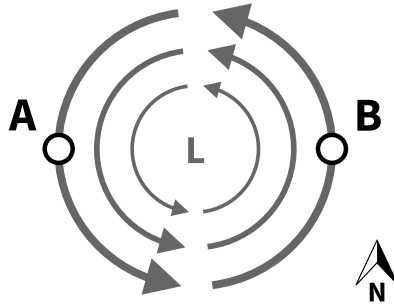
14. Which of the following properties generally describe clay-rich soils?

- I) High moisture retention rate in dry seasons
 II) High plant available water content in wet seasons

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

Solution: Clay has high porosity and low permeability, making it difficult for water to leave soil pores during the dry season - I is true. Similarly, it is hard for plants to withdraw most of the water present in clay-rich soils - II is false.

15. Consider two points A and B on the westernmost and easternmost points, respectively, of a Northern Hemisphere cyclone. Each point on the cyclone has a relative vorticity ζ and planetary vorticity f such that $\zeta + f = \eta$, where the absolute vorticity η is conserved during the movement of an air parcel.

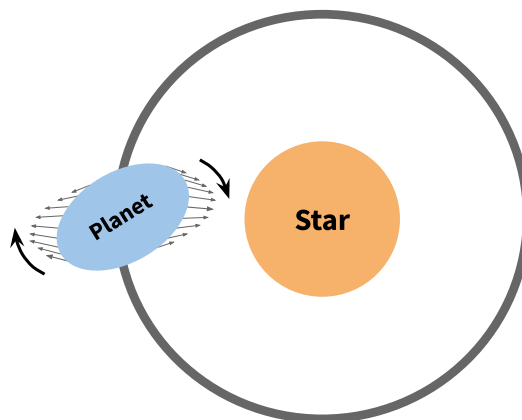


Consider how the vorticity of air parcels located at points A and B changes when parcels follow the cyclonic wind direction at each point. How do these changes affect the motion of the cyclone?

- A. Relative vorticity increases at A and decreases at B, causing net movement to the north and west
- B. Relative vorticity increases at A and decreases at B, causing net movement to the south and east
- C. Relative vorticity decreases at A and increases at B, causing net movement to the north and east
- D. Relative vorticity decreases at A and increases at B, causing net movement to the south and west

Solution: The southward motion of air at A brings the parcel closer to the equator and decreases planetary vorticity, requiring relative vorticity to increase. The opposite is true for B, where planetary vorticity increases and relative vorticity decreases. Since vorticity corresponds to cyclonic rotation, this results in a net movement of the cyclone to the west. The center of the cyclone is now to the east of the center of rotation, causing it to be under the influence of winds that move it to the north. This is the cause of the so-called beta effect, one of the driving forces of cyclone movement across Earth.

16. Consider the tidal locking of a planet to a star. As shown in the diagram, the mechanism of tidal locking works by creating a torque on the planet's tidal bulge, which is unaligned with the planetary orbit. Identify all of the following that are true of this mechanism.



- I) Tidal locking is stable under a perturbation in planetary axial rotational velocity in either direction.
- II) Given the star's angular momentum stays constant, a planet that becomes tidally locked from a previously retrograde axial rotation will move to a closer orbital distance from its star.

A. I only

B. II only

C. I and II

D. None

Solution: The torque always seeks to realign the tidal bulge with the to-star axis. It is thus a negative feedback loop and is stable under a perturbation - I is true. Considering prograde rotation/orbit as positive angular momentum, a planet switching from previously retrograde rotation to prograde rotation, would represent an addition of angular momentum. The orbital angular momentum must decrease as a result. Since a planet's linear momentum is constant, the only remaining way to decrease orbital angular momentum is decreasing the orbital radius - II is true.

17. Researchers have discovered coesite, a weakly metastable, high-pressure polymorph of quartz within continental crust. This finding supports the idea that continental crust can subduct deep into the mantle, forming coesite, then returning to the surface as semi-coherent continental crust where it is later exhumed. Identify all of the following statements that are true of this discovery.

I) Coesite is often found both included within mineral grains and amongst the matrix.

II) Coesite-hosting mineral grains can be identified by radial compression fractures.

III) The presence of coesite provides a precise measure of subduction depth.

A. I only

B. II only

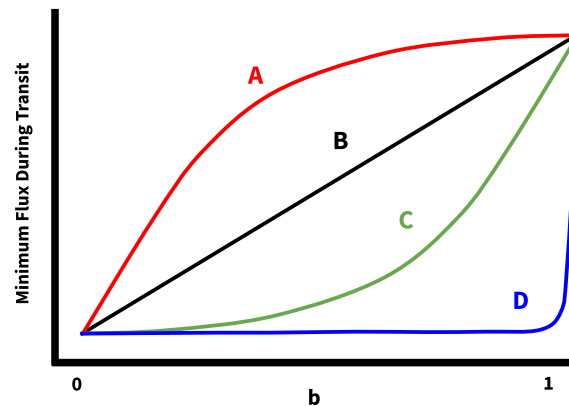
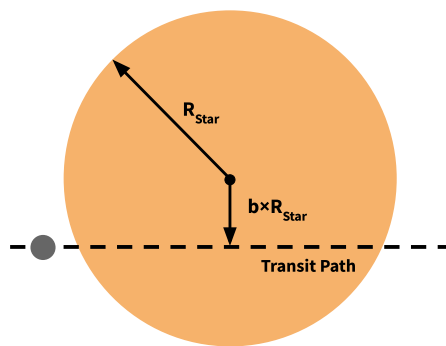
C. I and II

D. II and III

E. None

Solution: Since coesite is weakly metastable, it is susceptible to transition back to quartz without a rigid material to maintain pressure around it. The matrix does not provide high enough pressures, but grains of strong minerals such as garnet do - I is false. Coesite is favorable under high pressures and is thus denser. When it transitions to quartz, it expands to create radial expansion fractures - II is false. While quartz typically transitions to coesite at a specific depth, we do not know how far below that depth a sample is from - III is false.

18. The b value of a transiting system is defined as the fraction of the transiting path's minimum distance from the center of the stellar disk out of the total radius of the star, as seen from Earth. Assuming $R_{\text{Star}} \gg R_{\text{Planet}}$, which of the following curves most accurately graphs minimum flux during transit against the value of b ?



A. A

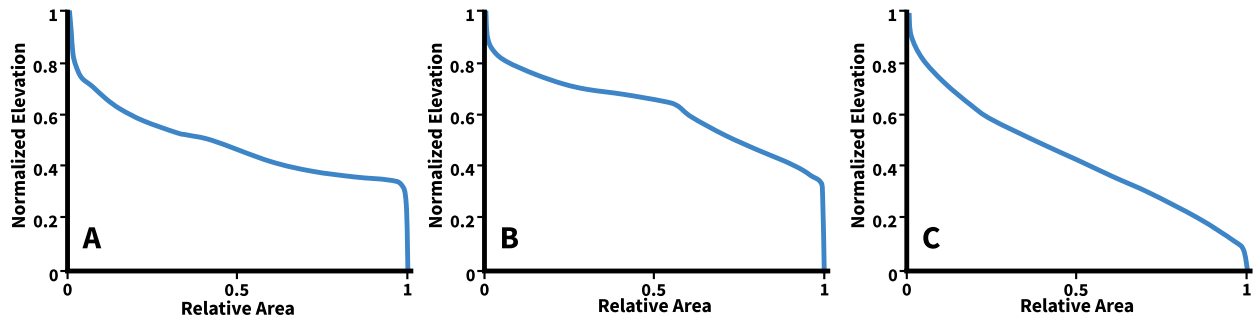
B. B

C. C

D. D

Solution: The flux is lowest when the planet covers the brightest portion of the star, thus the the graph of minimum flux against b value is the function of stellar intensity as a function of radius. This function can be approximated by the optical depth to the photosphere which grows gradually over the entire star, but faster at larger values of b . This best matches the function in C.

19. Shown in the figure are the hypsometric curves for three different river subbasins in the Chalakudy River Basin in South India, plotting the normalized elevation versus the relative cumulative area. Identify all of the following statements that are likely true regarding these basins, assuming they have a similar age.



- I) A higher hypsometric integral (area under the curve) correlates with more base material eroded.
 II) Basin B is made of more resistant materials than Basin A.
 III) Basin C is closest to the mouth of the Chalakudy River Basin.
- A. I only B. II only C. I and II **D. II and III** E. I, II, and III

Solution: A higher hypsometric integral indicates, on average, land at higher elevations. Since erosion works to decrease elevation, a higher integral corresponds with a lesser extent of erosion - I is false. The subbasins are geographically close, so we can assume the erosional power is similar across sub basins. Since Basin B has a higher hypsometric integral than A, Basin B is likely more resistant than A - II is true. Basin C has the largest proportion of basin at relatively low elevations, which is indicative of an area near the more eroded areas of a basin, i.e. the mouth - III is true.

20. Which of the following are true about how climate change generally affects avalanches?
- I) Weak layers within snowpacks are less likely to form, decreasing avalanche risk, since the formation of ice layers by melting and refreezing is disfavored.
 II) Lower elevation regions are likely to have more frequent avalanches, since the amount of liquid precipitation and runoff from higher elevations increases.
 III) Higher elevation regions are expected to see more frequent avalanches, since the amount of mixed-type precipitation increases.
- A. II only **B. III only** C. I and II D. I and III E. II and III

Solution: Weak layers, typically made of ice, are more likely to form given spikes in warmer temperatures, which are more common due to global warming - I is false. Lower elevation regions are likely to have less avalanches, as there is less snow precipitated there - II is false. Higher elevations have more snow precipitation, and a greater amount of rain, which leads to weak layers of ice - III is true.

21. The Froude number, a comparison between a stream's inertial and gravitational forces, can give valuable insight into fluid flow in hydrogeological systems. It is calculated by the formula below, where u is the stream velocity, g is the gravitational acceleration, and L is the stream depth. Which of the following statements are true regarding the Froude number?

$$Fr = \frac{u}{\sqrt{gL}}$$

- I) For two streams with the same volumetric flow rate and width, a more sinuous stream has a smaller Froude number.
- II) For a given location along a stream, the Froude number at that location will initially decrease, given that the location was originally a knickpoint.

A. I only

B. II only

C. I and II

D. None

Solution: Straighter streams will have a higher velocity and thus shallower channel depths, both of which contribute to a higher Froude number - I is true. Over time, knickpoints will migrate upstream due to greater erosion at the lower levels of strata. Thus locations that were previously knickpoints will transition to having slow flow and deep channels, such as seen in the pools at the bottom of waterfalls. This corresponds to a lower Froude number - II is true.

22. Peter is studying the effect of ocean acidification on the Calcite Compensation Depth (CCD) and the Aragonite Compensation Depth (ACD). Aragonite is less stable than calcite under most conditions in the ocean. Which of the following correctly describes both the relationship between the CCD and ACD, and the Atlantic region that would experience the greatest shallowing of the CCD due to ocean acidification?

A. The ACD is deeper than the CCD; the Western Equatorial Atlantic

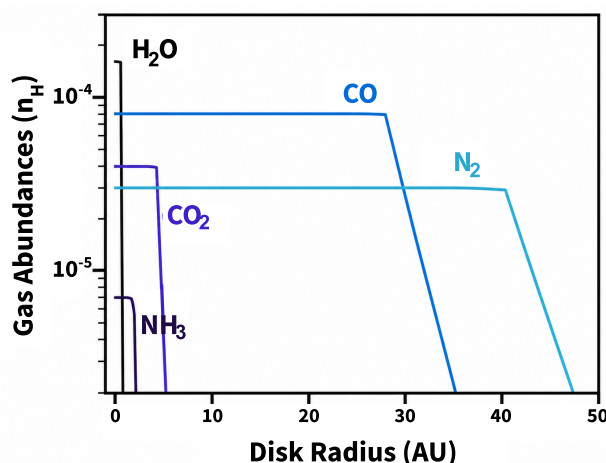
B. The ACD is deeper than the CCD; the Eastern Equatorial Atlantic

C. The ACD is shallower than the CCD; the Western Equatorial Atlantic

D. The ACD is shallower than the CCD; the Eastern Equatorial Atlantic

Solution: Since aragonite is less stable than calcite, it is more soluble and dissolves at a shallower depth. Along the equator, the western side of ocean basins is generally dominated by downwelling, while the eastern side is dominated by upwelling. Ocean acidification occurs through atmospheric carbon dioxide dissolving into surface ocean waters, meaning downwelling would transport the more acidic surface waters to greater depths, resulting in a shallower CCD in the Western Equatorial Atlantic.

23. The figure below shows the concentration of certain compounds in a planetary disk as a function of distance from a central star.



The majority of hydrogen in space is found in compounds of H_2O and H_2 , and deuterium preferentially bonds to oxygen over hydrogen. Given this information and the above figure, which of the following statements are true?

- I) As the star's surface temperature increases over time, the shown curves primarily shift up.
- II) Compounds of all phases found at the frost line for CO would have a higher D/H (deuterium to hydrogen) ratio than those found at the frost line for N_2 .

A. I only

B. II only

C. I and II

D. None

Solution: As the surface temperature and thus luminosity of the central star increases, the frost lines shift away from the star as compounds need to be further away to remain stable. These shifts would be reflected in the curves as a shift to the right - I is false. Hydrogen is increasingly present as water ice further from the star because photolysis closer to the star causes hydrogen to exist as H_2 . As described, H_2O is more deuterated, leading to a higher D/H ratio in colder areas. Since the frost line is closer for CO, compounds at the frost line for CO would have a lower D/H ratio - II is false.

24. The Earth's atmosphere can be modeled as an N -layer atmosphere. This model assumes each layer to be transparent to incoming solar radiation and partially opaque to outgoing radiation. Assuming each layer emits absorbed energy uniformly, which of the following statements are true for a planet in equilibrium?

- I) Higher values of N always correspond to higher surface temperature.
- II) Regardless of the value of N , the temperature at the top of the atmosphere is equal to the surface temperature of the same planet with no atmosphere.
- III) Surface temperature can be equal to the temperature of the layer directly above it.

A. I only

B. III only

C. I and II

D. I and III

E. I, II, and III

Solution: Higher values of N correspond to more atmospheric layers, causing more outgoing radiation to be trapped. This leads to a stronger greenhouse effect, causing higher surface temperatures - I is true. The TOA temperature is equal to the emission temperature of the planet. Since the emission temperature only depends on the incoming solar radiation, which remains the same regardless of the value of N , the TOA temperature will remain constant (even with no atmosphere) - II is true. Each atmospheric layer absorbs and re-emits radiation both up and down. This downward emission gives the surface an extra energy input that the layer above it doesn't receive - III is false.

25. The Volcanic Explosivity Index (VEI) measures the power of an eruption by the volume of erupted rock, including void spaces within tephra. The Dense Rock Equivalent (DRE) tephra component, on the other hand, estimates the total volume of erupted tephra excluding the air inside. Which of the following conditions would be associated with the highest discrepancy between the VEI and DRE?

- I) Relatively slow magmatic ascent
 II) Relatively small average tephra diameters

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

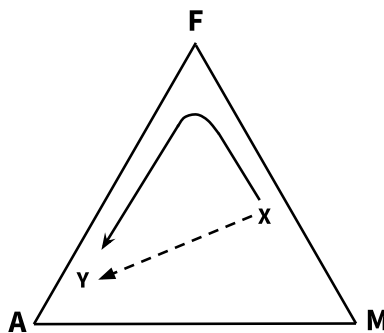
Solution: A larger discrepancy means higher tephra void space. Slow magmatic ascent gives more time for degassing, so the tephra will be less vesicular - I is not associated. Small tephra diameters mean a larger surface area to volume ratio resulting in lower internal void space. Thus small diameters will lead to less tephra void space - II is not associated.

26. Suppose an ocean surface buoy is blown around by a strong storm so that it is given some initial velocity in the northward direction in the Northern Hemisphere. Which of the following equations best gives the northward and eastward velocities of the buoy as a function of time?

- A. $V_n = \cos(t)$, $V_e = \sin(t)$ D. $V_n = e^{-t} \cos(t)$, $V_e = e^{-t} \sin(t)$
 B. $V_n = e^t \cos(t)$, $V_e = e^t \sin(t)$ E. $V_n = e^{-t} \cos(t)$, $V_e = -e^{-t} \sin(t)$
 C. $V_n = e^t \cos(t)$, $V_e = -e^t \sin(t)$

Solution: The buoy motion will decay over time due to friction, and this exponential decay is only encoded by D and E. The buoy should also circulate by turning to the right (clockwise) due to the Coriolis effect. This motion is encoded by the form $(\cos(t), \sin(t))$.

27. Aashray is studying a relatively oxidized initial melt X enriched in Fe^{3+} compared to Fe^{2+} . They found it evolved from its initial composition to melt Y through the fractional crystallization of mafic minerals. The diagram below plots melts by the relative weight percents of MgO , FeO , and $\text{Na}_2\text{O} + \text{K}_2\text{O}$, shown by letters M, F, and A, respectively. Two possible melt evolution paths are shown below. Which of the following statements is true?



- I) Based on iron ion ratios, magnetite (Fe_3O_4) crystallization is expected to be more favorable than ilmenite ($\text{FeTi}^{4+}\text{O}_3$) crystallization.
 II) Melt X is likely from a subduction arc.
 III) Simultaneous crystallization of magnetite and forsterite (Mg-rich olivine) would result in evolution along the dashed line from X to Y.

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

Solution: Magnetite is made of iron (II) and iron (III) while ilmenite is only iron (II). Since the magma is enriched in iron (III), magnetite is more likely to precipitate - I is true. Melt X is oxidized, matching the conditions of a subduction arc - II is true. Magnetite is iron-rich while forsterite is magnesium-rich. Simultaneous precipitation will reduce both F and M concentrations, enriching the melt in alkalis, moving it towards A as the dashed path shows - III is true.

28. Uranus is unique among the giant planets in that it has relatively little heat transport out of its interior, equal to about one-eighth of the energy it absorbs from the Sun. Identify all of the following statements that are true of Uranus as a result of this effect:

- I) Its surface atmospheric circulation is highly seasonal.
II) Its surface atmospheric circulation extends far into its interior.

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

Solution: The planet's large axial tilt means regions receive sunlight in different seasons. Since the Sun is the main driver of atmospheric circulation, circulation is expected to be highly seasonal - I is true. Deep convection is associated with rapid internal heat loss, which Uranus lacks - II is false.

29. Emmanuel is studying a geological structure he found on a horizontal outcrop. As he walks from north to south, he notes the composition of each layer he comes across, as well as the dip direction of some of the layers. In order, they are: composition Z, dipping north; composition X, unknown dip; composition W, dipping east; composition X, unknown dip; composition Z, dipping south. Assuming the outcrop is not overturned, what type of feature did Emmanuel encounter?

- A. Syncline **D. Plunging Anticline**
B. Anticline E. Unable to determine
C. Plunging Syncline

Solution: Since the outcrop is not overturned and layer Z dips away from the hinge (layer W), the feature is an anticline. Since W dips perpendicular to the outer layers, the anticline must have a nonzero plunge.

30. The heterosphere occurs in the upper atmosphere, where composition changes as some gases begin to separate due to their chemical properties. Which of the following statements are true as altitude increases in the heterosphere?

- I) Ionized atoms appear more frequently from photoionization.
II) The ratio of the concentration of all phases of oxygen to that of nitrogen increases.
III) Hydrogen and helium mole fractions decrease.

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

Solution: At higher altitudes, stronger solar radiation causes more photoionization in atmospheric gases - I is true. Because of its triple bond, diatomic nitrogen is much harder to break apart compared to diatomic oxygen, so N_2 remains bonded while $O_2 \rightarrow 2O$. Atomic oxygen is much lighter compared to diatomic nitrogen, so oxygen's abundance relative to nitrogen increases as altitude increases - II is true. Helium and hydrogen have low molecular weight, so their abundance increases with altitude - III is false.

END OF SECTION I