USESO 2024

National Open Exam

Section II

Instructions:

- Section II consists of 4 multipart questions 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.

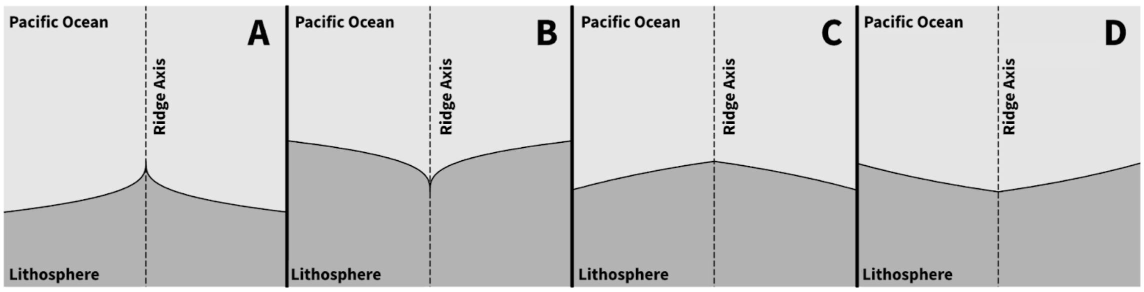
Problem 1

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

This problem will explore several aspects of the ocean floor.

1. The production of new crust occurs at mid-ocean ridges.

   (a) (1 point) Which of the following diagrams best models the topography of a mid-ocean ridge?



   Referencing the diagram you selected, answer the following questions.

   (b) (1 point) Why does ocean depth increase or decrease farther from the ridge axis?

   (c) (2 points) Does the topography near the ridge axis enhance or inhibit plate motion? **Explain.**

   (d) (2 points) The presence of certain compounds or organisms within a sediment layer can provide information about where that layer was formed. Would a sediment layer containing significant amounts of calcareous ooze be more likely to form close to or away from the ridge axis? **Explain.**

2. Mid-ocean ridges are commonly surrounded on either side by belts of faulting known as fracture zones. The figure below displays a segment of the Mid-Atlantic ridge and its associated fracture zones.

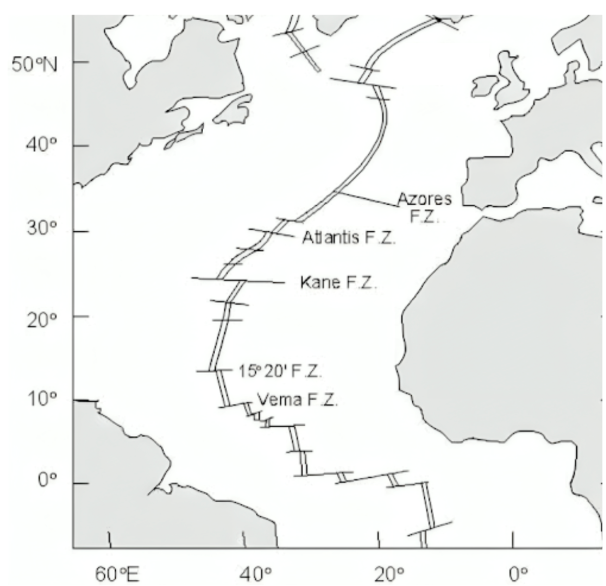


Figure 1: Map of fracture zones (abbreviated F. Z.) in the Atlantic Ocean.

(a) (2 points) **Briefly explain** why fracture zones often form along mid-ocean ridges. As part of your response, identify the dominant type of faulting at these zones.

(b) (2 points) The presence of fracture zones allows seawater to seep into oceanic crust. **Explain** how this introduction of fluids affects the rate of metamorphism at mid-ocean ridges.

A typical example of the metamorphism described in part (b) is the alteration of anorthite ($CaAlSi_2O_8$). The chemical equation for this alteration is as follows:

$$Mg^{2+} + CaAlSi_2O_8 + \frac{12}{5} H_2O + \frac{1}{5} SiO_2 \longrightarrow Ca^{2+} + \frac{1}{5} Mg_5Al_2SiO_3O_{10}(OH)_8 + \frac{4}{5} Al_2Si_2O_5(OH)_4$$

(c) (2 points) If the rate of seafloor spreading increased, would magnesium concentration in the ocean be expected to increase or decrease? **Explain.**

3. (3 points) During the Late Miocene Cooling (LMC) lasting from 7.0 to 5.3 million years ago, global ocean surface temperatures decreased by about 6°C. What change most likely occurred to the rate of crustal production at mid-ocean ridges during this period? **Explain.**

Problem 2

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

This problem will explore several implications of rising air.

1. Uneven heating of Earth's surface generates a pressure system at the surface in the state of Oklahoma as shown in Figure 1.

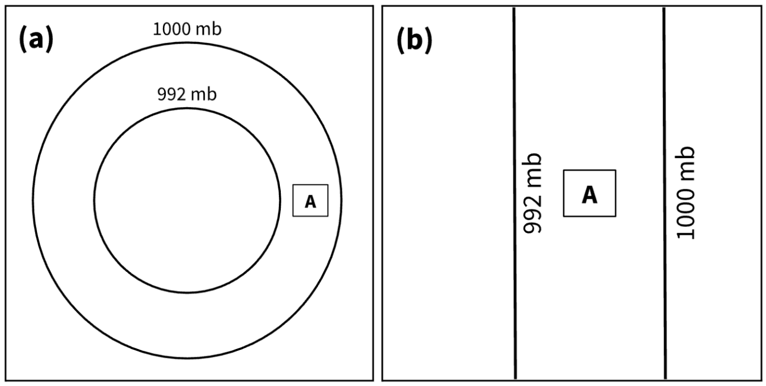


Figure 1a: Simplified surface weather map with curved isobars and Region A within the system; **Figure 1b**: Enlarged view of Region A with isobars **approximated** as straight.

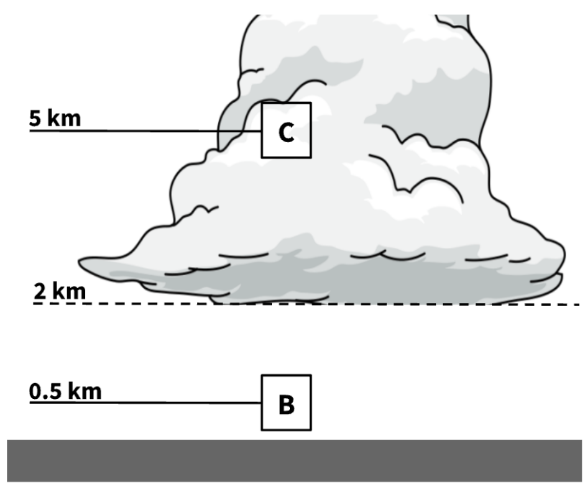
Assume for this question that **friction is negligible** and wind is in **geostrophic balance**. Isobars are approximated as straight under these conditions (see Figure 1b).

(a) (1 point) Does the system shown in Figure 1 represent a low or high pressure center?

(b) (2 points) **Draw and label** two vectors (each represented by an arrow) originating from Region A representing the Coriolis force (CF) and pressure gradient force (PGF) exerted on air at Region A. Indicate direction and relative magnitude for each vector.

(c) (2 points) Still assuming geostrophic conditions, **draw and label** an arrow originating from Region A approximating the wind direction at Region A. **Briefly explain** your reasoning.

2. In reality, the lower part of the troposphere is affected by friction and thus air spirals inward before rising. At a certain point on its journey upward, air cools below dew point and condensation occurs as shown in Figure 2.



Environmental lapse rate (ELR)	13°C/km
Dry adiabatic lapse rate (DALR)	11°C/km
Moist adiabatic lapse rate (MALR)	6°C/km
Dew point lapse rate	1.5°C/km

Figure 2: Diagram of cloud formed from rising air with table of associated lapse rates.

(a) (3 points) **Explain** why the MALR is less than the DALR. As part of your response, indicate at what elevation the DALR shifts to the MALR as air rises.

(b) (2 points) Suppose that a parcel of air rises from Elevation B to Elevation C. **Calculate** the temperature of air at Elevation C given that the temperature of air at Elevation B is 17°C. **Show your work.**

3. Heating of Earth's surface can lead to the development of thunderstorms by influencing stability and cloud formation.

(a) (2 points) Reference the diagram below.

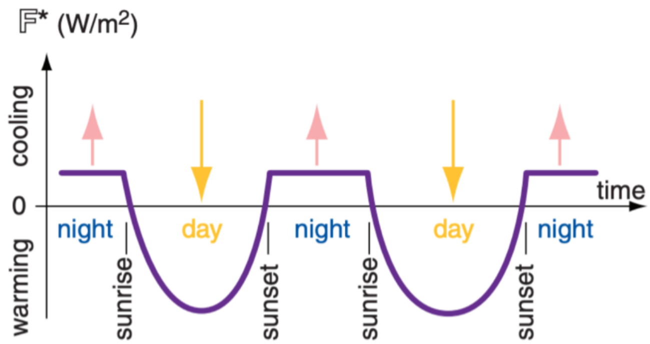


Figure 3: Diagram of daily warming and cooling cycles over the land surface during summer; arrows represent direction of net energy flux at the surface (adapted from Stull 2017).

Would thunderstorms be most likely to develop around midnight, midday, sunset, or sunrise? **Explain.**

(b) (2 points) **Explain** whether divergence of air aloft promotes or inhibits the formation of thunderstorms. As part of your response, indicate the effect of this divergence on pressure at the surface.

(c) (1 point) Thunderstorms that develop due to updrafts initiated by rising air also exhibit downdrafts during their mature phase. What effect do these downdrafts have on the subsequent evolution of the storm? **Briefly explain** your reasoning.

Problem 3

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

Thwaites Glacier, located on the edge of Antarctica, has been extensively studied due to its large size and potential for causing significant sea level rise. This problem will explore several aspects related to Antarctic circulation and Thwaites' melting.

1. (2 points) Thwaites Glacier's melting is primarily driven by changes in Antarctic ocean currents, which are created by two different sets of winds. To the north of the Southern Ocean are the mid-latitude westerlies, which blow water eastward to create the strong Antarctic Circumpolar Current (ACC). To the south, the polar easterlies blow in the opposite direction to create the weaker Antarctic Subpolar Current (ASC) on the edge of the continent.

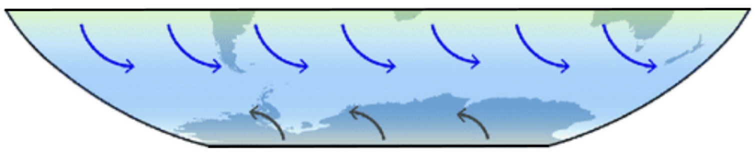


Figure 1: Map of large-scale wind patterns in the Southern Ocean.

Briefly describe how these winds cause upwelling of deep water surrounding Antarctica.

2. The Southern Annular Mode (SAM) is an oscillation of wind patterns in the Southern Ocean that affects the ACC.

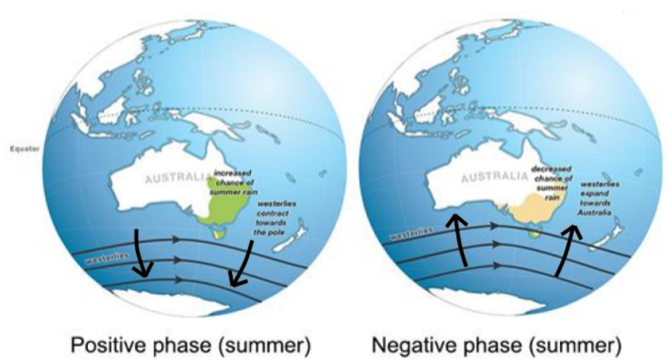


Figure 2: Diagram showing the two phases of the SAM.

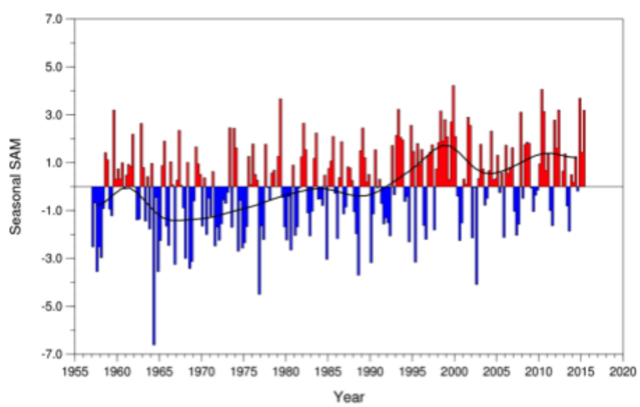


Figure 3: Graph of SAM phases since 1956. Notice the overall positive trend.

(a) (1 point) When the SAM is in its positive phase, it extends the range of the mid-latitude westerlies, causing the ACC to contract inward towards Antarctica. **Explain** how this change contributes to upwelling of deep water surrounding Antarctica.

(b) (1 point) When the SAM is in its positive phase, it causes the mid-latitude westerlies and the ACC to strengthen. **Explain** how this change contributes to upwelling of deep water surrounding Antarctica.

(c) (3 points) A researcher tries to construct a timeline of SAM changes before active records were kept. They intend to do this using the oxygen content of oceanic sediment deposited by Antarctic deep water as a proxy. Would a positive SAM phase correspond to high or low sediment oxygen content? **Explain.**

3. The main deep water mass surrounding Antarctica is the warm Circumpolar Deep Water (CDW) as shown in the image below.

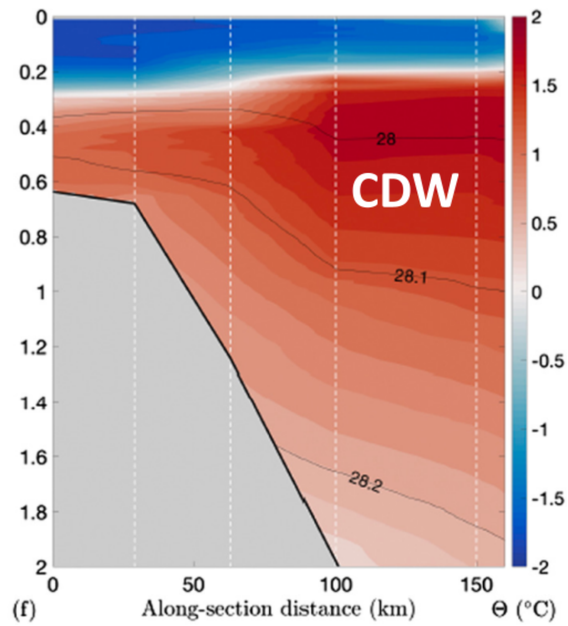


Figure 4: Figure displaying water temperature (shading) and salinity (numbered lines) near Thwaites Glacier, with a continental shelf present on the left (adapted from Thompson et al. 2018).

(a) (3 points) Notice the downward slope of the salinity gradient as the distance from the coast increases. How could coastal water movement create this trend? Does this correspond to a positive or negative-phase SAM? **Explain.**

(b) (2 points) The influx of the CDW onto the continental shelf is the primary mechanism of Thwaites Glacier's subsurface melting. Considering how the recent trend towards positive SAM affects this influx, does this constitute a positive or negative climate feedback loop? **Explain.**

4. (3 points) Thwaites Glacier contains about 258,000 km^3 of ice above sea level. Given that Earth has a radius of 6378 km and 71% of Earth's surface is covered by water, **estimate** the sea level change, in meters, that would be caused by the complete melting of Thwaites Glacier. Assume that the proportion of land covered by water stays constant and thermal expansion does not occur. **Show your work.**

Problem 4

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

This problem will explore several aspects of Mars' surface, atmosphere, and orbit around the Sun.

1. The image below depicts a network of erosional features found in Warrego Valles, a region located along the southern edge of a Martian plateau.

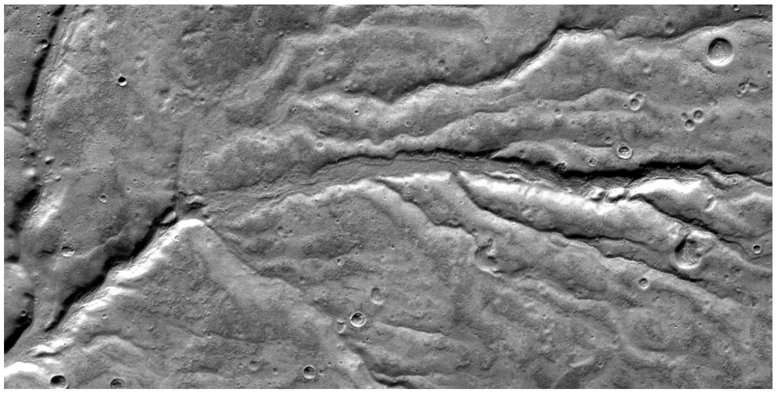


Figure 1: Erosional features found in Warrego Valles on Mars.

   (a) (1 point) What do these erosional features indicate about Mars' past climate?

   (b) Features similar to those found in Warrego Valles are no longer being produced on Mars' surface.

      i. (2 points) **Give one reason** why the thinning of the Martian atmosphere may have contributed to this change.

      ii. (2 points) A major contributor to atmospheric escape is the relatively low gravity of Mars. **Describe** how Mars' rate of heat loss relative to Earth may have also contributed to the loss of its atmosphere.

2. (2 points) The surface of Mars appears red due to the presence of iron oxides. **Explain** how Mars' lower mass contributed to the significantly higher concentration of iron oxides at its surface compared to Earth despite both planets forming from roughly the same material.

3. Assume for this question that Mars and Earth have circular, coplanar orbits.

Orbital radius of Mars	2.28×10^{11} m
Orbital radius of Earth	1.50×10^{11} m
Mass of Mars	6.39×10^{23} kg
Mass of Earth	5.97×10^{24} kg
Mass of the Sun	1.99×10^{30} kg
Gravitational constant (G)	6.67×10^{-11} N m^2 kg^{-2}

   (a) (2 points) **Calculate** Mars' sidereal orbital period in days given the parameters in the table above. **Show your work.**

If you cannot obtain an answer for part (a), take Mars' sidereal orbital period to be 840 days.

(b) (3 points) Mars reaches opposition when it moves into a straight-line configuration with Earth and the Sun, where Earth is located between Mars and the Sun. **Calculate** the number of days it would take Mars to next reach opposition. **Show your work.**

4. The figure below compares the surface topography of Earth to that of Mars.

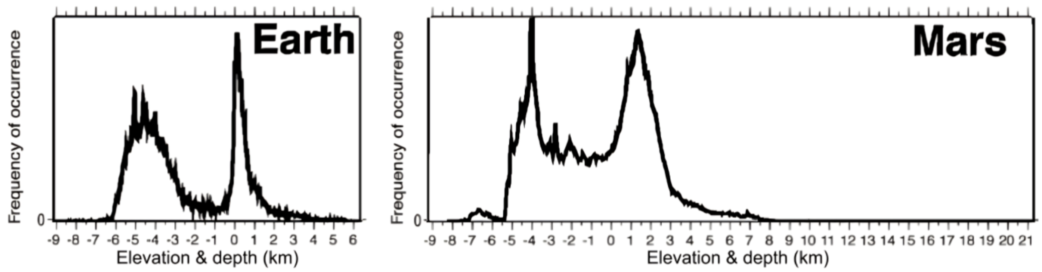


Figure 2: Distribution of surface elevation and depth on Earth and Mars (adapted from Dohm et al. 2016).

(a) (2 points) Given your understanding of Earth's surface, **explain** how one might use these diagrams to justify the existence of plate tectonics on Mars.

(b) (1 point) In reality, Mars does not exhibit plate tectonics. **Name or describe** the feature of Mars' surface that accounts for the shape of the curve in the right diagram.

END OF SECTION II