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%)

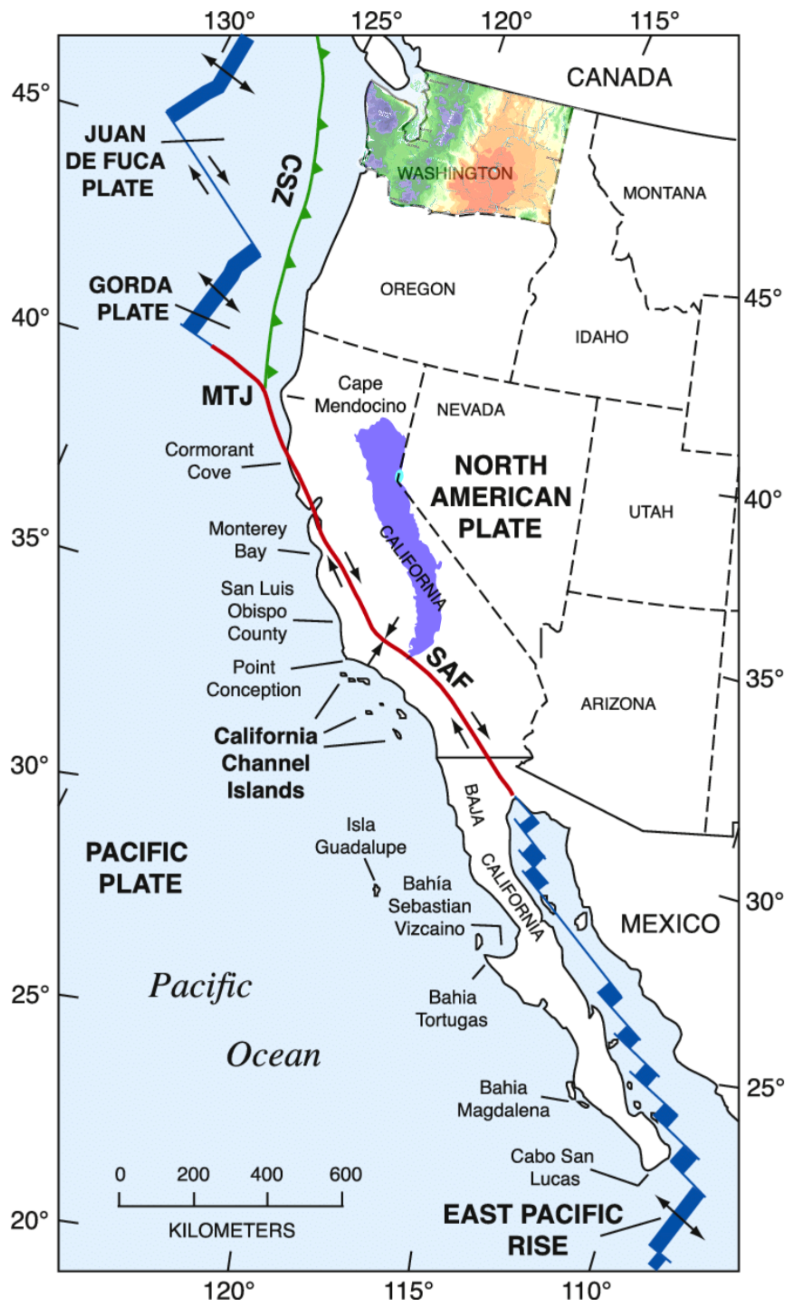


Figure 1: Tectonic settings in western North America. Abbreviations: SAF, San Andreas Fault; MTJ, Mendocino Triple Junction; CSZ, Cascadia Subduction Zone.

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

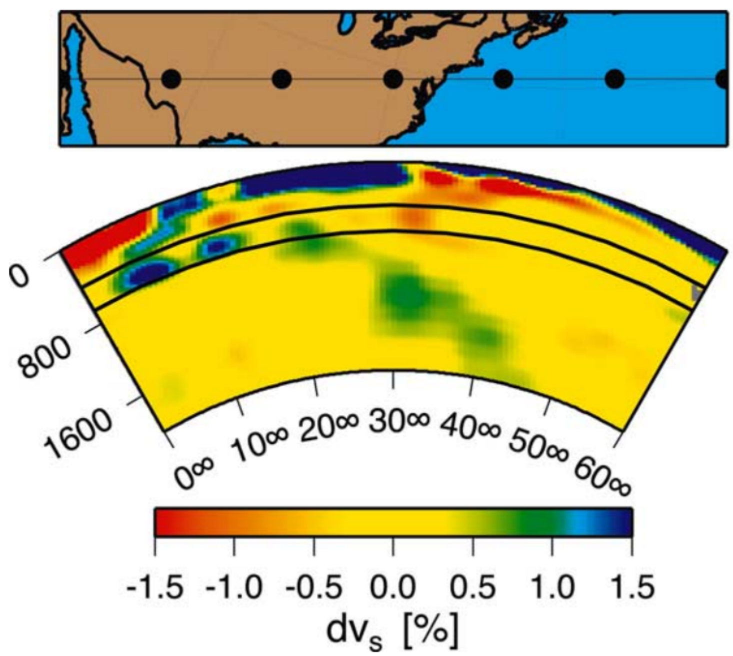
    B. Felsic, fined-grained

    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.

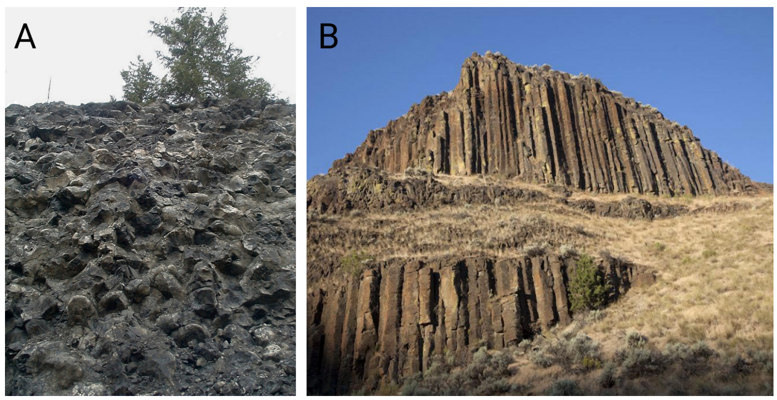


Figure 3: Two basalt formations in Washington: the Columbia River Flood Basalts and the Crescent Formation Basalts (a Mid-Ocean Ridge Basalt, or MORB), in no particular order.

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

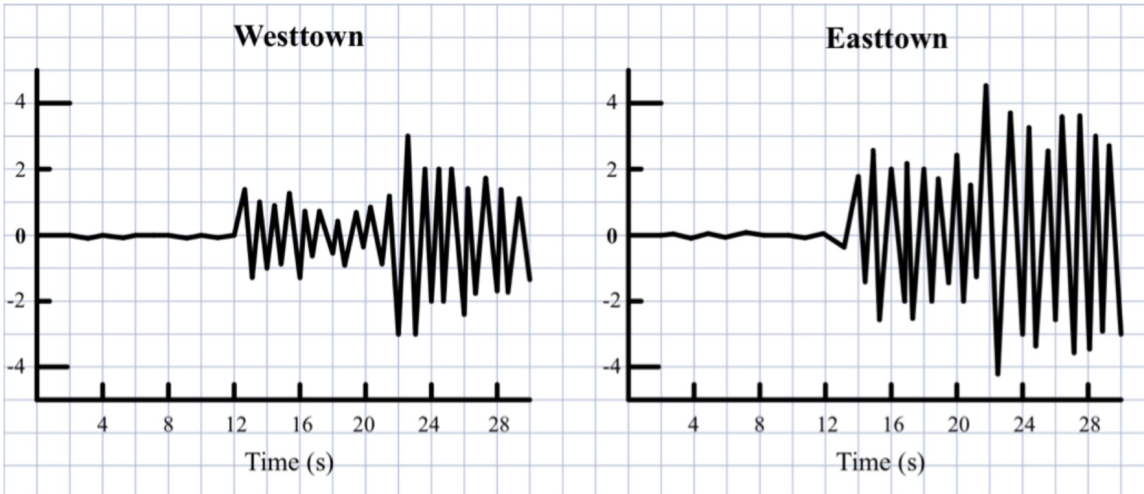
   C. II and IV

   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 $*\tan(\delta)$.

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

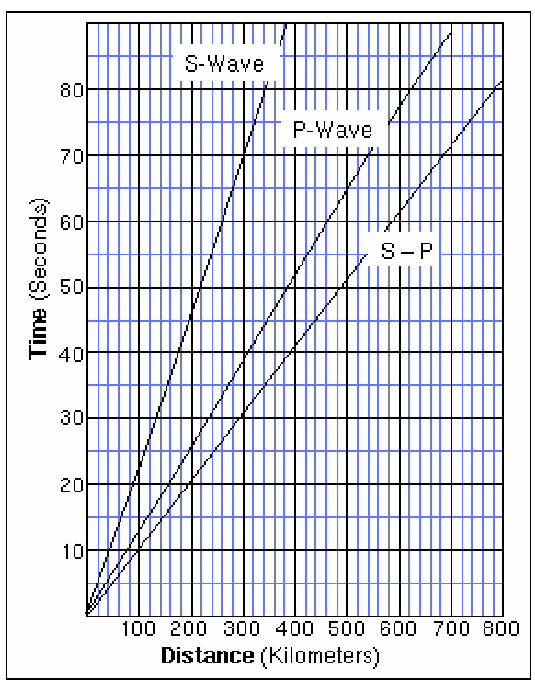
B. Westtown, because the frequency of the seismic waves is lower

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.

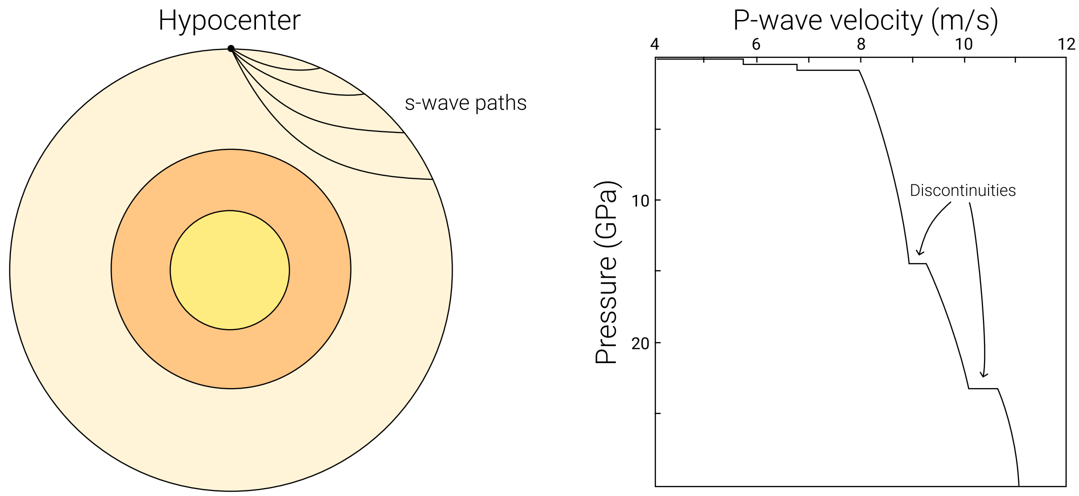


Figure 4: (left) S-wave paths through the mantle; (right) P-wave velocity with pressure (depth) in the mantle.

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

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

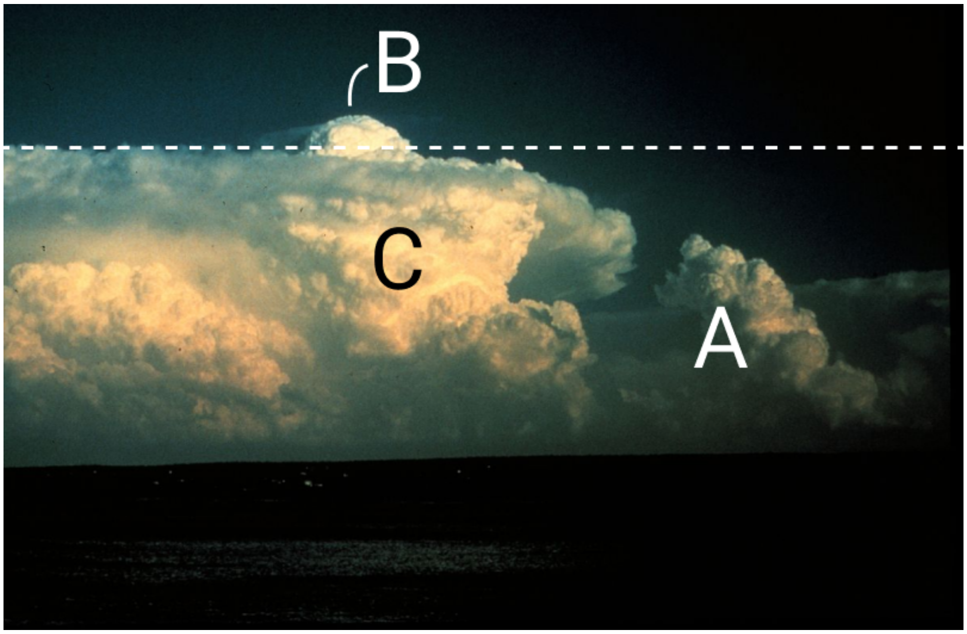
   Solution: S-wave velocity generally increases with depth, hence, the S-waves refract towards the surface.

   (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?

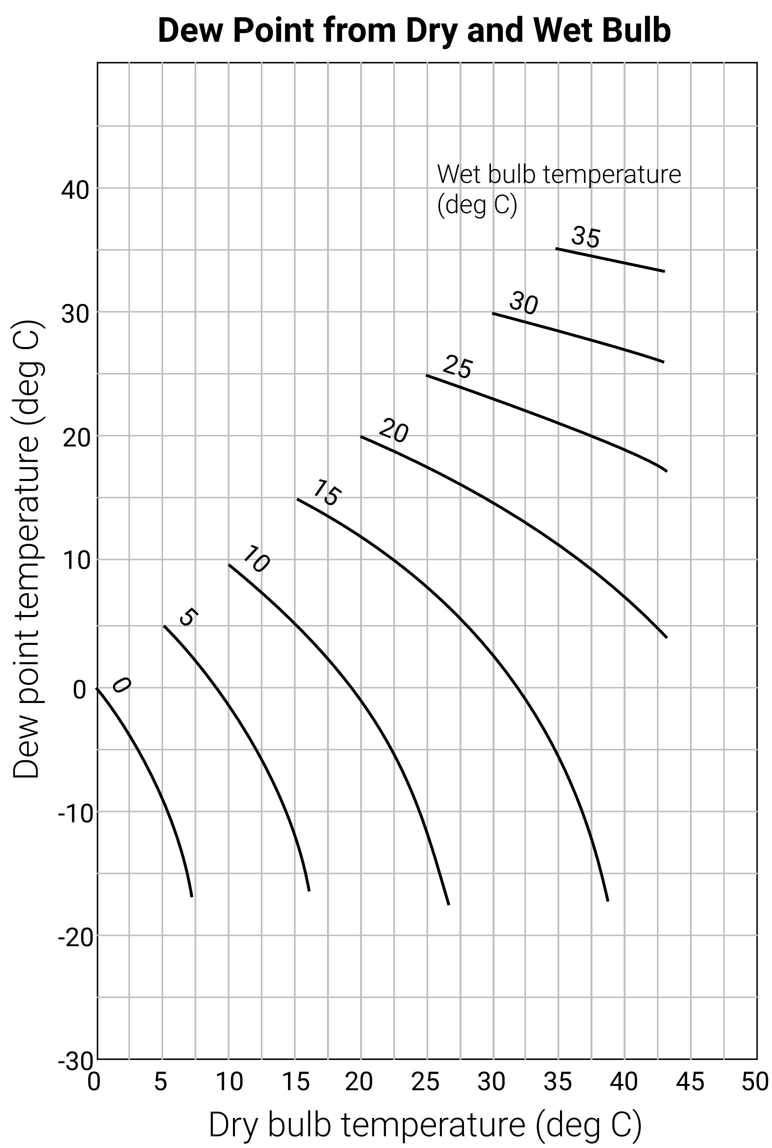
   Solution: The overshooting top occurs because of an extremely dense and strong updraft in the thunderstorm.

(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%)

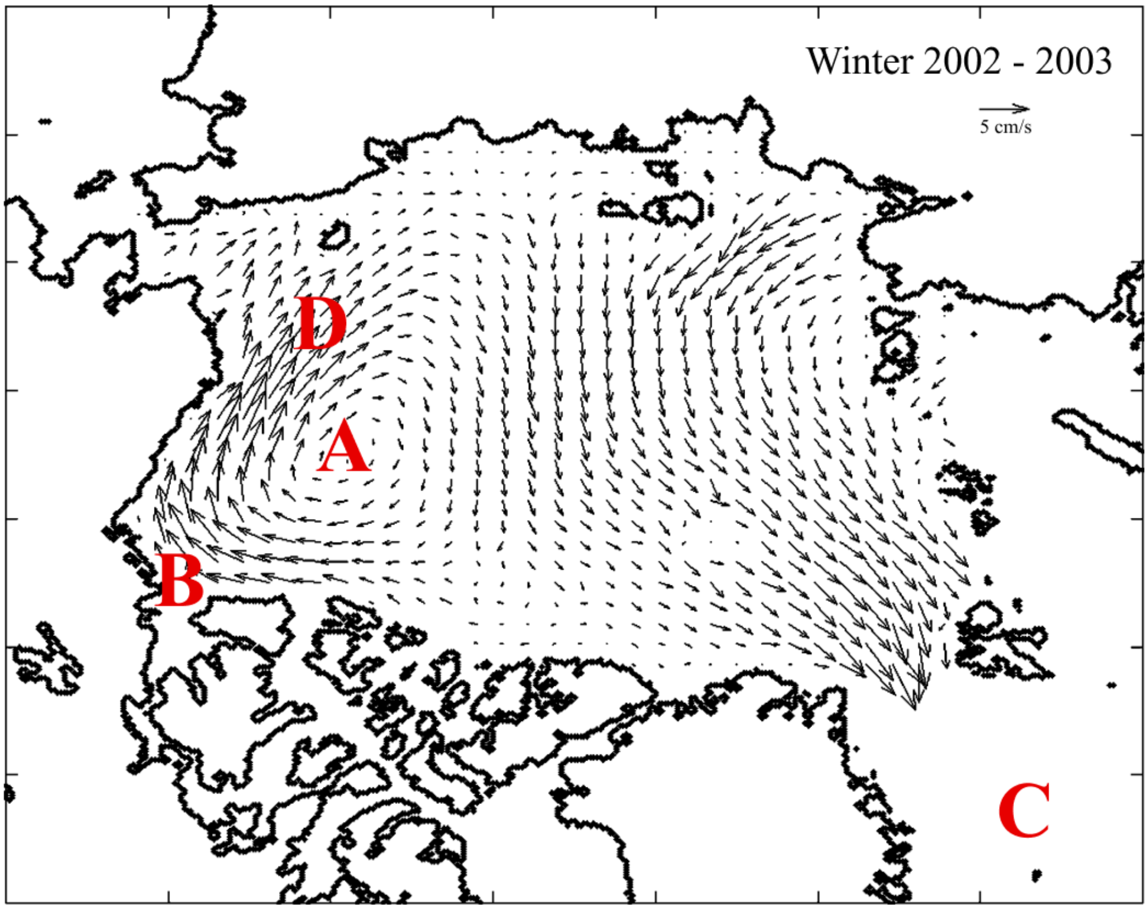


Figure 5: Arctic Ocean mean sea-ice motion map of the 2002-2003 winter season. Figure adapted from Zhao and Liu (2007).

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.

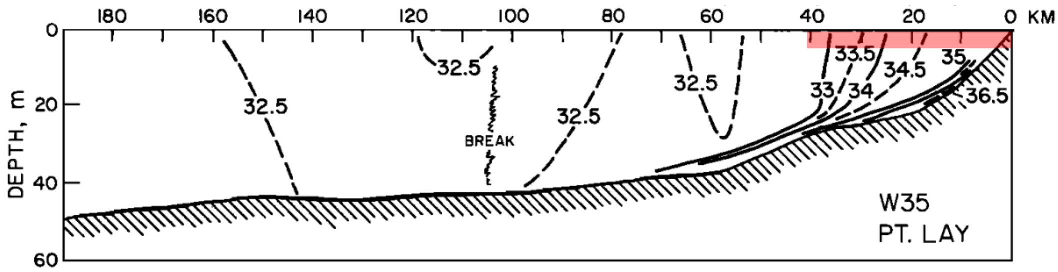


Figure 6: Salinity profile at an Arctic polynya (colored red). The bottom topography is denoted with the shaded portion. Figure adapted from Aagaard et al. (1985)

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 $\rightarrow$ decreased Arctic albedo $\rightarrow$ greater ocean heat absorption $\rightarrow$ increase in ocean temperature $\rightarrow$ 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.

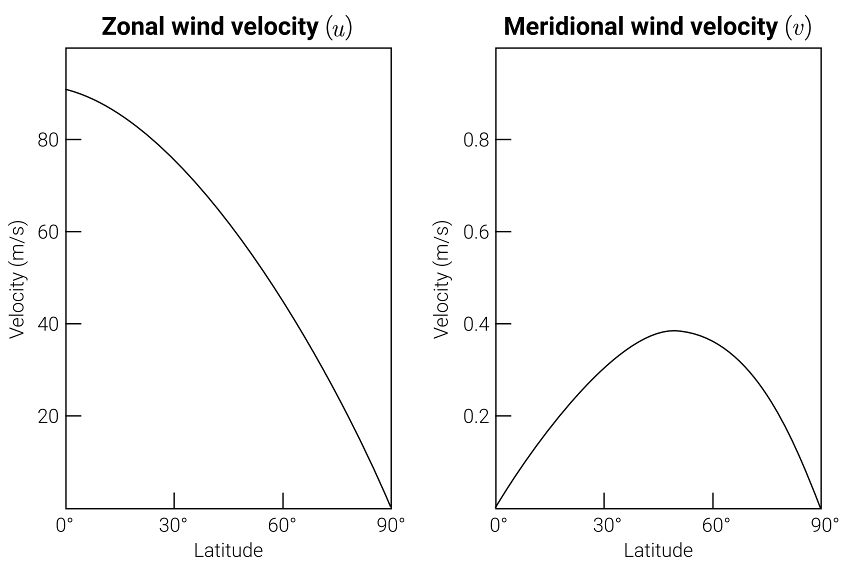
Solution: An apparent solar day is 0.520 of an orbit. Because Venus rotates in the opposite direction of its revolution, an apparent day is 1 - 0.520 = 0.480 of a rotation. 116.75/0.480 = $\boxed{\text{243 days}}$.

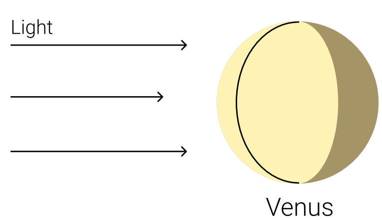
Alternatively, consider viewing the Sun from the perspective of Venus. The observed motion of the Sun around Venus would be 1/116.75 rotations per day. This motion comes from the revolution of Venus around the Sun, which is $-1/224.65$ rotations per day (negative sign because rotation goes in opposite 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 $\boxed{\text{243 days}}$.

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