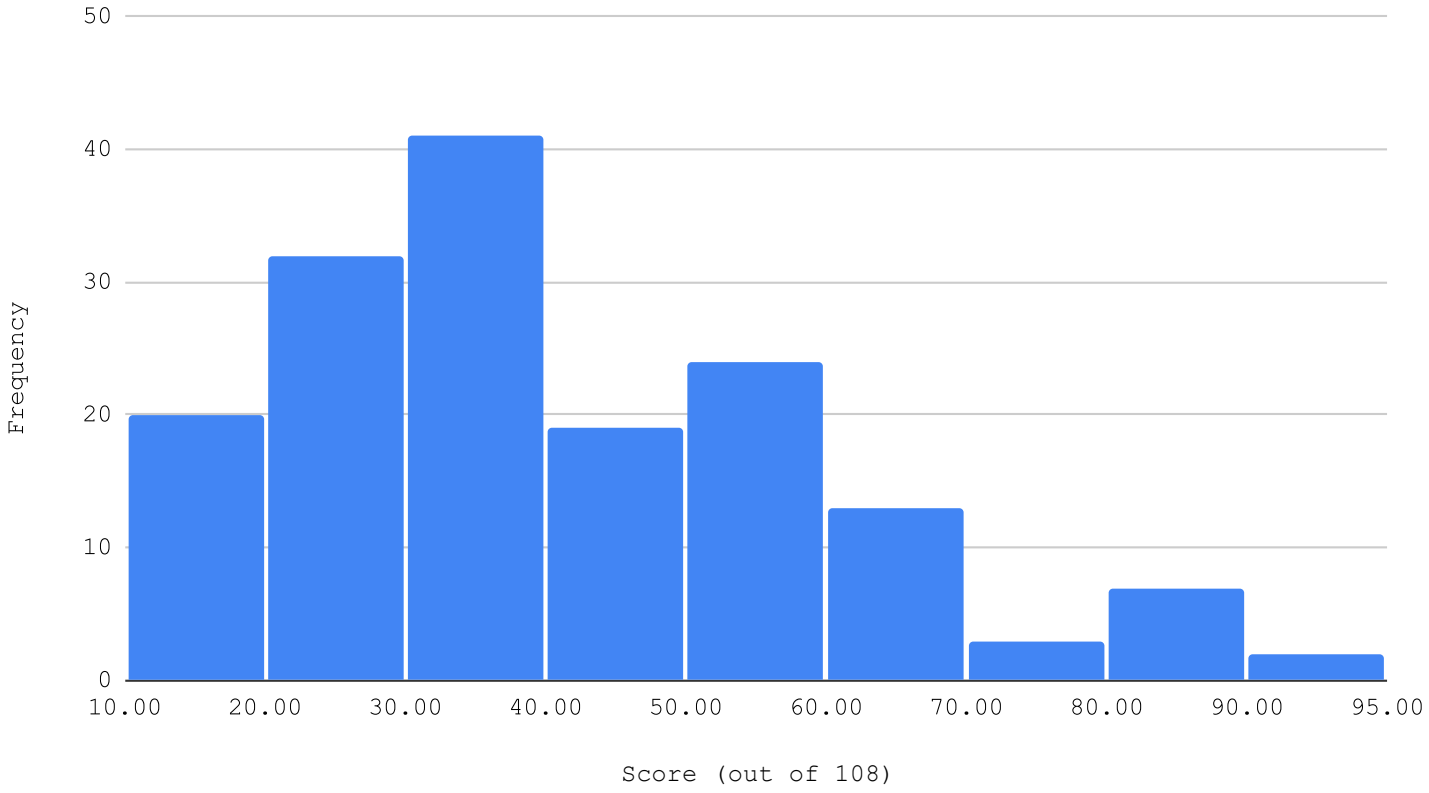
Total Score

USESO 2021 Open Exam | Section I + Section II



note: the highest possible score is 109 in the published exam.

average: 40.26
median: 37.5
std: 18.92
max: 91

USESO 2021

Open Exam

Section I - Key

Instructions:

- Section I is 60 minutes and consists of 30 multiple choice and multiple select questions
- Questions marked with a (*) may have one or more correct answers
- For multiple select questions: correct answers earn 1 pt, incorrectly marked answers deduct 1 pt, and unmarked correct answers do not earn nor deduct points

ANSWER FORM HERE

1. A volcano currently extrudes rhyolitic magmas but used to extrude basaltic magmas. Which of these is likely true about the volcano's history? (*)

   A. The silica content of the magma increased over time

   B. The solidification temperature of the magma increased over time

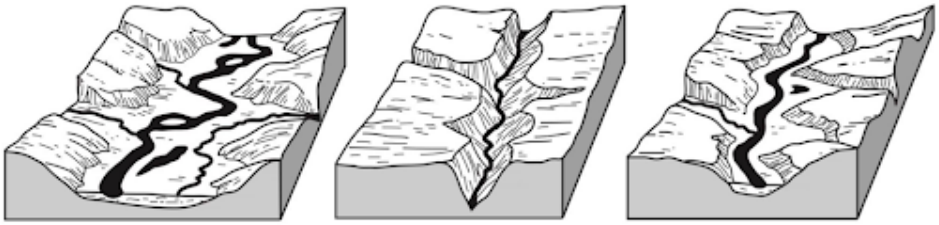
   C. The explosivity of the volcano decreased over time

   D. The viscosity of the magma from the volcano decreased over time

   E. The magma may have assimilated felsic continental crust

   Solution: Volcanoes typically undergo magmatic differentiation, such that the magma becomes more rhyolitic/felsic in composition over time (and has a higher silica content). Rhyolitic magmas have relatively low solidification temperatures and high viscosities, which favor explosive eruptions. Assimilation of felsic crust, relatively high in silica, is another mechanism that causes magma composition to become more felsic.

2. Refer to the following river valleys for this question.



   Identify all of the following statements regarding these river valleys that are true. (*)

   A. River valley A is older than river valley B

   B. The stream in river valley A has the most angular sediments

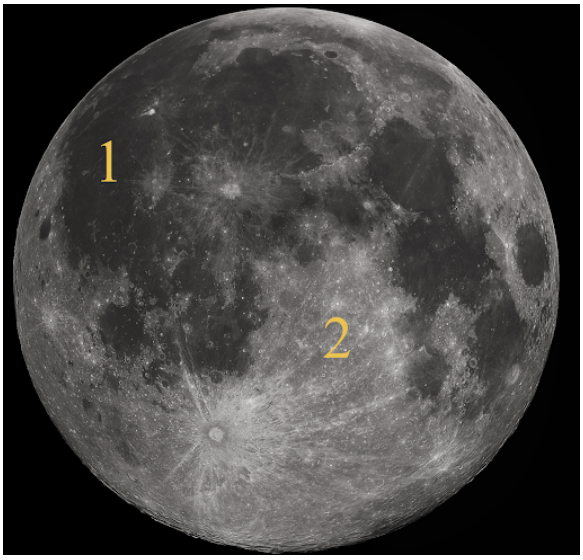
   C. The stream in river valley B has the highest stream discharge

   D. The stream in river valley B has the greatest channel roughness

   E. The stream in river valley C has the most poorly-sorted sediments

   Solution: River valley A shows evidence of an older, more eroded landscape than B with its wider floodplain and greater river meandering. River valley A is more likely located in a downstream location, so the sediments should be rounder having been transported over a longer distance. The narrow landscape of river valley B suggest that it is likely to be located upstream closer to the source of the river, and discharge generally increases downstream. Channel roughness decreases downstream, so river valley B has the greatest channel roughness. Sorted sediment is more common downstream, and river valley C is an intermediate between A and B.

3. Lunar rock samples are collected from two sites, labeled 1 and 2 in the image below.



Lunar rock sample	Ca-rich plagioclase content	Olivine content
A	45%	35%
B	90%	5%

Data from chemical analysis of two of the lunar rock samples, A and B, are presented in the table above. Based on this information, which of the following could be reasonably concluded? (*)

A. Sample A is from site 1

B. Sample A is from site 2

C. Sample B is from site 1

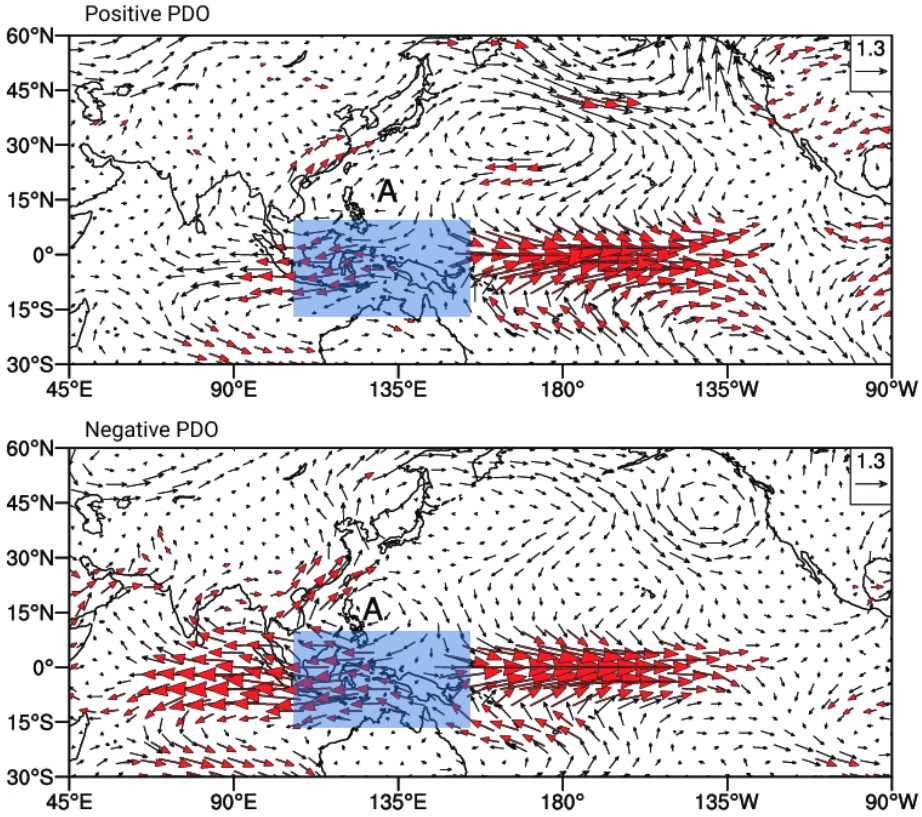
D. Sample B is from site 2

E. Sample A formed earlier than sample B

F. Sample B formed earlier than sample A

Solution: Site 1 is located in a mare, composed of basalt, and site 2 is located on the highlands, composed of the less mafic rock anorthosite. Based on the high olivine content, sample A is basalt, and based on the high calcium-rich plagioclase content, sample B is anorthosite. Since mafic rocks are generally darker, it can be concluded that site 1 corresponds to the sample with more olivine. Since the highly cratered highlands are older than the smooth maria, sample B would be older than sample A.

4. The figure below shows the wind velocity anomalies at 850 hPa for both phases of the Pacific Decadal Oscillation (PDO), a mode of climate variability in the Pacific Ocean. The region highlighted in blue will be denoted as Region A.



(adapted from Li et al., 2017)

(a) Which phase of ENSO is shown?

A. El Niño

B. La Niña

(b) Which of the following is true?

A. There is greater sinking of air in Region A during positive PDO

B. There is greater sinking of air in Region A during negative PDO

Solution: Anomalous westerly wind in the equatorial Pacific is an indication of weakened Trades, indicating this is an El Niño phase. We see there is greater divergence in the wind velocity anomaly at Region A during negative PDO, which suggests there is greater sinking. Note that 850 hPa (compare to the average sea-level pressure of about 1013 hPa) is at about 1.5 km altitude, which is still within the lower limb of the Walker Circulation.

5. Wanda, an active member of the Swellesley Institute of Technology Crew Team, notices her wind vane indicating that the predominant direction of the wind is 195 degrees clockwise from North. Assuming Wanda is in the Northern Hemisphere and that there are no frictional effects from the ocean bottom, what direction should she expect the surface currents to be pushing her boat in?

A. 105°

B. 150°

C. 195°

D. 240°

E. 285°

Solution: In Ekman theory, surface waters are deflected 45 degrees to the right of wind stress in the Northern Hemisphere. Hence, the correct answer is D. (*Note*: this question was omitted from grading because necessary information was not given at the time of the exam.)

6. Which of the following sequences of processes will lead to the formation of a nonconformity?

A. Deposition → uplift and tilting → erosion → deposition

B. Deposition → erosion → uplift and tilting → deposition

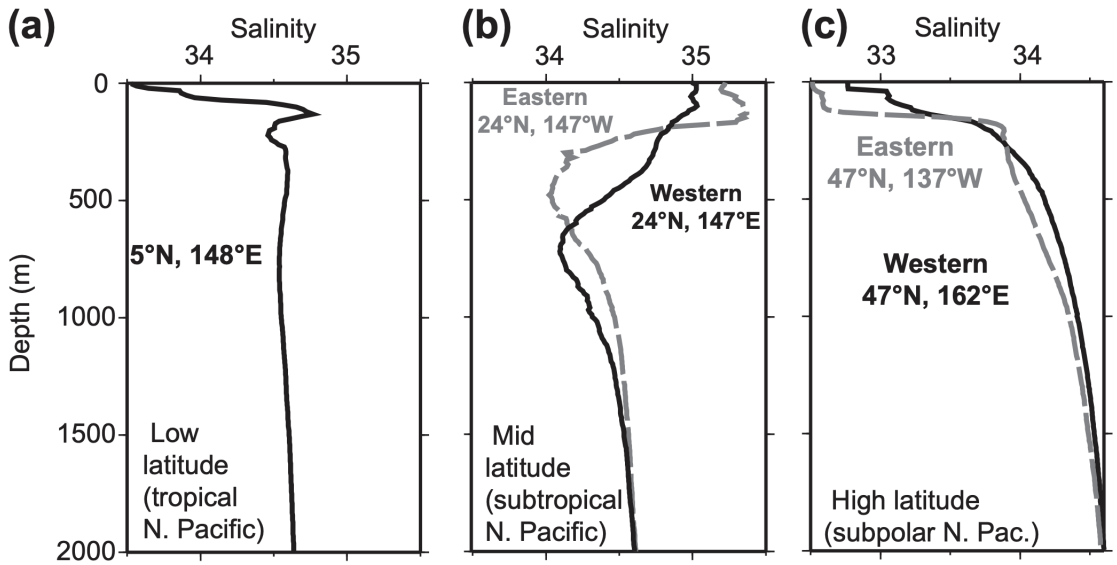
C. Deposition → weathering and erosion → deposition

D. Pluton emplacement → weathering and erosion → deposition

E. Pluton emplacement → deposition → weathering and erosion

Solution: A nonconformity is defined by sedimentary rock deposited above a basement of igneous or metamorphic rock. D is the only reasonable option, as there needs to be weathering and erosion to expose the pluton for a nonconformity to form below newly deposited sediment.

7. The diagrams below are the typical salinity profiles (ppt) of low, mid, and high latitude regions of the North Pacific Ocean.



Identify all of the following statements regarding these salinity profiles that are true. (*)

A. The surface salinity at low latitudes can be explained by high evaporation rates

B. The surface salinity at mid latitudes can be explained by high precipitation rates

C. For mid latitudes, the Eastern region receives more abundant rainfall than the Western region

D. For mid latitudes, the Western region receives more abundant rainfall than the Eastern region

E. At low latitudes, the pycnocline depends more on the salinity profile than the temperature profile

Solution: Low latitudes have low surface salinities due to high precipitation rates. Meanwhile, mid latitudes have high surface salinities caused by high evaporation rates. On average, the Western N. Pacific has a slightly lower surface salinity from more abundant rainfall. Since high latitude regions are cold throughout the year, density variations depend on salinity variation more than temperature variation.

8. Which of the following statements regarding our solar system's formation is **not** true?

A. Since the planets formed from the same rotating protoplanetary disk, they orbit the sun in the direction of the sun's axial rotation

B. The composition of the matter that condensed at a given region of the solar nebula was primarily determined by the temperature of the gas

C. Interstellar dust present in the solar nebula slowed down planetary accretion by disrupting gravitational attractions

D. After the protoplanets accreted a large amount of mass, gravitational collapse allowed them to rapidly accumulate additional gas from the nebula

Solution: Dust, like gas, is conducive to planetary accretion. Early accretion is caused by small-scale (non-gravitational) forces between dust grains, but dust does not disrupt gravitational attraction. Hence, the correct answer is C.

9. A hiker encounters this wide, U-shaped valley (shown below) and begins to explore the area.

Which of the following features is the hiker likely to find? (*)

A. Symmetrical ripple marks

B. Ridges of unsorted sediment

C. Boulders that are different from the bedrock of the area

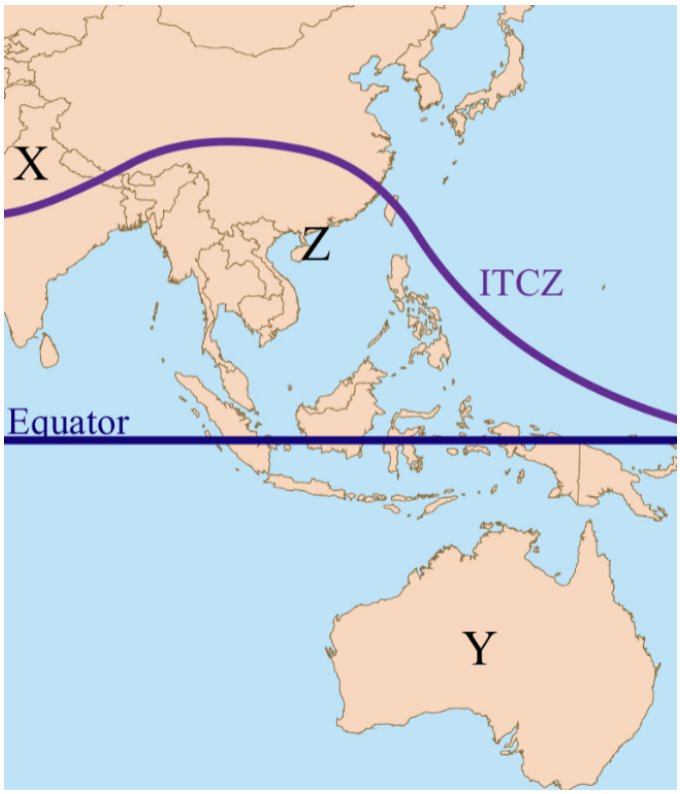
D. Large scale cross-stratification

E. Stalagmites

F. Turbidity current deposits

Solution: U-shaped valleys are formed by erosion due to mountain glaciers. Symmetrical ripple marks indicate bi-directional paleocurrents, which would not be found in glacial environments. Ridges of unsorted sediment such as moraines and foreign boulders known as glacial erratics are common glacial deposits. Coal beds, stalagmites, and turbidites all correspond to non-glacial depositional environments.

10. Shown below is a figure of the position of the ITCZ (Intertropical Convergence Zone) in East Asia. X, Y, and Z refer to labeled locations on the map.



(a) Identify all of the following statements concerning the figure that are likely true. (*)

A. This figure represents the ITCZ in January

B. This figure represents the ITCZ in July

C. Location X is a surface low-pressure center, and location Y is likely a surface high-pressure center

D. Location X is a surface high-pressure center, and location Y is likely a surface low-pressure center

E. The ITCZ represents a zone where winds converge aloft, instead of at the surface

(b) Which of the following is the mean prevailing surface wind direction at Z?

A. NE

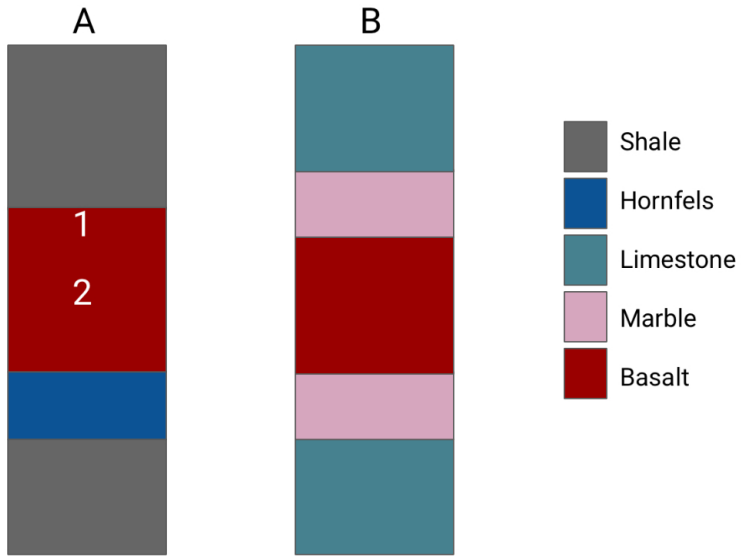
B. NW

C. SE

D. SW

Solution: The ITCZ roughly follows the latitude of maximum insolation, which is north of the Equator in July. Location X is located near the ITCZ, an area of low pressure due to air converging and rising at the surface. During the Northern Hemisphere summer, the land heats up more than the ocean, so surface air pressure is lower over land. Location Y represents the position of a surface subtropical high, a region of sinking air. Rising air diverges aloft near the ITCZ. During July, a southwest monsoon is affecting location Z, so southwesterly winds (named by their direction of origin) are predominant.

11. A geologist observes cross-sections of two separate outcrops A and B, shown below. It is found that each of the basalt units were formed in a single event.



Which of the following can be inferred from the outcrops above? Assume there has been no overturning. (*)

A. The basalt in outcrop A formed extrusively

B. The basalt in outcrop A is a sill

C. The largest crystals in outcrop A are found in the area labeled "1"

D. The largest crystals in outcrop A are found in the area labeled "2"

E. The basalt in outcrop B formed extrusively

F. The basalt in outcrop B is probably younger than the surrounding limestone

G. The marble in outcrop B was formed by partial melting and solidification

Solution: Outcrop A shows evidence of contact metamorphism at the bottom of the basalt layer (hornfels), but not at the top, so the shale on top was deposited after the basalt formation. Larger crystals indicate a slower cooling time. Given that the basalt cooled in a single event, lava in the interior likely cooled the slowest and thus has the largest grain size. Outcrop B shows evidence of contact metamorphism on both sides of the basalt layer, suggesting that it intruded into pre-existing limestone. Finally, marble is a metamorphic rock and does not form due to igneous processes.

12. Jupiter's four largest moons, from innermost to outermost, are Io, Europa, Ganymede, and Callisto. The first three exhibit 1:2:4 orbital resonances. Callisto, which is not part of this resonance, has a much more homogenous interior than the other moons because it:

A. Formed earlier in Jupiter's history

B. Is a captured satellite

C. Has a significantly inclined orbital plane

D. Is tidally locked with Jupiter

E. Experiences less tidal heating

Solution: All four moons accreted from Jupiter's protoplanetary disk. The interiors of the first three are subjected to friction-generated heating by tidal forces, which are enhanced by the resonance among all but Callisto. Tidal heating at some point in time allowed the interiors of Io, Europa, and, albeit to a smaller extent, Ganymede, to differentiate by density.

13. Which of the following phenomena could occur due to a thermal inversion, in which a layer of warm air overlays a layer of cool air? (*)

    A. Accumulation of air pollutants

    B. Formation of fog

    C. Isolated rain showers

    D. Supercell thunderstorms

Solution: In a thermal inversion, the environmental lapse rate becomes positive at some height (i.e., temperature increases with elevation). Hence, the local atmosphere is absolutely stable, conducive to fog formation (e.g., radiation fog) and accumulation of air pollutants below the inversion. Isolated rain showers and supercell thunderstorms are associated with atmospheric instability.

14. Initially (before 8:00 AM), measurements of the dry-bulb temperature (T_D) and the wet-bulb temperature (T_W) show a relative humidity of 60%. From 8 AM to noon, T_D increased by 2 °C. From 1 to 5 PM, T_W also increased by 2 °C. Given that the relative humidity must be below 60% for a school to safely reopen during a pandemic, when should the school hours be?

    A. From both 8 AM to noon and 1 to 5 PM, because in both instances the relative humidity is lower than 60%

    B. From 8 AM to noon, because the relative humidity is lower than 60%

    C. From 1 to 5 PM, because the relative humidity is lower than 60%

    D. Neither instance, because relative humidity is higher than 60% in both cases

    E. This setup does not give information about relative humidity; investigators should use a different method instead

Solution: From 8 AM to noon, the difference between the dry-bulb and wet-bulb temperatures (ΔT) increases while the wet-bulb temperature remains constant. The saturation vapor pressure increases without change in total water content, resulting in a decrease in relative humidity. Saturation vapor pressure increases exponentially with temperature (see Clausius-Clapeyron equation). Hence, from 1 to 5 PM, the relative humidity is more than 60% because the linear increase in both temperatures does not compensate for the exponential increase in saturation vapor pressure. In other words, at higher temperatures, there needs to be a larger ΔT to maintain the same relative humidity.

15. Karst topography is associated with high relief terrain and extensive systems of underground caves. What general kind of weathering is most relevant to karst, and which of the following would likely contribute most to further weathering?

    A. Mechanical weathering; abrasion from more running water

    B. Mechanical weathering; frost wedging with lower temperature

    C. Chemical weathering; elevated water table from precipitation

    D. Chemical weathering; higher groundwater carbonic acid content

Solution: Regions with karst features are usually composed of rocks that can readily dissolve, such as limestone. While calcium carbonate has a very low solubility in pure water, groundwater often contains carbonic acid, greatly increasing carbonate solubility.

16. Tsunamis are fast waves that are often seismically induced and can be very destructive. Identify all of the following statements about tsunamis that are true. (*)

    A. Tsunami waves have very short wavelengths

    B. As tsunamis encounter shallower waters, their speed decreases

    C. A tsunami event consists of a single, large wave

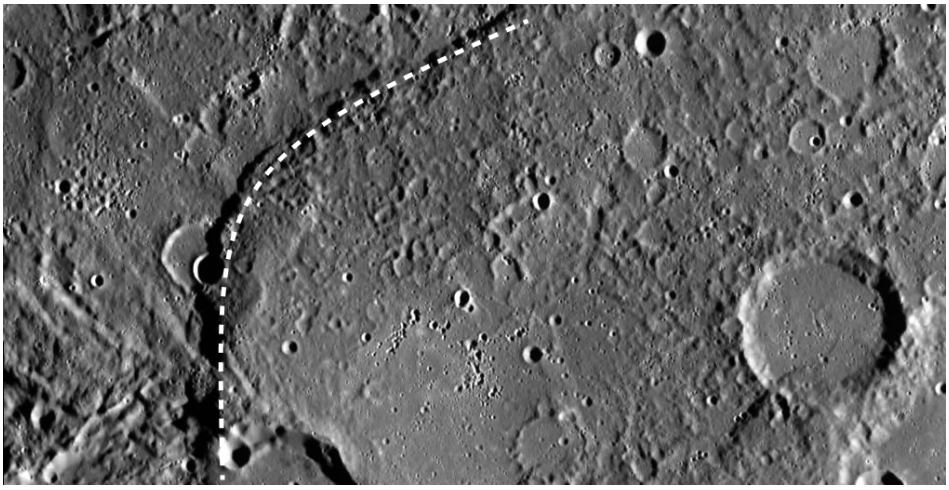
    D. Tsunamis are considered to be tidal waves due to the long distances that they travel

    E. The most destructive tsunamis occur as a result of earthquakes originating from mid-ocean ridges

    F. Abnormal retreat of water from the coast could be a warning sign of a tsunami

Solution: Tsunami waves are long-period, long-wavelength waves that behave like shallow-water waves. Their speed is proportional to depth, so tsunamis travel slower in shallow waters. Tsunami events can contain multiple waves. Although tsunamis travel for long distances, they are distinctly different from tidal waves, which are not tectonic in nature. The most destructive tsunamis occur from large earthquakes associated with subduction zones instead of mid-ocean ridges. Before the first tsunami wave, water can withdraw from the coast more than usual.

17. Lobate scarps (dashed line) are long thrust faults that are ubiquitous on the surface of Mercury.



Which of the following best explains the presence of these lobate scarps?

    A. Mercury has active tectonics that generate areas of compression

    B. Mercury has shrunk after its formation due to cooling

    C. Mercury experiences abundant impact cratering

    D. Tidal forces due to Mercury's proximity to the Sun

    E. Mercury experiences strong solar wind

Solution: Lobate scarps are thrust faults, which indicates planetary compression. Mercury does not have active tectonics, which eliminates A. The only reasonable answers are B and C, but because lobate scarps are large and not localized around craters, B is the most plausible answer. Indeed, lobate scarps are thought to be formed by planetary shrinking.

18. Nimbostratus clouds generally lack considerable vertical development and form in relatively stable atmospheric conditions. Identify all of the following statements that are true about nimbostratus clouds and the precipitation that they may produce. (*)

    A. They are more often associated with warm fronts

    B. They are more often associated with cold fronts

    C. They generally produce heavy precipitation lasting for a short time

    D. They generally produce light to moderate precipitation lasting for a long time

    E. They are likely to produce large hail if there is a shallow layer of above-freezing air aloft above a deeper layer of sub-freezing air

    F. They are likely to produce freezing rain if there is a shallow layer of above-freezing air aloft above a deeper layer of sub-freezing air

Solution: Nimbostratus clouds are common near warm fronts, associated with a more stable atmosphere as warm air overrides a retreating mass of cold air. The atmosphere ahead of cold fronts is typically more unstable, due to warm, rising air. Warm fronts are slower moving and produce light, but longer lasting precipitation, whereas cold fronts are faster moving and produce heavy but short bursts of precipitation. Hail is formed by strong updrafts within the cloud, commonly in thunderstorms. Freezing rain is formed when there is a relatively deep layer of above-freezing air and a shallow layer of sub-freezing air, so the rain freezes upon contact with the surface. Rain falling into a deep layer of sub-freezing air would refreeze into sleet before reaching the surface.

19. Which of the following characteristics do **not** differ between active continental margins and passive continental margins? (*)

    A. Presence of submarine canyons

    B. Presence of an offshore trench

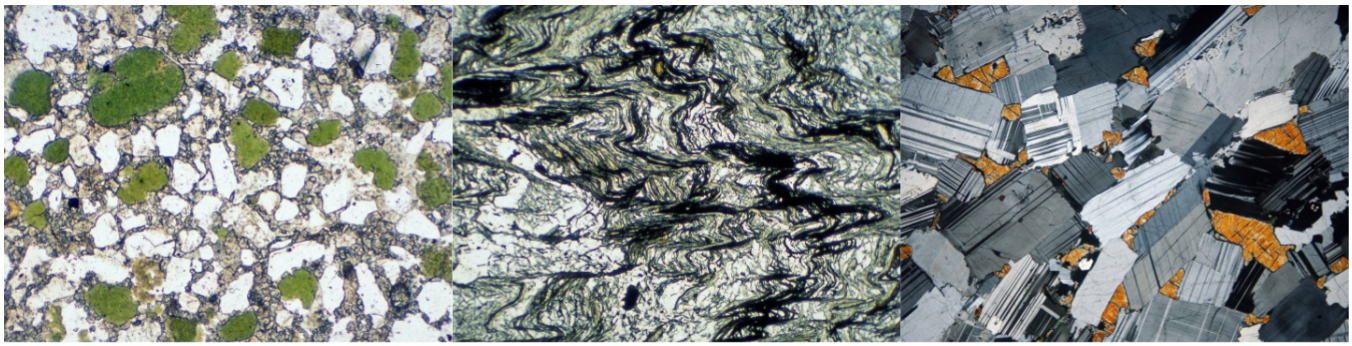
    C. Presence of a continental rise

    D. Continental shelf width

    E. Continental slope steepness

Solution: An active continental margin is characterized by a subduction zone offshore. The only characteristic not affected by an subduction zone is submarine canyons, which form from turbidity currents that can occur at both passive and active margins.

20. Photomicrographs are close up images of thin slices of rock seen under a microscope. The three photomicrographs below represent samples of the three major rock types.



Rock 1 Rock 2 Rock 3

Identify all of the following statements regarding these photomicrographs that are true. (*)

A. The formation of Rock 1 involved the crystallization of magma

B. The formation of Rock 1 involved the lithification of sediment

C. The formation of Rock 1 involved the metamorphosis of a parent rock

D. Rock 2 is commonly found in a stream channel

E. Rock 2 is commonly found adjacent to an igneous intrusion

F. Rock 2 is commonly found in areas under differential stress

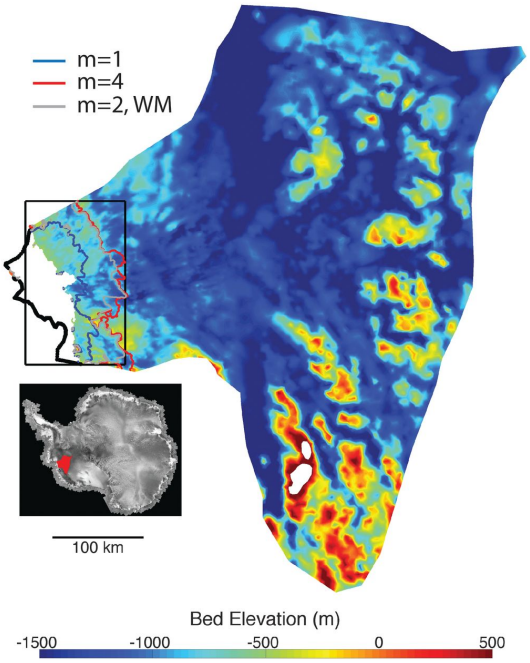
G. The formation of Rock 3 involved the crystallization of magma

H. The formation of Rock 3 involved the lithification of sediment

I. The formation of Rock 3 involved the metamorphosis of a parent rock

Solution: Rock 1 is sedimentary because it appears to have various fragments cemented together. Rock 2 is metamorphic because the highly crumpled folds indicate deformation and metamorphism. Rock 3 is igneous because it appears to have various interlocking mineral crystals. Sedimentary rocks, such as Rock 1, would be formed by lithification of unconsolidated sediment. Since Rock 2 exhibits schistosity, it would be formed by uneven stress rather than by contact metamorphism from an igneous body.

21. The Thwaites Glacier in West Antarctica is of particular interest because its bed is hundreds of meters below sea level, as shown in the bathymetric map below.



(Joughlin et al., 2014)

Which of the following is the primary reason for accelerated ablation (i.e., mass loss) of the Thwaites Glacier?

A. Calving

B. Sublimation of ice

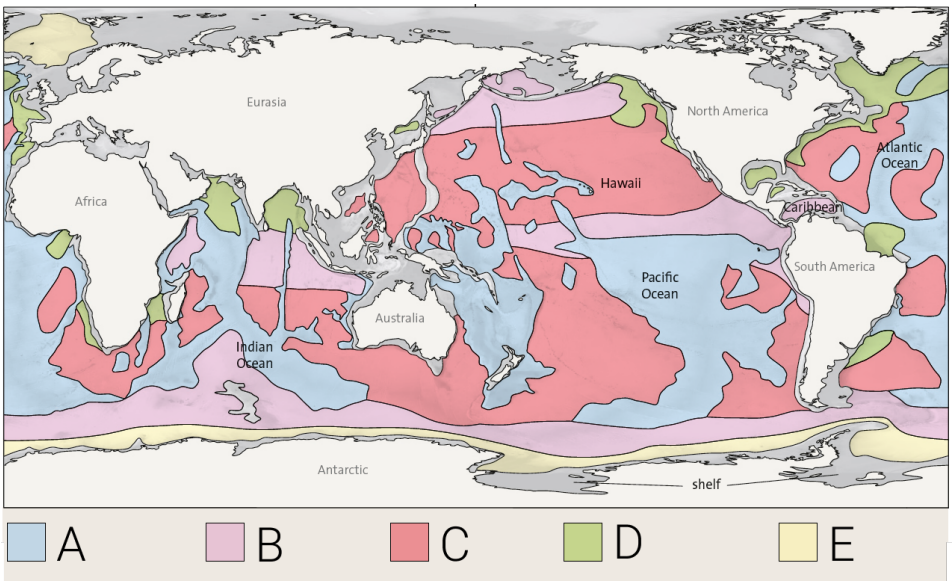
C. Warming of circumpolar deep water

D. Surficial meltwater streams

E. Avalanches

Solution: The bed of the Thwaites Glacier is exposed to the ocean. Accelerated ablation is indeed caused by warming of the surrounding water mass, which melts the glacier's underwater underbelly. This is of potential concern because instability of the ice shelf could cause an irreversible collapse of the glacier and lead to sea level rise.

22. Refer to the following figure for this question:



(adapted from Frisch et al., 2011)

Region B represents areas dominated by what type of sediment?

A. Alluvial deposits

B. Glacial deposits

C. Pelagic red clay

D. Siliceous ooze

E. Calcareous ooze

Solution: Siliceous sediment is present in large quantities in the equatorial Pacific due to the productivity of silica-secreting organisms like radiolarians. It is also dominant in the Southern ocean, where diatom productivity is high.

23. Oftentimes, a sudden warm wind may descend from mountains and evaporate up to a foot of snow in less than a day, leading to their nickname, "snow eaters." Why do Chinook winds such as "snow eaters" lead to a sudden increase in temperature?

A. A chinook wind travels long distances over desert areas, retaining heat, before being diverted into cooler areas nearby

B. A chinook wind warms through adiabatic heating after travelling over and descending from a mountain

C. A chinook wind gains moisture after travelling over a body of water, leading to an increased environmental lapse rate that warms the wind

D. A chinook wind follows a warm front, bringing heat to previously cold areas

Solution: Chinook winds are a type of foehn wind, which are descending winds that warm due to adiabatic compression (and hence, warming). B is the only reasonable option.

24. Most of the primordial Martian atmosphere has since escaped to space while Earth has maintained its atmosphere. Identify all of the following comparisons between the present-day Mars and Earth that contribute to this difference. (*)

A. Mars has a lower mass than Earth

B. Earth is closer to the Sun than Mars is

C. Average atmospheric pressure varies seasonally on Mars

D. Earth has a liquid outer core while Mars does not

E. Mars no longer has liquid water at its surface while Earth still does

F. Mars displays more impact cratering than Earth does

Solution: With a much lower mass than Earth, Mars is less able to retain its atmosphere by gravitational attraction. Also lacking a rotating liquid core to generate a magnetic field like that of the Earth, the Martian atmosphere is vulnerable to bombardment from solar wind particles.

25. A geologist encounters a large granite outcrop and examines the various minerals included in the matrix. When the geologist visits the outcrop much later, which of the following minerals would have weathered the most since her previous visit?

A. Quartz

B. Orthoclase feldspar

C. Biotite

D. Muscovite

E. All of the minerals would have weathered the same amount

Solution: Minerals forming at higher temperatures (higher on Bowen's reaction series/Goldich dissolution series) tend to weather faster than minerals lower on the series since the surface conditions differ greatly from their formation conditions. Since biotite forms at the highest temperature, it would weather fastest.

26. Mimas is a shepherd moon of Saturn that clears the Cassini Division, a gap in Saturn's rings. Particles on the inner edge of the Cassini Division are known to have a 2:1 orbital resonance with Mimas. If Mimas is 3 planetary radii (R) away from Saturn, estimate the distance from Saturn to the Cassini Division in terms of R.

A. $1.5R$

B. $1.9R$

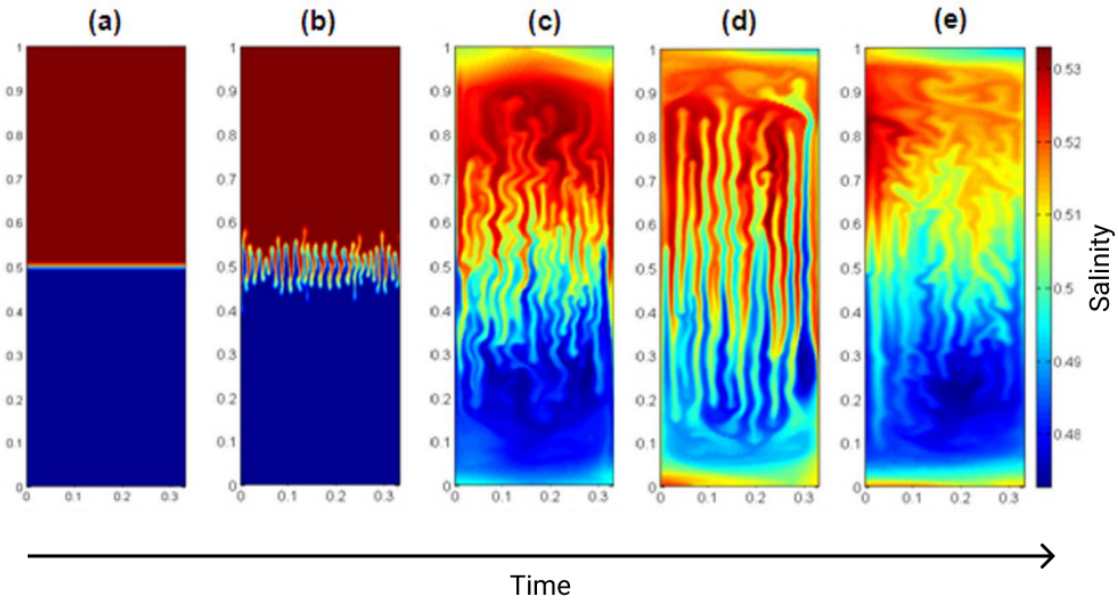
C. $2.7R$

D. $3.5R$

E. $4.8R$

Solution: An orbital resonance of 2:1 means that Mimas orbits once for every 2 orbits of the Cassini Division. By Kepler's Third Law we have $T^2/a^3 = k$ where k is a constant. Plugging in numbers, we have $a = (3^3/2^2)^{1/3} = 1.89$. Hence, the answer is B.

27. Salt fingers, shown below, are a curious phenomenon caused by density variation in the oceans.



(modified after Singh and Srinivasan, 2014)

Identify all of the following statements regarding salt finger formation that are true. (*)

A. A cold, salty layer contacts warm freshwater, forming warm, salty fingers

B. A warm, salty layer contacts cold freshwater, forming cold, salty fingers

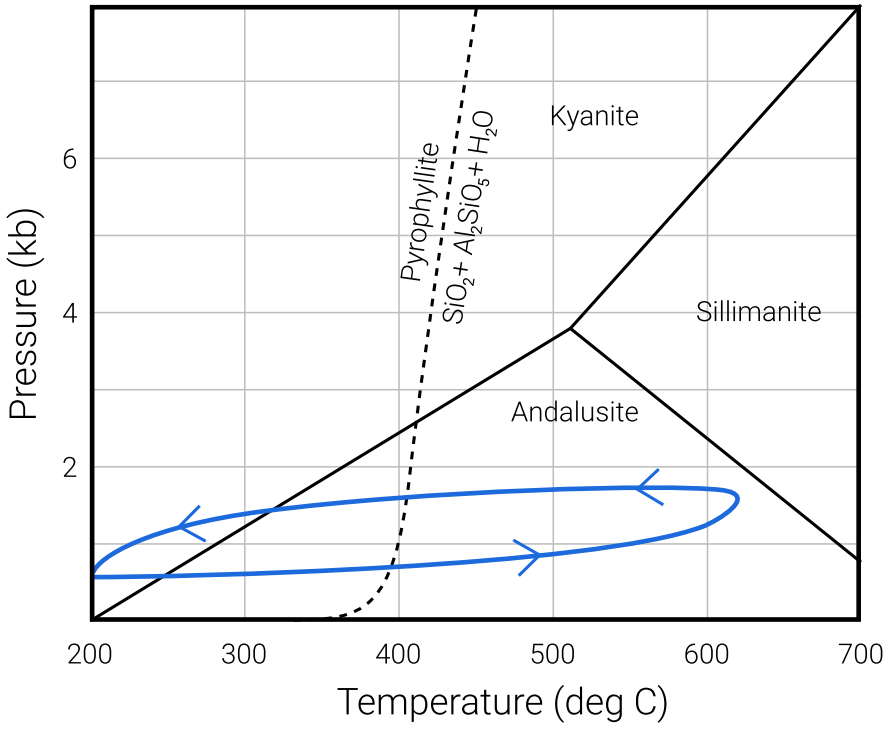
C. Salt diffusion is faster than heat diffusion, which causes fingers to sink

D. Heat diffusion is faster than salt diffusion, which causes fingers to sink

E. Salt water is less dense than fresh water at the same temperature

Solution: Salt fingers are governed by double diffusion, where two properties affecting density (e.g., temperature and salinity) have different rates of diffusion. Intuitively, heat diffusion (transfer of motion of molecules) is faster than salt diffusion (transfer of a solute through a solvent). Indeed, we see this in the figure, where cold, salty (dense) fingers extend down over time.

Use the following diagram for questions 28 and 29.



28. The phase diagram above shows the stability field of Al_2SiO_5, present as either kyanite, andalusite, or sillimanite. The dashed line divides the stability field of pyrophyllite ($Al_2Si_4O_{10}(OH)_2$) and its dehydrated components. Pyrophyllite dehydrates as such:

$$Al_2Si_4O_{10}(OH)_2 \longrightarrow Al_2SiO_5 + 3\,SiO_2 + H_2O$$

A mass of pure pyrophyllite undergoes metamorphism via the pressure-temperature-time (P-T-t) path shown in blue. Which of the following petrogenic environments is most closely associated with the P-T-t path?

A. Subduction zone

B. Impact crater

C. Pluton aureole

D. Orogenic belt

Solution: The P-T-t path shows that the metamorphism is relatively low P, high T. Hence, this suggests contact metamorphism, which may be present around a pluton.

29. Upon analysis, it is determined that the molar composition of the rock at the end of the P-T-t path is 20% pyrophyllite, 60% quartz, and 20% andalusite. Which of the following statements are true?

I) The retrograde reaction did not readily occur because water was lost to the surroundings.

II) The retrograde reaction did not readily occur because it is kinetically unfavorable at low temperatures.

A. I only

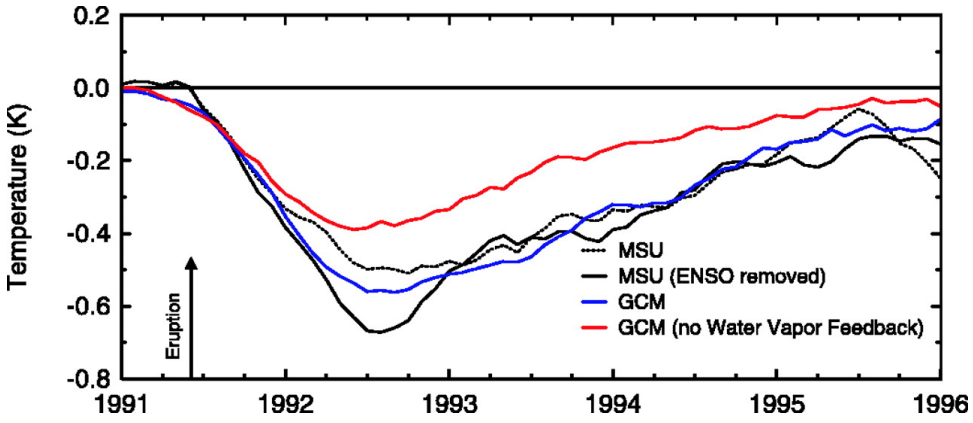
B. II only

C. I and II

D. None

Solution: By the end composition of the rock, we know that the retrograde reaction converting the metamorphism products back to pyrophyllite did not occur readily. I is likely true: water formed in these conditions is supercritical and rises rapidly; hence, it is rare for there to be enough water to complete retrograde reactions. II is also true: while retrograde reactions may be thermodynamically favorable, they are often kinetically unfavorable at low temperatures (reaction rates are too low).

30. The figure below shows the change of the global average lower-troposphere temperature following the 1991 Pinatubo eruption. The blue and red lines represent the temperature response simulated by a general circulation model (GCM), with the red model having no water vapor feedback.



(Soden et al., 2002)

(a) Identify all of the following statements that are true. (*)

A. The eruption increased atmospheric shortwave reflectivity

B. The eruption caused atmospheric warming

C. The global response in temperature is mainly driven by the release of aerosols by the volcano

D. The presence of the water vapor feedback significantly speeds up the return of the climate to equilibrium

E. The effect of the water vapor feedback on temperature may only be seen on decadal timescales

(b) The water vapor feedback may be best characterized as a:

A. Positive feedback loop

B. Negative feedback loop

Solution: Volcanic eruptions release both aerosols and GHGs in the atmosphere, which have opposing radiative forcings. Generally though, eruptions are dominated by aerosols, which have a negative radiative forcing by reflecting more shortwave radiation coming from the sun. We see the GCM run without the water vapor feedback has less of a response to the eruption, hence suggesting that the water vapor feedback amplifies this forcing and that it is a positive feedback. Indeed, this is true: decreased global temperatures → decreased equilibrium vapor pressure of water → less water vapor, a GHG, in the atmosphere → decreased temperatures.

END OF SECTION I

USESO 2021

Open Exam

Section II - Key

Instructions:

- Section II is 90 minutes and consists of 5 multipart questions that further assess geoscience knowledge in the form of free response and multiple choice quesions
- A non-graphing, non-programmable calculator is allowed; show all work for calculations
- Questions marked with a (*) may have more than one answer
- For multiple select questions: correct answers earn 1 pt, incorrectly marked answers deduct 1 pt, and unmarked correct answers do not earn nor deduct points

ANSWER FORM HERE

Problem 1

Question	1	2	3	4	5	6	Total
Points	1	2	3	2	3	1	12 (20%)

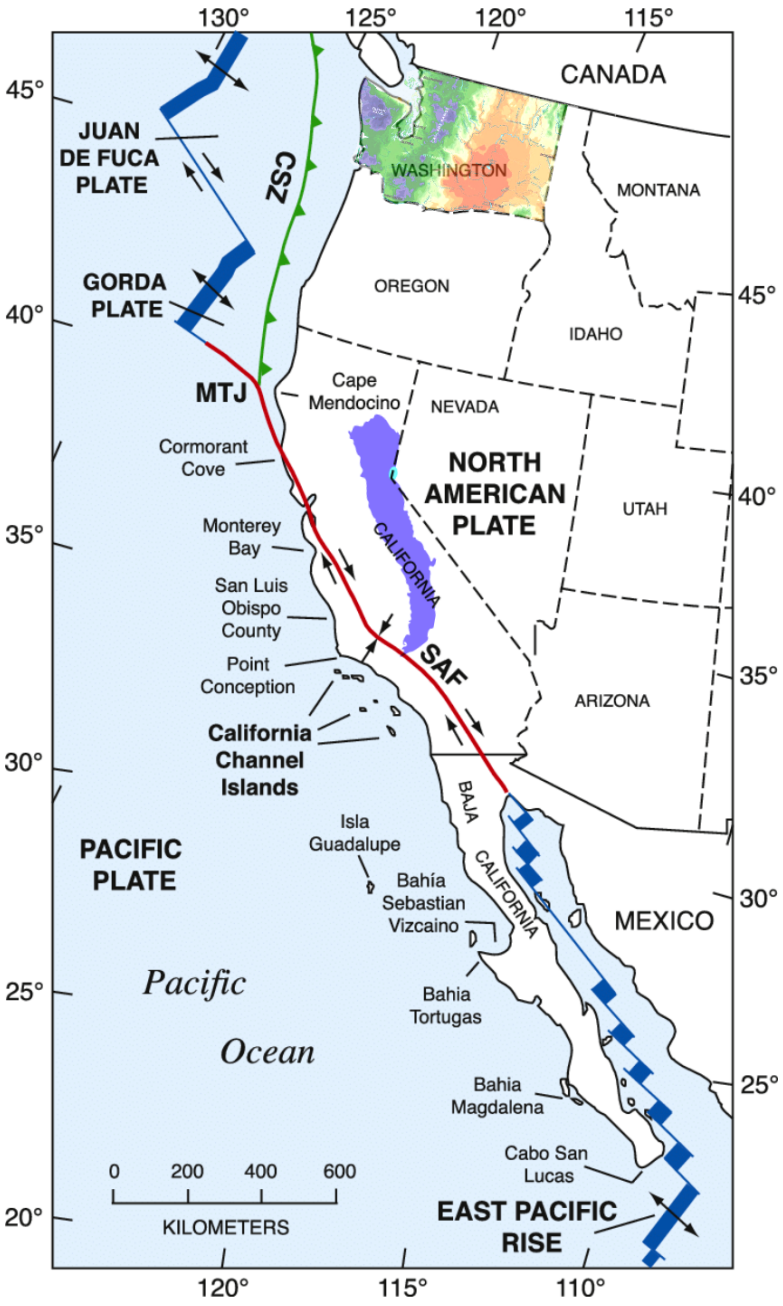


Figure 1: Tectonic settings in western North America. Abbreviations: SAF, San Andreas Fault; MTJ, Mendocino Triple Junction; CSZ, Cascadia Subduction Zone.

1. (1 point) The Sierra Nevada, marked in violet in Figure 1, is a mountain range in California. Which of the following describes the predominant composition and texture of igneous rocks found in the core of the Sierra Nevada?

   A. Felsic, coarse-grained

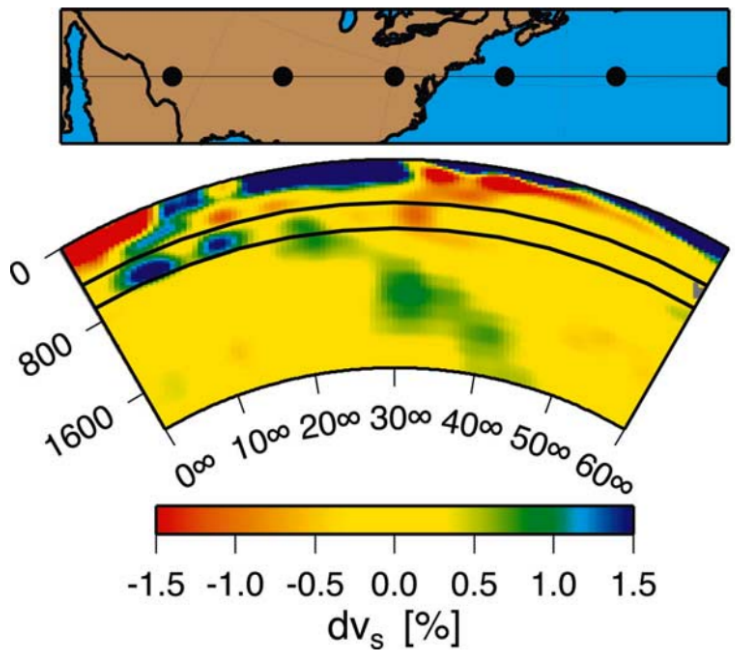
   B. Felsic, fined-grained

   C. Mafic, coarse-grained

   D. Mafic, fined-grained

2. (2 points) Half Dome is a well-known example of an exfoliation dome, a structure with joints that parallel the surface of the dome. Describe a change in the environment after the initial crystallization of the pluton and how it is responsible for this jointing.

   Solution: The exfoliation dome begins as a pluton emplaced far below the surface, where confining pressure is high from overlying material. With eventual uplift and weathering, the pluton is exhumed and confining pressure drops, causing rock to expand.



(Schmid et al., 2002)

Figure 2: A seismic tomography cross section along the line in the map above. Positive values of dv_s represent relatively cold regions in the mantle.

3. While California is mostly bordered by a transform boundary, volcanic activity in the Sierra Nevada is still detected today.

   (a) (1 point) Identify the green feature sloping down towards the east in Figure 2.

   Solution: As shown in the seismic tomography, part of the subducted Farallon plate lies beneath the Sierra Nevadas although the original convergent boundary is no longer present.

   (b) (2 points) Describe the mechanism responsible for melt formation in the Sierra Nevada. How does the feature in (a) support this?

   Solution: The igneous activity at the Sierra Nevadas has been, and still is, driven by flux melting. Water from the green feature, subducted lithosphere, lowers the melting point of the mantle for any given depth, and partial melting produces the melt that eventually ascends to the surface.

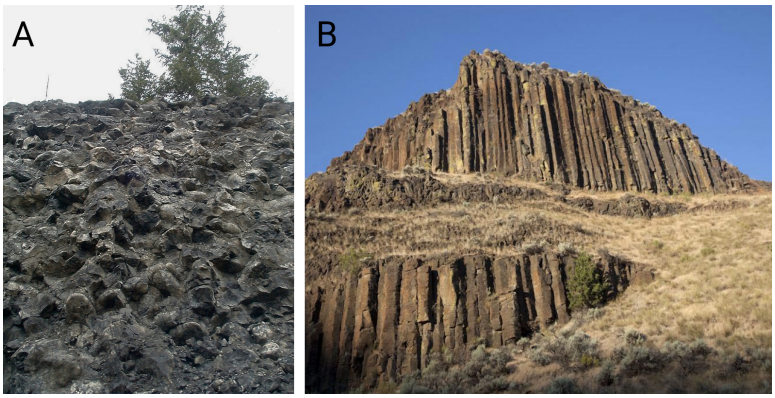


Figure 3: Two basalt formations in Washington: the Columbia River Flood Basalts and the Crescent Formation Basalts (a Mid-Ocean Ridge Basalt, or MORB), in no particular order.

4. (2 points) Classify A and B as either the Columbia River Flood Basalt or the Crescent Formation. Provide one piece of evidence for the classification.

   Solution: A represents the Crescent Formation Basalts and B represents the Columbia River Flood Basalts. A has pillow basalts, which are formed underwater at mid-ocean ridges. B has columnar jointing, which forms from large scale flood basalt flows.

5. (3 points) A sample from Formation A is crushed and analyzed. The following data are gathered:

^{39}K mass	1.290 g
^{40}K/^{39}K mass fraction	$1.254 * 10^{-4}$
^{40}Ar mass	$5.084 * 10^{-6}$ g
Half-life of ^{40}K	$1.248 * 10^{9}$ years

   Potassium-40 (^{40}K) decays to argon-40 (^{40}Ar), an inert gas that is trapped after crystallization. Assume that ^{40}Ar does not escape the rock. If Formation B has an age of 16.7 million years (Ma), how many times as old is Formation A than Formation B? Show work for all calculations.

Solution: K-39 is much more common than K-40. We can use the mass ratio to find that the mass of K-40 is $1.618 * 10^{-4}$ grams. The mass of the original K-40 is m(Ar-40) + m(K-40), which is $1.669 * 10^{-4}$ g. m(K-40)/m(K-40 original) = 0.970; this is the fraction of K-40 remaining. $\ln(0.970)/\ln(0.5) = 0.0446$ half-lives. Then multiplying by the half-life we find the age is 55.70 Ma. Formation A is $\boxed{\text{3.3 times}}$ as old as Formation B.

6. (1 point) In Figure 1, Washington state is overlaid with a map of the local precipitation, with warm colors indicating low precipitation. Briefly account for why the eastern half of Washington receives significantly less precipitation than the west.

Solution: The Cascade mountains prevent moist air from travelling from the Pacific into Eastern Washington via the rainshadow effect.

Problem 2

Question	1	2	3	4	5	6	Total
Points	1	3	2	1	2	2	11 (18%)

In the following map, Westtown and Easttown are separated by a normal fault. The red X represents the epicenter of an earthquake the same distance away from both towns. Assume no other faults are located nearby.

1. (1 point) Identify the type of stress that resulted in the formation of the fault.

Solution: Tensional (extensional) stress

2. (3 points) After the earthquake, which town, if any, was uplifted relative to the other town? Justify your answer.

Solution: Based on position of fault and epicenter, the fault dips to the east. In a normal fault, the footwall moves up relative to the hanging wall. Hence, Westtown is uplifted relative to Easttown.

3. (2 points) What additional pieces of information would need to be known to calculate the depth of the earthquake's focus (hypocenter)?

I) The strike direction of the fault

II) The dip angle of the fault

III) Map distance from the epicenter to the fault

IV) Map distances from the epicenter to Westtown and Easttown

A. I and III

B. II and III

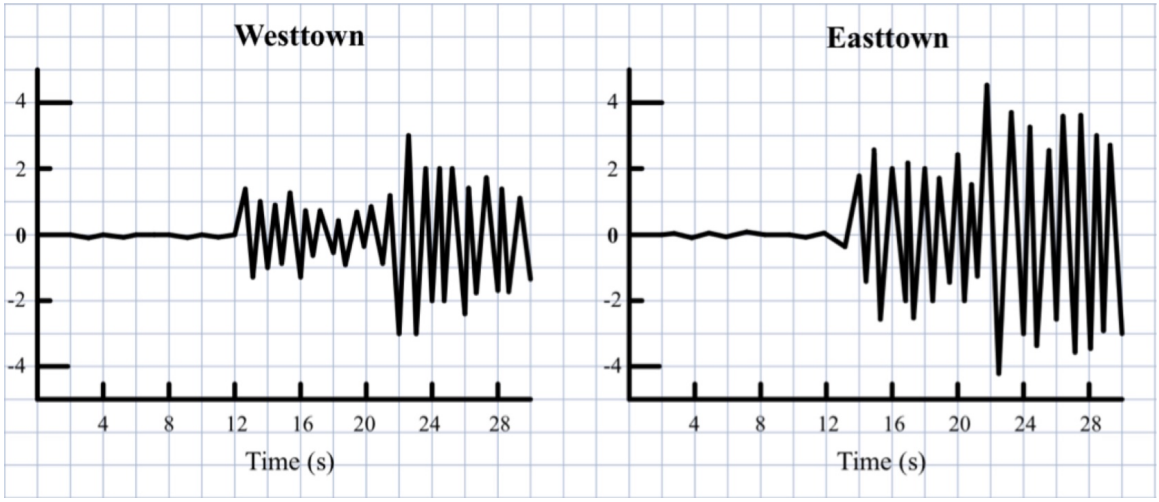
C. II and IV

D. II, III, and IV

E. I, II, and III

Solution: Only II and III are needed. The depth of the focus would be equal to dist $*$ tan(δ).

4. (1 point) Shown below are two seismograms (records of seismic waves) for Westtown and Easttown.



Which of the towns, if any, is more likely to be located on alluvial deposits than solid bedrock?

A. Westtown, because the amplitude of the seismic waves is lower

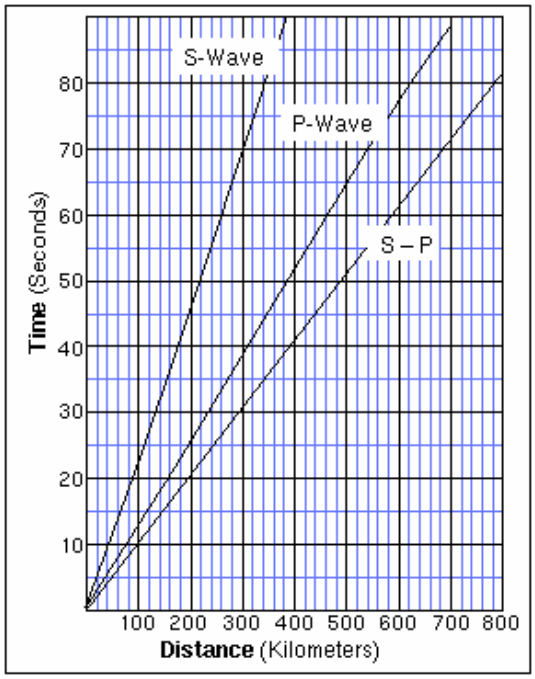
B. Westtown, because the frequency of the seismic waves is lower

C. Easttown, because the amplitude of the seismic waves is higher

D. Easttown, because the frequency of the seismic waves is higher

E. Neither, because the P-waves arrive at the same time for both towns

5. (2 points) Shown below are travel time curves for S-waves, P-waves, and the SP interval (lag time).



Using the information from both the seismograms and the above chart, how far away is Westtown from the epicenter of the earthquake, in kilometers? Justify your answer.

Solution: From the seismogram, we see that P-wave arrival is at about 12 s, while S-wave arrival is at about 22 s. From the graph, this corresponds to a distance of 100 km.

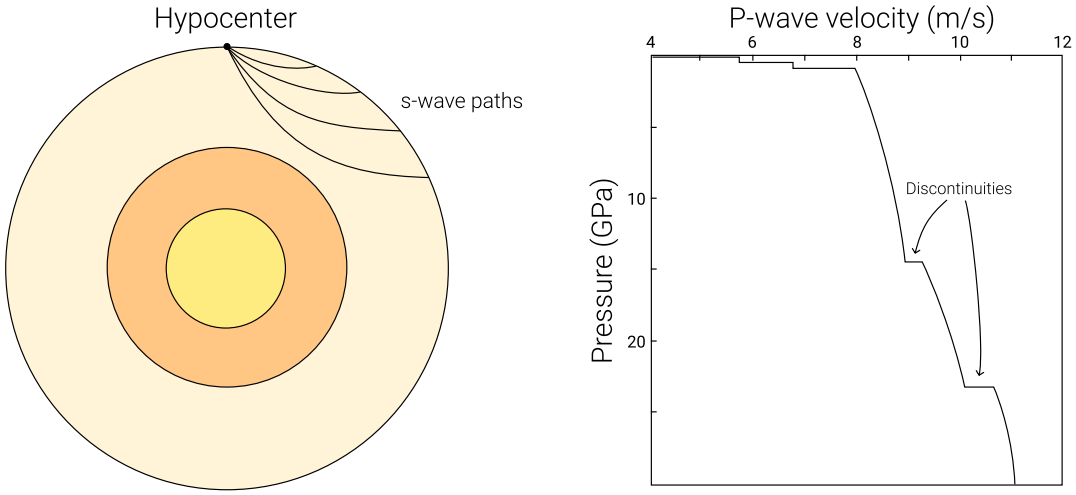


Figure 4: (left) S-wave paths through the mantle; (right) P-wave velocity with pressure (depth) in the mantle.

6. (2 points) Give brief explanations to account for the following observations:

   (a) S-wave paths are curved and concave-up towards the surface.

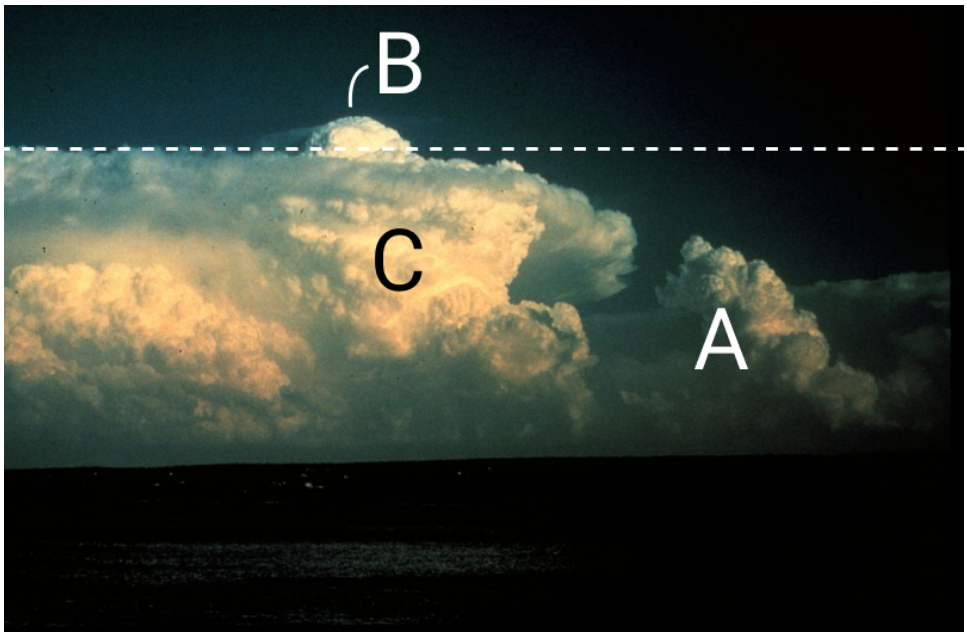
   Solution: S-wave velocity generally increases with depth, hence, the S-waves refract towards the surface.

   (b) There are discontinuities in P-wave velocities at certain depths.

   Solution: Minerals shift towards denser, less compressible phases at those depths, which cause a sudden increase in the P-wave velocity.

Problem 3

Question	1	2	3	4	5	Total
Points	1	1	3	2	5	12 (20%)



1. (1 point) Cloud A is called a cumulus congestus cloud, which is simply a large cumulus cloud. What is the primary direction of motion of the air in cloud A?

   Solution: Upwards

2. (1 point) What is the name of the dashed line?

   Solution: Tropopause

3. (3 points) Why is most of cloud C limited to elevations below the dashed line? What occurs when a cloud overshoots this line?

   Solution: The stratosphere exhibits absolute stability, where air temperature increases with altitude. Therefore, as air rises through the stratosphere, it will always be colder than its surroundings, and will sink back below the stratosphere.

4. Feature B is called an overshooting top.

   (a) (1 point) Why does it extend above the dashed line?

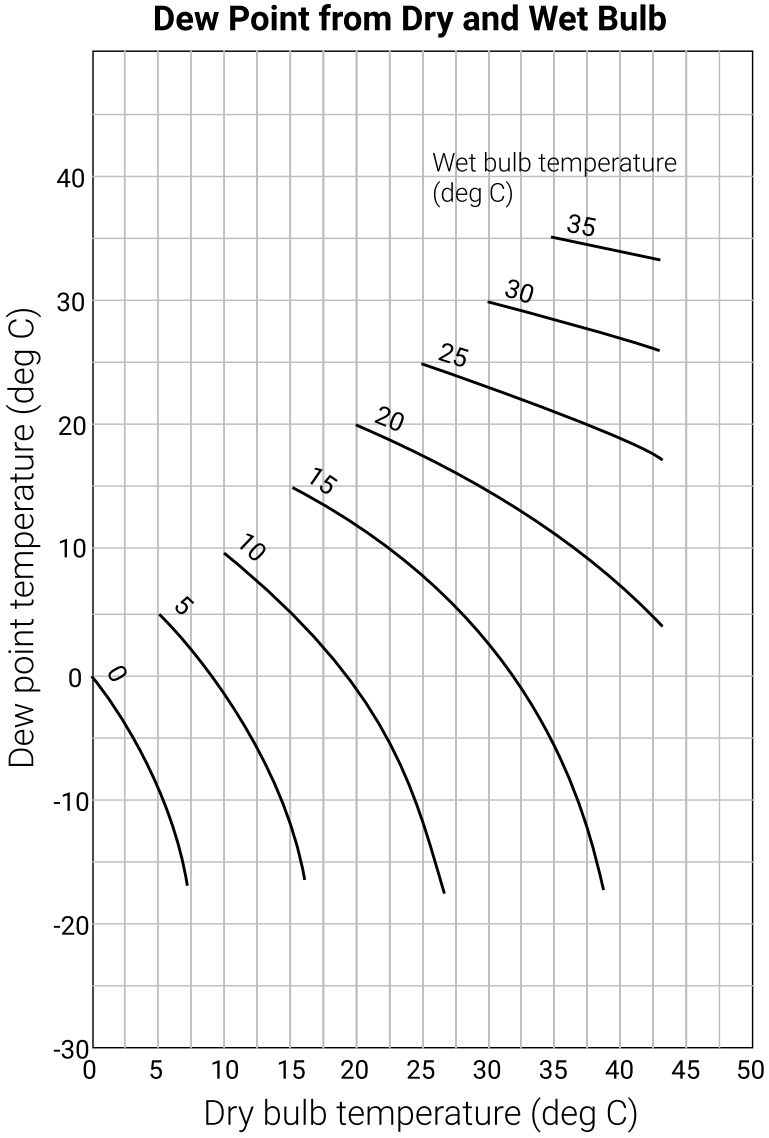
   Solution: The overshooting top occurs because of an extremely dense and strong updraft in the thunderstorm.

(b) (1 point) What does this indicate about the condition of the underlying atmosphere?

Solution: This occurs in a very unstable troposphere. See: convective available potential energy.

5. A parcel of air at ground level has a dry bulb temperature of 15°C and a wet bulb temperature of 12.5°C. To analyze its interactions with the environment, radiosonde observations and thermodynamic calculations revealed the following parameters:

Environmental lapse rate (ELR)	7.80 °C/km
Dry adiabatic lapse rate (DALR)	9.69 °C/km
Moist adiabatic lapse rate (MALR)	6.75 °C/km
Dew point lapse rate	2.00 °C/km



(a) (1 point) What is the dew point at the surface?

Solution: There is no isotherm for a WB temperature of 12.5 °C. Instead, we can interpolate between the curves for 10 and 15 °C. Thus, we see that the dew point is about 10 °C at ground level.

(b) (1 point) The local atmosphere is:

A. Absolutely stable

B. Absolutely unstable

C. Conditionally unstable

Solution: MALR < ELR < DALR. Hence, the air is conditionally unstable (stable when unsaturated but unstable when saturated).

(c) (3 points) At what elevation, in meters, will the cloud base be? Show work for all calculations.

Solution: Because the dry bulb temperature is greater than the dew point, the air parcel is unsaturated. Hence, it cools by the dry adiabatic lapse rate until cloud formation, which occurs when the air temperature equals the dew point temperature.

We can solve a system using the DALR and dew point lapse rate like so:

$$10 - 2z = T_{dew}$$
$$15 - 9.69z = T$$

Setting the temperatures equal then solving for elevation z, we find $z \approx 0.65\,\text{km}$, which is $\boxed{650\text{ m}}$. This is the cloud base.

Problem 4

Question	1	2	3	4	Total
Points	2	4	4	4	14 (23%)

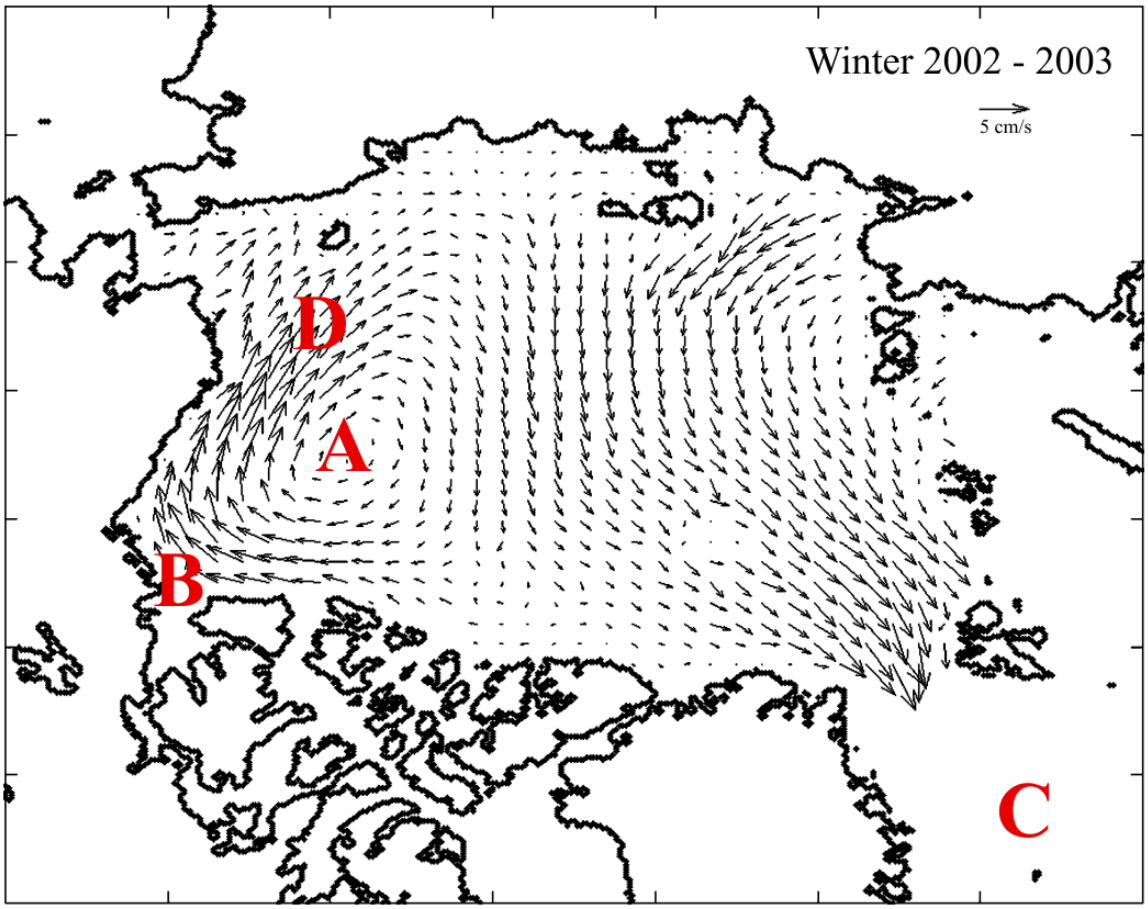


Figure 5: Arctic Ocean mean sea-ice motion map of the 2002-2003 winter season. Figure adapted from Zhao and Liu (2007).

1. (2 points) Letter A denotes the center of the Beaufort Gyre. Classify the Beaufort Gyre as either anticyclonic or cyclonic and describe the relative sea surface heights at A and B (i.e., higher or lower).

Solution: The Beaufort Gyre rotates clockwise. In the northern hemisphere, the Coriolis force deflects to the right; hence, the Beaufort Gyre is anticyclonic. Approximating the gyre to be in geostrophic balance, it follows that the pressure gradient force must point outwards. Hence, the SSH of A is higher than SSH of B.

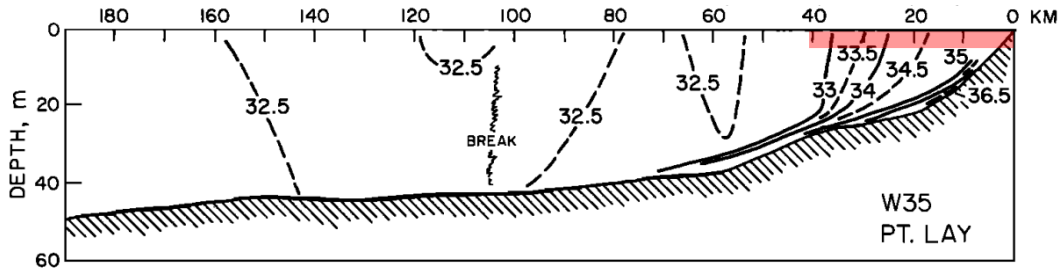


Figure 6: Salinity profile at an Arctic polynya (colored red). The bottom topography is denoted with the shaded portion. Figure adapted from Aagaard et al. (1985)

2. Water masses in the Arctic are largely altered through sea ice formation.

   (a) (1 point) Briefly describe one way by which sea ice formation may alter the temperature or salinity of a water mass.

   Solution: Salts generally do not crystallize with ice during sea ice formation; hence, sea ice formation increases the salinity of surrounding water (brine rejection). Another minor effect is from the negative latent heat of crystallization, which may slightly warm the surrounding water.

   (b) (3 points) Letter B marks the location of the Cape Bathurst Polynya. Polynyas are areas of coastal ocean that are semi-permanently exposed to air (i.e., no ice cover) and function as zones of active ice formation. Describe the vertical movement of water at a polynya, and justify why it may move as such.

   Solution: Sea ice formation, as established above, causes a considerable increase in surrounding seawater salinity due to brine rejection. The salty, denser water will thus sink. Figure 2 illustrates this process, showing the isohalines sinking at the polynya. (*Note*: this is the dominant mechanism in most coastal polynyas, but valid descriptions of noncoastal polynya types were also accepted)

3. Circulation in the Arctic Ocean may be simplified as a combination of Ekman (i.e., wind driven) and geostrophic components.

$$v_{tot} = v_{Ek} + v_{geo} \tag{1}$$

   (a) (1 point) Which two of the following forces must be balanced for geostrophy? (Select two)

   A. Pressure gradient force

   B. Coriolis force

   C. Centripetal force

   D. Centrifugal force

   E. Buoyant force

   (b) (3 points) Would the ratio of Ekman to geostrophic velocity v_{Ek}/v_{geo} be greater at (the surface of) D or C? Justify your answer.

   Solution: Ekman transport is driven by the wind stress on the ocean surface. Because the Arctic Ocean (specifically, D) is covered by ice, this significantly reduces the wind stress on the ocean below. Hence, the Ekman component of circulation is quite low at D. Further, geostrophic velocities (i.e., driven by pressure gradient) are likely to be greater at D, because D is in a gyre, while C is not. Thus, v_{Ek}/v_{geo} is lower at D.

4. (4 points) The Arctic is one of the most rapidly evolving regions on Earth due to the effects of anthropogenic climate change. An important feedback loop in the Arctic is the sea-ice albedo feedback. Describe its mechanism and characterize it as either a positive or negative feedback.

Solution: Starting with an initial forcing, let's say warming ocean temperature, where sea-ice cover is expected to decrease. Decreased sea ice cover → decreased Arctic albedo → greater ocean heat absorption → increase in ocean temperature → decrease in ice cover. This is an amplification; hence, the sea-ice albedo feedback is a positive feedback loop.

Problem 5

Question	1	2	3	Total
Points	3	6	2	11 (18%)

1. (3 points) Venus has an orbital period of 224.65 days. On Venus, an apparent solar day (i.e., the amount of time it takes for the sun to pass over the same spot in the sky) is 116.75 earth days. Calculate the rotation period of Venus, to the nearest day. Note that Venus spins in retrograde, meaning that its rotation is in the opposite direction of its revolution about the Sun. Show work for all calculations.

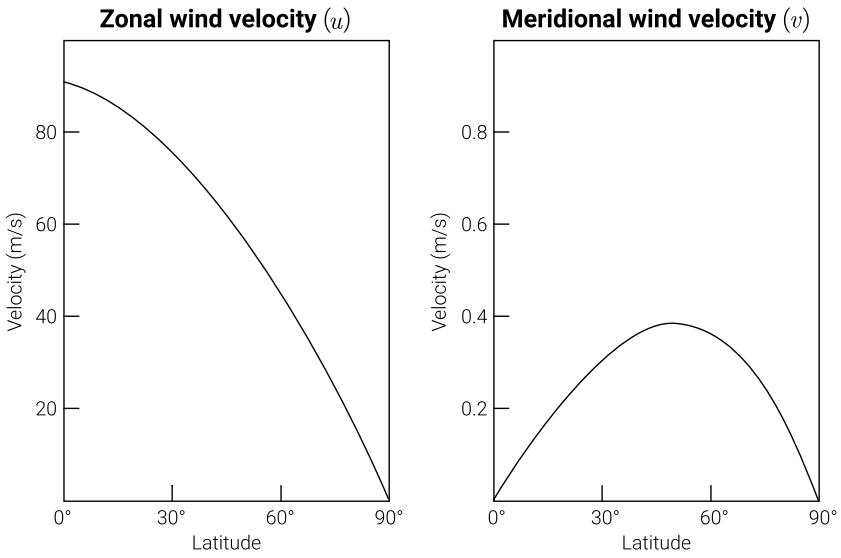
Solution: An apparent solar day is 0.520 of an orbit. Because Venus rotates in the opposite direction of its revolution, an apparent day is 1 - 0.520 = 0.480 of a rotation. 116.75/0.480 = $\boxed{243 \text{ days}}$.

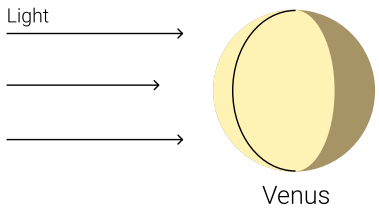
Alternatively, consider viewing the Sun from the perspective of Venus. The observed motion of the Sun around Venus would be 1/116.75 rotations per day. This motion comes from the revolution of Venus around the Sun, which is $-1/224.65$ rotations per day (negative sign because rotation goes in opposite direction of revolution) and the rotation of Venus around its axis, which is $1/x$ rotations per day. Hence, we have:

$$\frac{1}{116.75} = \frac{-1}{224.65} + \frac{1}{x} \tag{2}$$

Solving for x, we find that the rotation period is $\boxed{243 \text{ days}}$.

2. An idealized atmospheric model of Venus gives the following zonal (i.e., in the east-west direction) and meridional (i.e., in the north-south direction) wind velocity profiles. The profiles are taken along the meridian shown in the model below.





Provide a brief explanation for each of the following observations:

(a) (2 points) Meridional velocity is strictly positive, meaning there is only one atmospheric convection cell, contrary to the three on Earth.

Solution: Venus spins very slowly, meaning the Coriolis force is much less dominant than other forces, e.g., the pressure gradient force. Hence, the lack of deflection allows for a single meridional convection cell to transport heat poleward.

(b) (2 points) Zonal velocity is two orders of magnitude greater than meridional velocity.

Solution: Zonal convection occurs due to the heat imbalance between the dayside and nightside of Venus. We can expect the pressure gradient formed from this to be much greater than that of the meridional heat gradient (which is due to the effect of latitude on insolation); hence, the zonal velocity is much greater than meridional velocity.

(c) (2 points) Zonal wind velocity is the greatest at the equator and weakest at the poles.

Solution: Insolation decreases with increasing latitude (it is proportional to $\cos(\varphi)$). Hence, the zonal heat gradient (and hence the pressure gradient) is less strong closer to the poles than it is at the equator.

3. (2 points) A surface map of Venus is shown above. Notice the lack of craters, despite Venus lacking an active tectonic cycle. Propose an explanation for the relative lack of impact craters on Venus.

Solution: Venus has a very dense atmosphere, hence most meteorites vaporize before they can hit the ground.

END OF SECTION II