

# DYNAMIC PLANET C - KEY

## SSSS 2020-2021

Written by: Celerity



TEAM NAME: \_\_\_\_\_ TEAM NUMBER: \_\_\_\_\_

PARTICIPANTS: \_\_\_\_\_ AND \_\_\_\_\_

This test consists of 3 parts.

- Part 1: True or False [20 pts total]
- Part 2: Multiple Choice [80 pts total]
- Part 3: Extended Response [92 pts total]

SCORE: 192/192

Part 1 [True/False] – 1pt each

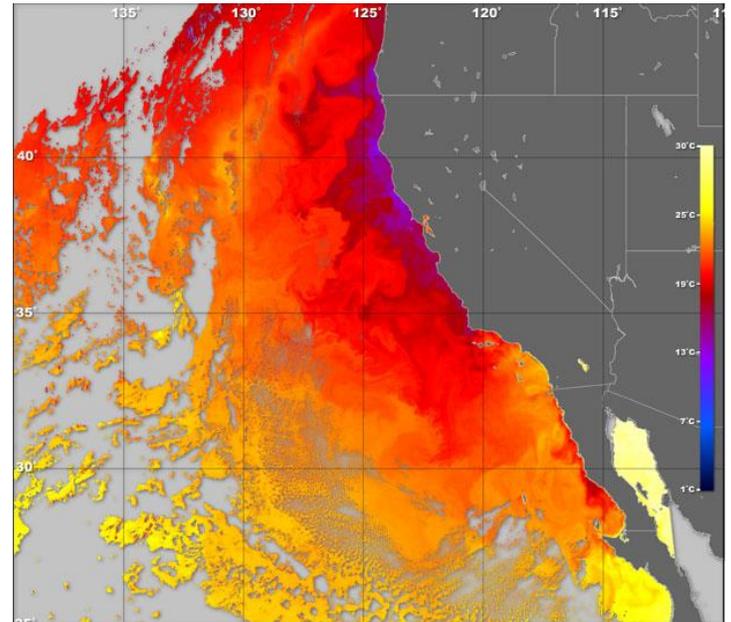
1. Average ocean salinity is 35 parts per thousand [T/F] **TRUE**
2. In the presence of thick clouds, the majority of shortwave radiation is reflected [T/F] **TRUE**
3. Sea surface temperature remains consistent wherever you measure it [T/F] **FALSE**
4. There are 4 major ocean basins [T/F] **TRUE**
5. Basalt is the main rock type found in oceanic crust [T/F] **TRUE**
6. Salinity changes rapidly with depth in the halocline [T/F] **TRUE**
7. Atolls are formed when longshore currents strike the beach at an angle [T/F] **FALSE**
8. Wave height is unaffected by fetch. [T/F] **FALSE**
9. Objects are deflected to the left in the southern hemisphere due to the Coriolis effect [T/F] **TRUE**
10. Geostrophic currents are a result of the balance between pressure gradient and Coriolis force [T/F] **TRUE**
11. Upwelling leads to surface water becoming nutrient deficient [T/F] **FALSE**
12. Deep ocean currents are primarily affected by temperature and salinity [T/F] **TRUE**
13. Meteorological tides result from gravitational effects [T/F] **FALSE**
14. The rate of sea level rise is not the same everywhere [T/F] **TRUE**
15. Niskin bottles are designed to obtain samples of water at a specific depth [T/F] **TRUE**
16. Phases of the pacific decadal oscillation typically lasts for 12 to 15 years [T/F] **FALSE**
17. The equation for the speed of an intermediate (transitional) water wave is  $\sqrt{\frac{gL}{\pi a} \tanh\left(\frac{d}{T}\right)}$  [T/F] **FALSE**
18. Wave speed is more correctly known as celerity [T/F] **TRUE**
19. Concentrations of mercury (Hg) can be used as a powerful tracker of oceanic processes [T/F] **FALSE**
20. The rate at which pressure increases as you descend in the ocean is exponential [T/F] **FALSE**

Part 2 [Multiple Choice] – 2pts each

21. Which of the following is correct about seawater salinity?
- Sea surface salinity increases as you move towards the poles
  - It has a greater impact on density than temperature
  - Salinity does not affect pH**
  - Freshwater is denser than sea water
22. Place the following ionic constituents of seawater in order of highest to lowest concentration in typical seawater. Bromide (Br<sup>-</sup>), Fluoride (F<sup>-</sup>), Chloride (Cl<sup>-</sup>), Calcium (Ca).
- Cl<sup>-</sup>, Br<sup>-</sup>, Na, Ca, F<sup>-</sup>
  - Cl<sup>-</sup>, Na, Ca, Br<sup>-</sup>, F<sup>-</sup>**
  - Na, Ca, Br<sup>-</sup>, F<sup>-</sup>, Cl<sup>-</sup>
  - Na, Cl<sup>-</sup>, Br<sup>-</sup>, Ca, F<sup>-</sup>
23. Which of the following is a result of water's high specific heat capacity?
- Its effects help to moderate temperatures near large bodies of water**
  - It is known as a universal solvent
  - It creates surface tension
  - Its effects contribute to the formation of common weather patterns
24. The Redfield ratio of 106:16:1 describes the near constant ratio of \_\_\_\_\_ : \_\_\_\_\_ : \_\_\_\_\_ in the deep ocean.
- Oxygen : Sodium : Fluoride
  - Carbon : Nitrogen : Phosphorus**
  - Carbon : Sodium : Nitrogen
  - Oxygen : Phosphorus : Fluoride
25. Primary coasts are...
- Found where the ocean's energy tears apart rock outcrops on a shoreline
  - Generally young and shaped by terrestrial processes**
  - Generally older and shaped mainly by ocean processes
  - Characterized by abundant sediment supply that results in the net deposition of sediment

Eastern boundary currents flow from high latitudes down to the equator. The following image is composed of Sea Surface Temperature (SST) data from the MODIS instrument aboard a NASA satellite. The reds and oranges represent higher SSTs while the blues and purples (near the coast) represent lower SSTs.

Image depicting the California Current



26. From the image above, specifically the purple region by the Californian coast, what process can you infer as occurring?
- A decrease in salinity
  - Coastal upwelling
  - A decrease in pH
  - Coastal downwelling**
27. Which of the following best describes water beneath the thermocline?
- Highly variable in temperature
  - Warmer than most surface waters
  - Relatively uniform and cold in temperature**
  - Variable by latitude
28. Terrigenous sediments are commonly found...
- Spread throughout the ocean floor
  - In the central region of ocean basins
  - Near the shoreline of continents**
  - They are spread out evenly in the ocean

29. Oxygen minimum zones, as the name suggests, are areas of low oxygen concentration in the oceans. These areas are normally found at depths of 200m to 1500m. Oxygen minimum zones typically occur along the \_\_\_\_\_ of continents due to \_\_\_\_\_.

- a. West coast; upwelling
- b. West coast; downwelling
- c. East coast; upwelling
- d. East coast; downwelling

30. The majority of earthquakes occur along/within the...

- a. Circum-superior belt
- b. Neritic zone
- c. Circum-pacific belt
- d. Sino-Japanese region

31. \_\_\_\_\_: An isolated undersea hill or mountain.

- a. Isthmus
- b. Guyot
- c. Seamount
- d. Tombolo

32. The presence of siliceous sediments in sediment cores allow paleoclimatologists to identify if...

- a. There had been a meteorite impact
- b. Ocean environments were relatively cool
- c. Marine life had developed yet
- d. There were ancient deposits of minerals

33. A container of oxygen at sea level contains 100L of air. The container is lowered to a depth of 500 meters. Calculate its new volume.

- a. 0.52L
- b. 5L
- c. 0.2L
- d. 2L

34. Climate change can lead to which of the following?

- a. Increased average ocean pH
- b. Less extreme weather patterns
- c. Expanding oxygen minimum zones
- d. Increased biodiversity due to speciation

Imagine that you have a personal yacht, and you decide to go off the Southern tip of South Africa for a swim. After some diving, you realize that you forgot to anchor down your boat!

35. If the wind is blowing due north, in which general direction should you start looking?

- a. North
- b. East
- c. South
- d. West

36. The Wilson Cycle refers to the...

- a. Lifecycle and evolution of ocean basins
- b. Recurring cycle of ocean-atmosphere climate variability centered over the mid-latitude Pacific basin
- c. Monthly tidal cycle of 29½ days
- d. The processes by which carbon and nitrogen nutrients are cycled throughout oceanic ecosystems

37. Bjerknes feedback describes how...

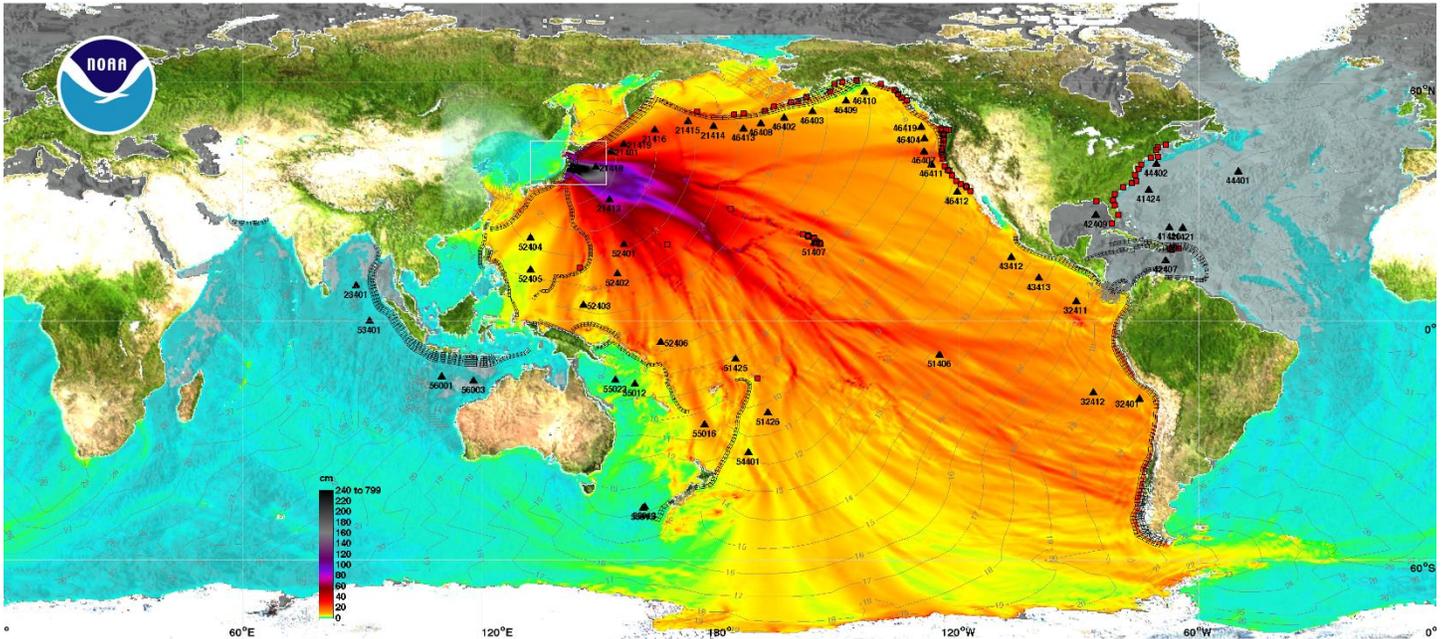
- a. Positive SST anomalies in the Pacific reduces the east-west SST gradient, strengthening Walker circulation, in turn enhancing positive SST anomalies.
- b. Ocean-atmosphere interactions results in the Hadley Circulation Cell
- c. Warm SSTs increases evaporation rates, the extra water vapor absorbs more heat, → higher temperatures → warmer SSTs
- d. Warming temperatures will result in events that lead to further warming

38. The following image depicts a...



- a. Rip tide
- b. Rip current
- c. Undertow
- d. Longshore current

Tōhoku Earthquake and Tsunami – March 11, 2011



39. What does the image above highlight?
- The spread of radiation from the Fukushima Daiichi nuclear disaster due to the Tōhoku Tsunami
  - Maximum wave amplitudes from the Tōhoku Tsunami**
  - Areas of high tectonic activity
  - Concentrations of the radioactive particle Cesium-137

40. The bending of waves around an obstacle is known as \_\_\_\_\_.
- Wave train
  - Wave dispersion
  - Wave diffraction**
  - Wave shoaling

Oh no! An earthquake was just reported off the coast of Seward Alaska. The earthquake has produced a tsunami at a depth of 4000 meters with a wavelength of 400 km.

41. Estimate the speed of the tsunami (in km/h) and the time it will take for the tsunami to reach Kodiak, Alaska (310 km) and Kauai Island, Hawaii (4300 km)
- 284 km/h; 1 hour 5 minutes; 15 hours
  - 198 m/s; 1 hour 34 minutes; 22 hours
  - 713 km/h; 26 minutes; 6 hours**
  - 62 km/h; 5 hours; 70 hours

42. A hypothetical wave traveling along a section of the Pacific Ocean (depth of 2500 meters) has a wavelength of 150 meters. What type of wave is it? And roughly what speed is it traveling at?
- Deep Water Wave; 15.296 m/s**
  - Deep Water Wave; 156.525 m/s
  - Shallow Water Wave; 15.296 m/s
  - Shallow Water Wave; 156.525 m/s

43. If the wind is traveling south, where would downwelling hypothetically occur?
- The east coast of Mozambique
  - The west coast of the United States
  - The west coast of Chile**
  - The west coast of Portugal

44. Which of the following are responsible famous surfing waves off the west coast of the US?
- Diurnal tides
  - Meteorological tides
  - Semi-diurnal tides
  - Mixed tides**

45. Tidal resonance effects are greatest when...?
- The wavelength is 1/7 the basin's length
  - The wavelength is 1/2 the basin's length
  - The basin's length is 1/8 wavelength
  - The basin's length is 1/4 wavelength**

46. Waves at the surface of the ocean are classified as \_\_\_\_\_ waves.

- a. Medial
- b. Longitudinal
- c. **Orbital waves**
- d. Rotational

47. Below is a list of geographic locations paired with continental margins classified as either “passive” or “active” margins. Which of the following is incorrectly paired?

- a. **East coast of India; Active margin**
- b. West coast of Japan; Active margin
- c. East coast of Australia; Passive margin
- d. West coast of Chile; Active margin

48. We can envision tides as a point on Earth rotating through two \_\_\_\_\_ caused by gravity from the Moon and Sun, and inertia.

- a. Tidal waves
- b. Swells
- c. Elliptic declinations
- d. **Tidal bulges**



49. What oceanic tool used for research is shown in the image above?

- a. Bathyphotometer
- b. **CTD Sensor**
- c. Acoustic Doppler Current Profiler
- d. Niskin bottles

50. What are piezolytes responsible for in deep sea organisms?

- a. Preventing cell membranes from solidifying
- b. Making echolocation possible
- c. **Helping them withstand the pressure**
- d. Optimizing the absorption of oxygen

51. The historic average for ocean pH is ~8.16. Due to excessive greenhouse gas emissions, it is now ~8.07 today. Calculate the change in pH.

- a. 1.46
- b. 1.01
- c. 1.53
- d. **1.23**

52. James Cameron is attributed for...

- a. **Being the first person to solo dive to the deepest part of the Mariana trench**
- b. Setting a record for the deepest dive without a tether
- c. Discovering and exploring the wreckage of the RMS Titanic
- d. None of the above

53. A hypothetical wave is traveling along a section of the Australia with a depth of 800 meters. This wave has a wavelength of 4800 meters. What speed is this wave traveling at?

- a. 113.87 m/s
- b. 86.53 m/s
- c. **76.45 m/s**
- d. 88.54 m/s

54. Which of the following is not a tidal constituent?

- a. Principal lunar semi-diurnal
- b. **Principal lunar semi-annual**
- c. Lunar fortnightly
- d. Elliptical lunar semi-diurnal

55. The rate at which a wave loses its energy is \_\_\_\_\_ to its \_\_\_\_\_.

- a. Inversely proportional; Velocity
- b. Proportional; Depth
- c. Proportional; Period
- d. **Inversely proportional; Wavelength**

56. How do cold core eddies affect tropical cyclones?

- a. **CCE's weakens their intensity and limits their development**
- b. They increase barotropic instability which inevitably strengthens TCs
- c. The cold water of CCEs enhances the temperature gradient that leads to TCs
- d. They do not affect tropical cyclones

### Part 3 [Extended Response] – Point Values Indicated

57. As you know, our climate is a vastly complex system with a multitude of inputs. Two of these inputs are ENSO and PDO. Depending on their phase, they can have widely varying effects, from increasing droughts to flooding. All of which have very tangible economic effects. **[12 pts total]**

a. Identify a major difference between ENSO and PDO. **[1 pt]**

ENSO occurs on a much smaller time scale than PDO. PDO mainly effects the North Pacific while ENSO primarily effects lower latitudes (there is some overlap though).

b. What climate variations occur when both processes are in sync (Southeast US)? **[2 pts]**

Positive PDO: Below average temperature. Above average precipitation.

Negative PDO: Above average temperature. Below average precipitation.

c. Describe the relationship between trade winds and La Niña and its effects **[2 pts]**

During La Niña, enhanced pressure gradients (high over central equatorial Pacific and low over western equatorial Pacific) create stronger trade winds. Thus increasing upwelling along the equator.

d. Using your knowledge of how the thermocline interacts with warm/cool water, predict how the general structure of the thermocline will change during an El Niño year. **[3 pts]**

During an El Niño year, due to warmer sea surface temperatures, it results in a deeper and flatter thermocline in the Pacific.

e. Climate change denialists tend to perpetrate the myth that “climate change” is merely a phase of the PDO. Explain why this is untrue. Provide specific evidence. **[4 pts]**

The PDO primarily drives regional variations in climate and has no clear effect on global temperatures. Moreover, while the PDO has fluctuated, global temperatures have continued to rise. For instance, during the period 2000-09, the PDO was largely in its negative phase while global warming trends persisted.

58. There are three major theories for the formation of barrier islands. Two of these theories are the Offshore Bar Theory (1845), proposed by Elie de Beaumont and the Spit Accretion Theory (1885), proposed by Grove Karl Gilbert. Please answer the following questions. **[6 pts total]**

a. Name the third major theory, who proposed it, and when it was proposed. **[1 pt]**

The Submergence Theory. William John McGee. 1890

b. Briefly explain the importance of barrier islands **[2 pts]**

They protect the mainland from severe storms and provide habitats for a wide variety of fish and wildlife.

c. Predict the effects on barrier reefs if sea levels continue to rise (Assume above normal rate of sea level rise) **[3 pts]**

Due to higher sea levels, the amount of coastal erosion increases. This increase in coastal erosion leads more and more sediments being dumped on the corals. Which inevitably smothers their development. (Don't forget that because of climate change, warmer water temperatures lead to coral bleaching which further stifles coral development).

59. During the time around 1819-1822, Alexander Marcet performed some of the first measurements of the concentrations of major salts in seawater. These observations would later be formulated into what is known as Marcet's principle. [12 pts total]

a. Provide a rough run down of Marcet's principle. [3 pts]

Regardless of how the salinity may vary from place to place, the ratios between the amounts of the major ions in the waters of the open ocean are nearly constant.

b. Explain the use of Marcet's Principle when measuring salinity. [2 pts]

It is only necessary to measure the concentration of a single major constituent to approximate salinity.

c. State another possible name for this general principle. [1 pt]

Forchhammer's Principle **OR** Principle of Constant Proportions

d. When does this principle hold true? Your answer must reference residence time. [2 pts]

When the residence time of an ion is greater than the ocean's mixing time (~1000 years).

e. Identify two elements/ions that holds true with Marcet's principle and their residence times. [1 pt]

Possible Answers: Cl<sup>-</sup> (100myr), Na (68myr), Mg (10myr), SO<sub>4</sub><sup>2-</sup> (10myr), K (7myr), Ca (1myr)

f. Name two areas and/or circumstances where this principle does not hold true. And provide an explanation as to why this is. [3 pts]

Possible Answers: Coastal regions, Anoxic basins, Marginal seas, Hydrothermal vents, Estuaries, Isolated basins, Air-sea interfaces, Interstitial waters, Areas around sea ice

Generally due to inputs from a variety of sources. Ex: Estuaries: Input of river water of varying makeup; Hydrothermal vents: Discharge of different materials; Anoxic basins: bacterial reduction of SO<sub>4</sub><sup>2-</sup> to S<sup>2-</sup>

60. Climate change is undeniably one of the greatest threats of the century. By 2050, it is estimated that there will be over 200 million climate refugees globally. Its effects on land will be/are devastating, but just as devastating are its effects to the ocean. Please answer the following questions [8 pts]

a. Explain the difference between shortwave and longwave radiation and relate this back to the greenhouse effect. [3 pts]

Shortwave radiation encompasses ultraviolet and visible light. Longwave radiation includes infrared light. ~70% of incoming SW radiation is absorbed by the Earth. This is then emitted back out as LW radiation. However, some of this radiation is trapped by greenhouse gasses (ex: CO<sub>2</sub>, H<sub>2</sub>O) thus warming the planet.

b. According to the IPCC's 5th Assessment Report, since the 1970s over 90% of excess heat trapped by greenhouse gasses have been absorbed by the ocean. Why is this? [4 pts]

High specific heat capacity: The ocean can absorb ~1000x more heat than the atmosphere w/o drastically increasing in temperature. Albedo: The ocean has an albedo value of 0.06 while land sits at ~0.3, meaning the oceans absorb a lot more heat than land (don't forget that ~70% of the Earth's surface is water).

c. Under a high emissions scenario (RCP8.5), how much will sea levels rise by 2100? [1 pt]

50-130 centimeters (Up to 2.5 meters in worst case scenario)

61. Aside for their beauty, coral reefs are hosts to some of the most diverse ecosystems on the planet. Despite covering less than 1% of the ocean’s floor, they contain nearly 25% of all known marine species. Please answer the following questions on coral reefs. **[9 pts total]**

a. List the three major types of coral reefs. Additionally, who proposed the Subsidence Hypothesis of Coral Reef Development? **[2 pts]**

**Barrier Reefs, Fringing Reefs, Atolls. Charles Darwin**

b. Identify a primary cause of coral bleaching and expand upon it. Additionally, assuming business as usual, what percentage of corals will be dead within the next 20 years? **[3 pts]**

**Rising ocean water temperatures leads to corals expelling algae (zooxanthellae). In the next 20 years, approximately 70% to 90% of corals will be dead.**

c. Use the following four chemical reactions to both explain how increasing levels of CO<sub>2</sub> relates to ocean acidification and identify how an overabundance of CO<sub>2</sub> leads to the stymieing of coral growth **[4 pts]**

$H^+ + CO_3^{2-} \rightarrow HCO_3^-$	$H_2CO_3 \rightarrow H^+ + HCO_3^-$	$CO_3^{2-} + Ca^{2+} \rightarrow CaCO_3$	$CO_2 + H_2O \rightarrow H_2CO_3^-$
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1	$CO_2 + H_2O \rightarrow H_2CO_3^-$	CO <sub>2</sub> reacts with water to form carbonic acid (H <sub>2</sub> CO <sub>3</sub> <sup>-</sup> )
2	$H_2CO_3 \rightarrow H^+ + HCO_3^-$	H <sub>2</sub> CO <sub>3</sub> <sup>-</sup> dissociates into hydrogen ions (H <sup>+</sup> ) and bicarbonate ions (HCO <sub>3</sub> <sup>-</sup> )
3	$H^+ + CO_3^{2-} \rightarrow HCO_3^-$	The H <sup>+</sup> combines with carbonate ions (CO <sub>3</sub> <sup>2-</sup> ), forming more HCO <sub>3</sub> <sup>-</sup>
4	$CO_3^{2-} + Ca^{2+} \rightarrow CaCO_3$	Less CO <sub>3</sub> <sup>2-</sup> is available to form CaCO <sub>3</sub> for marine organisms

CO<sub>2</sub> combines with H<sub>2</sub>O to form H<sub>2</sub>CO<sub>3</sub><sup>-</sup> (1), H<sub>2</sub>CO<sub>3</sub><sup>-</sup> is then broken down into H<sup>+</sup> and HCO<sub>3</sub><sup>-</sup> (2). Increased levels of hydrogen ions drive ocean acidification. And on top of decreasing pH, some excess hydrogen ions will combine with CO<sub>3</sub><sup>2-</sup> to form even more HCO<sub>3</sub><sup>-</sup> (3). By combining H<sup>+</sup> with CO<sub>3</sub><sup>2-</sup>, it removes valuable carbonate ions that are important for marine organisms in shell formation, exoskeleton formation, coral reef formation, etc (4).

62. One defining feature standing in the way of the exploration of the ocean is pressure. The immense pressures make it virtually impossible to even begin exploring the ocean depths without a pressurized vehicle. Answer the following questions on pressure **[8 pts total]**

a. What factors does pressure within a liquid depend on? **[2 pts]**

**Density of the liquid, the acceleration due to gravity, and the depth within the liquid**

b. Many fish species that live in the Epipelagic and Mesopelagic zones have swim bladders (gas filled organ) that allows them to control their buoyancy. However, may organisms living below the upper layers of the ocean do not a have swim bladder. Using your understanding of pressure, explain why this is. **[3 pts]**

**Due to the majority of deep sea fish traversing an incredible range of depths, as they ascend, according to Boyle’s law, the gas in their swim bladder would expand, and thus potentially killing the organism.**

c. Black smokers are a type of hydrothermal vents that can emit water with upwards of 350°C. Despite this being considerably above boiling point, the water emitted from these vents remain in as a liquid. Hypothesize as to why this is and justify your claim. **[3 pts]**

**As pressure increases the space between the molecules of a liquid is forced to decrease. Thus when trying to boil a liquid, it requires an even greater amount of energy to force it into a gaseous state.**

63. The importance of the study and understanding of tides affects tasks ranging from the study of sea levels to coastal navigation. Not only that, but by placing a dam of sorts in bays and estuaries, tidal energy can be harnessed. Please respond to the following questions on tides. **[10 pts total]**

a. Why tides are considered shallow water waves. **[1 pt]**

They have a wavelength of half the circumference of the Earth.

b. If focused only on the Equilibrium (Static) Theory of Tides, one would expect any given location to experience high tide twice a day. However this is not the case. Explain why this is. **[3 pts]**

The two main reasons as to why this is are due to the topography of the ocean and the Coriolis Effect. Regional topographical changes can lead to changes in the speed of a tide. And the Coriolis effect deflects the tide to the right (left in the Southern Hemisphere).

c. Based on what you identified in part (b), describe the general path of a tide in the Northern Hemisphere. Fully (in detail) explain your reasoning. **[4 pts]**

In the Northern Hemisphere, a tide follows a circular pattern that rotates counterclockwise (clockwise in the Southern Hemisphere) around a central point (called an amphidromic point or node). This is due to the fact that as a tide enters a basin, it is deflected right towards the eastern landmass, however, now that the western side of the basin contains less water, the tide rushes westward. It is deflected towards the north. Now the southern side of the basin contains less water, and the cycle continues.

d. Renewable energy is now in more demand than ever. Identify one location that can provide a strong source of tidal energy and justify your choice. **[2 pts]**

The Bay of Fundy in Canada. Because it has the largest tidal range in the world (around 13 meters).

64. Estuaries, commonly referred to as the “nurseries of the sea” are not only important to wildlife but also provide incredible economic benefits, including but not limited to tourism, fisheries, and areas for recreational activities. Please answer the following questions on estuaries. **[9 pts total]**

a. Based on the densities of freshwater and seawater, describe the pattern of circulation of water in and out of an estuary. **[3 pts]**

Freshwater from a river is less dense than the saline water from the ocean/sea. Thus the less dense (therefore lighter) water remains towards the top of the outlet and flows out. While the more saline water coming in from the ocean/sea flows into the estuary from the bottom.

b. On a geologic timescale the majority of estuaries are actually quite young (>10,000 years old). Briefly explain why this is so. Provide evidence. **[3 pts]**

Most estuaries are relatively young due to the fact that many of them were formed during/towards the end of the last ice age which ended around 11,000 years ago. For instance, many estuaries were formed when sea levels rose and flooded low lying river valleys. [other answers may be acceptable]

c. Following the arrival of the Māori in what is now known as New Zealand and the eventual arrival of European settlers, large swaths of forests were cleared to make way for farmland. Predict the effects of deforestation on local estuaries. **[3 pts]**

Once stripped of forest coverage, the lands became significantly more vulnerable to soil erosion during heavy rainfall. Much of the soil would end up in rivers, later depositing in estuaries. From the increased deposition of soil, they create mud layers, which if thick enough, can bury both plants and animals.

65. From surfing to tsunamis, waves can be anything from a source of recreation to a deadly force. And although uncommon, some waves have been recorded with heights in excess of 34 meters (USS Ramapo). Answer the following questions. [18 pts]

a. The wave height of a wind generated wave is a function of... [2 pts]

Wave speed, wind duration, and fetch

b. After a equilibrium condition called a fully developed sea is achieved, waves can no longer grow. Briefly state why this is. [2 pts]

This is because waves lose as much energy breaking as they receive from the wind.

c. As a wave enters shallower water, its wavelength generally decreases while its height increases. Explain why this is. [3 pts]

Due to the shoaling depths interfering with water particle movement at the base of the wave, wave speed decreases. As one wave slows, the following waveform, which is still moving at its original speed, moves closer to the wave that is being slowed, causing a decrease in wavelength. Furthermore, though some wave energy is lost due to friction, the remaining energy must go somewhere. That somewhere being increasing wave height.

d. Following part (c), describe the conditions that results in a wave breaking [3 pts]

A combination of an increase in height and a decrease in wavelength leads to an increase in wave steepness. Additionally, because the surface of a wave is unhindered while the bottom is (as described in part b), the surface travels faster than the bottom, thus resulting in a breaking wave.

e. The group velocity for deep water waves is about 1/2 the phase velocity. While with a shallow water wave, the group velocity is equal to the phase velocity. Hypothesize as to why this is and justify your answer. (HINT: Wave dispersion) [4 pts]

Deep water waves are dispersive while shallow water waves are not. Deep water waves are dispersive because the speed of the wave depends on the wavelength ( $\sqrt{g\lambda/2\pi}$ ). Thus waves with larger wavelengths travel faster while waves with shorter wavelengths travel slower. Resulting in the sorting of waves based upon their wavelengths. This is not true for shallow water waves because their speed depends on the depth of the water instead of their wavelength ( $\sqrt{gd}$ ).

f. Based on the formula for the velocity of an idealized wave (presumably the same formula you used to solve question #53) demonstrate how you can derive the formula for a shallow water wave from it. Show and explain all steps. [4 pts]

Formula for the Velocity of an Idealized Wave

$$\sqrt{\frac{g\lambda}{2\pi} \tanh\left(\frac{2\pi d}{\lambda}\right)}$$

To be classified as a shallow water wave, the depth must be less than  $\frac{1}{20}\lambda$ , and because we know that a shallow water wave will always have a significantly “larger” wavelength compared to its depth, thus...

$$\lim_{x \rightarrow 0} (\tanh(x)) = x$$

Now we can start cancelling

$$\sqrt{\frac{g\lambda}{2\pi} \tanh\left(\frac{2\pi d}{\lambda}\right)} \rightarrow \sqrt{\frac{g\lambda}{2\pi} \left(\frac{2\pi d}{\lambda}\right)} \rightarrow \sqrt{gd}$$

If you have any questions, feel free to contact me @ dolphins0248@gmail.com