USESO 2022

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 non-graphing, non-programmable calculator is allowed; show all work for calculations

Problem 1

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

Our current understanding of the plate tectonics system is based on an idea of a fractured crust with plates growing and shrinking at boundaries between plates. However it is thought that in the Archaean eon, pressure-temperature conditions were such that the lithosphere was contiguous and did not subduct. Instead the Earth is proposed to have operated through "drip tectonics."

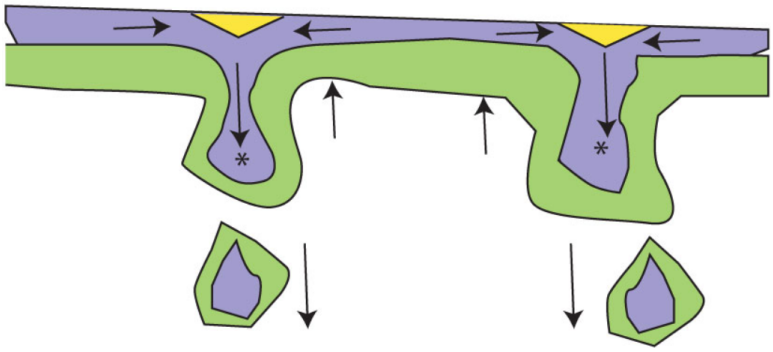


Figure 1: Simplified schematic of drip tectonics.

1. (2 points) Which of the following play a significant role in driving mantle convection?

   I) A large thermal gradient between the upper mantle and the core-mantle boundary

   II) A large compositional gradient between the asthenosphere and the core-mantle boundary

   A. I only

   B. II only

   C. I and II

   D. None

2. The mechanisms of drip tectonics may still influence modern lithospheric evolution.

   (a) (1 point) In which of the following modern tectonic environments would a "dripping" lithosphere most likely be present?

   A. Continental orogen

   B. Oceanic hotspot

   C. Continental rift

   D. Mid-ocean ridge

   (b) (2 points) Briefly justify your answer above. How does dripping lithosphere at that tectonic environment influence its future evolution?

3. Most preserved surface rocks from the Archaean eon are mafic to ultramafic in composition.

   (a) (1 point) What are two igneous rocks that comprise the majority of these deposits?

(b) (1 point) Today, intermediate and felsic rock are commonplace on the surface despite the mafic composition of the mantle. Identify all of the following locations in which you'd be likely to find predominantly felsic or intermediate rock.

I) Continental rift

II) Oceanic hotspot

III) Oceanic-continental subduction zone

IV) Mid-ocean ridge

A. II only

B. IV only

C. I and III

D. II and IV

E. I, II and III

(c) (3 points) Explain how intermediate and felsic rocks form at the areas you identified in the previous part.

4. The age of Archaean rocks are often found using U-Pb dating in zircon ($ZrSiO_4$) crystals.

(a) (1 point) Why is zircon a good mineral to analyze for U-Pb dating?

(b) (3 points) The U-Pb system has two decay pathways: $^{238}U \longrightarrow {}^{206}Pb$ (half-life = 4.47 Ga) and $^{235}U \longrightarrow {}^{207}Pb$. A zircon crystal is analyzed with a mass spectrometer to determine the concentrations of U and Pb. The following results are obtained:

^{235}U	25.3 ppm
^{238}U	38.9 ppm
^{206}Pb	1.10 ppm
^{207}Pb	4.70 ppm

Using the experimental data, determine the half-life of $^{235}U \longrightarrow {}^{207}Pb$.

5. (1 point) For each of the following geologic ages, give the corresponding period of which it is a subset:
1) Messinian; 2) Tortonian; 3) Valanginian; 4) Lutetian; 5) Lochkovian.

Problem 2

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

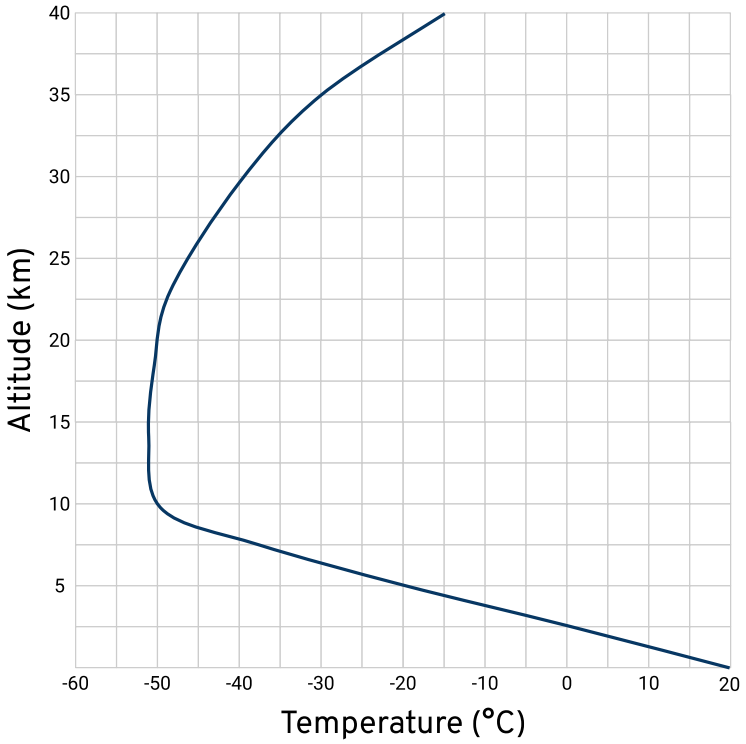


Figure 2a: Atmospheric profile plotting air temperature from the surface to 40 km altitude.

For all of the following questions, assume that the dry adiabatic lapse rate is a constant 10°C/km and the moist adiabatic lapse rate is a constant 6°C/km.

1. (2 points) Which of the following best describes the conditions at the surface?

   A. Absolutely stable

   B. Absolutely unstable

   C. Conditionally unstable

2. A volcanic eruption occurs, creating a hot mass of air at approximately 100°C.

   (a) (1 point) Why would a volcanic cloud never remain unsaturated as it rises?

   (b) (2 points) Assume the air parcel becomes saturated immediately after formation. Approximately how high will the volcanic cloud rise?

3. (3 points) In the real world, the air parcel will not remain isolated, and it will be subject to more factors than just adiabatic heating or cooling. If the parcel is always saturated, would the actual cloud height be greater than or less than the predicted height? Why?

4. (3 points) Would a volcanic cloud likely have a larger or smaller average droplet size than a typical cumulus cloud? Explain.

5. A satellite image of a volcanic eruption and its associated ash cloud is shown below.

Figure 2b: An ash cloud.

(a) (1 point) Describe the general wind patterns that would be created by a volcanic eruption and a hot volcanic cloud.

(b) (1 point) How would these wind patterns affect the spread of aerosols, dust, and debris?

(c) (2 points) Briefly describe how the release of volcanic aerosols can influence Earth's radiative balance and the average global surface air temperature.

Problem 3

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

The Southern Ocean is special in many regards, though it still remains relatively poorly understood. Here, we will explore several aspects of its circulation.

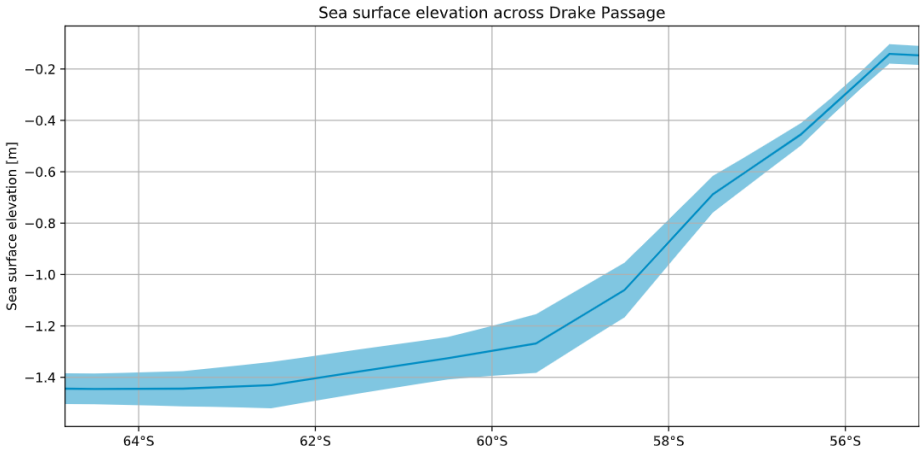


Figure 3a: A north-south transect of the sea surface height (SSH) along the Drake Passage, the narrowest section of the Southern Ocean between Cape Horn and the Antarctic Peninsula (see Figure 3c for a map).

1. The Antarctic Circumpolar Current (ACC) flows through the Drake Passage.
   (a) (1 point) Towards what cardinal direction does the ACC flow?
   (b) (3 points) At what latitude(s) is the ACC the strongest through the Drake Passage? Justify your answer.

2. (3 points) A recent study found that there is a robust trend in the strength of the zonal (i.e., east-west) circulation in the Southern Ocean. They attributed this trend to changes in the ocean's thermal structure, rather than changes in wind.

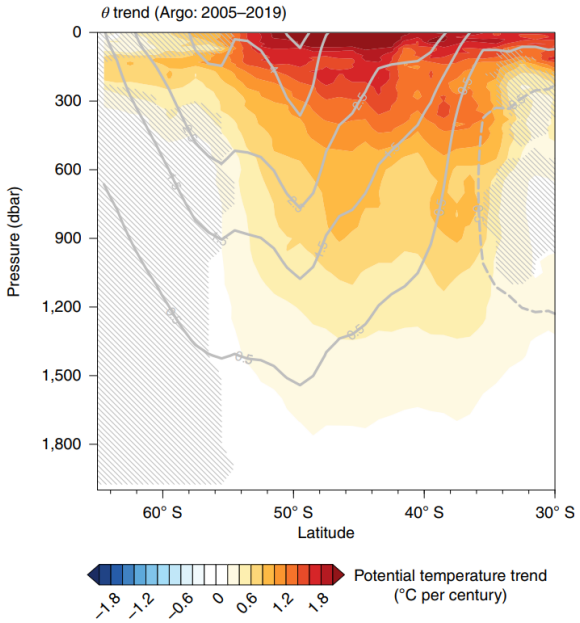


Figure 3b: zonally-averaged potential temperature trend in the Southern Ocean. Disregard the gray contours.

Is the Southern Ocean zonal circulation accelerating or decelerating? (*Hint: how might the spatially-varying temperature forcing shown above lead to a trend in zonal flow?*)

3. (3 points) In addition to horizontal circulation, the Southern Ocean also features significant vertical circulation.

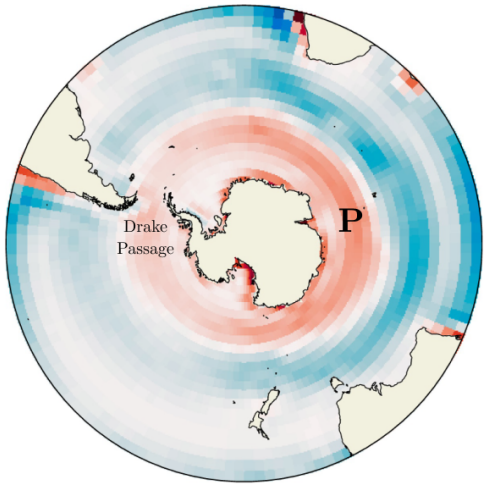


Figure 3c: climatological (1980 to 2017) annual-mean vertical velocities.

Are areas colored red (e.g., at point P) regions of downwelling or upwelling? Justify your answer.

4. The Southern Ocean is also where various water masses are formed.

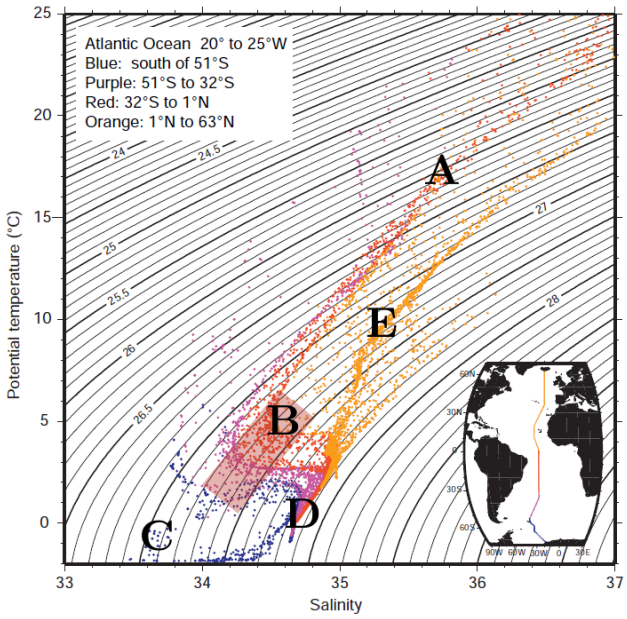


Figure 3d: T-S diagram of water samples (at various depths) along the transect shown in the bottom right.

(a) (1 point) Antarctic Bottom Water (AABW), is a water mass formed in the Southern Ocean. Its formation can be represented as a transformation from an initial water mass. Which two letter sequence best represents AABW formation? (e.g., A $\longrightarrow$ B)

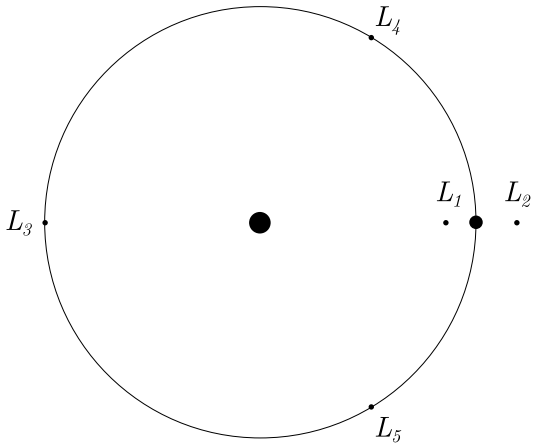
(b) (2 points) Briefly explain how AABW is formed.

(c) (2 points) In the blue, purple, and red transects, there is a clear salinity minimum (see shaded area). However, it disappears further north in the orange transect. Briefly explain why this is the case.

Problem 4

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

Lagrange points are five equilibrium points for a small mass in a two-body system (shown below). The Jupiter trojans are a group of asteroids that share Jupiter's orbit around the Sun. The trojans librate around Jupiter's Lagrange points L_4 and L_5, 60 degrees ahead and behind the planet's orbit, respectively.



1. (2 points) Trojans have a wide range of possible diameters, the largest observed being 203 km. For those within 4.4 to 40 km, their size distribution is similar to the size distribution of the asteroid belt. What is a likely explanation of how these smaller Trojans formed?

2. (2 points) For this question, we will assume that Jupiter trojans do not librate around their Lagrange point; rather, they are stationary relative to L_4 and L_5. Which of the following is true about the planetary phase of Jupiter when viewed from trojan asteroids?

   A. Jupiter is gibbous as seen from L_4 trojans and crescent as seen from L_5 trojans

   B. Jupiter is crescent as seen from L_4 trojans and gibbous as seen from L_5 trojans

   C. Jupiter is gibbous as seen from both L_4 and L_5 trojans

   D. Jupiter is crescent as seen from both L_4 and L_5 trojans

   E. Jupiter's phase seen from the trojans is time-varying

3. It is exceptionally difficult to observe Jupiter trojans due to their small size and low albedo. Consider a hypothetical trojan T located at L_4 with an albedo of 0.05 and a radius of 5.0 km.

Apparent magnitude of Sun ($m_\odot$)	-26.74
Semi-major axis of Jupiter (a_J)	5.2 AU
1 AU	1.496×10^8 km

   (a) (1 point) Describe the orbital configuration in which T will be the brightest (i.e., minimum apparent magnitude) as observed from Earth.

   (b) (4 points) Calculate the minimum apparent magnitude of T as seen from Earth. (Hint: $m - n = 2.5 \log(f_n/f_m)$, where m and n are two apparent magnitudes and f_m and f_n are their respective fluxes). **Show your work**.

4. (2 points) Similarly, Mars has trojan asteroids that congregate around L_4 and L_5 of its system with the Sun. A new study hypothesizes that Mars' trojans are Martian ejecta; thus, the asteroids are likely:

    A. Rich in olivine

    B. Smoothly shaped

    C. Relatively young

    D. Slow-spinning

5. (4 points) Satellites are also uniquely positioned in order to have certain orbital characteristics with their main bodies. What *elevation* above Earth's surface would a 1,000 kg satellite orbit in order to have a geosynchronous orbit? The mass and radius of the Earth are $M_\oplus = 6.0 \times 10^{24}$ kg and $R_\oplus = 6.4 \times 10^3$ km, respectively. The gravitational constant $G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}. **Show your work**.