USESO 2025

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	Total
Points	2	7	4	2	15 (25%)

The Sierra Nevada mountain range was primarily formed by the subduction of the Farallon Plate beneath the North American Plate during the Mesozoic Era. This problem will explore several aspects of this region's geology and Earth's interior.

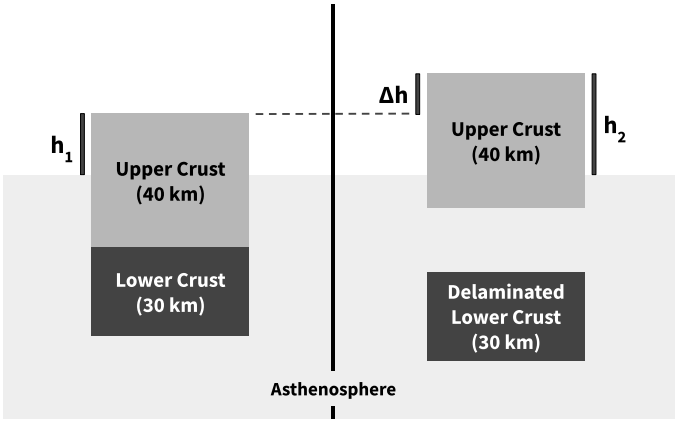
1. (2 points) The Farallon Plate exhibited a shallower subduction angle compared to typical subduction zones. Which of the following sets of conditions would be most likely to create a shallow-angle subduction zone?

   A. High convergence rate, old oceanic crust
   B. High convergence rate, young oceanic crust
   C. Low convergence rate, old oceanic crust
   D. Low convergence rate, young oceanic crust

2. Crustal delamination is the process by which lower layers of the crust and asthenosphere separate from the upper continental crust. Delamination is common along convergent margins.

   (a) (2 points) Although the crust is less dense than the asthenosphere upon formation, the section of the lower crust that delaminates from the upper crust becomes denser than the asthenosphere that replaces it. Briefly explain why this occurs.

   Consider a simple model of an isolated crustal block "floating" in the asthenosphere. The block consists of an upper and lower section with different densities and only experiences the forces of gravity and buoyancy. At some point in time, the lower crust separates from the upper crust, as shown in Figure 1 below.



Upper block thickness	40 km
Lower block thickness	30 km
Upper block density	2700 kg/m^3
Lower block density	4500 kg/m^3
Asthenosphere density	4000 kg/m^3

Figure 1: A diagram depicting the initial state of the crustal block (left) and the state of the crustal block after delamination (right). A table of relevant quantities is provided.

   (b) (2 points) Given the information in the table, calculate the initial height of the crustal block, h_1, above the asthenosphere. **Show your work.**

   (c) (3 points) Calculate the change in height of the crustal block, Δh, that results from delamination. **Show your work.**

3. The mantle's 660-km discontinuity is characterized by a mineral phase transition, represented by Figure 2 below. A geologist synthesizes a mineral sample at conditions within the gray region of the figure.

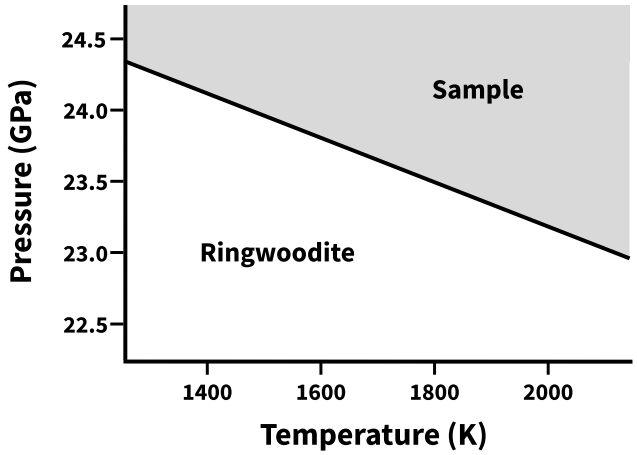


Figure 2: A diagram of the transition between ringwoodite and an unknown mineral phase. The solid line denotes the conditions at which this transition occurs.

(a) (1 point) The 660-km discontinuity is associated with a transition from ringwoodite to what **two** minerals?

(b) (3 points) Based on the diagram, would you expect the actual depth of the discontinuity to be greater than, equal to, or less than 660 km beneath a delaminating slab? Explain.

4. (2 points) Extremely dense subducted plates can sink to the bottom of the mantle and accumulate in what is known as the D" region. Was this phenomenon more or less likely to occur early in Earth's history during the Archean Eon? Explain.

Problem 2

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

In June 1991, Mount Pinatubo in the Philippines erupted and released enormous amounts of aerosols that rose into the stratosphere and spread around the world. This problem will explore the impact of these aerosols on Earth's atmosphere.

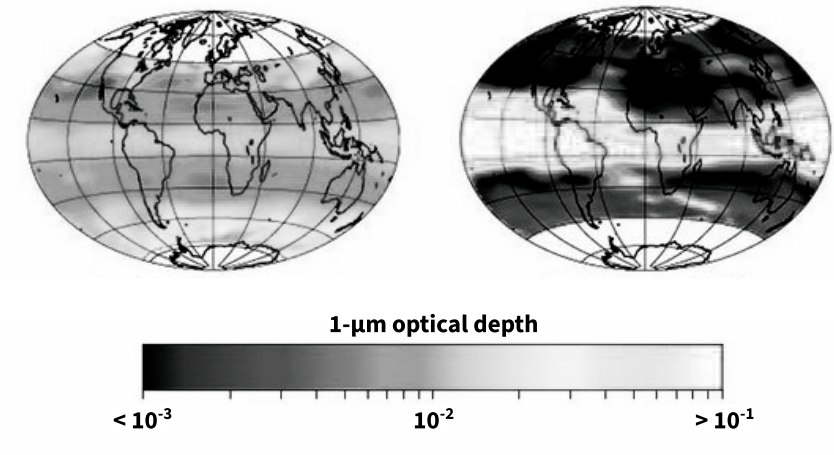


Figure 1: Depiction of stratospheric optical depth, a proxy for aerosol concentration, after the eruption of Mount Pinatubo. White represents high optical depth (i.e. high aerosol concentration).

1. (1 point) The two images in Figure 1 correspond to stratospheric conditions in different years. Data from which time period is represented in each image?

   A. Left: June-July 1991; Right: August 1993

   B. Left: August 1993; Right: June-July 1991

2. Answer the following questions regarding prevailing winds in the Northern Hemisphere.

   (a) (2 points) In the Northern Hemisphere Hadley cell, _____ air **aloft** near the equator and _____ air **aloft** near the Tropic of Cancer create a net movement of air towards the _____.

   A. Converging; diverging; north

   B. Converging; diverging; south

   C. Diverging; converging; north

   D. Diverging; converging; south

   (b) (1 point) The Coriolis force deflects the winds described in the previous part to the _____, creating net movement of air to the _____ in the upper troposphere.

   A. West; southwest

   B. West; northeast

   C. East; southwest

   D. East; northeast

3. The quasi-biennial oscillation (QBO) refers to a cycle of wind patterns in the stratosphere near the tropics in which the dominant wind direction reverses with a period of approximately two years. Figure 2 graphs the dominant wind direction at different altitudes over time.

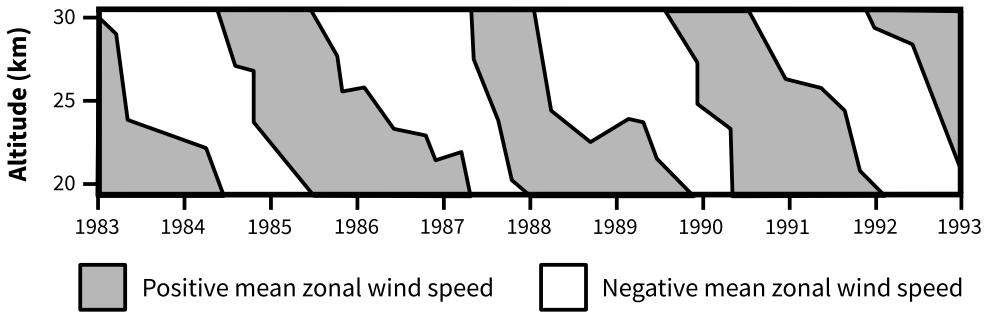


Figure 2: A graph of QBO flow measurements as a function of altitude and time. Positive zonal flow indicates westerly winds; negative zonal flow indicates easterly winds.

(a) (2 points) Given that aerosols from the Pinatubo eruption were primarily injected at altitudes of 20-25 kilometers, in which direction did they generally move?

A. North B. South C. East D. West

When comparing the aerosol distribution of this volcanic eruption to similar low-latitude volcanic eruptions, researchers noticed that aerosols exited the lower stratosphere at a rate higher than expected, while they exited the upper stratosphere at a lower rate than expected.

(b) (2 points) Would you expect aerosol-carrying air parcels to have an easier time mixing across an area with high rates of change in wind velocity (i.e. high **horizontal** wind shear) or areas with low rates of change in wind velocity (i.e. low **horizontal** wind shear)? Explain.

(c) (2 points) Given that stratospheric winds **outside** the tropics are primarily westerly, would you expect poleward aerosol transport to be faster in the lower or upper stratosphere in 1991? Explain.

4. (2 points) Stratospheric aerosol injection (SAI) is a proposed strategy to mitigate climate change that would increase the albedo of aerosols in the stratosphere. However, SAI would also increase the absorbance of the stratospheric aerosol layer. How would you expect the temperatures of the troposphere and stratosphere to change due to SAI? Explain.

5. Recall that the optical depth τ of a cloud is a proxy for aerosol concentration. It can be calculated using the expressions:

$$\tau = LWC \times \frac{3h}{2\rho_w r} \qquad \textit{or} \qquad \tau = \ln\left(\frac{\phi_i}{\phi_t}\right)$$

where LWC is the liquid water content of the cloud, h is the thickness of the cloud, ρ_w is the density of water, r is the average radius of aerosols, ϕ_i is the incident radiation flux, and ϕ_t is the transmitted radiation flux.

(a) (1 point) Assuming similar values for aerosol radii, cloud thicknesses, and incident radiation, which of the following cloud types would you expect to reflect the least amount of radiation?

A. Stratus B. Cumulus C. Cumulonimbus D. Cirrus

(b) (2 points) Explain your answer to the previous part.

Problem 3

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

This problem focuses on several aspects of the Ganges Delta on the Indian subcontinent.

1. The Ganges Delta is fed by a network of rivers that carry sediment suspended in their waters. Figure 1 depicts idealized profiles for two properties relevant to this sediment.

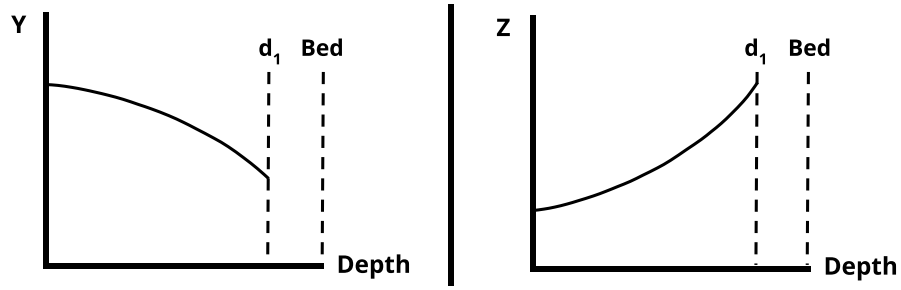


Figure 1: Graphs of two functions Y and Z related to properties of sediment suspended in a river. No sediment is suspended in the river below depth d_1.

(a) (1 point) A hydrologist determines that one property corresponds to wave-averaged sediment concentration and the other corresponds to current velocity. What do properties Y and Z correspond to, respectively?

(b) (1 point) Briefly explain why you assigned Y to sediment concentration or current velocity.

(c) (1 point) Briefly explain why you assigned Z to sediment concentration or current velocity.

(d) (1 point) Notice that no sediment is suspended in the river below depth d_1. Does sediment transport occur below d_1? If so, briefly describe one method of transport in this region. If not, briefly explain why not.

The sediment transported by the rivers is eventually deposited into the Ganges Delta and the regions around it.

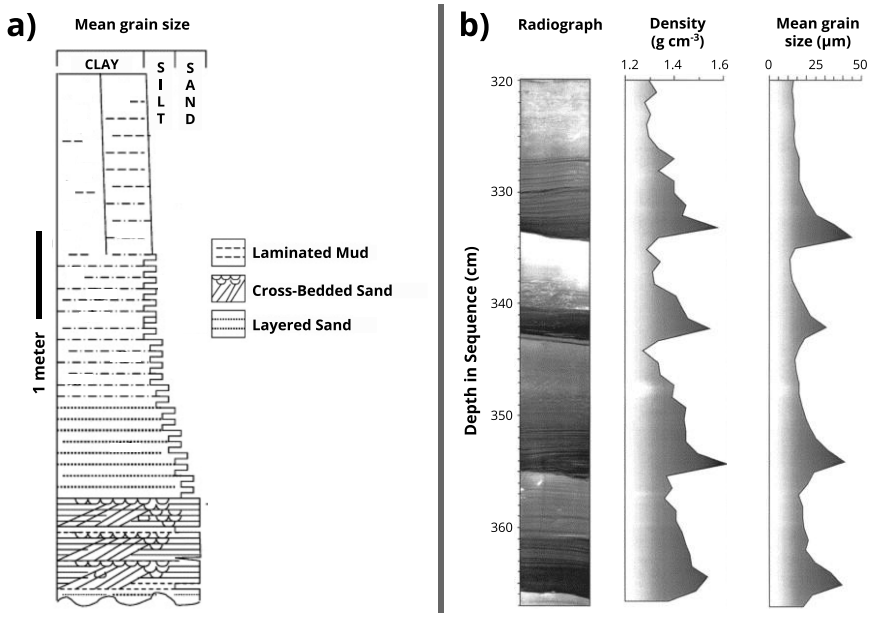


Figure 2a: Depiction of a depositional sequence taken from the Ganges Delta.
Figure 2b: Depiction of a depositional sequence imaged from a submarine canyon south of the Ganges Delta.

2. The following parts refer to the sequence in Figure 2a taken from the lower plain of the Ganges Delta.

   (a) (2 points) The regions above and below the intertidal zone are referred to as the supratidal and subtidal zones, respectively. Assuming no overturning occurred, does the sequence represent a transition from a supratidal to a subtidal environment or from a subtidal to a supratidal environment? Explain your reasoning using **two** distinct pieces of evidence from the figure.

   (b) (1 point) Which of the following best characterizes the processes responsible for forming the sequence?

   A. Delta retrogradation associated with marine transgression

   B. Delta retrogradation associated with marine regression

   C. Delta progradation associated with marine transgression

   D. Delta progradation associated with marine regression

3. The following parts refer to the sequence in Figure 2b taken from the Swatch of No Ground, a submarine canyon in the Indian Ocean to the south of the Ganges Delta.

   (a) (1 point) Identify the process responsible for the cyclic pattern seen in the sequence.

   (b) (2 points) As the Ganges Delta has migrated east in the last several thousand years, portions of the southwest region of the delta face increased threats of coastal erosion. Considering your answer to part (a), briefly explain whether the presence of the Swatch of No Ground region contributes to or prevents this erosion.

4. The Ganges Delta discharges into the Bay of Bengal located in the northeastern part of the Indian Ocean.

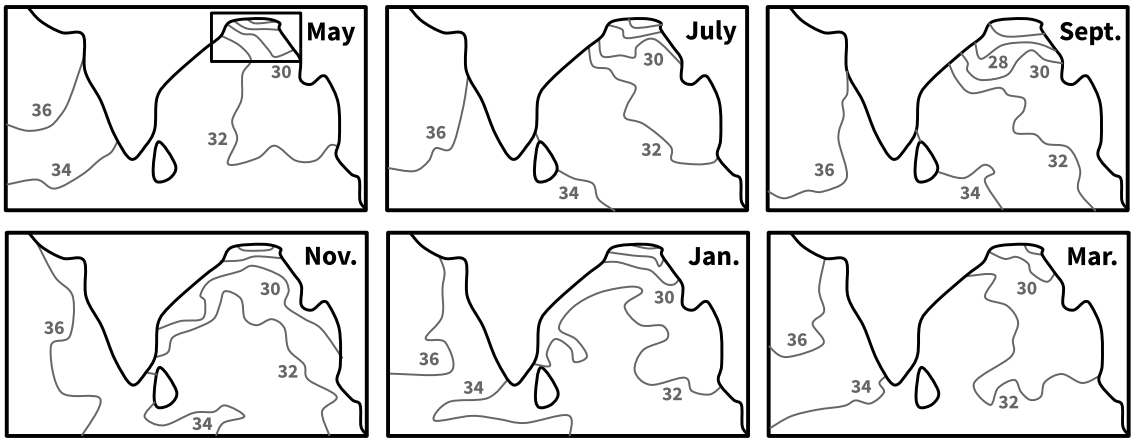


Figure 3: A map of sea surface salinity throughout the year in the Bay of Bengal. The boxed region in the first panel denotes approximately where the Ganges Delta discharges into the bay.

   (a) (2 points) Notice that low-salinity water accumulates where the delta discharges into the bay between May and September. Given that this phenomenon repeats annually, briefly explain why it occurs.

   (b) (3 points) Consider a map of surface chlorophyll-a concentration for the Bay of Bengal in July. In what region(s) would you expect the map to indicate elevated chlorophyll-a levels? Explain your reasoning. *Hint: Consider factors other than sea surface salinity.*

Problem 4

Question	1	2	3	Total
Points	4	4	7	15 (25%)

This problem analyzes and draws comparisons between several aspects of Mercury and the Moon.

1. Figure 1 depicts the orbits of Earth and Mercury around the Sun and the orbit of the Moon around Earth. Locations A, B, and C represent potential orientations of Mercury relative to Earth. Assume that the orbits of each body are counterclockwise and perfectly circular in the plane of the ecliptic and that each body is small enough such that it does not block light from reaching other bodies.

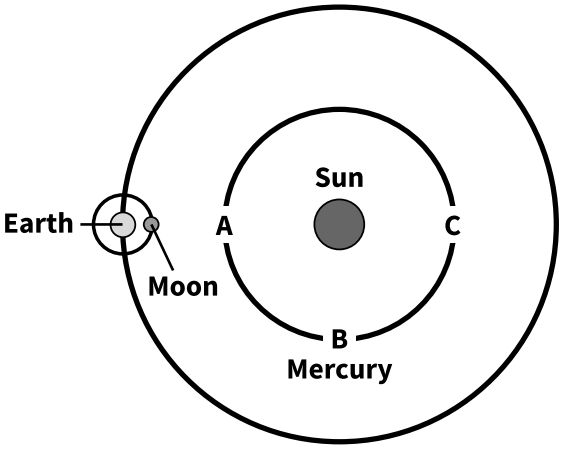


Figure 1: An idealized model of the orbits of Earth, Mercury, and the Moon. Not to scale.

(a) (2 points) At which location in Mercury's orbit will the planet appear to be exactly half illuminated as seen from Earth?

A. At location A

B. Between locations A and B

C. At location B

D. Between locations B and C

E. At location C

(b) (1 point) If Mercury is at location B, an observer on Mercury would see that Earth is in what phase?

A. New B. Crescent C. Half D. Gibbous E. Full

(c) (1 point) If Mercury is at location B, an observer on Mercury would see that the Moon is in what phase?

A. New B. Crescent C. Half D. Gibbous E. Full

2. Since the 1980s, scientists have generally accepted the giant-impact hypothesis, which states that the Moon formed after a large planetary body called Theia collided with Earth. Briefly explain whether the following two observations support or oppose the giant-impact hypothesis.

   (a) (2 points) The Moon has a much smaller core relative to Earth.

   (b) (2 points) The Moon has a much lower volatile content relative to Earth.

3. You will now estimate the ratio between the maximum height of mountains on the Moon and Mercury assuming similar crustal compositions.

   (a) (2 points) Let g_{Moon} and g_{Mercury} equal the gravitational accelerations at the surfaces of the Moon and Mercury, respectively. Given the following table of information, calculate the ratio $\frac{g_{\text{Moon}}}{g_{\text{Mercury}}}$. **Show your work.**

Radius of the Moon	1738 km
Radius of Mercury	2440 km
Average density of the Moon	3344 kg/m^3
Average density of Mercury	5429 kg/m^3

   Mountains on Mercury and the Moon cannot be arbitrarily tall because after a certain point, the pressure exerted by the mountain on the underlying material becomes so great that material begins to "flow" from beneath the mountain. The maximum pressure that can be sustained by the material is given by Young's modulus Y, typically given in units of newtons per square meter.

   (b) (3 points) The formula for the maximum height a mountain can reach is given by $h_{\text{max}} = kY^a\rho^b g^c$, where k is a dimensionless constant, Y is Young's modulus, ρ is the density of the material, and g is the gravitational acceleration at the surface of the body. Find the values of a, b, and c. **Show your work.**

   If you cannot obtain an answer for (a), use $\frac{g_{\text{Moon}}}{g_{\text{Mercury}}} = 0.5$ for (c).

   (c) (2 points) Synthesizing your answers from (a) and (b), estimate the value of $\frac{h_{\text{max, Moon}}}{h_{\text{max, Mercury}}}$. Assume that mountains on the Moon and Mercury are made of similar material. **Show your work.**

END OF SECTION II