USESO 2024

Training Camp Exam

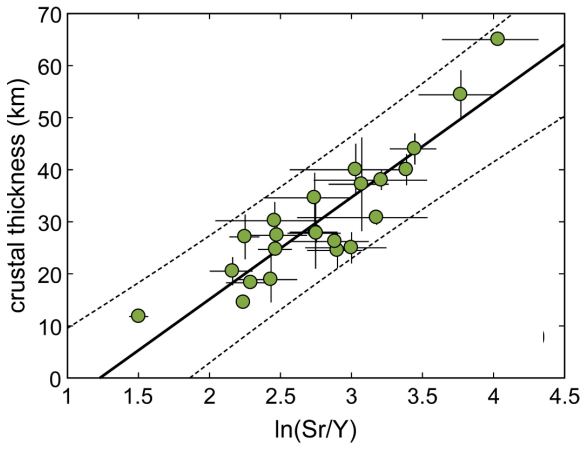
Multiple Choice

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. Crustal thickness (H^{tot}) in volcanic arc regions can be estimated by interpreting the geochemical properties of surface igneous rocks through a process known as mohometry. A Sr/Y mohometer is shown below.



Let $H^{tot} = H + h$, where H represents the depth of the Moho discontinuity relative to sea level and h represents the elevation of the land surface. Which of the following statements is/are likely true?

I) H correlates negatively with h

II) Measured SiO_2 correlates negatively with H^{tot}

III) Strontium is incompatible at high pressures (i.e. it does not fit well into the crystal structure of most minerals) while yttrium is compatible

A. II only

B. III only

C. I and II

D. I and III

E. None

Solution: Recall that mountains (with high elevation) have crustal roots that extend deep below the surface, resulting in greater Moho depth – I is false. Processes such as assimilation enrich magmas with silica as they travel through the crust, so measured SiO_2 tends to increase with crustal thickness – II is false. We can infer from the diagram that increasing Sr content and decreasing Y content correlates positively with greater crustal thickness and thus greater subsurface pressure. Therefore, Sr must be incompatible at high pressures to preferentially enter melt, while Y must be compatible to preferentially remain in solid phase at depth – III is true.

2. Marc examines object X with circular orbit about star Y. He finds four different expressions for X's orbital velocity using each of the four methods described below.

I) Equating the sum of X's kinetic and potential energy to X's total energy

II) Equating the centripetal force exerted on X to the gravitational force exerted on X

III) Dividing X's angular momentum by the product of X's orbital radius and mass

IV) Dividing the distance X travels in a single orbit by X's orbital period

Marc realizes that by equating two of the derived expressions for X's orbital velocity and rearranging terms (without substitution), he can produce an expression for Kepler's third law. Which two expressions does he equate?

A. I and III

B. I and IV

C. II and III

D. II and IV

E. III and IV

Solution: Let m, R, E, L, and T represent the mass, orbital radius, total energy, angular momentum, and orbital period of object X, respectively. Let M represent the mass of star Y. Solve for orbital velocity in all four scenarios:

$$v_I = \sqrt{\frac{2(E + GMmR)}{m}}$$
$$v_{II} = \sqrt{\frac{GM}{R}}$$
$$v_{III} = \frac{L}{mR}$$
$$v_{IV} = \frac{2\pi R}{T}$$

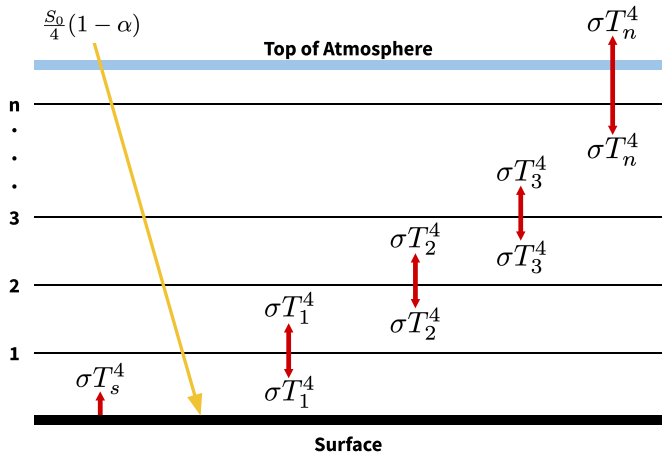
Equating v_{II} and v_{IV} and squaring both sides gives us:

$$\frac{GM}{R} = \frac{4\pi^2 R^2}{T^2}$$

If we move each term except for T^2 to the right, we get an equation for Kepler's third law:

$$T^2 = \frac{4\pi^2}{GM} R^3$$

3. The model below describes an N-layer atmosphere transparent to incoming solar radiation in which each layer absorbs all outgoing terrestrial infrared radiation. If $\frac{S_0}{4}(1-\alpha)$ equals the average incoming solar radiation across the planet and σT_i^4 represents blackbody radiation emitted by a given layer, which of the following is/are true regarding the model?



I) The top of the atmosphere has a radiative balance given by $\frac{S_0}{4}(1-\alpha) = \sigma T_n^4$

II) The planetary surface has a radiative balance given by $\frac{S_0}{4}(1-\alpha) + \sigma T_1^4 = \sigma T_s^4$

III) Each individual layer has a radiative balance given by $2\sigma {T_i}^4 = \sigma T_{i-1}^4 + \sigma T_{i+1}^4$

A. I only

B. II only

C. I and II

D. II and III

E. I, II, and III

Solution: For a system in radiative equilibrium, the amount of incoming and outgoing radiation must balance. The total radiation absorbed by Earth equals the total outgoing radiation - I is true. The total radiation absorbed by the surface equals the total outgoing radiation at the surface - II is true. The total radiation emitted by each interior layer equals the total radiation absorbed by the same layer - III is true.

4. Below are three structures formed by deformation. Which of the following best characterizes the stress that likely produced each structure?

A. Compressional; extensional; compressional

B. Compressional; extensional; extensional

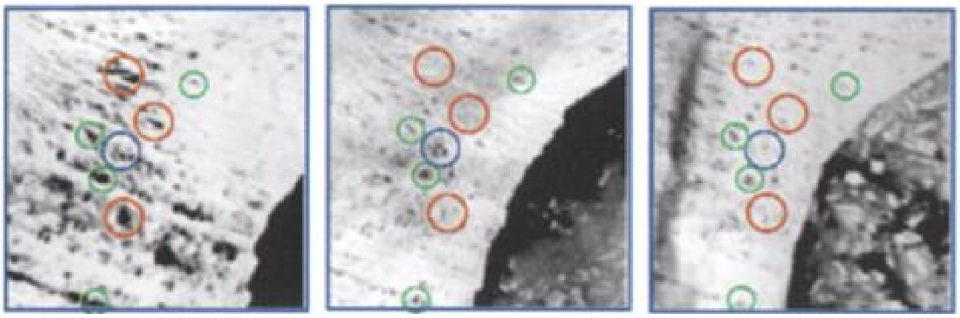
C. Shear; compressional; compressional

D. Shear; compressional; extensional

E. Extensional; extensional; shear

Solution: The first image displays a buckle fold, which is formed by compressional stress. Since layers of similar colors/textures are shifted down on the hanging wall, the second image displays a normal fault, which is formed by extensional stress. The third image displays pinch-and-swell structures, which are predominantly by extensional stress.

5. The 2002 Larsen B calving event was distinctive due to its splinter-style calving. Based on ice loss data and images of the calving areas, which of the following processes was most likely responsible for ice loss during this event?



Circled dark areas are melt ponds.

Date	Ice Loss
Jan 31 - Feb 17	611 km^2
Feb 17 - Feb 23	164 km^2
Feb 25 - Mar 5	1973 km^2

A. Higher albedos led to more melting, which led to further melting of the ice

B. Ocean water intruded into the ice sheet, which split apart the ice

C. Meltwater formed and solidified, which wedged apart the ice

D. Meltwater infiltrated beneath existing fractures, which weakened the ice

Solution: The images of the calving areas suggest that the melt ponds decreased in size first, then significant ice loss occurred. In the scenarios described in A and B, we would expect more water to be visible before more calving occurred, which is not what we see - A and B are incorrect. C is consistent with a reduction in melt pond size, but a freeze-thaw cycle this significant is unlikely to occur in the given time frame - C is incorrect. It is most likely that surface meltwater infiltrated into the glacier, allowing fault propagation and later calving - D is correct.

6. The four Galilean moons, listed in order of increasing distance from Jupiter, are Io, Europa, Ganymede, and Callisto. Which of the following statements is/are likely true of these moons?

I) Meteorites strike Io and Europa more often than Callisto and Ganymede due to inward focusing of debris caused by Jupiter

II) Io and Europa have more internal heat than Callisto and Ganymede because their larger masses allow them to maintain a higher geotherm

A. I only

B. II only

C. I and II

D. None

Solution: Jupiter's strong gravity pulls many asteroids close to itself, meaning we would expect Io and Europa, which are closer to the planet, to receive more debris than Callisto and Ganymede, which are further from the planet - I is true. Io and Europa are the smallest of the Galilean moons, and their internal heat is mostly due to gravitational tidal forces - II is false.

7. A geologist studying a lava lake is interested in the settling rates of cooling crystals. Which of the following rock formations would be of most use to the geologist?

   A. Large, closely packed olivine crystals in an intermediate groundmass that is finest near the top

   B. Ripples of lava trending from higher to lower elevation that grow blockier as they progress downslope

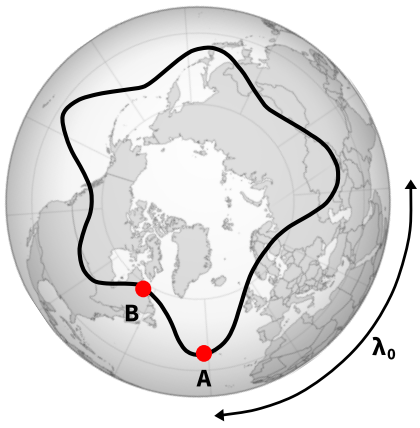
   C. Layers of rock fading from light to dark in repeated patterns that increase in thickness toward a central region

   D. Repeated vertical intrusions separated by baked contacts

Solution: To interpret crystal settling rates in a lava lake, the geologist needs information about the vertical distribution of crystals in a large mass of igneous rock. Ripples of lava would occur in lava flows, not in lava lakes - B is incorrect. Vertical and radial patterns of igneous rock indicate the presence of intrusions from a central magma source, not a lava lake - C and D are incorrect. A vertical gradient in crystal size indicates that crystals settled out of a large body of lava - A is correct.

The following two questions should be approached sequentially.

8. The absolute vorticity η of an air column is a measure of rotation calculated as $\eta = \zeta + f$, where ζ represents relative vorticity (derived from the column's rotation) and f represents planetary vorticity (derived from Earth's rotation). Absolute vorticity is conserved in the case of atmospheric Rossby waves. This explains why they move in sinuous patterns with wavelength λ, as shown below by a contour of constant η.



   At position A, f is _____ than f at position B. In the Northern Hemisphere, ζ is negative when rotation is _____.

   A. greater; cyclonic

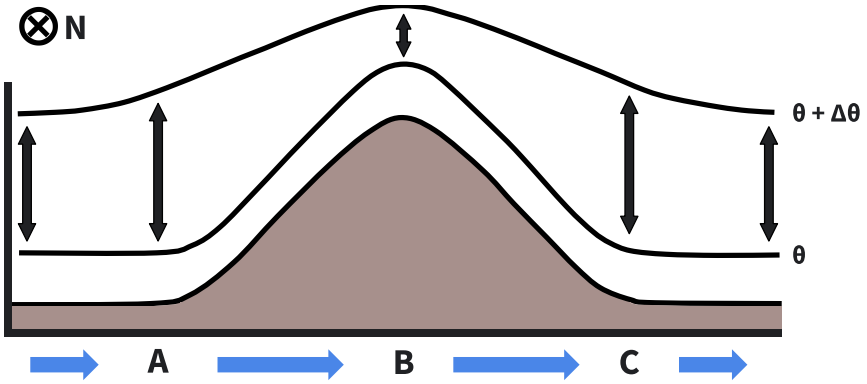
   B. greater; anticyclonic

   C. smaller; cyclonic

   D. smaller; anticyclonic

Solution: Coriolis deflection due to Earth's rotation is maximized at the poles. This suggests that planetary vorticity (f), derived from Earth's rotation, increases with latitude – f at position A is smaller than f at position B. To conserve absolute vorticity ($\eta = \zeta + f$), relative vorticity (ζ) is positive at position A and negative at position B. As Rossby waves move from west to east, this corresponds to ζ being positive when rotation is cyclonic and negative when rotation is anticyclonic in the Northern Hemisphere.

9. Air bounded by two isentropes, surfaces of constant potential temperature (θ), flows adiabatically over the Rockies at 45°N as shown below.



The circled cross indicates that north is directed into the page.

The potential vorticity (Q) of an air column is a measure of rotation calculated as $Q = \eta/H$, where H represents column height. Because Q accounts for stretching and contracting of the column, it is conserved regardless of column height (i.e. Q remains constant from A to B to C in the diagram above). Considering your answer to the previous question, which of the following statements is/are likely true?

I) An atmospheric ridge develops at C

II) Northerly geostrophic winds develop between B and C

A. I only

B. II only

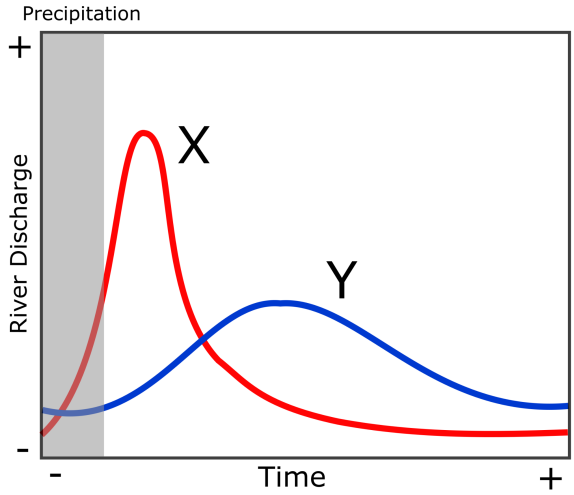
C. I and II

D. None

Solution: Potential vorticity (Q) is conserved unless diabatic heating occurs (e.g. latent heat release), similar to how angular momentum is conserved unless external torques are applied. As column height (H) increases from B to C, relative vorticity (ζ) must increase to keep Q unchanged (planetary vorticity can be approximated as constant). This induces cyclonic rotation that results in the formation of a trough (i.e. lee cyclogenesis) – I is false. Due to the eastward pressure gradient created by the low pressure system leeward of the Rockies, geostrophic winds blow from the north – II is true.

Error carried forward was applied to this question. Students who selected A or C in the previous question should have inferred the formation of an atmospheric ridge and geostrophic winds blowing from the south. For these students, choice A was considered the correct answer.

10. Shown below are two different hydrographs representing river discharge after a precipitation event. Which of the following drainage basin changes would result in a shift from hydrograph X to Y? Assume that the total amount of precipitation that enters the basin is constant.



A. Increase in impervious surface area

B. Increase in basin elongation

C. Increase in basin slope

D. Decrease in surface plant cover

Solution: Increasing impervious surface area, increasing basin slope, and decreasing surface plant cover would all reduce infiltration and cause runoff to move more quickly, resulting in a faster and stronger flash flood - A, C, and D are incorrect. Increasing basin elongation would result in the water reaching a confluence point over a longer period of time, which would result in a weaker extended flooding event - B is correct.

11. One of the leading models for mantle convection is known as the double-layered model, which describes the mantle as having two distinct convection cells separated by a mid-mantle boundary at a depth of around 660 km. Which of the following observations would support the double-layered model?

I) Subducting tectonic plates in the boundary region typically create compressional earthquakes

II) Mid-Atlantic Ridge Basalts are generally depleted in volatile elements while Hawaiian Ocean Island Basalts are generally rich in volatile elements

A. I only

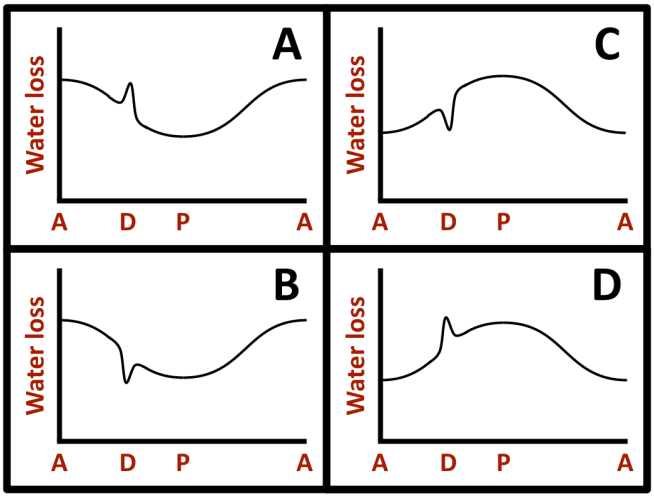
B. II only

C. I and II

D. None

Solution: Given a double-layered model, subducting plates would face pressures resisting their movement past the boundary layer. This would create compressional stresses resulting in earthquakes - I is true. MARBs originate from upper-mantle partial melting while OIBs originate via mantle hotspots from lower-mantle partial melting. The differing compositions of these two basalts indicate that their parent magmas are not closely related, suggesting the presence of two distinct convection cells - II is true.

12. Mars' lower atmosphere contains a small amount of water vapor that is slowly lost over time. A group of researchers measured the rate of Mars' water loss throughout a full orbit from November 2017 to October 2019. They found that the most extreme values occurred at aphelion (labeled A), at perihelion (labeled P), and during a violent dust storm (labeled D) that occurred during May 2018. Which of the graphs below would likely be closest to the researchers' observed results?



A. A

B. B

C. C

D. D

Solution: Water loss on Mars occurs when water vapor is lifted high in the atmosphere where it can escape. This happens more often at perihelion because Mars is significantly warmer, increasing the height of its atmosphere and giving water vapor more energy to escape. This also occurs more often during dust storms because their darker clouds absorb more sunlight, warming up water vapor, and because violent atmospheric activity mixes low-altitude water vapor into the upper atmosphere. The only graph that shows both an increase in water loss at perihelion and during the 2018 dust storm is D.

13. The cross-section of a surface wave moving westward in the North Atlantic Ocean is shown below. Which of the following arrows best approximates the direction of net force on the water particle marked in red?

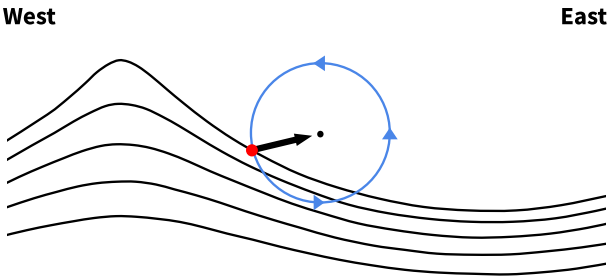
A. A

B. B

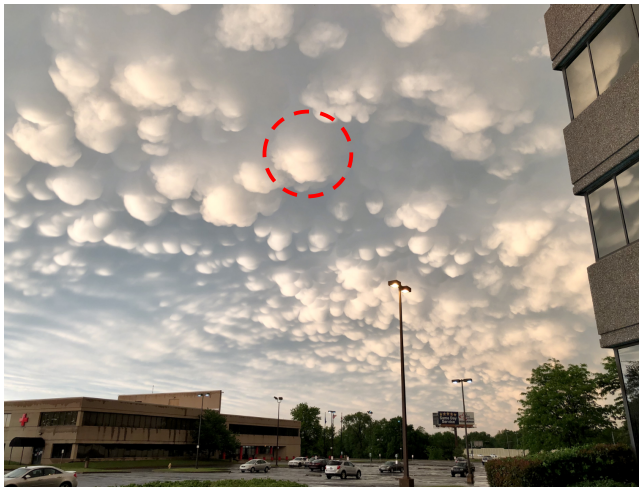
C. C

D. D

Solution: Water particles in this scenario exhibit orbital motion. As the wave propagates west, the marked particle would move down into the trough before moving up into the crest roughly along the circular path shown below. Net force at the current position would be directed toward the center of this path - A is correct.



14. Mammatus clouds are typically observed following the passage of thunderstorms and form underneath storm anvil clouds as shown below.



(a) Which of the following best characterizes the primary direction of motion of air in the circled region?

A. Upward

B. Downward

C. Lateral

Solution: As a thunderstorm passes, the anvil typically spreads laterally at the tropopause and then gradually sinks. Thus, the primary direction of motion of the air associated with mammatus clouds is downward.

(b) Considering the conditions favorable for cloud development, which of the following choices regarding energy balance in the circled region best supports a potential mechanism for mammatus cloud formation and sustenance?

A. Less heat energy is consumed by evaporation of precipitation than is released by adiabatic heating

B. More heat energy is consumed by evaporation of precipitation than is released by adiabatic heating

C. Less heat energy is consumed by adiabatic cooling than is released by condensation of water vapor

D. More heat energy is consumed by adiabatic cooling than is released by condensation of water vapor

Solution: To sustain the sinking motion of mammatus clouds, more energy must be consumed than released by adiabatic heating so that air remains cooler than its surroundings. Note that there are many theories regarding the formation of mammatus clouds.

15. Since zircon incorporates almost no lead (Pb) upon formation, the ratio of ^{206}Pb to ^{207}Pb can be used to date the crystal. ^{206}Pb forms from ^{238}U with a half-life of 4.468 billion years and ^{207}Pb forms from ^{235}U with a half-life of 703.8 million years.

A scientist discovers a zircon crystal that she believes formed 500 million years ago and lost some of its lead to external sources. When the crystal formed, the ratio of ^{238}U to ^{235}U on Earth was approximately 91.0. Which of the following ratios of ^{206}Pb to ^{207}Pb would the researcher expect to find in the crystal if 50% of Pb was lost during an event 250 million years ago?

A. 15.86

B. 17.47

C. 18.09

D. 19.52

Solution: Let $[^{x}\text{Pb}]_{y}$ equal the concentration of lead with mass number x at time y, assuming no Pb is lost, measured in millions of years ago. This concentration is equal to 1 minus the amount of the Pb isotope's parent isotope, which follows the standard formula for radioactive decay with half-lives measured in millions of years:

$$[^{206}\text{Pb}]_{250} = [^{238}\text{U}]_0(1 - 0.5^{250/4468})$$
$$[^{206}\text{Pb}]_{500} = [^{238}\text{U}]_0(1 - 0.5^{500/4468})$$
$$[^{207}\text{Pb}]_{250} = [^{235}\text{U}]_0(1 - 0.5^{250/703.8})$$
$$[^{207}\text{Pb}]_{500} = [^{235}\text{U}]_0(1 - 0.5^{500/703.8})$$

Including Pb loss, the actual ratio of ^{206}Pb to ^{207}Pb equals:

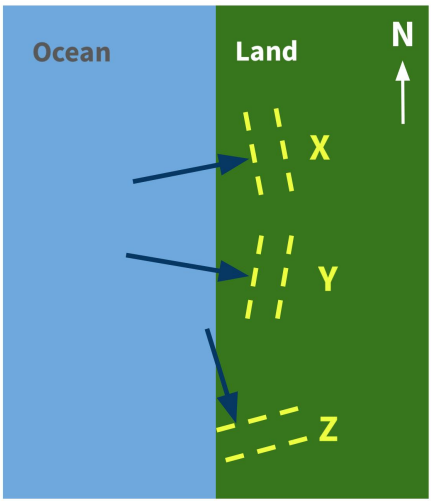
$$\frac{[^{206}\text{Pb}]_{500} - 0.5([^{206}\text{Pb}]_{250})}{[^{207}\text{Pb}]_{250} - 0.5([^{207}\text{Pb}]_{500})}$$

Substituting our previously defined terms and simplifying gives us:

$$\left(\frac{[^{238}\text{U}]_0}{[^{235}\text{U}]_0}\right)\left(\frac{(1 - 0.5^{500/4468}) - 0.5(1 - 0.5^{250/4468})}{(1 - 0.5^{500/703.8}) - 0.5(1 - 0.5^{250/703.8})}\right)$$

Knowing that the ratio $\frac{[^{238}\text{U}]_0}{[^{235}\text{U}]_0}$ equals 91.0, we can plug in the rest of the formula to get a final ratio of 18.09.

16. Wind turbines are most efficient when oriented perpendicular to the wind. Suppose you are deciding where to place rows of wind turbines (oriented according to the dashed lines) in a forested region. The map below shows three possible wind vectors and corresponding sets of turbines.



(a) On a warm, sunny day in the Northern Hemisphere, which wind turbine placement would be most efficient?

A. X

B. Y

C. Z

Solution: Winds are affected by the pressure-gradient force, the Coriolis force, and friction. The pressure-gradient force points eastward as sea breezes blow towards lower pressure air over land, and in the Northern Hemisphere, the Coriolis force deflects winds to the right. This slight deflection is accounted for in the wind turbines labeled Y.

(b) As the winds move onshore, what happens to them?

A. They converge and turn slightly to the left

B. They converge and turn slightly to the right

C. They diverge and turn slightly to the left

D. They diverge and turn slightly to the right

Solution: Friction is greater over land than over water, so winds would slow down and thus converge over land. As winds slow down, the Coriolis force decreases, so the winds become less deflected to the right and turn slightly to the left.

17. Hydrostatic pingos are typically found in regions underlain by permafrost. They form as trapped groundwater freezes and expands, creating ice cores that exert an upward pressure on overlying sediments. Identify all of the following environments that would be favorable for the development of hydrostatic pingos.

I) A still-water lake that has been recently infilled with sediment

II) A sloping hill underlain by coarse gravel

III) A compacted ground moraine deposited by a valley glacier

A. I only

B. I and II

C. II and III

D. I and III

E. I, II, and III

Solution: Hydrostatic pingos form in areas where groundwater is trapped, allowing it to freeze and form ice cores. Sediment deposited within a still-water lake would likely have a high clay content due to the low competence of the water, which would act as an impermeable layer preventing groundwater from escaping – I is favorable. A sloping and high permeability of gravel would promote the movement of groundwater rather than trapping it – II is unfavorable. Compacted glacial till found in a ground moraine would prevent groundwater from escaping by a mechanism similar to the impermeable clay layer– III is favorable.

18. The Bowen ratio B is the ratio of sensible heat flux (SHF) to latent heat flux (LHF), defined to be positive in the surface-to-atmosphere direction. Given that SHF is relatively small and more uniform across latitudes compared to LHF, which of the following can be inferred about B?

I) If the air is warmer than the surface and net evaporation is occurring, B is negative

II) If the surface is warmer than the air, decreasing soil moisture in a dry atmosphere lowers B

III) On average, B decreases with increasing latitude

A. I only

B. II only

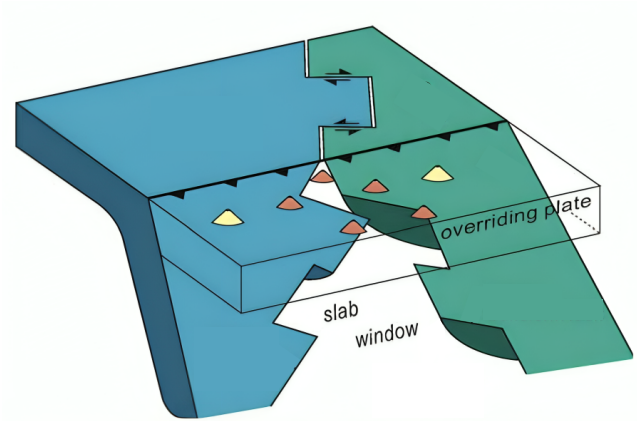
C. I and II

D. I and III

E. II and III

Solution: If the air is warmer than the surface, SHF would be directed downward (i.e. toward the surface). As water vapor absorbs latent heat from the ground via evaporation, LHF would be directed upward (i.e. away from the surface). Since the fluxes are in opposite directions, B would be negative - I is true. If the surface is warmer than the air, SHF would be directed upward, but less soil moisture corresponds to less evaporation and reduced LHF. The SHF/LHF ratio would thus increase - II is false. Since LHF is associated with evaporation, it is dependent on temperature. LHF is higher in the tropics due to warmer temperatures. Assuming SHF to be relatively uniform, B decreases with decreasing, not increasing, latitude - III is false.

19. A slab window, depicted below, is a gap formed when a mid-ocean ridge subducts and both divergence at the ridge and convergence at the subduction zone continue.



Which of the following statements is/are likely true?

I) Mantle within slab windows exhibits increased water content

II) Slab windows can be identified by the presence of positive P wave velocity anomalies

III) The degree of decompression melting within slab windows decreases away from the subduction zone

A. I only

B. III only

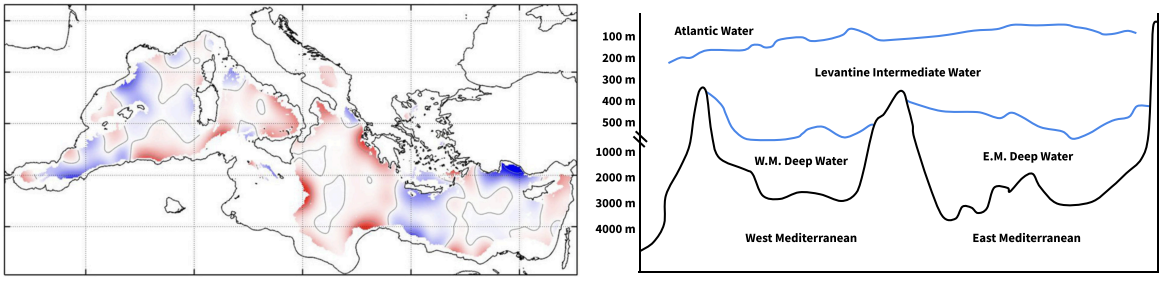
C. I and II

D. II and III

E. I, II, and III

Solution: Subducting plates typically increase the water content of the mantle by introducing volatiles at depth. Because slab windows are characterized by an absence of these plates, mantle within these windows would exhibit decreased water content - I is false. Slab windows are associated with an upwelling of asthenospheric mantle. Because P waves travel slower in less rigid material, slab windows can be identified by negative P wave velocity anomalies - II is false. Further away from slab windows, the area over which the mantle upwells becomes larger and the pressure drop becomes more diffuse - III is true.

20. An oceanographer finds a map of the Mediterranean Sea with colors corresponding to an unknown property (shown on the left). To help determine the identity of this property, they roughly sketch an east-west cross-section of the sea and label the major water masses (shown on the right).



Which of the following best characterizes the unknown property?

A. Sea surface conductivity; blue shading corresponds to regions of low conductivity

B. Sea surface conductivity; blue shading corresponds to regions of high conductivity

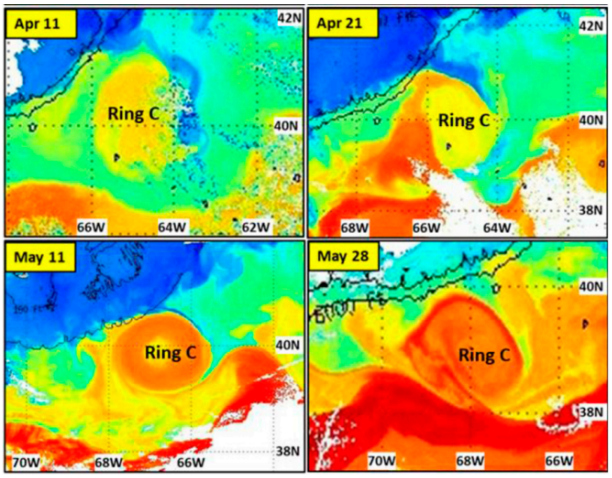
C. Temperature at 300 m; blue shading corresponds to regions of low temperature

D. Vertical velocity at 1000 m; blue shading corresponds to regions of downward velocity

E. Vertical velocity at 1000 m; blue shading corresponds to regions of upward velocity

Solution: Notice that the blue shading is most intense in coastal regions of the Mediterranean Sea underlain by deep water. It can then be inferred that the blue shading corresponds to downwelling triggered by friction with the surrounding topography and indicates the formation of deep water. Additionally, note that surface temperature generally increases southward and sea surface conductivity generally increases eastward due to evaporation of surface water moving to the east. These patterns are not observed on the map.

21. The Gulf Stream can create large circulating water masses known as eddies. The diagram below depicts the evolution of multiple eddies, with red regions indicating high sea surface temperatures (SSTs) and blue regions indicating low SSTs. Identify all of the following statements that are likely true regarding Ring C:



I) Water within Ring C rotates counterclockwise

II) The center of Ring C has abnormally low productivity

III) Hurricanes passing over Ring C would strengthen

A. I only

B. III only

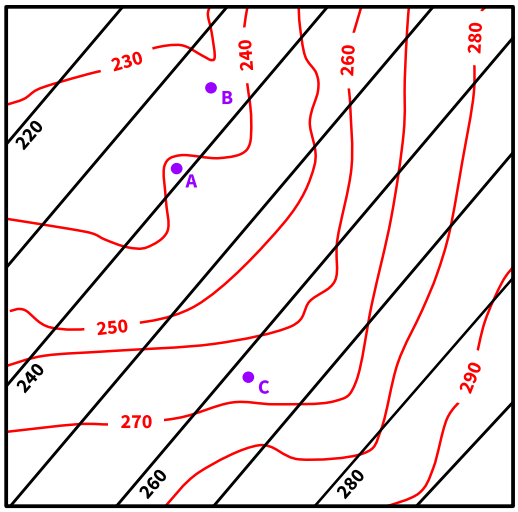
C. I and II

D. I and III

E. II and III

Solution: Ring C is a warm core ring located along the northern edge of the Gulf Stream. Thus, the Gulf Stream meander that formed the ring circulated in a clockwise direction, and this direction is maintained in the ring itself - I is false. Downwelling occurs at the center of warm core rings due to convergence of water at their centers. This results in low productivity due to a lack of nutrients from deep water - II is true. Hurricanes are generally strengthened by warm waters - III is true.

22. Consider the following topographic map. The black contours describe the elevation of a coal seam and the red contours describe the surrounding topography. At which of the three labeled points is the seam likely to outcrop?



A. A only

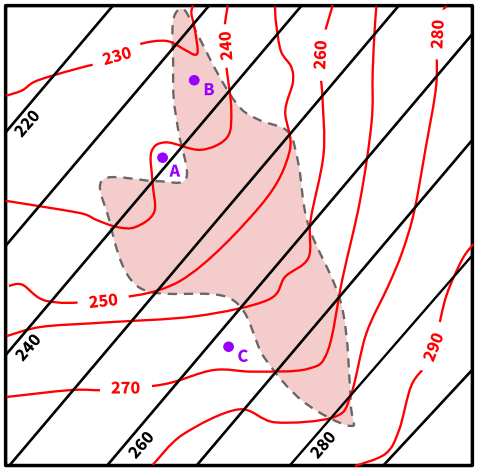
B. B only

C. A and B

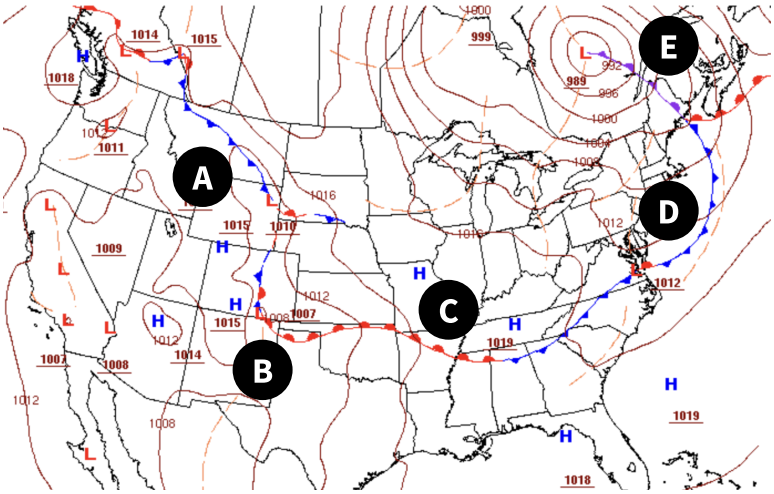
D. A and C

E. B and C

Solution: Draw a curve through the points where the black and red contours have equal values. The area contained within represents the region where the coal seam outcrops. It is apparent that given a straightforward interpretation of the bounded region, the seam outcrops at B only.



23. Refer to the following surface air map.



At what location would you most likely expect to find mid-to-high altitude clouds, such as altostratus and cirrus?

A. Location A

B. Location B

C. Location C

D. Location D

E. Location E

Solution: Mid-to-high altitude clouds often form ahead of an approaching warm front due to the gentle rise of warm air on the slope at the end of the colder air mass. The only location ahead of an approaching warm front is C.

24. Jupiter and Saturn share similar structures due to commonalities in their formation and composition. They are, however, not entirely the same. Which of the following correctly contrasts properties of these two planets?

A. Jupiter's higher mass results in it having more liquid metallic hydrogen than Saturn

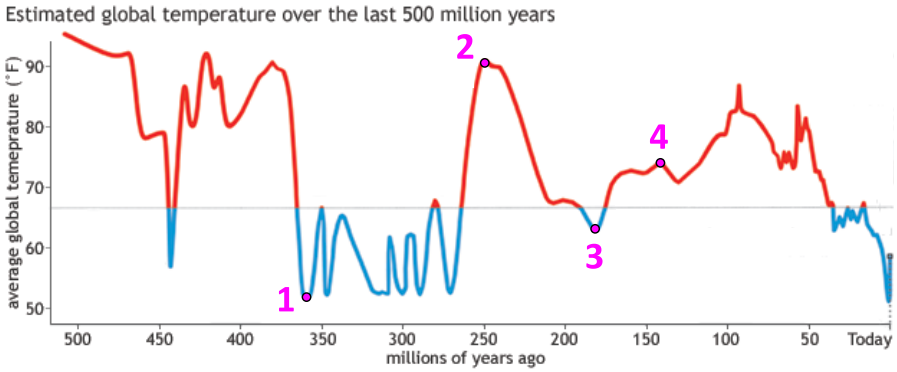
B. Jupiter's stronger magnetic field results in it having a higher density than Saturn

C. Tidal forces from Ganymede induce storms on Jupiter while Titan's magnetic field inhibits storms on Saturn

D. Jupiter's magnetic field is produced from the convection of iron and nickel while Saturn's magnetic field is produced from the convection of silicate material

Solution: Jupiter's magnetic field has little to no bearing on its high density, which mostly results from its high mass - B is incorrect. Ganymede does not exert an appreciable tidal force on Jupiter and Titan does not have a significant magnetic field - C is incorrect. Both Jupiter's and Saturn's magnetic fields are primarily produced by metallic hydrogen rather than iron and nickel or silicate material - D is incorrect. Jupiter's higher mass pressurizes gaseous hydrogen and transforms it into more liquid metallic hydrogen - A is correct.

25. Jason samples and analyzes four ice cores on a research trip to the Arctic. He finds that cores A, B, C, and D are increasingly enriched in ^{18}O. He also knows that each core was taken from one of the four points in time indicated below.



Which of the following statements is/are likely true?

I) Core C was taken from Point 4

II) Core D was taken from Point 1

III) An ocean sediment core taken from the same time as Core D would also be significantly enriched in ^{18}O

A. I only

B. II only

C. I and III

D. II and III

E. None

Solution: As water evaporates, the resulting vapor contains both ^{16}O and ^{18}O in a known ratio. However, as it travels towards the poles, Earth's temperature determines the ratio of ^{16}O to ^{18}O. When the climate is colder, precipitation can occur at lower latitudes and the heavier ^{18}O is preferentially rained out. When the climate is warmer, the vapor can stay gaseous for longer, and more ^{18}O reaches the poles. Thus, a greater ^{18}O to ^{16}O ratio indicates higher global temperatures and ice cores A-D correspond to increasingly warmer climates - I is true while II is false. Given that Core D is significantly enriched in ^{18}O, we would expect ocean sediment cores taken from the same time to be relatively depleted in the same isotope given that a relatively large quantity of ^{18}O is instead located on land - III is false.

26. Tidal height is recorded at two locations on Earth's surface when the Moon is at a declination of 23°N. Location A is at 10°N latitude while Location B is at 60°N latitude. Assuming equilibrium tides, which of the following best categorizes the expected tidal patterns at Location A and Location B, respectively?

A. Diurnal; diurnal

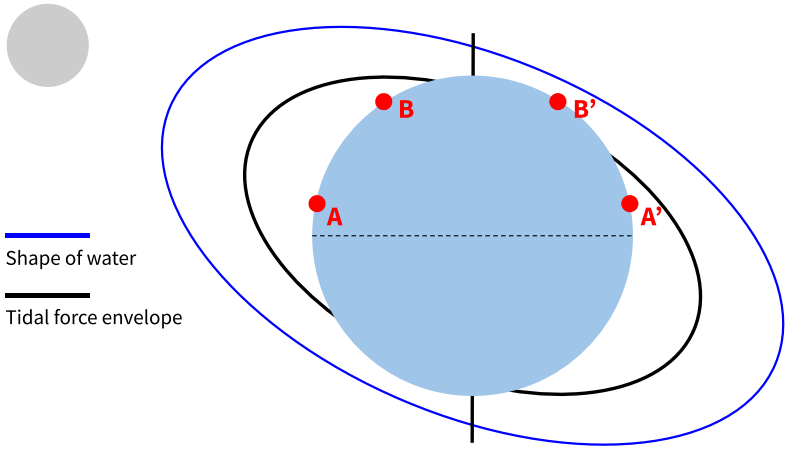
B. Diurnal; mixed semidiurnal

C. Semidiurnal; mixed semidiurnal

D. Mixed semidiurnal; diurnal

E. Mixed semidiurnal; semidiurnal

Solution: Sketch the tidal force envelope formed as a result of the Moon's gravitational pull. An observer at Location A would rotate through two high tides of unequal height within a 24 hour period, a phenomenon known as tidal inequality that is characteristic of a mixed semidiurnal tide. Meanwhile, an observer at Location B would rotate through a single high tide, characteristic of a diurnal tide. A perfectly semidiurnal tide could not occur at Location B because the water heights at B and B' are different.



27. Serpentinization is an important metamorphic process that may have played a role in the development of early life on Earth. Although there are multiple pathways, one of the basic serpentinization reactions involves Fe_2SiO_4, the iron-rich endmember of the olivine solid solution:

$$3\,Fe_2SiO_4 + 2\,H_2O \longrightarrow 2\,Fe_3O_4 + 3\,SiO_2 + 2\,H_2$$

Which of the following statements is/are likely true?

I) Crust undergoing serpentinization generally increases in volume

II) Serpentinized rocks are commonly found in ophiolite structures

III) Infiltration of silica-rich groundwater would hinder serpentinization

A. I only

B. II only

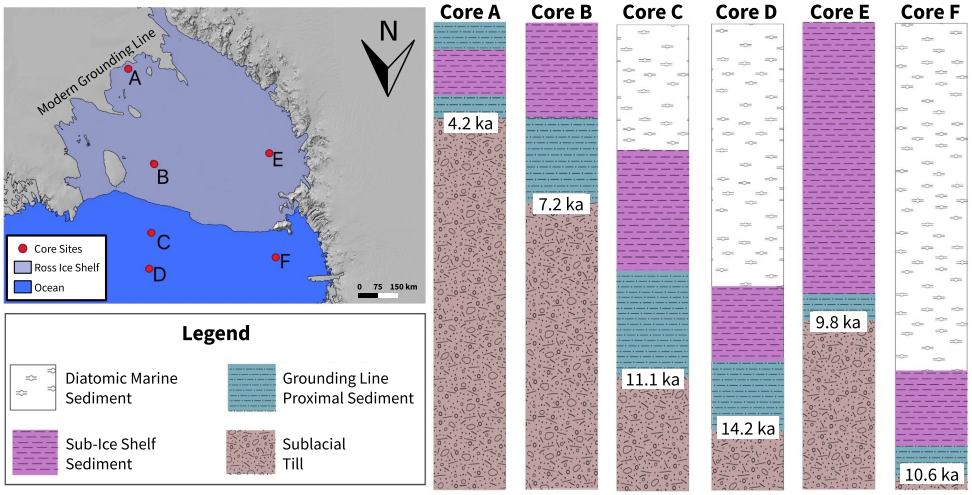
C. II and III

D. I and II

E. I, II, and III

Solution: Serpentinization takes in water, generally resulting in an increase in oceanic crust volume - I is true. Serpentinization most often occurs along mid-ocean ridges, so the remnant rocks would likely form ophiolite structures - II is true. Silica-rich groundwater would make magma components more felsic. Given that serpentinization begins with members of the olivine solid-solution, a lower olivine concentration would hinder serpentinization - III is true.

28. Sediment cores A-F were collected in the Ross Sea in Antarctica. The corresponding sedimentary sequences can be used to understand changes in grounding line position, where ice shifts from being in contact with land to floating on the ocean. Which of the following statements about Ross Sea deglacial history are supported by the sediment cores? Assume sedimentation rates are equal at all sites.



I) The grounding line retreated more rapidly in the Western than the Eastern Ross Sea

II) The grounding line retreated past its modern extent, then readvanced to its current position

III) The grounding line remained near site C longer than any other site

A. I only

B. I and II

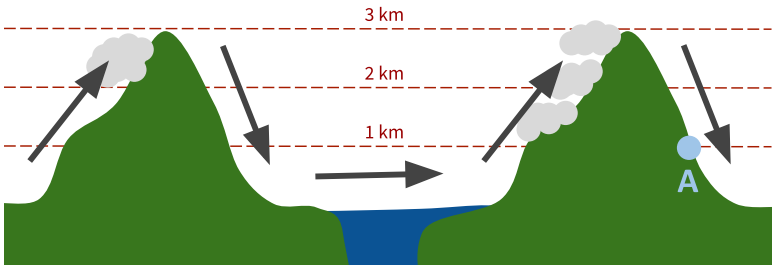
C. I and III

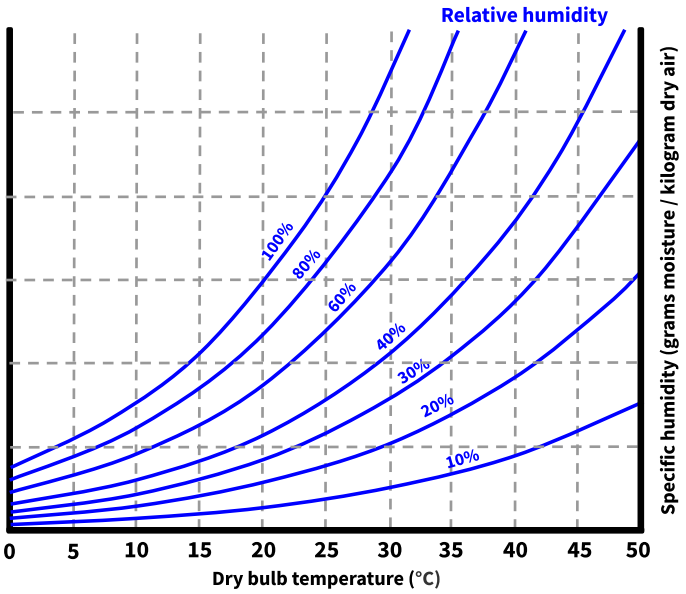
D. II and III

E. I, II, and III

Solution: Comparing the difference in timing between the core sites E and F (0.8 kyr) and the sites B and D (7 kyr), it is apparent that the grounding line retreated more rapidly in the Western Ross Sea - I is true. Core A has a typical readvance sequence consisting of grounding line proximal sediment overlain by sub-ice shelf sediment (suggesting a retreating glacier), which is then overlain by more grounding line proximal sediment (suggesting an advancing glacier) - II is true. The thickness of the grounding line proximal sediment is greatest in Core C, and assuming equal accumulation rates at all sites, a thicker layer indicates a longer time of deposition - III is true.

29. An air parcel moves across two mountains with a lake between them. Clouds begin forming at an altitude of 2 km while crossing the first mountain and 1 km while crossing the second mountain. The air parcel begins at the surface with an initial temperature of 25°C, does not change in temperature while crossing the lake, and does not change in specific humidity while descending. Using the psychrometric chart below, if the dry adiabatic lapse rate is 10°C/km and the moist adiabatic lapse rate is 5°C/km, which of the following is closest to the relative humidity at point A?





A. 10%

B. 20%

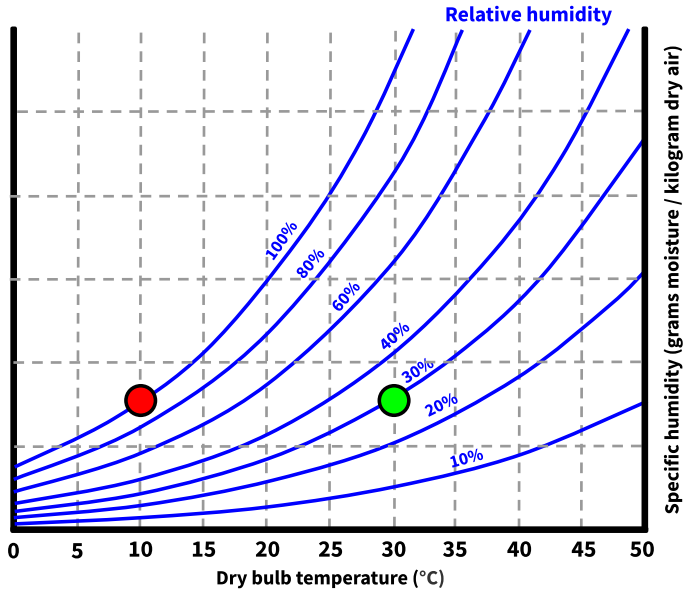
C. 30%

D. 40%

Solution: Over the first mountain, the air parcel decreases in temperature and loses moisture to condensation, then increases in temperature. Over the second mountain, the same process occurs after receiving more moisture from the lake. When there is no condensation, the air parcel changes temperature according to the dry adiabatic lapse rate (10°C/km). When condensation is occurring, the air parcel is saturated and changes temperature according to the moist adiabatic lapse rate (5°C/km).

While passing over the first mountain, the air parcel temperature decreases by 25°C then increases by 30°C for a final temperature of 30°C. While passing over the second mountain, its temperature decreases by 20°C to reach 10°C at the top of the mountain, then increases by 20°C to reach 30°C at point A.

At the top of the second mountain, the specific humidity is such that the air parcel will have 100% relative humidity at 10°C. This point is marked in red on the graph below. Since the specific humidity does not change while descending, the air parcel will have the same specific humidity at 30°C, which corresponds to a relative humidity of about 30%. This point is marked in green below.



30. Large shield volcanoes are common on the surfaces of Venus and Mars. Although these volcanoes have similar compositions and structures, they are significantly shorter on Venus than on Mars. Which of the following processes best explains this difference?

A. Rapid weathering by Venus' atmosphere

B. Underground magma chamber collapse

C. Isostatic adjustment

D. Fracturing of magma pathways

Solution: Venus has a much less rigid mantle than Mars and is more geologically active. When massive shield volcanoes form on its surface, their weight causes them to sink through isostatic adjustment.

END OF MULTIPLE CHOICE