USESO 2026

National Open Exam

Section II

Instructions:

- Section II consists of 4 multipart problems that further assess geoscience knowledge in the form of free-response and multiple choice questions.
- A calculator is allowed. Show all work for calculations.
- Any space on the page may be used for scratch paper, but only work on your Answer Sheet will be graded.
- Print your **USESO Student ID** on every page of the Answer Sheet.

Problem 1

Question	1	2	3	4	5	Total
Points	2	3	2	4	4	15 (25%)

This problem will examine melt production and chemistry at mid-ocean ridges (MOR) and subduction-zone oceanic-island-arcs (OIA).

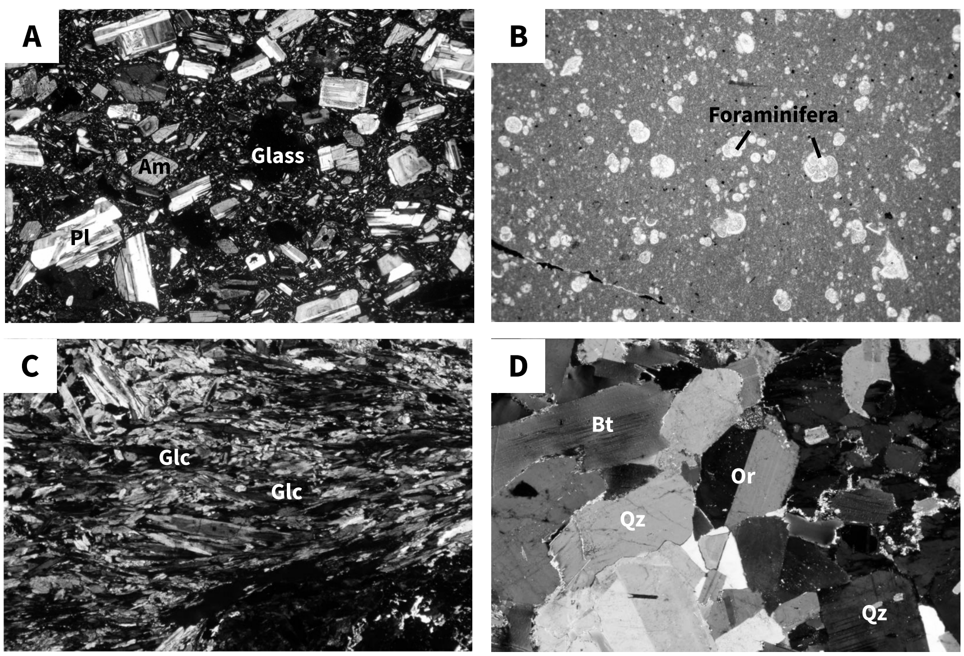
1. (2 points) **Briefly describe** the mechanism and relative depth of magma generation at MORs and at OIAs, respectively.

2. Researchers can use the chemical composition of the melt to determine what minerals were settling out of the melt and thus the pressure at which the magma existed.

   (a) (2 points) Why might researchers examine samples of glass from mid-ocean ridges instead of the basalts that are produced in order to determine the chemical composition of the melt? **Explain.**

   (b) (1 point) Why might glass found at the surface of an OIA be less useful for discerning the chemical composition of the melt source than glass from a MOR? **Explain.**

3. Shown are four thin sections of rocks formed under different environments, with a selection of minerals labeled. Each sample has a field of view of 7 mm across.



Key: Pl - plagioclase, Am - amphibole, Glc - glaucophane, Bt - biotite, Qz - quartz, Or - orthoclase

   (a) (1 point) Which thin sections would you expect to be the primary constituent of OIA volcanoes?

      A. A

      B. B

      C. C

      D. D

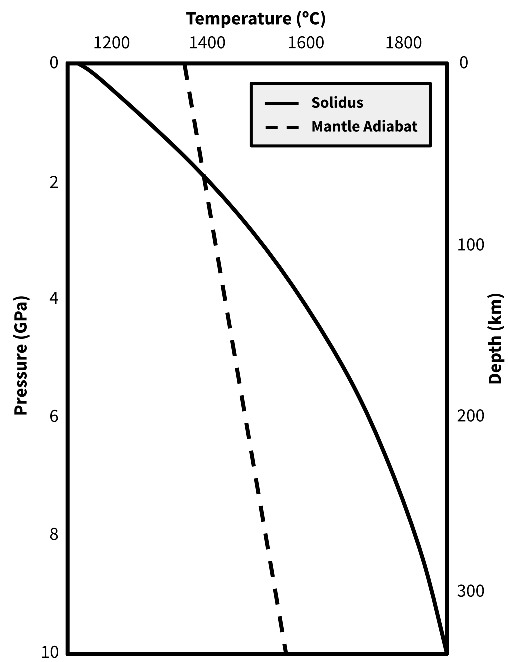
   (b) (1 point) **Justify** your choice.

4. As a plate subducts under an OIA, a metamorphic process called eclogitization changes the mineral makeup of the plate to favor mineral phases stable under higher pressures.

   (a) (2 points) **Explain** how this process can create earthquakes.

   (b) (2 points) How does eclogitization affect the rate of subduction? **Explain.**

5. Consider the graph below illustrating typical mantle conditions. The solid line traces the solidus, the temperature at which the mantle begins to melt under different pressures. The dotted line traces the ideal mantle adiabat, the temperature-depth path followed by mantle material as it moves adiabatically.



   (a) (2 points) Notice that according to the diagram, melting should begin around 2 GPa ($\sim$ 70 km depth), where the adiabat intersects the solidus. **Explain** why empirical evidence suggests that the mantle is nearly entirely solid at this pressure.

   (b) (2 points) **Describe** how you would expect the solidus beneath an MOR and OIA, respectively, to differ (or remain the same) compared to the typical solidus depicted in the diagram.

Problem 2

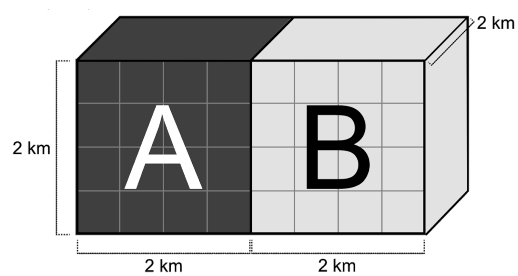
Question	1	2	3	4	5	Total
Points	2	2	2	5	4	15 (25%)

This problem will explore several phenomena related to atmospheric circulation.

1. Between 30°S and 30°N, energy is moved primarily by convection in the Hadley cell. For each of the following scenarios, **indicate** whether cloud formation near the equator would increase or decrease and **briefly explain** your reasoning.
   (a) (1 point) Increase in sea surface temperature near the equator.
   (b) (1 point) Increase in explosive volcanic activity near the equator.
2. Cloud formation can play a significant role in poleward heat transport.
   (a) (1 point) How does condensation during cloud formation affect local atmospheric temperatures? **Explain.**
   (b) (1 point) Given your answer to (a), how would you expect increased cloud formation near the equator to affect poleward heat transport? **Explain.**

The primary method of atmospheric heat transport in the mid latitudes is through eddies which form due to baroclinic instability, a condition where air masses of different densities meet and mixing occurs.

3. (2 points) Would you expect the typical latitudinal temperature gradient to be greater along a 900 mb isobaric surface or a 300 mb isobaric surface? **Explain.**
4. To better understand the thermodynamics of baroclinic instability, we can construct a toy example with two immiscible (cannot mix), incompressible fluids placed adjacent to each other as shown in the figure. Let the density of A be 1 $\frac{\text{kg}}{\text{m}^3}$, the density of B be $2\frac{\text{kg}}{\text{m}^3}$, and the acceleration due to gravity (g) be 10 $\frac{\text{m}}{\text{s}^2}$.



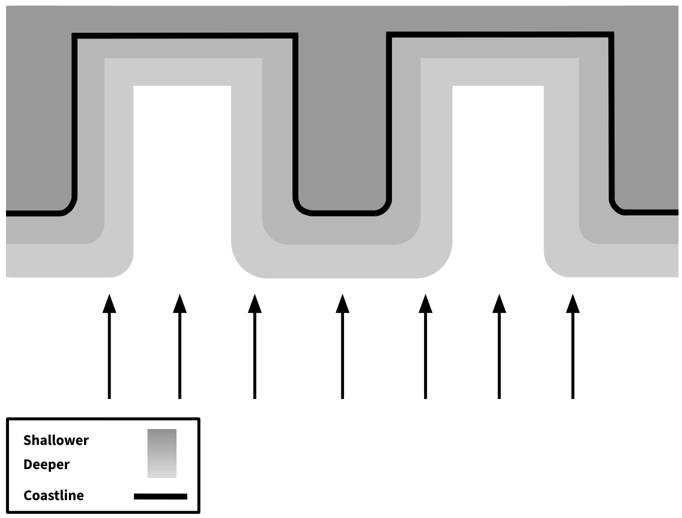
   (a) (3 points) **Calculate** the change in gravitational potential energy of the system after it reaches its lowest energy state. *Hint: find and use the center of gravity of the fluids to simplify the calculation.*
   (b) (1 point) Now suppose that A and B are perfectly miscible. **Calculate** the new change in gravitational potential energy of the system from its initial state?
   (c) (1 point) In the case of part (a) where the two fluids are immiscible, **describe** how the resulting circulation in our model explains the heat transported by the baroclinic instability mechanism.
5. Climate change is affecting the typical latitudinal heat distribution on Earth and thus Earth's thermal gradients.
   (a) (2 points) Modeling baroclinic instability as we did in 4(a), **describe** the average effect of climate change on meridional circulation in the middle latitudes.
   (b) (2 points) Is the evolution of the planet's heat distribution under climate change due to baroclinic instability a positive or negative feedback loop? **Explain.**

Problem 3

Question	1	2	3	Total
Points	6	3	6	15 (25%)

This problem will explore several aspects of coastal circulation.

1. Bays and headlands are recessed and jutting features, respectively, formed along a coastline that is undergoing differential erosion. The arrows in the figure below represent the direction of waves approaching the coast.



   (a) (2 points) **Draw** a continuation of each arrow showing how the wave flow patterns would be affected by the bathymetry.

   (b) (2 points) Based on the arrows you drew, would you expect bays or headlands to experience more erosion? Which would you expect to experience more deposition? **Briefly explain.**

   (c) (2 points) Considering the influence of bays and headlands on wave patterns, do they exhibit a positive or negative feedback loop with coastline profile in the long run? **Briefly explain.**

2. Within certain bays, standing waves may develop. Standing waves, also known as stationary waves, are vertical oscillations of water that appear to slosh up and down within an ocean basin without noticeable lateral movement of crests and troughs. The period for a standing wave in a rectangular bay can be calculated using Merian's formula,

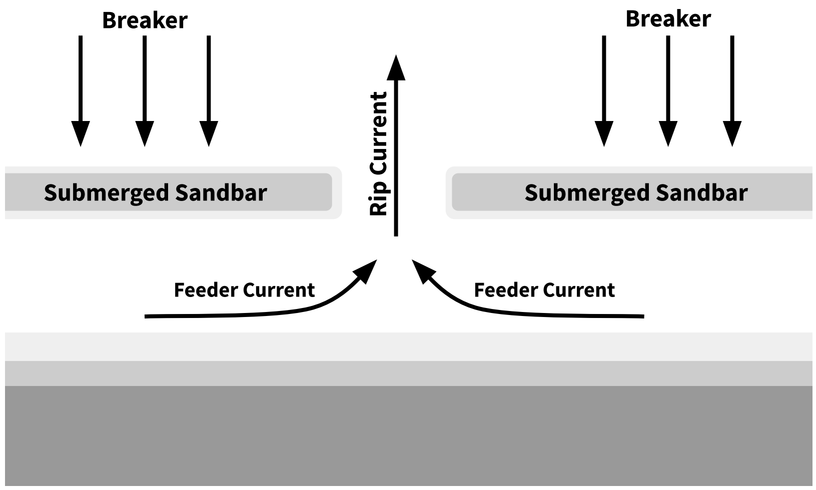
$$T = \frac{4l}{\sqrt{gh}},$$

   where T represents the oscillation period, l represents the basin length, h represents the depth of water in the basin, and g is the acceleration due to gravity.

   (a) (1 point) The Bay of Fundy in Canada experiences particularly extreme resonance with semidiurnal tides. Given that a lunar day lasts 24 hours 50 minutes, **identify** the theoretical period of waves in the Bay of Fundy.

   (b) (2 points) The Bay of Fundy experiences deepening due to erosion from strong tidal currents. Would you expect the amplitude of tides in the bay to increase or decrease over time? **Briefly explain.**

3. Rip currents also play a significant role in coastal erosion. Rip currents are strong, narrow surface currents that return backwash on a shore. The figure below shows a simplified process of their formation.



(a) (2 points) Based on the model described in the figure above, do rip currents tend to increase or decrease the rate of formation of future rip currents? **Briefly explain.**

(b) Would you expect rip currents to be relatively strong or weak under the following conditions? **Briefly explain** your answer for each condition.

i. (1 point) Low tide (as opposed to high tide).

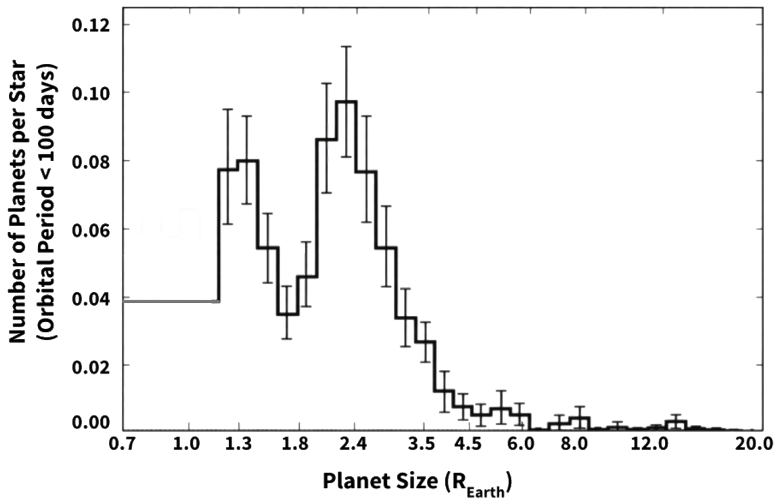
ii. (1 point) Strong onshore winds.

(c) (2 points) Based on the model described in the figure above, are rip currents more likely to form on active or passive continental margins? **Briefly explain.**

Problem 4

Question	1	2	3	4	5	6	Total
Points	2	2	3	4	3	1	15 (25%)

The "small planet radius gap" or "radius valley" was discovered by the California-Kepler survey of exoplanets in 2017. In this survey, scientists studied tidally-locked exoplanets close to their host stars (period < 100 days) and plotted the frequencies at which they found exoplanets compared to their radius, as shown in the figure below. This problem will explore several features of these exoplanets.



1. (2 points) Scientists noticed a dip in the occurrence of radii between 1.5 and 2 Earth radii, which they attributed to the presence or absence of an atmosphere. Would you expect planets with these short periods to be primarily rocky planets or gaseous planets? **Explain.**

Scientists have found that these exoplanets frequently evolve from above to below the radius valley.

2. (2 points) Current modeling suggests that this evolution happens relatively quickly. If the evolution happened at a slower rate, would you expect the "valley" on the histogram to be shallower or deeper? **Briefly explain.**

3. One of the primary explanations for this evolution is the atmospheric photoevaporation hypothesis. Photoevaporation occurs when incident stellar energy heats the top of the atmosphere enough for gas to escape the planet's gravity.

Mass of Hydrogen Molecule (m)	3.32×10^{-27} kg
Mass of Planet (M)	6×10^{24} kg
Planetary Radius (R)	9000 km
Gravitational Constant (G)	$6.67 \times 10^{-11} \frac{\text{Nm}^2}{\text{kg}^2}$

(a) (2 points) **Derive** the formula for the escape velocity of hydrogen gas, v_{esc}, using the formulas for kinetic energy and gravitational potential energy. **Calculate** v_{esc}, in meters per second, using the values in the table above.

(b) (1 point) The root mean squared velocity v_{rms} for hydrogen gas at temperature T Kelvins can be approximated as $112\sqrt{T}\,\frac{\text{m}}{\text{s}}$. **Calculate** the temperature, in Kelvin, required at the top of the atmosphere in order for a molecule of hydrogen gas moving at v_{rms} to escape.

4. Because of the tidally locked nature of these exoplanets, large temperature gradients can develop between their Sun-side and space-side hemispheres.
   (a) (2 points) What general effect would the presence of an atmosphere have on the magnitude of these temperature gradients? **Explain.**

   (b) (2 points) These temperature gradients can cause an exoplanet to undergo atmospheric collapse, a positive feedback loop in which the atmosphere is deposited onto the planet's cold side as a solid. **Explain** the mechanism behind this feedback loop.

5. One common method astronomers use to detect thin exoplanet atmospheres is thermal phase-curve analysis. Typically, a planet's brightness is due to a combination of reflection of the host star's light and blackbody radiation. When a planet transits its host star, the reflection component becomes insignificant and the planet appears to dim.
   (a) (2 points) Would you expect a tidally locked exoplanet with an atmosphere to exhibit a smaller or larger drop in observed light compared to a similar exoplanet with no atmosphere? **Explain.**

   (b) (1 point) **Explain** why this method is significantly less useful for detecting atmospheres if the exoplanet is not tidally locked.

6. (1 point) Thermal phase curves can also give insight into the behaviors of the atmospheres of exoplanets. What atmospheric pattern explains the stationary Kelvin and Rossby wave response to equatorial heating that shifts thermal hotspots eastward on tidally locked exoplanets?

END OF SECTION II