USESO 2025

National Open Exam

Section I

KEY

Instructions:

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

1. A geologist is studying a hand sample of schist in the lab. They determine that the rock formed in a region of compacted sediment adjacent to a subduction zone known as an accretionary wedge. Which of the following is likely true regarding the rock?

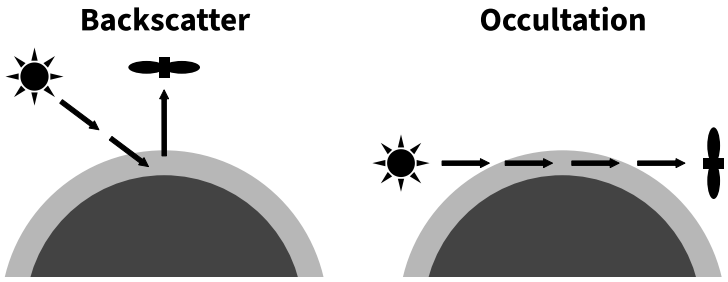
I) The rock formed in a relatively low-temperature, high-pressure environment

II) The rock contains well-preserved fossils of ancient marine organisms

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

Solution: Accretionary wedges are regions of high pressure and low temperature due to their positioning adjacent to subduction zones and close to the surface – I is true. The pressure and temperature that create metamorphic rocks such as schist also deforms fossils that may have been present in the protolith – II is false.

2. Satellites can analyze backscattered light (the "backscatter method") or light passed directly through the atmosphere (the "occultation method") to gather meteorological data. The image below shows how these methods are used to collect data.



Identify all of the following statements that are true of these methods:

I) Use of the occultation method to measure stratospheric air is generally not affected by weather

II) A satellite orbiting Earth using the occultation method cannot collect data during all 24 hours of the day

III) The backscatter method would be more useful for measuring the vertical profile of aerosol concentrations

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

Solution: The satellite does not have to look through the troposphere to observe the stratosphere, and almost all weather happens in the troposphere – I is true. Employing the occultation method for 24 continuous hours requires that the satellite be behind the terminator at all times. It is impossible for an orbit to exist only in one "hemisphere" of Earth's space at all times – II is true. Backscatter satellites get data from light that passes through the entire vertical profile of the atmosphere, resulting in a diminished ability to discern patterns at specific heights – III is false.

3. Identify all of the following three events that would likely increase the volatile content of a magma chamber:

I) An earthquake occurs nearby

II) The magma intrudes into limestone

III) The magma chamber contacts an aquifer

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

Solution: The two most common volatiles in magma are carbon dioxide and water. The occurrence of an earthquake provides no method for volatiles to enter magma and only serves to agitate the magma chamber - I is false. Intrusion into limestone causes the decomposition of calcium carbonate to produce carbon dioxide, which can then enter the magma - II is true. Contact with an aquifer will cause water to enter the magma - III is true.

4. Shown below is a map of part of the Pacific Ocean with two locations labeled A and B. Which of the following combinations of location and atmospheric phenomenon would produce a thermocline with the greatest depth?

A. A, El Niño **B. A, La Niña** C. B, El Niño D. B, La Niña

Solution: The thermocline is deepest in regions with excess warm water at the surface. Because trade winds blow equatorial water to the west, location A experiences a warm current while location B experiences a cold current. La Niña strengthens these trade winds, while El Niño has the opposite effect, usually reducing equatorial wind strength. Thus, the deepest thermocline would occur at location A during La Niña, since this is where the most surface warm water would be present.

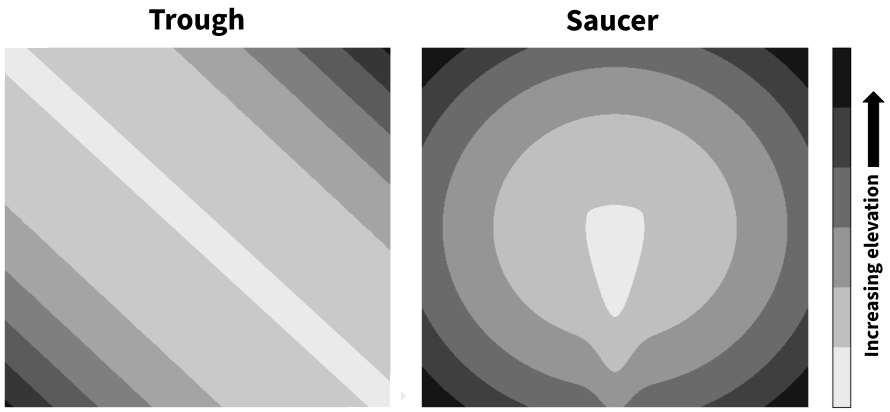
5. A meteorologist predicts that a warm front will pass through Norman, Oklahoma. Which of the following gives the chronological order of clouds an observer in Norman should expect to see as the front passes?

A. Cirrus, nimbostratus, altostratus C. Nimbostratus, altostratus, cirrus

B. Cirrus, altostratus, nimbostratus D. Altostratus, nimbostratus, cirrus

Solution: As the warm front approaches, the front boundary gets closer to the ground surface. Since clouds generally form just above the front boundary, the highest-altitude clouds would be observed first, followed by lower-altitude clouds. The ordering that reflects this reasoning is given by choice B.

6. While exploring a coastal dune system, a geologist observes two distinct types of blowout depressions. They create topographical representations of an example of each type as shown.



Which of the following most plausibly describes how wind interacts with each blowout type?

A. Trough-shaped blowouts: winds are deflected outward and erosion is reduced; saucer-shaped blowouts: winds disperse more evenly and erosion is slower but more widespread

B. Trough-shaped blowouts: winds are deflected outward and erosion is reduced; saucer-shaped blowouts: winds are faster due to cyclonic rotation and erosion is increased

C. Trough-shaped blowouts: winds are funneled along the depression and erosion deepens the trough; saucer-shaped blowouts: winds disperse more evenly and erosion is slower but more widespread

D. Trough-shaped blowouts: winds are funneled along the depression and erosion deepens the trough; saucer-shaped blowouts: winds are faster due to cyclonic rotation and erosion is increased

Solution: Blowout depressions significantly modify local wind flow, and their effects can be expected to differ based on their shape. Trough-shaped blowouts are elongated depressions where wind is funneled through the feature, causing an increase in velocity along the depression's axis. This directed erosion deepens and extends the blowout in the direction of prevailing winds. Saucer-shaped blowouts have a more circular, fan-like shape and experience more evenly distributed wind flow. While erosion still occurs, it is slower and more uniform due to the broader dispersion of wind energy. Thus, trough-shaped blowouts tend to grow in length as wind accelerates through them, whereas saucer-shaped blowouts expand more gradually due to multidirectional wind effects. Choice C best describes this effect.

7. Which of the following statements regarding flooding is/are true?

I) Flash flood risk increases directly after a wildfire

II) A 100-year flood has a 1% chance of occurring in any given year

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

Solution: Wildfires leave a burn scar that results in reduced vegetation and drier, more hydrophobic soils. This leads to reduced infiltration and a greater risk of flash flooding – I is true. A 100-year flood refers to a flood size that has a 1% chance of occurring in any given year, not a flood that is guaranteed to occur once every 100 years – II is true.

8. Identify all of the following changes that would likely increase the rate of meltwater production at the bed of a moving glacier:

I) Increase in the roughness of underlying rock

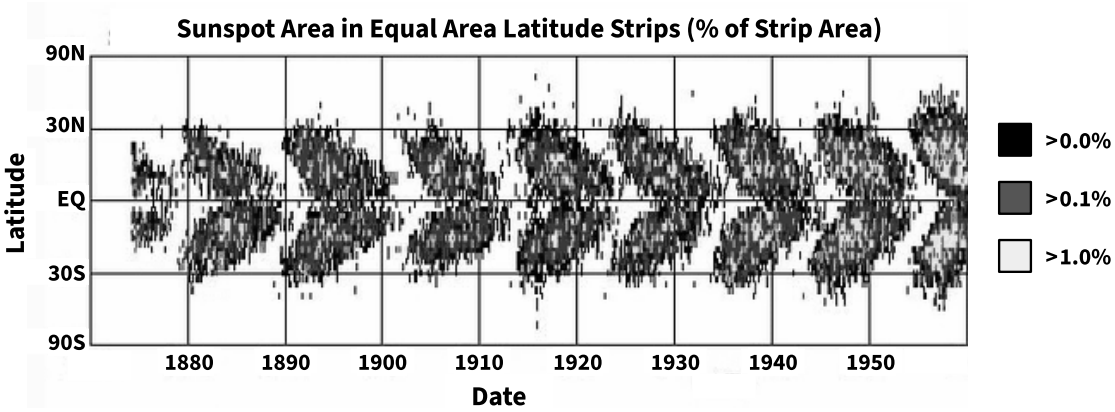
II) Increase in the thickness of the glacier

III) Decrease in the salinity of basal ice

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

Solution: Increasing roughness increases friction, which leads to greater heat transfer into the glacier and increased meltwater production – I is true. Increasing glacier thickness increases the pressure exerted on ice near the bed, decreasing the melting point and making it easier to create meltwater – II is true. Decreasing the salinity of basal ice increases the melting point of the ice, making it harder to create meltwater – III is false.

9. Flora invents a time machine and decides that she wants to see the Northern Lights during a time period with less light pollution. Using the graph below, which of the following years should she travel to if she wants to maximize her chances of seeing an aurora?



A. 1875 B. 1912 C. 1930 **D. 1957**

Solution: The chart shown in the question is a butterfly diagram depicting the region covered by sunspots at certain latitudes of the Sun over time. Maximums in solar activity correspond with sunspots located at higher latitudes; additionally, greater interaction between solar particles and Earth's magnetosphere increases the likelihood of seeing auroras. Because 1957 is the year that coincides with sunspots being observed at the highest latitudes, D is the correct answer.

10. Two soils sampled several miles apart are found overlaying the same limestone bedrock.

Soil A	**Soil B**
Hematite	Quartz
Goethite	Calcite
Pyrite	Dolomite

Given that the significant minerals in each of the soils are shown in the table above, which of the following is the most likely explanation for their difference in compositions?

A. Differences in regional weathering led to the formation of different minerals in Soil A versus Soil B

B. The sediment composing Soil A was eroded from an ancient reef and was transported onto the limestone bedrock, while Soil B was weathered directly from the limestone

C. Soil A is older than Soil B and thus consists of minerals that are oxidation products of the minerals in Soil B

D. The sediment in Soil A eroded from a mafic batholith and was transported onto the limestone bedrock, while Soil B was weathered directly from the limestone

Solution: Soil A is rich in iron-based minerals, meaning its parent material was likely mafic. As this composition does not match the underlying limestone bedrock, which is made of carbonates, the soil was likely transported instead of weathered in place. D is therefore the best answer.

11. After analyzing a layer of limestone, an oceanographer notices that it has a higher $^{18}O/^{16}O$ ratio than the surrounding strata. Which of the following statements best characterizes the conditions of the ocean when the layer of limestone was deposited?

A. The surrounding ocean was warmer when the layer was deposited

B. The surrounding ocean was colder when the layer was deposited

C. The surrounding ocean had a higher pH when the layer was deposited

D. The surrounding ocean had a lower pH when the layer was deposited

Solution: As water evaporates, the resulting vapor contains both ^{16}O and ^{18}O in a known ratio. When the climate is colder, precipitation can occur at lower latitudes and the heavier ^{18}O is preferentially rained out, thus accumulating in greater abundance in ocean sediments and strata. A higher $^{18}O/^{16}O$ ratio in limestone is most directly indicative of a colder climate and B is the best answer.

12. During a certain period in Earth's geologic past, the planet experienced a prolonged hothouse climate. Which one of the following statements is most likely **not** true regarding this period?

A. Rates of feldspar weathering decreased

B. Large, equatorial biogenic calcareous deposits formed

C. Rates of glacial ablation increased

D. Atmospheric CO_2 concentrations were anomalously high

Solution: Biogenic calcareous deposits at the equator are commonly formed from coral reefs, which thrive in wide-scale tropical conditions at low latitudes favored during a hothouse period – B is true. The net loss of ice mass from glaciers and ice sheets will naturally increase given increased temperatures – C is true. High concentrations of CO_2, a greenhouse gas, correlate with a warmer climate – D is true. Hothouse conditions favor increased rates of feldspar weathering due to effects such as accelerating the hydrologic cycle and speeding up chemical reactions that break down rocks – A is false.

13. Comet Encke is notable for having the shortest orbital period of any reasonably bright comet, at 3.3 years. At its closest, Encke is a distance of 0.34 AU away from the Sun. In which of the following ranges does Encke's aphelion fall?

A. 1 to 2 AU B. 2 to 3 AU C. 3 to 4 AU **D. > 4 AU**

Solution: Using Kepler's 3rd law yields Encke's semi-major axis, denoted by a: $a^3 = 3.3^2 \implies a = 2.2$ AU. The semi-major axis is equal to the average of the perihelion and aphelion (x) distances, so $2.2 = \frac{0.34+x}{2} \implies x = 4.1$ AU. The correct choice is D.

14. In late summer, the influx of nutrient-rich freshwater from the Mississippi and Atchafalaya River Basins contributes to the formation of a seasonal hypoxic zone in the Gulf of Mexico known as the "Gulf Dead Zone". Which of the following conditions would be conducive to the continued existence of this dead zone?

I) Increased precipitation over the river basins

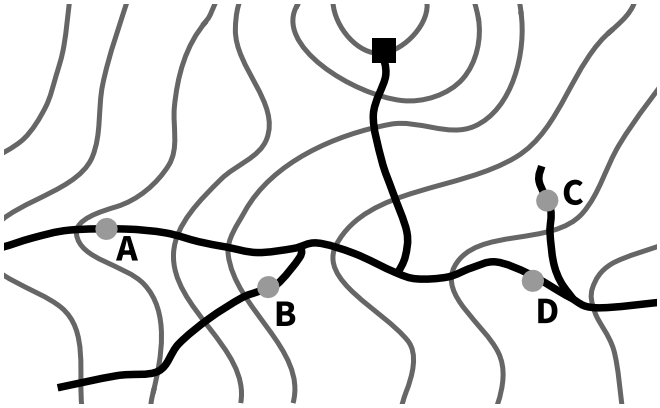
II) Increased sea surface temperatures in the Gulf of Mexico

III) More intense tropical storms in the Gulf of Mexico

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

Solution: Increased precipitation over the river basins and increased sea surface temperatures reduce surface water density and maintain density-based stratification, resulting in bottom waters remaining relatively unoxygenated and maintaining the dead zone – I and II are true. Meanwhile, intensified tropical storms in the Gulf would lead to greater disturbances in the water column and promote mixing, resulting in the dissipation of the dead zone – III is false.

15. Katherine surveys the course of a river. She produces the topographic map shown below, where the square represents the origin of a natural spring that runs through quartz and gold-rich veins.



Which point in the river should Katherine go to if she wants to maximize her chance of finding flakes of gold?

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

Solution: Gold flakes follow the movement of water in the river and move downstream. As the contour lines bend to the left on the map, the downhill direction is to the right according to the rule of V's. D is therefore the best option as locations A, B, and C would all require uphill flow for gold flakes to deposit.

16. A desert composed predominantly of which of the following types of sediment would result in the formation of the largest dunes?

A. Rounded silt B. Rounded sand C. Angular silt **D. Angular sand**

Solution: The maximum angle a pile of sediment can reach before collapsing is known as the angle of repose. Angular sediments tend to have a larger angle of repose due to a greater degree of interlocking between grains compared to rounded sediments. Larger sediments tend to have increased friction between grains and are less likely to slide over each other, resulting in a larger angle of repose as well. D is therefore the best answer.

17. Mercury possesses a 3:2 spin-orbit resonance (i.e. Mercury rotates three times for every two times it orbits the Sun) that is unique among the terrestrial planets. Which of the following can be inferred from this resonance pattern?

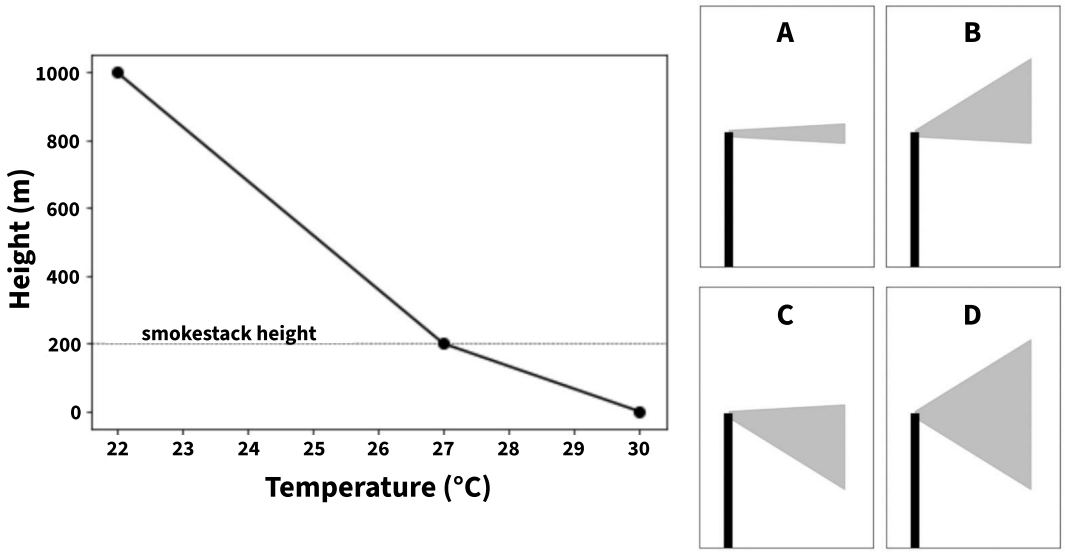
I) Mercury's period of rotation about its axis is longer than its solar day

II) Mercury exhibits a relatively large zonal (east-west) temperature gradient

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

Solution: Mercury's 3:2 spin-orbit resonance means that by the time Mercury completes one axial rotation, it has completed two-thirds of its orbit and moved relative to the Sun. It takes Mercury 1.5 axial rotations to complete one orbit, which equals half a solar day. Mercury's period of rotation is therefore shorter than its solar day (the time it takes for the Sun to appear in the same position in the sky as it did the day before) – I is false. Since Mercury's solar day is so long, its surface is exposed to sunlight for extended periods and the side facing the Sun becomes much hotter than the side facing away from the Sun, creating large zonal temperature gradients – II is true.

18. Consider the following temperature profile. Smoke initially leaves a 200-meter tall smokestack at the same temperature as the environment and with zero **average** vertical velocity, although it is subject to both upward and downward perturbations. Assume a dry atmosphere and treat the smoke as dry air parcels.



Given that the dry adiabatic lapse rate is approximately 9.8°C/km, which of the figures above best depicts the shape of the smoke plume?

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

Solution: The shape of the smoke plume and whether the smoke disperses well is related to the atmospheric stability of the two air layers. As the atmosphere is dry, a lapse rate less than 9.8°C/km indicates stability, whereas a lapse rate greater than 9.8°C/km indicates instability. The lapse rate of the top layer (above 200 m) is -(27-22°C)/(1-0.2 km) = 6.25°C/km, and the bottom layer (below 200 m) is -(30-27°C)/(0.2-0 km) = 15°C/km. The top layer is therefore stable, whereas the bottom layer is unstable. As some smoke is perturbed upward into the stable layer, it stops rising and stays close to 200 m. Smoke that is perturbed downward into the unstable layer will keep sinking and mix with the air below. The smoke plume that best matches this reasoning is shown in C.

19. Alex is given two pure, cubically-cut crystals and is told that one is halite while the other is calcite. They want to identify the two samples by conducting a series of tests. Which of the following tests would be the **least** effective for their investigation?

A. Applying dilute hydrochloric acid to the surface of each sample

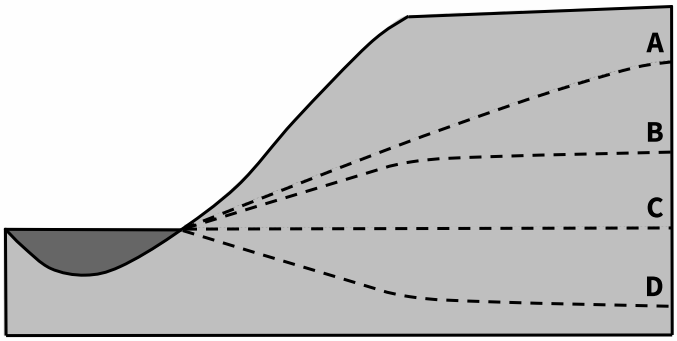
B. Shining a laser through each sample and observing how the light refracts

C. Trying to scratch a glass plate with a corner of each sample

D. Examining the cleavage planes of each sample after breaking them with a rock hammer

Solution: Calcite bubbles when dilute HCl is applied while halite dissolves but doesn't bubble – A is a valid method of differentiating the samples. Calcite exhibits characteristic birefringence resulting in a double refraction effect, while halite does not – B is a valid method. Calcite is monoclinic while halite is cubic, so the two samples would split differently – D is a valid method. As neither calcite or halite is hard enough to scratch glass, C would be the least effective at distinguishing the crystals.

20. The diagram below shows a cross-section of a river and the surrounding soil.



Given that the soil is uniform and the cross-section is taken in a relatively humid and temperate climate, which of the dashed lines most likely corresponds to the water table in the region?

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

Solution: Due to the capillary fringe effect, the water table tends to mimic the surface topography given that there is enough rainfall to replenish the groundwater that flows into the river. Since a temperate climate is likely to have sufficient rainfall, B is the best answer.

21. Max wants to study wet-season thunderstorms in La Paz, Bolivia, located at 16.5°S latitude. Based on the movement of the Intertropical Convergence Zone (ITCZ), which month should he choose to study and why?

A. December, due to a northward shift of the ITCZ

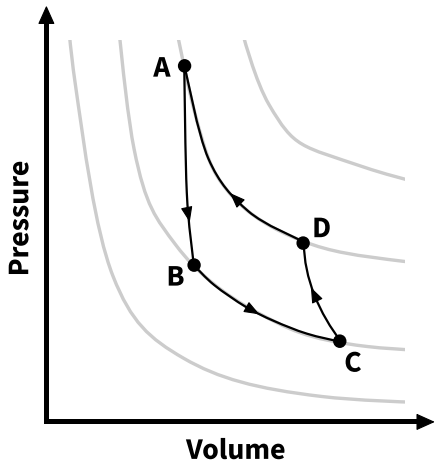
C. December, due to a southward shift of the ITCZ

B. June, due to a northward shift of the ITCZ

D. June, due to a southward shift of the ITCZ

Solution: The ITCZ shifts northward in June and southward in December from its mean position. The ITCZ is near the equator on average, so a southward shift brings it closer to Bolivia. As converging winds along the ITCZ result in rising air, clouds, and precipitation, December is part of the wet season in Bolivia. Meanwhile, in June, a northward shift of the ITCZ brings the subtropical high closer to Bolivia, supporting dry conditions. It would therefore be best to study wet-season thunderstorms in December when the ITCZ is shifted south - C is the best answer.

22. Katabatic winds carry dense air downslope under the force of gravity. Which of the following pathways on the pressure-volume diagram below best represents the transformation these winds experience as they descend? (Note that the gray lines represent isotherms.)



A. AB B. BC **C. CD** D. DA

Solution: Katabatic winds are driven by density differences between cold air upslope and warmer air at the base of a slope. The winds heat up adiabatically as they flow downhill and compress due to increased pressure. Curve CD represents an adiabatic process with pressure increasing and volume decreasing and is therefore the best answer.

23. Astronomers observing a terrestrial planet are investigating its magnetic properties. Which of the following pieces of evidence would support the hypothesis that the planet can generate and sustain its own magnetic field?

A. The planet has half the mass of Earth

B. The planet does not experience significant tidal forces from its host star

C. The planet's atmosphere is primarily composed of carbon dioxide

D. The planet has a high geothermal gradient

Solution: Larger terrestrial planets hold on to internal heat longer and consequently sustain magnetic fields for longer, so a planet less massive than Earth would be less likely to harbor a magnetic field – A is incorrect. Tidal heating can be a source of internal heat for planets, so a lack of significant tidal forces would not suggest that the planet hosts a magnetic field – B is incorrect. A planet's atmospheric composition has minimal bearing on the strength of its magnetic field – C is incorrect. A high geothermal gradient would suggest the planet harbors lots of internal heat, making it more likely to possess a molten layer that could sustain a magnetic field through the dynamo effect – D is the correct choice.

24. Dimictic lakes experience overturning twice per year. Which of the following types of lakes would most likely exhibit dimictic behavior?

A. A shallow, mid-latitude lake
C. A shallow, high-latitude lake
B. A deep, mid-latitude lake
D. A deep, high-latitude lake

Solution: Shallow lakes are more easily mixed by wind and are less likely to form large thermal gradients necessary for overturning to occur – A and C can be eliminated. At high latitudes, lakes tend to be frozen over for much of the year and only mix during the summer melting season. This means that high-latitude lakes are generally monomictic (overturning once a year) – D can be eliminated. B is therefore the best choice.

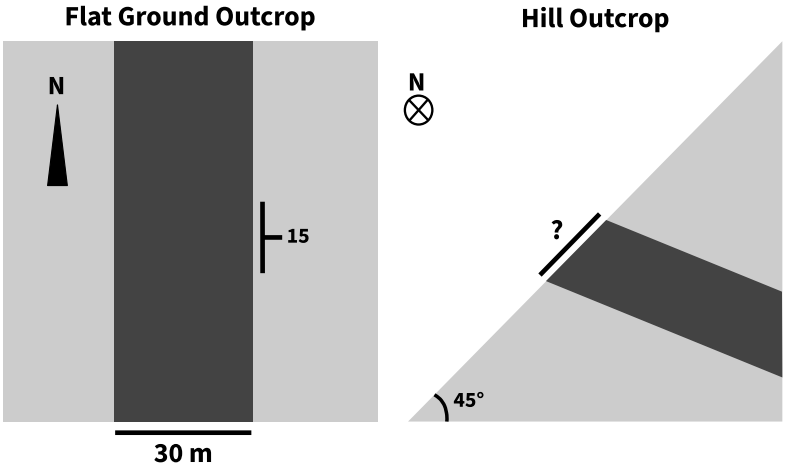
25. Milankovitch cycles play an important role in the regulation of glacial and interglacial periods. Assuming each cycle occurs independently, which of the following modulations would increase seasonal variations of temperature in the Northern Hemisphere?

I) A slight increase in Earth's axial tilt
II) A slight increase in Earth's orbital eccentricity
III) Axial precession 180° away from its current state

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

Solution: Increasing Earth's axial tilt increases the area over which insolation is spread and the amount of atmosphere that must be passed through during winter, decreasing wintertime temperatures and enhancing seasonal differences – I is true. Summer in the Northern Hemisphere occurs during aphelion and winter occurs during its perihelion. Slightly increasing eccentricity would thus result in Earth receiving less solar insolation during the summer and more during winter, decreasing seasonal variation – II is false. Axial precession 180° away from Earth's current state would lead to Northern Hemisphere summer occurring during perihelion and Northern Hemisphere winter occurring during aphelion, causing Earth to receive less solar insolation during Northern Hemisphere winter – III is true.

26. A geologist comes across a 30-meter wide outcrop of a planar coal seam on horizontal ground, depicted on the left of the image below. They find that the coal seam outcrops again on a hill directly to the west of the first outcrop, depicted on the right of the image below. They measure the slope of the hill to be 45°.

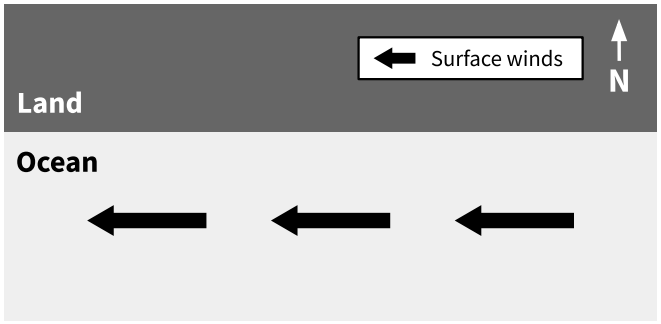


Assuming no tectonic uplift or subsidence occurred after the formation of the coal seam, what should the geologist measure the apparent thickness of the outcrop on the hill to be?

A. 7.76 meters **B. 8.97 meters** C. 10.97 meters D. 15.53 meters

Solution: Given the first outcrop, the true thickness of the coal seam is $30 \times \sin(15°) = 7.76$ meters. In the second outcrop, the angle between the dipping unit and the hill slope is $15° + 45° = 60°$. This means that the angle between a perpendicular plane (containing the true thickness) and the direction of apparent thickness is $(180° - 60°) - 90° = 30°$. Apparent thickness is then $\frac{\text{true thickness}}{\cos(30°)} = 8.97$ meters.

27. In a region of the Northern Hemisphere shown below, the winds are the dominant driver of ocean circulation.



Given the depicted surface wind pattern, which of the following best describes the expected sea-surface temperature (SST) anomaly in waters along the coast?

A. A warm SST anomaly due to downwelling

C. A cold SST anomaly due to downwelling

B. A warm SST anomaly due to upwelling

D. A cold SST anomaly due to upwelling

Solution: In the Northern Hemisphere, net water transport occurs 90°to the right (clockwise) relative to the wind direction due to Ekman transport. The wind anomalies in the image shown would result in the transport of water towards the shoreline, resulting in downwelling. Coastal downwelling prevents colder waters from reaching the surface, resulting in a warm SST anomaly. The correct choice is A.

28. Though Titan's atmosphere contains 5% methane, which on Earth acts as a greenhouse gas, the surface of Titan is quite cold at 94 K. Malachi argues that if Titan was moved to a distance of 1 AU from the Sun, its average surface temperature would be greater than that of Earth. Which of the following observations would support Malachi's claim?

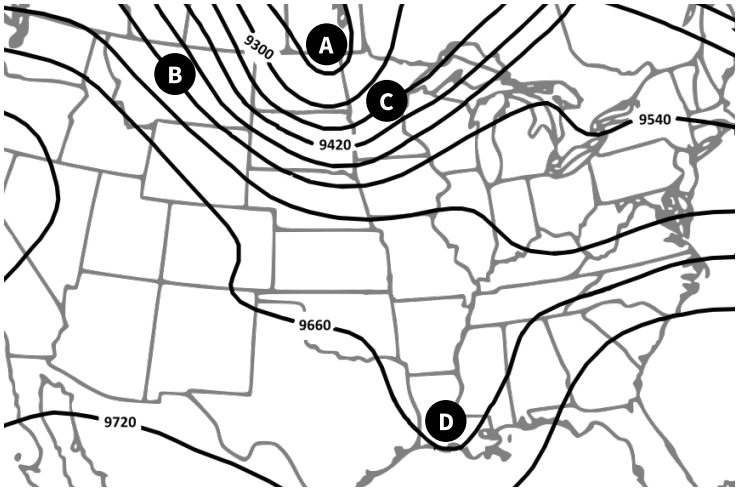
I) At higher temperatures, more methane evaporates into the atmosphere

II) Titan's haze dissipates due to photochemical reactions, which decreases planetary albedo

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

Solution: Greater atmospheric methane at higher temperatures would provide a positive feedback in reducing outgoing radiation – I supports Malachi's claim. More photochemical reactions closer to the Sun and decreasing the planetary albedo would increase the absorbed radiation, leading to a positive feedback loop in increasing absorbed radiation – II supports Malachi's claim.

29. The following image depicts a 300 mb constant pressure chart over the United States.

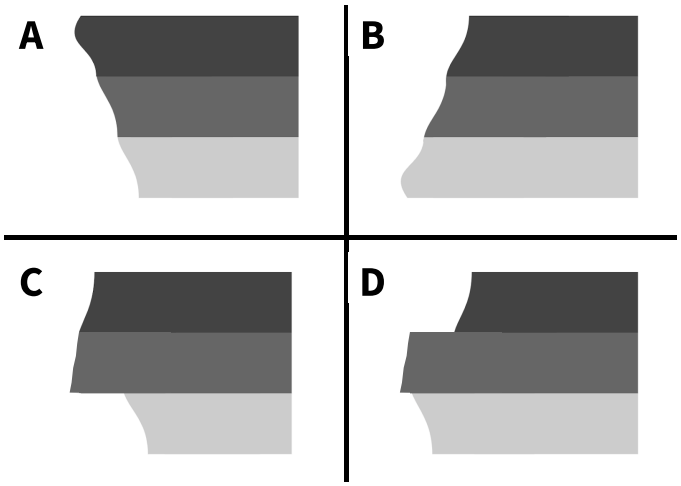


Which of the locations depicted is most likely to exhibit surface-level convergence?

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

Solution: The contour lines indicate the altitude at which the pressure is 300 mb, so a higher number signifies a higher pressure at that location. Winds aloft flowing from high to low pressure are bent towards the right in the Northern Hemisphere by the Coriolis effect, causing them to travel along the contour lines. At location Y the contour lines are spreading apart, which indicates that the wind would be diverging. Upper air divergence is associated with surface-level convergence, so the correct answer is C.

30. A geologist observes a section of a roadcut in a temperate region. They know that from top to bottom, the cut contains a layer of limestone, then basalt, and then sandstone. Based only on this information, which of the following most likely depicts the weathering profile of the roadcut?



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

Solution: Limestone is the most susceptible to weathering as it tends to dissolve in rainwater. Although sandstone is more resistant than limestone, it is weaker than basalt as its grains are less tightly bound compared to the interlocking crystals of an igneous rock. D is therefore the best answer.

END OF SECTION I