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# Oceanography 1 LECTURE

# *Spring 2021 Workbook*

**Oceanography 1 Workbook**

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Cover image from *Saddlebag Lake Area, High Sierra, Hoover Wilderness*

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# CLASS INTRODUCTION

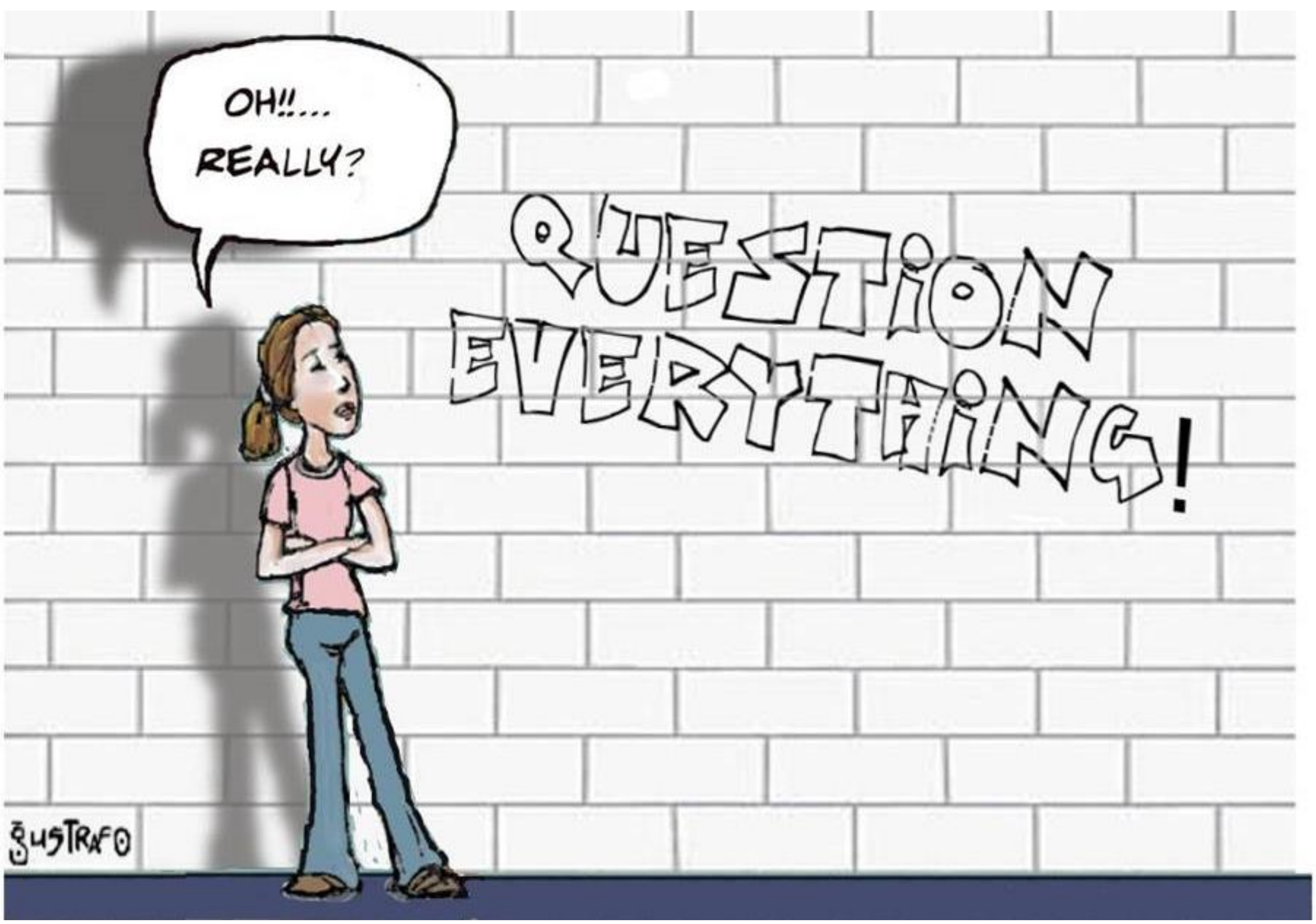
# What is Science? Activity

*Some of the content within has been borrowed and modified from the University of California's Museum of Paleontology UNDERSTANDING SCIENCE WEBSITE: http://undsci.berkeley.edu/article/coreofscience_01.*

- Science is a way of learning about the **natural world** – what is in it, how it works, and how it formed.
- Science relies on testing ideas by making **observations** to find out whether expectations hold true.
- Accepted scientific ideas are subjected to rigorous testing. As new evidence is acquired and new perspectives emerge these ideas are revised.
- Science is a community endeavor with checks and balances for greater accuracy and understanding.

## Scientific Inquiry

**CURIOSITY** – A question arises about an event or situation: why and how does this happen?
**OBSERVATIONS, MEASUREMENTS** – We observe and measure: What is happening? Under what circumstances? Does there appear to be a dependable cause-and –effect relationship at work?
**HYPOTHESES** – We make educated guesses about what is causing what we are seeing. A good hypothesis can predict future occurrences under similar circumstances. Creativity plays a BIG role here, as we often have to think outside the box. It also helps greatly if we can bring our understandings in a diverse range of scientific disciplines.
**EXPERIMENTS** – We plan controlled experiments to prove or disprove potential cause-and-effect relationships. These tests can happen in nature or the lab and permit manipulating and controlling the conditions under which we make future observations.
**BEYOND THE HYPOTHESIS** – Patterns emerge. If one or more of the relationships hold and acceptance is widespread, the hypothesis becomes a theory or principle.




*Cartoon: © Gustrafo – used with permission.*

**BEYOND THE SIMPLIFIED:**

- **Scientists engage in many different activities in many different sequences.** Scientific investigations often involve repeating the same steps many times to account for new information and ideas.
- **Science depends on interactions within the scientific community.** Different parts of the process of science may be carried out by different people at different times. Society influences greatly the questions that are researched, and many of the results of scientific investigations become a highly influential part of human culture and civilization.
- **Science relies on creative people thinking outside the box!**
- **Scientific conclusions are always revisable if warranted by the evidence.** Scientific investigations are often ongoing, raising new questions even as old ones are answered.
- **The process of science is iterative.** Science circles back on itself so that useful ideas are built upon and used to learn even more about the natural world. This often means that successive investigations of a topic lead back to the same question, but at deeper and deeper levels.
- **The process of science is not predetermined.** Any point in the process leads to many possible next steps, and where that next step leads could be a surprise.
- **There are many routes into the process**. Research problems and answers come from a variety of inspirations: serendipity (such as being hit on the head by the proverbial apple), concern over a practical problem (such as finding a new treatment for diabetes), a technological development (such as the launch of a more advanced telescope), or plain old poking around: tinkering, brainstorming, making new observations, chatting with colleagues about an idea, or reading.
- **Scientific testing is at the heart of the process.** All ideas are tested with evidence from the natural world — even if that means giving up a favorite hypothesis.
- **Ideas at the cutting edge of research may change rapidly.** In researching new medical procedures or therapies or researching the development of life on earth – making living cells from inorganic materials – scientists test out many possible explanations trying to find the most accurate.
- **The scientific community helps ensure science's accuracy.** Members of the scientific community (such as researchers, technicians, educators, and students) are especially important in generating ideas, scrutinizing ideas, and weighing the evidence for and against them. Through the action of this community, science self-corrects. Note: Authority is NOT a criterion. Just because a scientist has titles or degrees does not mean we must accept their ideas. We apply a healthy dose of skepticism to all.

## From Hypotheses to Theories and Principles

The process of science works at multiple levels — from the small scale (such as a comparison of the genes of three closely related North American butterfly species) to the large scale (such as half-century-long series of investigations of the idea that geographic isolation of a population can trigger speciation).

**HYPOTHESES** are proposed explanations for a fairly narrow set of phenomena. These reasoned explanations are not guesses. When scientists formulate new hypotheses, they are usually based on prior experience, scientific background knowledge, preliminary observations, and logic. *Example hypothesis: a particular butterfly evolved a particular trait to deal with its changing environment.*

**LAWS OR SCIENTIFIC PRINCIPLES** explain events in nature that occur with unvarying uniformity under identical conditions. These principles are arrived at by fact gathering and experimentation. They may have exceptions, and, like other scientific knowledge, may be modified or rejected based on new evidence and perspectives. *Example principle: Geology's principle of superposition, which states that in an undeformed sequence of rock layers, each laid down through natural processes, the oldest layer is at the bottom.*

**THEORIES** are broad explanations for a wide range of phenomena. They are concise (generally don't have a long list of exceptions and special rules), coherent, systematic, predictive, and broadly applicable. Theories often integrate and generalize many hypotheses and usually are more involved and complicated than a law or principle, with many more areas of doubt and refinement possible. *For example, the theory of natural selection broadly applies to all populations with some form of inheritance, variation, and differential reproductive success — whether that population is composed of alpine butterflies, fruit flies on a tropical island, a new form of life discovered on Mars, or even bits in a computer's memory. This theory helps us understand a wide range of observations (from the rise of antibiotic-*

*resistant bacteria to the physical match between pollinators and their preferred flowers), makes predictions in new situations and has proven itself time and time again in thousands of experiments and observational studies.*

In common usage, the word theory means just a hunch, but in science, a theory is a powerful explanation for a broad set of observations. To be accepted by the scientific community, a theory must be strongly supported by many different lines of evidence. Biological evolution is a theory (it is a well-supported, widely accepted, and powerful explanation for the diversity of life on Earth).

**OVER-ARCHING THEORIES** are particularly important and reflect broad understandings of a particular part of the natural world. Evolutionary theory, atomic theory, gravity, quantum theory, and plate tectonics are examples of this sort of over-arching theory. These theories have been broadly supported by multiple lines of evidence and help frame our understanding of the world around us. These over-arching theories encompass many subordinate theories and hypotheses. Changes to those smaller theories and hypotheses reflect a refinement (not an overthrow) of the over-arching theory. E*xample over-arching theory: as we learn more about the dynamics of subducting plates in real subduction zones like Japan and Costa Rica, we refine the over-arching theory of Plate Tectonics to reflect that understanding.*

**Applying Critical Thinking**

There are many places in our daily lives when we apply critical thinking and scientific inquiry to our decision making: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- Something we use stops working, and we try to figure out why so we can fix it.
- We plan a major purchase, and we shop around, check reviews, and test it out first.
- Someone tells us some potentially life-changing news item about our environment or our health or other important societal issue, and we research it and test it and reconsider it continually instead of relying on faith in our story teller.

## Gathering Data: Observation versus Evaluation

An important skill for scientists is to be able to distinguish between observations and evaluations. Scientists combine many and continuous observations of natural processes to come up with explanations for how these processes work. Observations clearly state "Just the facts!" Evaluation, in contrast, includes some kind of judgment or explanation of facts.

**Examples:** *It's hot outside. (Evaluation)* -- *It's 81°F outside. (Fact)*

*It's 81°F outside, and this is hotter than the average daily temperature for San Francisco. (Fact)*

*It's 81°F outside, and this heat is caused by a combination of it being summer season and there being no clouds in the sky. (Evaluation)*

**Exercise:** For each of the following statements, indicate whether it's an observation or an evaluation.

If an evaluation, rewrite the sentence in such a way that it would be a true observation.

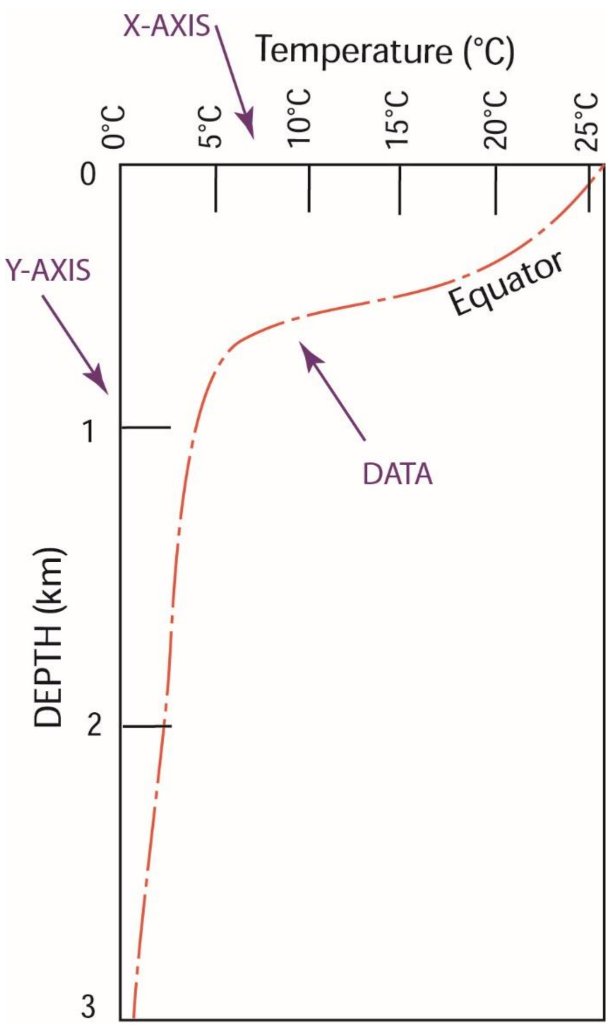
| | |
|---|---|
| 1. The Arctic Ocean is shallow.<br>**Rewrite?** | CIRCLE: Observation \| Evaluation |
| 2. Tuna are the fastest fish in the world, swimming at sustained speeds of 70 km/hr.<br>**Rewrite?** | CIRCLE: Observation \| Evaluation |
| 3. The oceans impact world weather.<br>**Rewrite?** | CIRCLE: Observation \| Evaluation |
| 4. The Dead Sea water tastes saltier than Pacific Ocean seawater.<br>**Rewrite?** | CIRCLE: Observation \| Evaluation |
| 5. Debris from the Japanese tsunami has been found on beaches across the northern Pacific Ocean. **Rewrite?** | CIRCLE: Observation \| Evaluation |
| 6. The water around Antarctica is cold.<br>**Rewrite?** | CIRCLE: Observation \| Evaluation |
| 7. The sand at Ocean Beach is produced from cliff erosion.<br>**Rewrite?** | CIRCLE: Observation \| Evaluation |

When scientists gather data, they have to define a clear method/process and document that process as well as the data. Only when data are gathered in a consistent way over long periods of time (or again, and again, and again), can we rely on the results. Some measurements must be taken directly. Others can be taken remotely. For example, satellites can accurately measure sea surface height. Some measurements happen by stationing an instrument in a single location – it doesn't move, but it measures the changing environment around it. Other instruments in the oceans are designed to move through the water (remotely operated vehicles or submarines or autonomous underwater vehicles) – measuring changing environments they travel through. Still other instruments are designed to drift with the water (drift buoys) – measuring through GPS the transit paths of the water.

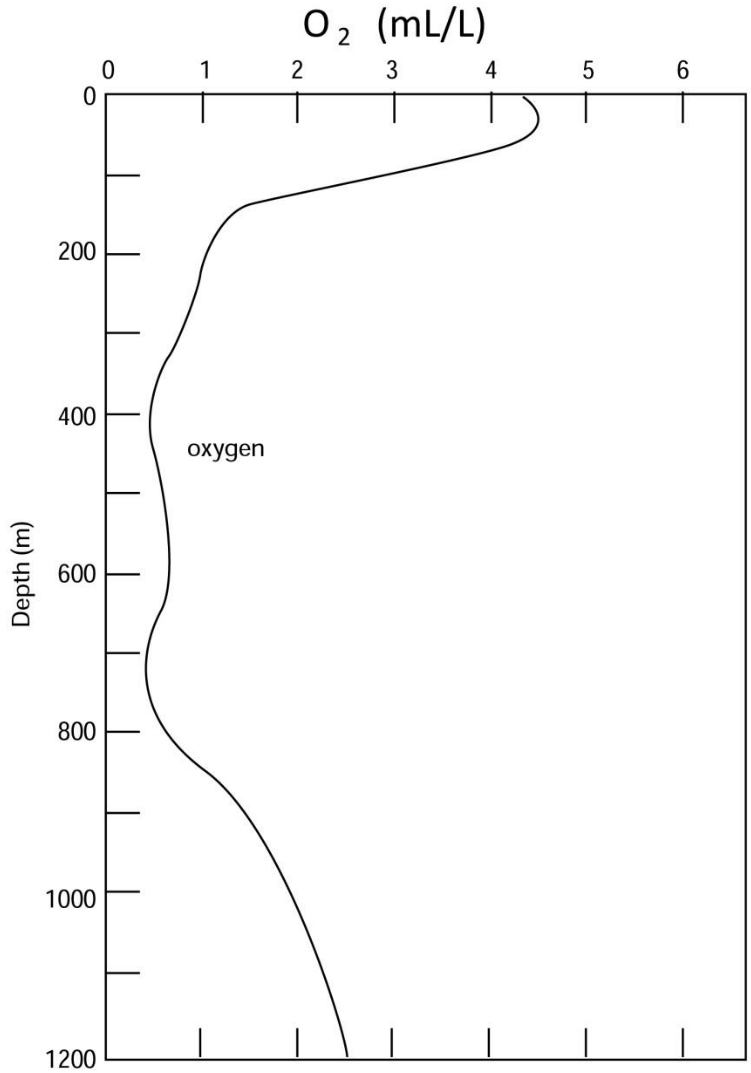
| **Example ways data are collected in the sciences:** | **Measurement type (circle)** |
|---|---|
| 8. Measuring sea level as centimeters above a wharf piling mark (set as our 0 level) | Stationary instrument (permanent or hand held)<br>Drifting instrument<br>Self- or remotely directed moving instrument |
| 9. Measuring salinity of water with depth by lowering a water bottle and take samples every meter | Stationary instrument (permanent or hand held)<br>Drifting instrument<br>Self- or remotely directed moving instrument |
| 10. Measuring air temperature at the top of Twin Peaks every minute over a few years | Stationary instrument (permanent or hand held)<br>Drifting instrument<br>Self- or remotely directed moving instrument |
| 11. Measuring speed and direction of ocean currents from a floating instrument not attached to seafloor. | Stationary instrument (permanent or hand held)<br>Drifting instrument<br>Self- or remotely directed moving instrument |
| 12. Taking pictures of beach slopes and profiles at a single location daily for years | Stationary instrument (permanent or hand held)<br>Drifting instrument<br>Self- or remotely directed moving instrument |
| 13. Towing a plankton net behind a boat. | Stationary instrument (permanent or hand held)<br>Drifting instrument<br>Self- or remotely directed moving instrument |

## Evaluating or Analyzing Data & Formulating and Modifying Hypotheses

Once we have gathered data of any kind – observational or remotely or directly measured – we start thinking about what it means. What does it tell us about the underlying truths of natural process and our human experience? We often find ways to display our data so that it makes those truths easier to see, including graphs, tables, lists, and illustrations. After we begin to formulate a hypothesis, what do we do next? We test it. We design experiments or projects that allow us to gather more data. As new data are evaluated, we confirm or modify our hypothesis as needed.




*Generalized depth profile for temperature at the equator (averaged over world's oceans) with main graph components labelled (axes and data line)*




*General variations of the concentrations of oxygen with depth in the world's oceans at midlatitudes.*

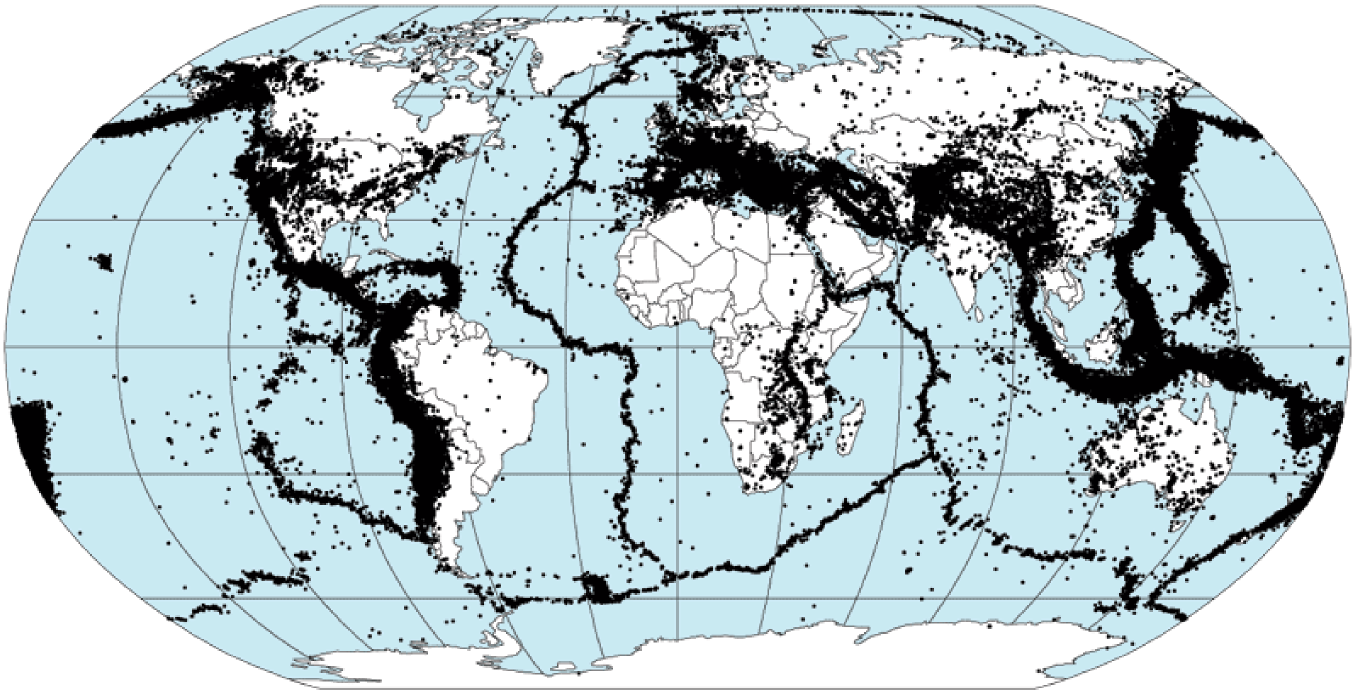
| 14. Review figures above and record below observations about the data (patterns, values, and more). *HINT: start with captions, review axes (labels and direction of increase), then describe line/curve (using x-axis/y-axis terms). | |
|---|---|
| **Left Figure** | **Right Figure** |
| | |

| 15. What questions, thoughts, hypotheses do you have after reviewing and thinking about these data? | |
|---|---|
| **Left Figure** | **Right Figure** |
| | |

| 16. What are the limitations of these data? Are there more data you'd like to collect? | |
|---|---|
| **Left Figure** | **Right Figure** |
| | |

17. Notice there are some data in the two previous graphs that correlate – meaning the trend of one line in the first graph (specifically the top of the trend) varies in the same direction over the same depth as data from the second graph. Locate and describe that correlation. (NOTE: 1000 m = 1 km)?

18. It's extremely important to notice correlation because it means there *might* be a relationship between the two characteristics. It might be that one causes the other, or it might mean that the cause of one is also the cause of the other. Example: there is an overall correlation worldwide between surface water temperature and water pH (acidity). Warmer waters are less acidic. Colder waters are more acidic. Just because these correlate, doesn't mean one causes the other. We cannot draw the conclusion that water temperature creates its acidity. What is actually happening in this case is that acidity in the oceans is caused by how much carbon dioxide gas is held in the water. Warmer waters are less viscous and can't hold as much gas as cold waters.
    **CORRELATION ≠ CAUSATION**
    Look at the correlation described in the images above and indicate below what hypotheses you have about its causation. It's okay NOT to know – just guess, and be creative.



*Global earthquake epicenters from 1963 to 1998. NASA, DTAM project team - http://denali.gsfc.nasa.gov/dtam/seismic/*

| |
|---|
| 19. Review figure above and record below observations about the data – patterns you see. |
| 20. What questions, thoughts, hypotheses do you have after reviewing and thinking about these data? |
| 21. What are the limitations of these data? Are there more data you'd like to collect? |

# Weekly Reflection

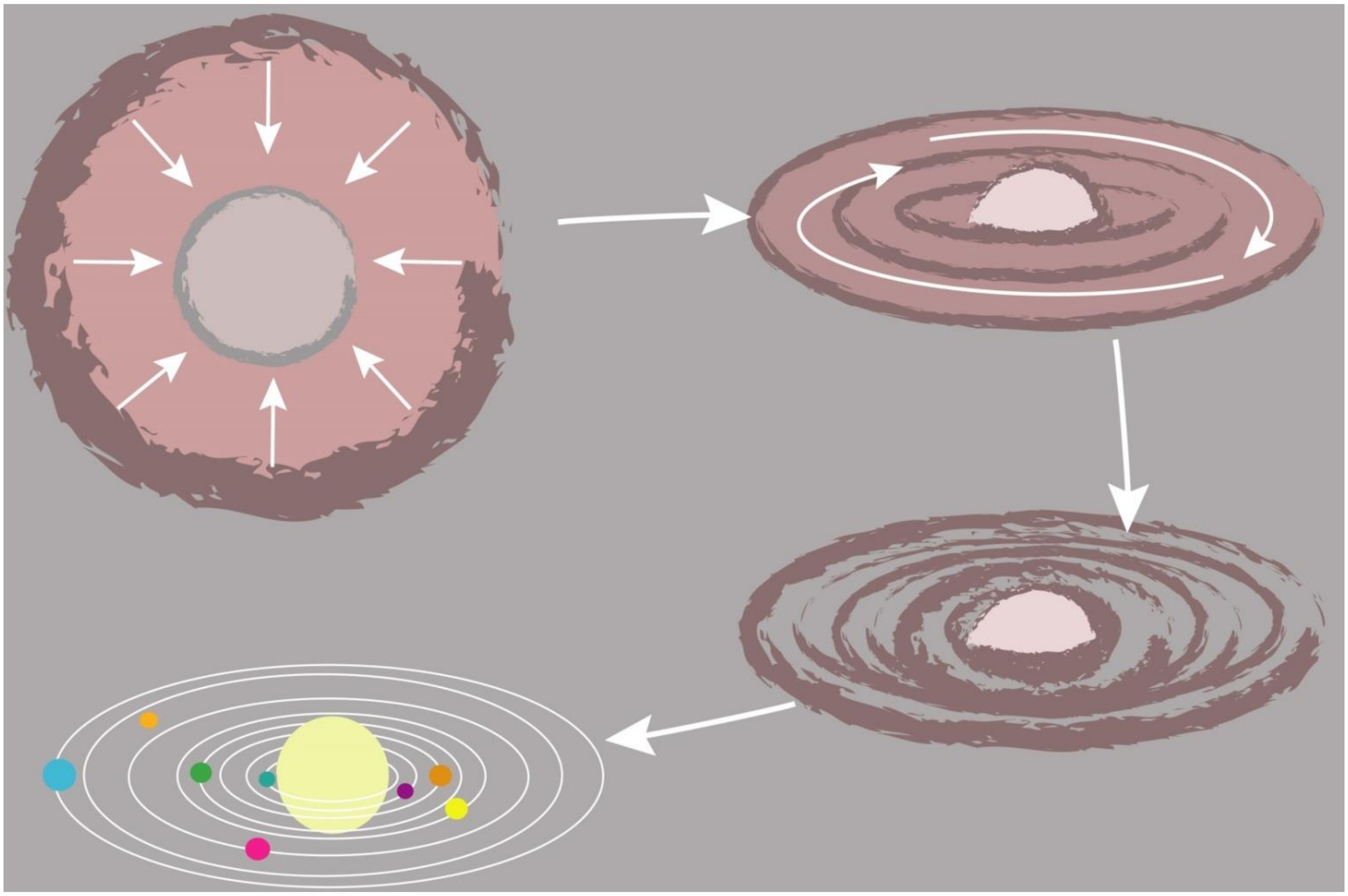
Take a moment to reflect on your comfort level and mastery of the week's objectives and describe an action plan for how you will practice or improve on anything that challenged you.

| **Weekly objective** | **Self-assessment of mastery level** | **Action plan for improvement** |
|---|---|---|
| Successfully accessing and navigating the course content and resources including the course workbook and textbook, CANVAS, and website. | A \| B \| C \| D \| F | |
| Identifying multiple methods by which you can communicate with your fellow students and instructor. | A \| B \| C \| D \| F | |
| Ensuring you have the right technology and sufficient time to complete class requirements. | A \| B \| C \| D \| F | |
| Comparing and contrasting the basic elements and tools of scientific inquiry, especially observation vs. evaluation. | A \| B \| C \| D \| F | |
| Describing and evaluating patterns in data and graphs and maps. | A \| B \| C \| D \| F | |

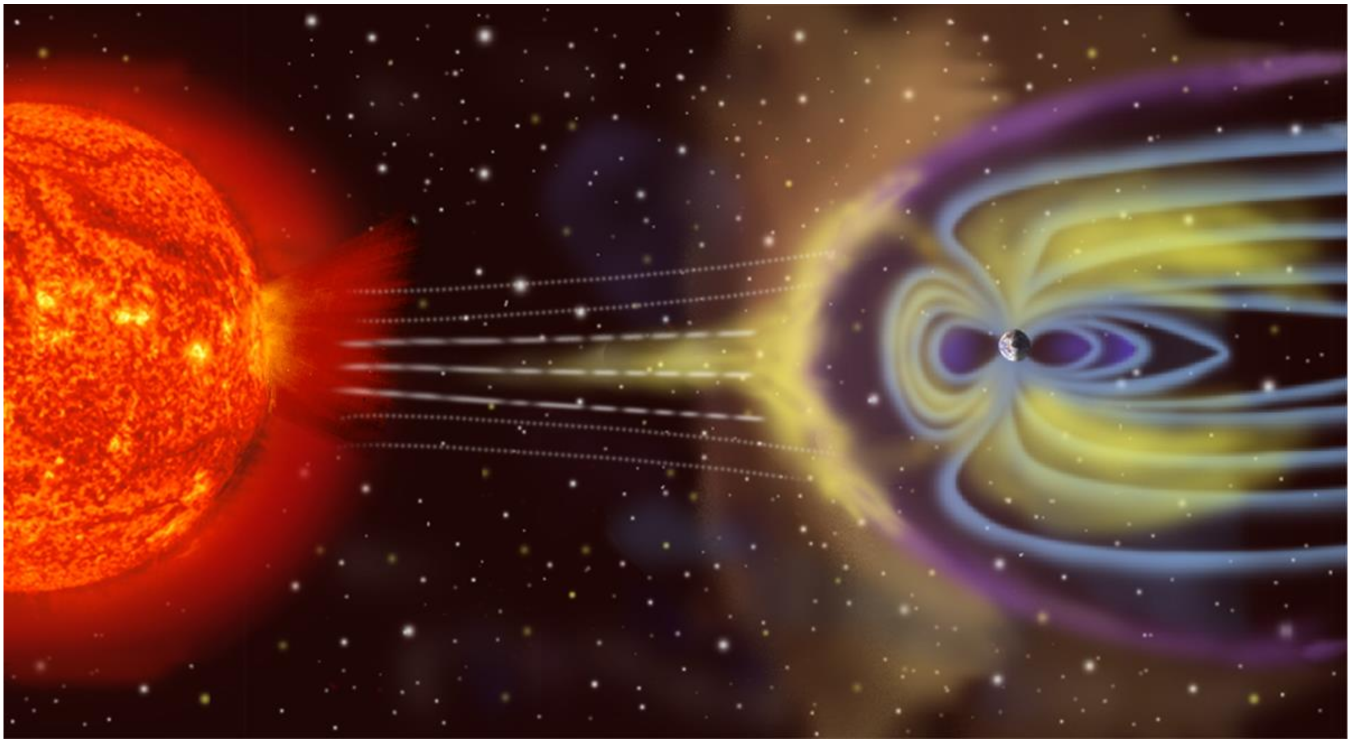
## AHA! Moments

What content from this week really resonated with you, helped you understand something you've always wondered about, or made you think about the world with new eyes?

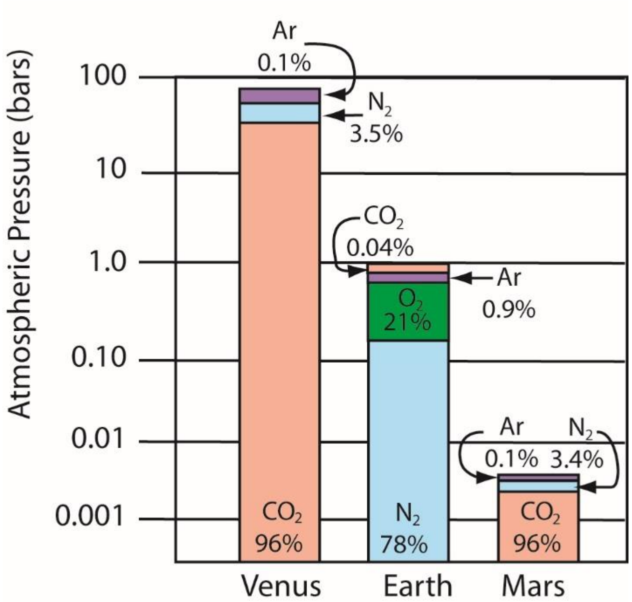
# WATER PLANET



*Time-progressive image of the Solar System formation through condensation from a nebula, increasing rotation into a disk, and planetary accretion from debris orbiting the sun.*

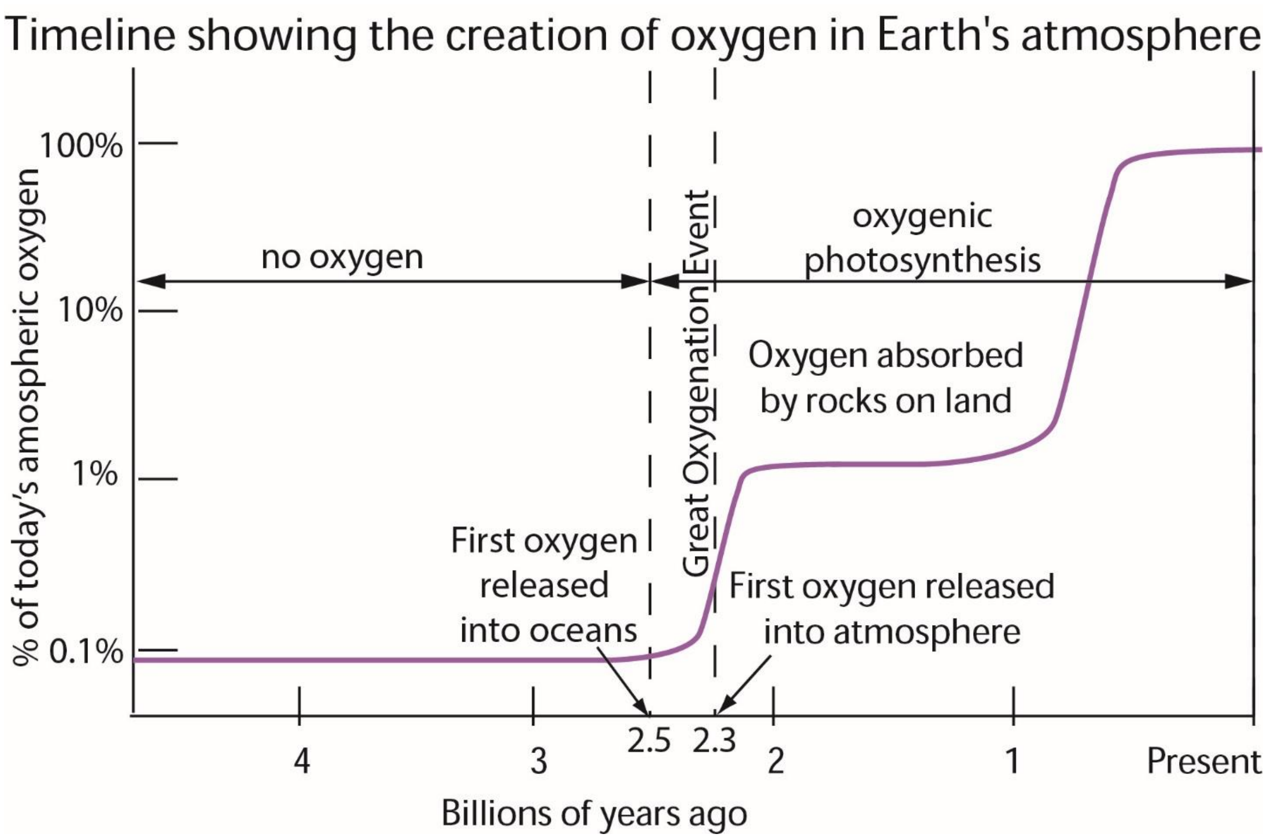


*Solar winds blowing towards Earth and deflected by Earth's Magnetic Field. (NASA)*

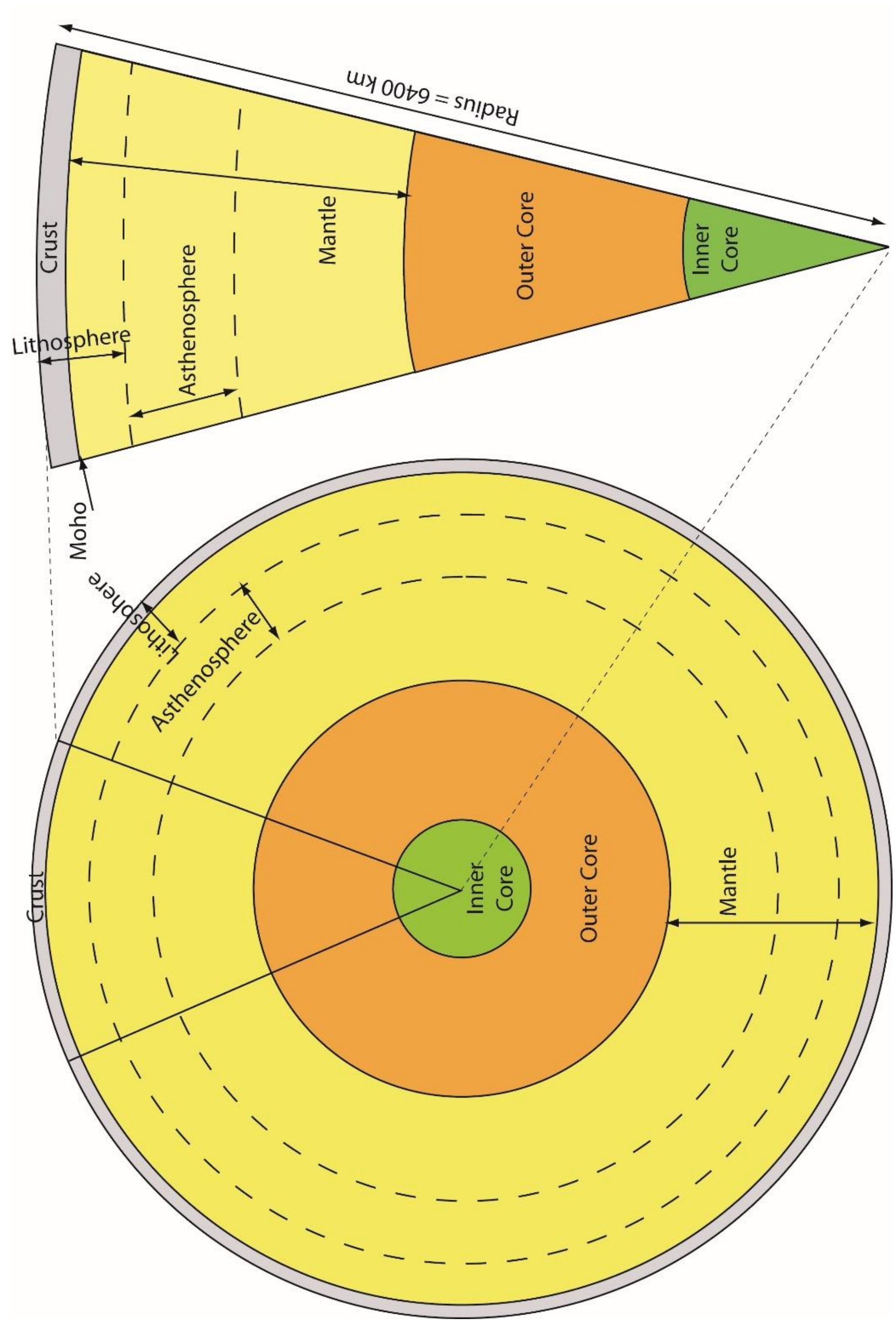



*Graphical comparison of the major gas components of the atmospheres of Earth and its neighboring planets, showing $CO_2$ as the dominant gas on Mars and Venus, while only a minor component on Earth.*

| **Composition of Earth's early atmosphere:** | **Composition of Earth's current atmosphere:** |
|---|---|
| In decreasing abundance | MAJOR |
| $CO_2$ (carbon dioxide) | 78% $N_2$ (nitrogen) |
| $N_2$ (nitrogen) | 21% $O_2$ (oxygen) |
| $H_2O$ (water vapor) | MINOR |
| $CH_4$ (methane) | 0-4% $H_2O$ (water) |
| $NH_3$ (ammonia) | 0.9% Ar (Argon) |
| CO (carbon monoxide) | 0.04% $CO_2$ (carbon dioxide) |
| $SO_2$ (sulfur dioxide) | |
| $H_2S$ (hydrogen sulfide) | |
| HCN (hydrogen cyanide) | |




*Oxygen likely first began being produced through photosynthesis, about 2.5 Ga. It either combined with dissolved iron to produce iron oxide minerals (rust) that settled to the seafloor and were buried OR it bubbled out into the atmosphere and was immediately used up in oxidizing the atmospheric gases. By 2.3 Ga, most of the dissolved iron in the oceans had been removed, and oxygen was starting to accumulate at levels of 1% of today's Oxygen levels in the atmosphere. We call this the Great Oxygenation Event. Oxygen in the atmosphere allowed for the first iron oxide minerals to form in surface rocks (above sea level). By about 700 Ma, the atmospheric gases were sufficiently oxidized, and oxygen began to accumulate in larger amounts in the atmosphere, bringing it to current day levels and allowing an ozone layer to form in the stratosphere.*




*Cross-section of Earth showing its layers (to scale, except for greatly exaggerated crust)*
*Note: the MOHO is the name given to the boundary between the crust and the mantle.*

| Layers | Thickness | Composition | Density/State |
|---|---|---|---|
| **Crust: Oceanic** | 3-10 km | Si, O, Fe, Mg, Al = Basalt | 2.9 g/cc SOLID |
| **Crust: Continental** | 30-50 km | Si, O, Al = Granite | 2.7 g/cc SOLID |
| **Mantle** | 2900 km | Mg, Fe, Si, O | 4.5 g/cc SOLID |
| **Outer core** | 2200 km | Fe, Ni (S, Si) | 11 g/cc LIQUID |
| **Inner core** | 1300 km | Fe, Ni (S, Si) | 16 g/cc SOLID |

Overlaid layers:

| | | | |
|---|---|---|---|
| **Lithosphere** | 100-200 km | 100% Crust + Upper Mantle | Rigid, solid, brittle: breaks into pieces: plates |
| **Asthenosphere** | 100-350 km | Portion of mantle | Plastic (flows), but solid |

# Brief History of Earth

***Notice that all these events are listed in reverse chronological order – oldest at bottom of table, youngest at top.***

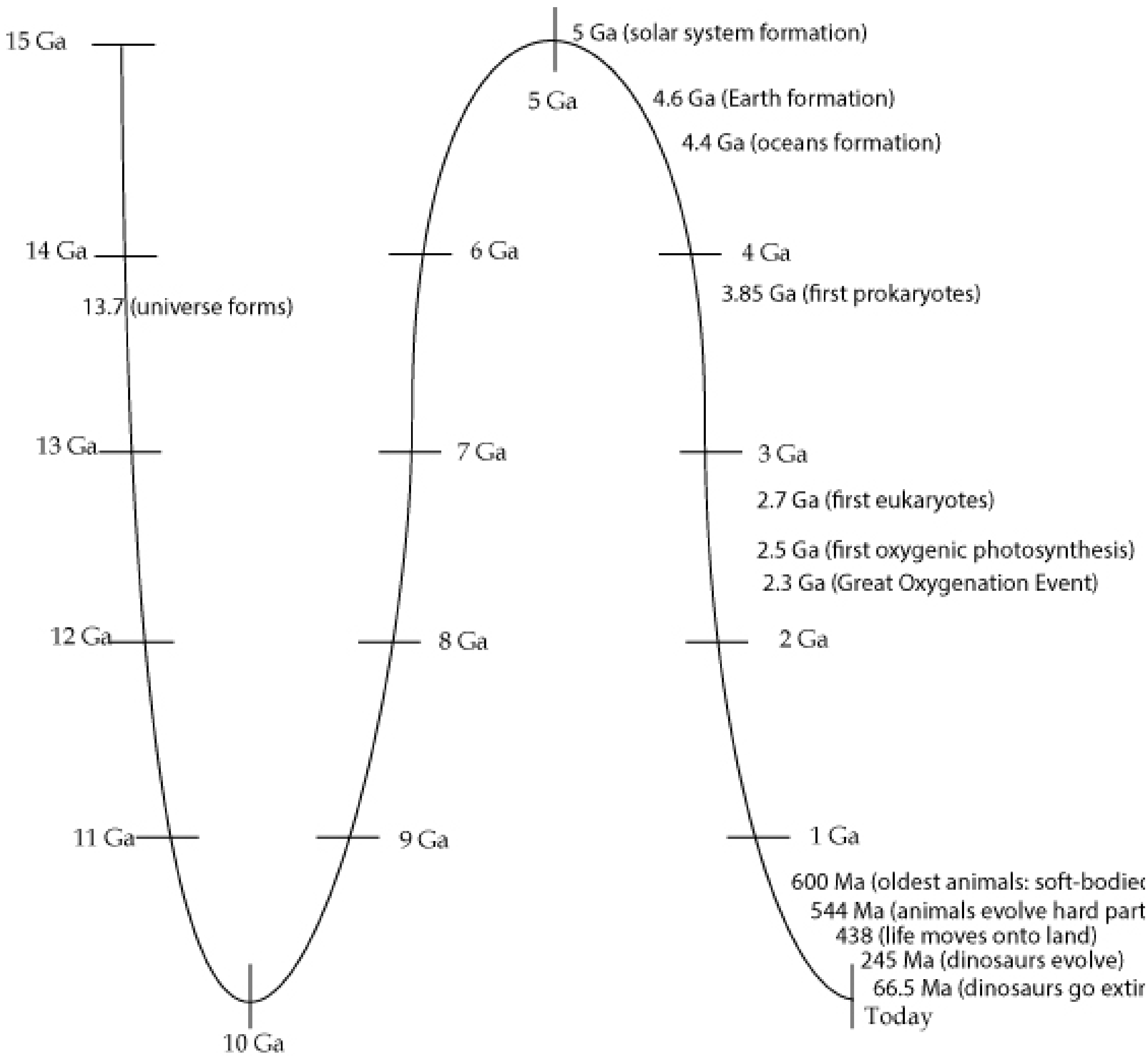
| | |
|---|---|
| 10-25 Ka | Wisconsin ice age (most recent one; land bridges form and humans migrate from Asia into North America) |
| 100-300 Ka | Homo Sapiens first appear. |
| 400 Ka | San Francisco Bay forms. |
| 1.6 Ma | Period of frequent ice ages begins and continues to today. |
| 2-4 Ma | Ancient Hominids first appear. |
| 50-25 Ma | San Andreas Fault forms as North American margin stops subducting. |
| 63 Ma | Primates evolve. |
| 65 Ma | Dinosaurs and other organisms go extinct making the way for the Age of Mammals. |
| 145 Ma | First mammals, including platypus, shrews, and opossums. |
| 152 Ma | First birds evolve from small, fast-running dinosaurs. |
| 230 Ma | First dinosaurs, reptiles that distinguished themselves by standing upright on two legs. |
| 240 Ma | First vertebrates to fly – the Pterosaurs, dinosaur cousins. |
| 245 Ma | The largest mass extinction in Earth's history. Over 75% of all marine groups eliminated, making way for the Age of Dinosaurs |
| ~300 to 200 Ma | **Pangaea**, the most recent supercontinent, completes its formation around 300 Ma (possible 335 Ma), and then begins to break up around 200 (or 175 Ma) into two halves: **Gondwanaland** (Australia, India, Africa, S. American, and Antarctica) and **Laurasia** (N. America, Greenland, Europe, and Asia). |
| 350-290 Ma | Giant Swamp Forests thrived in lowlands at the edges of rivers and seas (like today's Louisiana bayous). Tropical climates encouraged dense growth of ferns, tree ferns, and club-mosses. The buried material from these forests eventually became much of the world's current coal resources. |
| 400 Ma | First lungs. |
| 430 Ma | First jawed fish. |
| 438 Ma | First plants move onto land, followed within 10 million years by animals (aquatic scorpions and other arthropods). |
| 480 Ma | Large continent known as **Gondwanaland** forms from the collision of Australia, India, Africa, South America, and Antarctica.<br>Pacific Plate subducts under North America's western margin. The western margin grows through accretion of oceanic rocks and islands (**terranes**). |
| 520 Ma | First vertebrates (cartilaginous fish with tails and fins). |
| 570 Ma | First organisms with hard parts. Beginning of the Age of Trilobites. Also existing early on were brachiopods and ammonites. |
| 670 Ma | First multicelled animals evolve: Ediacaran fauna, soft-bodied marine animals that get their food primarily from small algae. |
| 700 Ma | **Rodinia** breaks up into pieces. |
| 1 Ga | Sexual reproduction begins leading to an increase in the rate of evolution. Red Beds stop forming in large amounts and free oxygen begins to accumulate in the atmosphere. The atmosphere begins to evolve to one closer to today's: 80% Nitrogen, 20% Oxygen. Eventually enough oxygen accumulates in the atmosphere that UV radiation interacted with it in the upper atmosphere to produce **ozone**, a gas that then acts as a UV shield, protecting life on Earth's surface. |
| 1.2 Ga | **Rodinia**, the oldest known supercontinent, forms through collision of Earth's plates. Plate Tectonics has likely been active for billions of years. |
| 2.3 Ga | **Great Oxygenation Event: Red Beds** form on land. These beds are land-based rust piles that take the place of the oceanic banded iron formations as free oxygen now leaves the oceans and enters the atmosphere. The Red Beds absorb most of the available oxygen. |
| 2.5 Ga | **Oxygenic photosynthesis.** $6H_2O + 6CO_2$ + sunlight = $C_6H_{12}O_6$ (sugar) $+6O_2$.<br>Ocean and atmospheric chemistry begins to change as $O_2$ is added and $CO_2$ removed.<br>Largest deposit of **Banded Iron Formations (BIFs)**. Earth's oceans would have had a lot of dissolved iron, due to the accumulation of hundreds of millions of years of rock weathering and underwater volcanic eruptions. Oxygenic photosynthesis produced sufficient oxygen gas to readily and quickly combine with the iron to form large deposits of rust. |
| 2.7 Ga | **Eukaryotes** evolve: organisms with a nucleus. |

| | |
|---|---|
| 3.7 Ga | Earliest evidence of stromatolites: layered rock mounds formed in shallow oceans as mats of cyanobacteria dome upward to capture energy from sunlight to produce sugar through anoxygenic photosynthesis. Live in mucous layers to avoid UV-radiation damage to the sun. |
| 3.85 Ga | Earliest evidence of microbial activity (carbon isotope ratios). This early life likely lived in the oceans where they were hidden from the sun's ultraviolet rays (no ozone layer yet, because no oxygen in the atmosphere). These early bacteria were known as **prokaryotes**: single celled organisms with no nucleus, otherwise known as bacteria. These early life forms were likely **chemosynthetic**, making food from energy derived from gases emitted at hydrothermal vents on the bottom of the seafloor. |
| 4.4 Ga | Earth's surface cools enough for a solid crust to form. Earth's atmosphere (accumulated gases from **volcanic outgassing** and comets) contains (in decreasing order) carbon dioxide, nitrogen, water vapor, methane, ammonia, carbon monoxide, sulfur dioxide, hydrogen sulfide, and hydrogen cyanide. Because of the solid cooler surface conditions, much of the atmospheric water now rains down and fills in basins to form the first oceans. |
| 4.5 Ga | A Mars-sized object crashes into Earth creating debris that ends up in orbit around the Earth, eventually coalescing through accretion to form the **Moon**. |
| 4.6 Ga | As the solar disk cools down, orbiting material collides and clumps to form larger objects (**accretion**). Continued accretion led to larger bodies with higher gravity that swept up more material within their orbits and ultimately became **planets**. Not all the material got swept up in this process. A large belt of leftover rocky debris – **asteroids** – exists between Mars and Jupiter. A belt of leftover icy debris – **comets** – orbits in the outer solar system.<br>At this point, the interior of the Earth is mostly molten from the heat of accretion. **Density stratification** occurs: dense material, like iron, sinks to form the **core** while less dense material rises to form the **crust**; the remainder becomes the **mantle** layer. All planets are hot from the accretion process. Volcanic activity and continual meteorite collisions dominate the surface. Gases from volcanoes and comets form an early, hot, toxic, atmosphere. |
| 5 Ga | Debris from past supernovas is perturbed, likely by nearby star activity, and starts to clump together to form a new star – a single hot, spinning mass of gas – our proto Sun. The gas giants (Jupiter, Saturn, Neptune, and Uranus) began forming soon after the Sun started coalescing, through similar processes. Large clumps of H and He separately coalesced and contracted, increasing in density and attracting material to become gas giant protoplanets. They are not stars because they never grew big enough and hot enough for fusion to occur in their cores. Eventually the material in the proto Sun completely condenses, fusion starts, and our **Sun** forms. As the Sun spins, the surrounding matter flattens into a rotating disk and begins to condense into solids, liquids, and gases – all very hot! It was too hot near the Sun for ices and many gases (like water, ammonia, and methane) to be stable, so condensates near the Sun consisted of iron oxides, aluminum oxides, and silicates – high-density minerals stable at high temperatures. In the cooler outer solar system, all materials were stable and condensed alongside each other. Hence, the inner rocky planets formed from the accretion of rocky material, whereas the moons, comets, and gas giants of the outer solar system formed (or completed their formation) from the accretion of all materials. |
| 12.7-5 Ga | Throughout most of the life of a star, deep in their cores, H nuclei are fused to produce He and energy. Stars "shine" because they are radiating the energy produced from this nuclear fusion. High-mass stars burn the hydrogen fuel in their core rapidly and are short lived—the largest lasting only 10 million years. Low-mass stars burn their fuel slowly—the smallest lasting hundreds of billions of years. (Note: our **Sun** is medium sized and will last 10 billion years.) Once the H is nearly used up, He atoms begin to fuse, and the core temperature of the star rises dramatically. As temperatures rise higher, elements of successively higher mass—like carbon, nitrogen, and oxygen—are produced through fusion. Stars that are ten times more massive than the Sun can create elements as heavy as iron. Eventually the energy produced can't be shed fast enough; a high-mass star explodes in a **supernova** event, ejecting much, if not all of its matter, and producing a **supernova remnant**. Elements up to uranium can form in the supernova's blast waves. New stars eventually form from supernova remnants. Through repeated generations of star birth and death by supernova, these remnants can be enriched enough in heavy elements to form planets. *(Based on the abundance of heavy elements in our solar system, our Sun is likely a third- or fourth-generation star.)* |

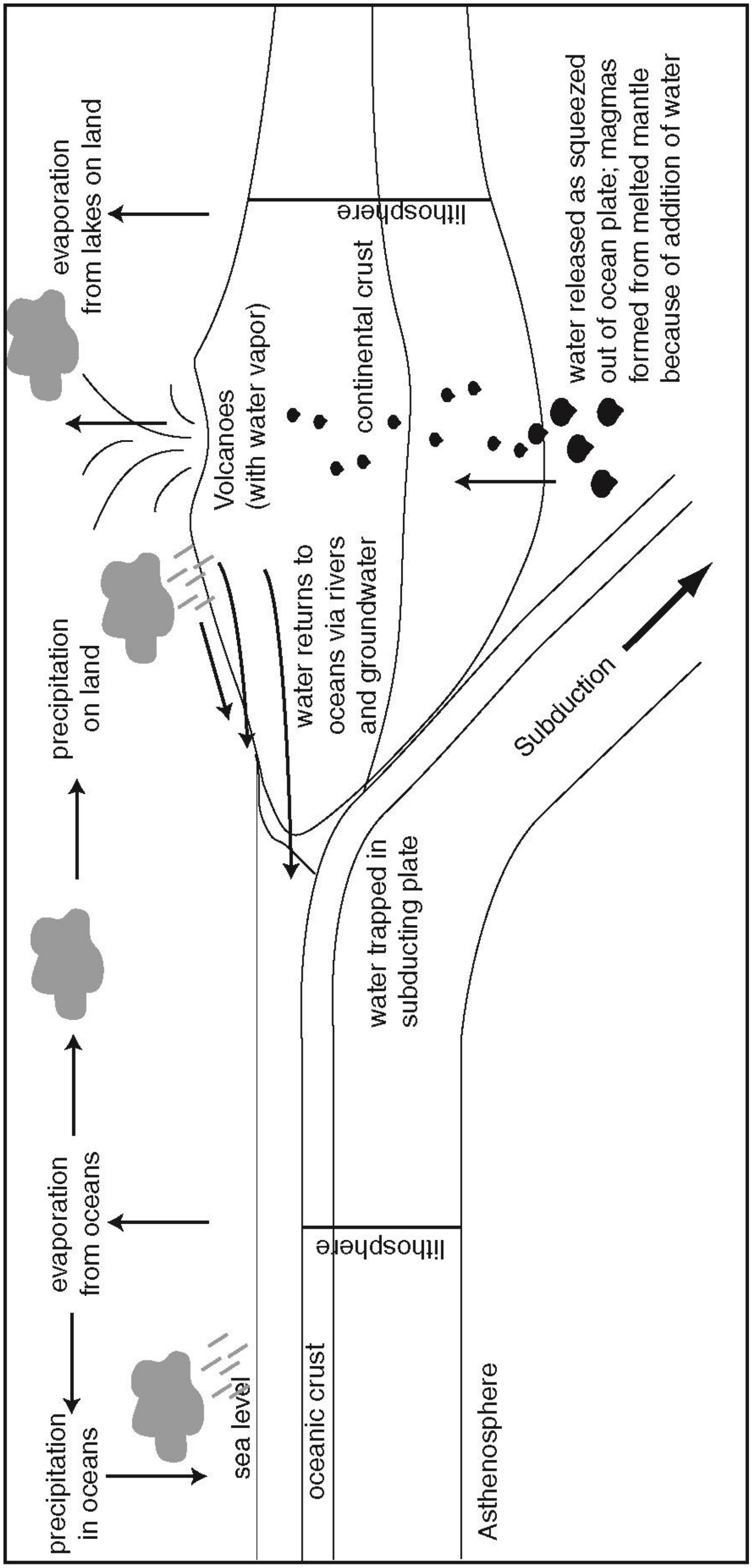
| | |
|---|---|
| 12.7 Ga | The universe is no longer smooth and uniform. High-density regions of H and He gas generate gravitational fields – the more mass, the more gravity. The more gravity, the more mass from surrounding areas is pulled in. Eventually localized regions condense under their own weight. Gravitational energy is converted into heat – temperature rises. Once the size of this dense spinning sphere of gas is great enough, and its core temperature rises above $10^6$ K, nuclear fusion begins – primarily the fusion of H to produce He and energy. As this newly created energy radiates outward, a shining **star** is born. When billions of stars orbit a shared center of gravity, we call them a **galaxy**. There are hundreds of billions of galaxies in the observable Universe. |
| 13.7 Ga | **Big Bang**: the universe is born in an instant in time and expands outwards from one infinitesimally small point. Original material = very high energy (hot) subatomic particles. Universe inflates and cools until protons, neutrons, and electrons form, and matter is governed by the laws of physics as we know them. 380 m.y. later, the universe is 75% Hydrogen (H) and 25% Helium (He) gas. |

*Age is when division begins: Ka = thousands of years old; Ma = millions of years old; Ga = billions of years old.

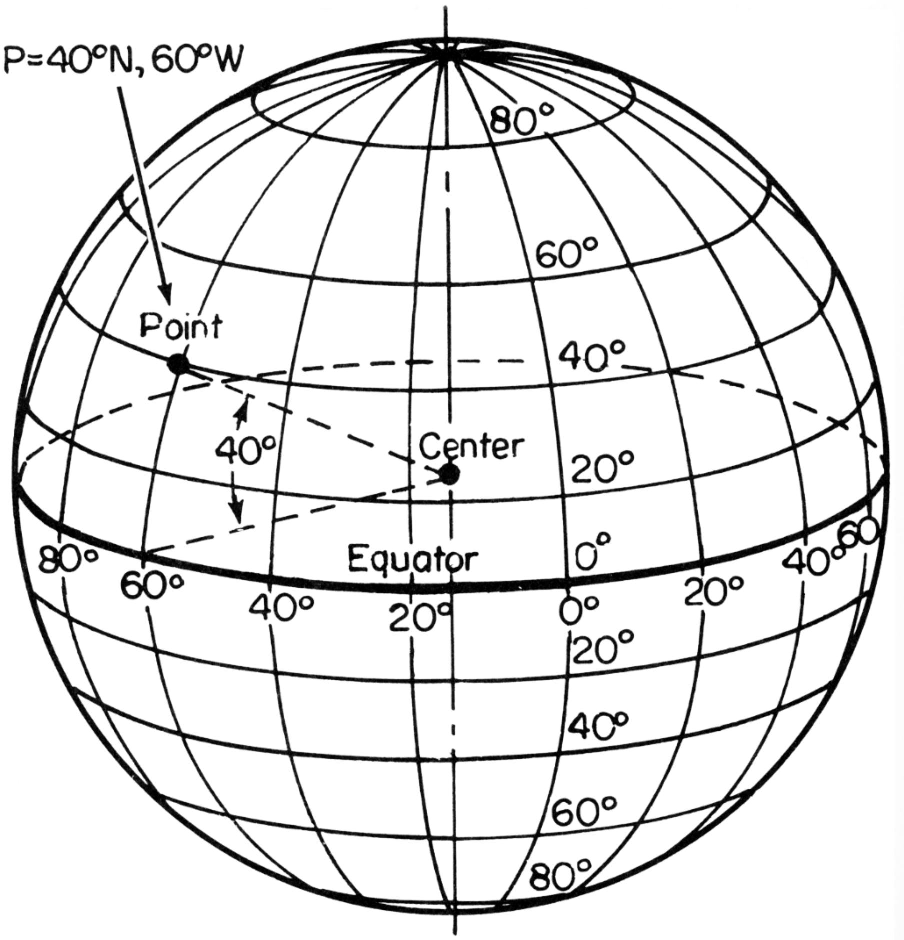
You can find this timeline laid out in a walk along the four floors of the CCSF, Ocean Campus Science Building. It is supported by panels, posters, fossils, murals, and models. You can also find the entire exhibit transcribed and photographed online at http://www.ccsf.edu/TimeLife.




*Scaled timeline of the history of the Universe from 13.7 Ga to today.*
** Ma = millions of years old; Ga = billions of years old.*




*Cross section through the top layers of Earth, including the atmosphere, showing movement of water through various reservoirs as part of Earth's Hydrologic Cycle.*




*Transparent globe cut by latitude and longitude. Image from National Oceanographic Partnerships Program – NOPP Drifters – (after Charton, 1988)*

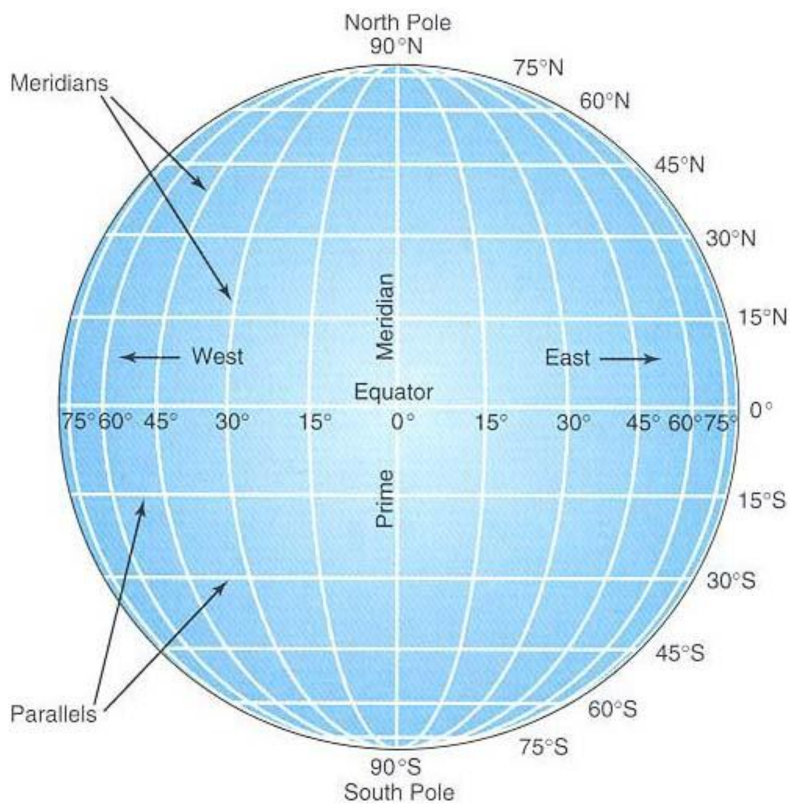



*Image Source Unknown*

# Water Planet Chapter Worksheet

| | |
|---|---|
| 1. The term used to describe the formation of the Universe from a single point is: | 2. Age of Universe? |
| 3. How do we know the age of the Universe? | |
| 4. Earth's formation: CIRCLE ALL THAT APPLY:<br>Processes/Characteristics: Accretion \| Collisions \| Gravity pulled \| Hot<br>Materials: Gas \| Comets \| Asteroids | 5. Age of Earth? |
| 6. How do we know when Earth formed? | |
| 7. Define **density**. Explain how objects of different density behave with each other when free to move in a liquid or gas. | |
| 8. What behavior do all liquid or plastic solids near a heat source exhibit? | 9. What drives the behavior? |
| 10. What major process formed Earth's layers? (Describe) When? | |
| 11. Which ONE layer **within** the Earth is **liquid**? | 12. What does this **liquid** layer produce or lead to globally? |
| 13. Which ONE layer **within** the Earth is **plastic**? | 14. What does this **plastic** layer produce or lead to globally? |
| 15. Sources of water to the early atmosphere of Earth:<br>CIRCLE ALL THAT APPLY: original nebula \| comets \| asteroids \| volcanoes) | |
| 16. When did these sources of water and other gases start collecting in the atmosphere (first atmosphere)? | |
| 17. When did first oceans form? (time when planet cooled enough and water in atmosphere finally **precipitated**): | 18. When did life evolve on Earth? |
| 19. Which type of organism can turn energy into sugar? CIRCLE: AUTOTROPH \| HETEROTROPH \| BOTH | |
| 20. Which type of organism can perform **photosynthesis**? CIRCLE: AUTOTROPH \| HETEROTROPH \| BOTH | |
| 21. Which type of organism performs **respiration**? CIRCLE: AUTOTROPH \| HETEROTROPH \| BOTH | |
| 22. What types of organisms first evolved that were able to perform photosynthesis? | |
| 23. What's the evidence for the evolution of oxygenic photosynthesis? | |
| 24. When did the first oxygenic photosynthesizers evolve? | 25. When did early life first leave the oceans and move onto land? |

26. Review table of planetary atmospheres in preceding figure pages.
Compare Earth's early and current atmospheric compositions.

| What major changes occurred? What's different? *(What appeared? What disappeared?)* | Why? For every appearance, explain why. For every disappearance, explain why. |
|---|---|
| | |

27. What % of the Earth's surface is covered by oceans?

28. In the image to the right, label each ocean: Arctic | Atlantic | Indian | Pacific

29. Which is the **biggest** ocean?
CIRCLE: Arctic | Atlantic | Indian | Pacific

30. Which is the **smallest** ocean?
CIRCLE: Arctic | Atlantic | Indian | Pacific

*World Physical Map (CIA/Public Domain)*

| 31. Which is greater in magnitude? (CIRCLE) | **Deepest spot on planet** | **Tallest spot on planet** |
|---|---|---|
| **VALUES IN METERS:** | | |
| **NAME:** | | |

| 32. Which is greater in magnitude? (CIRCLE) | **Average elevation of continental crust** | **Average depth of ocean crust** |
|---|---|---|
| **VALUES IN METERS:** | | |

33. Which is the **shallowest** ocean? CIRCLE: Arctic | Atlantic | Indian | Pacific

34. Which is the **deepest** ocean? CIRCLE: Arctic | Atlantic | Indian | Pacific

35. What % of Earth's water is held in the oceans?

36. What is the term used to describe the process whereby liquid water from the oceans turns into vapor that is transported into the atmosphere?

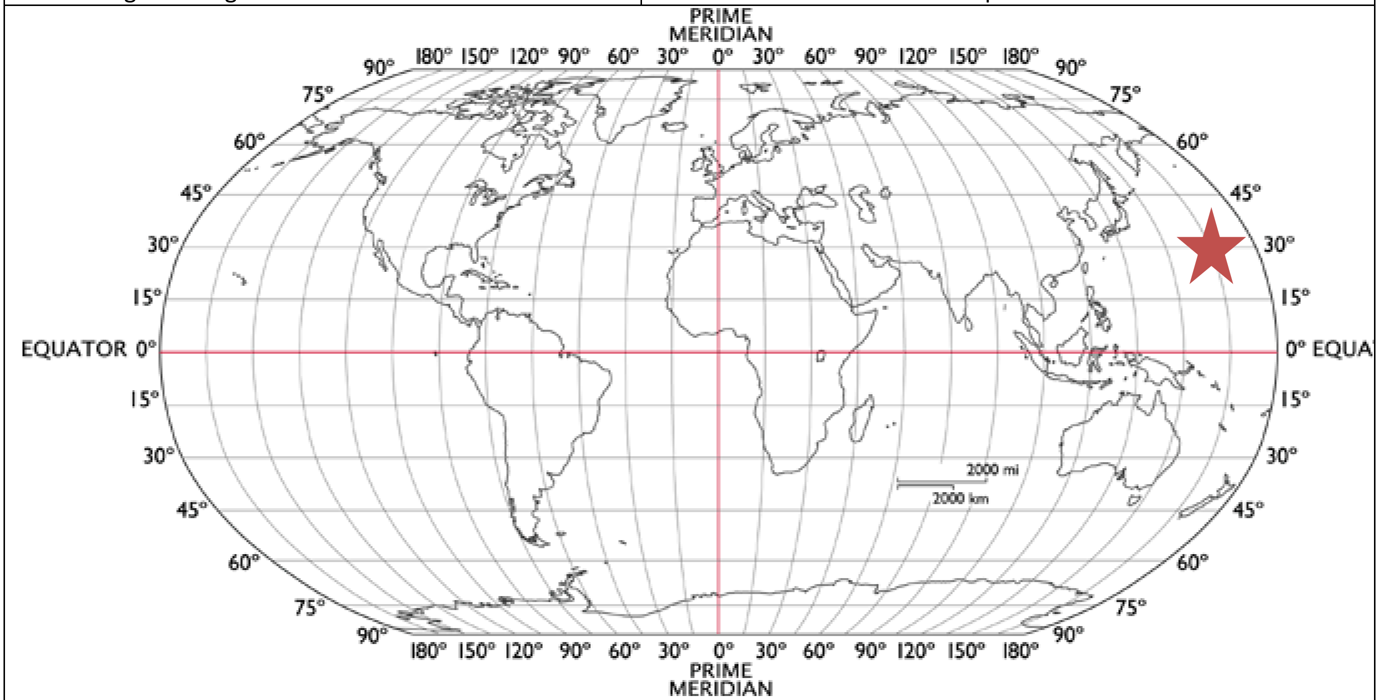
37. What is the term used to describe the process whereby water vapor from the atmosphere turns back into liquid water that drops into the ocean?

| 38. What major energy source drives the above transport? | 39. What is the residence time of an Ocan 1 student in this class? |
|---|---|

40. Where does water go when it leaves the oceans (SINKS)? CIRCLE: atmosphere | subduction zones | rivers | glaciers | sea ice | groundwater | ocean crust cracks | volcanoes

41. Where does the water in the oceans come from? (SOURCES) CIRCLE: atmosphere | subduction zones | rivers | glaciers | sea ice | groundwater | ocean crust cracks | volcanoes

| | |
|---|---|
| 42. How deep does sea level drop during an ice age? | 43. What is the name of the feature that marks this depth? |




*Source unknown*

44. What is the latitude and longitude of the southern tip of <u>Greenland</u> relative to the equator and prime meridian?

45. What is the latitude and longitude of southern tip of <u>Africa</u> relative to the equator and prime meridian?

46. What is the latitude and longitude of the <u>STAR</u> relative to the equator and prime meridian?

| | |
|---|---|
| 47. 45 W = Latitude \| Longitude (Circle correct one) | 48. 15 S = Latitude \| Longitude (Circle correct one) |

49. Place an X on the map at above coordinates (45W and 15S).

50. How does the **International Date Line** relate to the prime meridian?

51. What is **a nautical mile** and how does it relate to a statute mile? (A **knot**?)

52. What's wrong with these values?
100N and 300E

53. 1 degree of longitude at 60 North is the (circle: same | more | less) than 1 degree of longitude at the equator

# Photosynthesis, Chemosynthesis, Respiration, and Decomposition Activity

All living organisms on our planet can be classified as **autotrophs** (organisms that make their own food/stored energy) or **heterotrophs** (organisms that must eat/ingest other organisms to meet their food/energy needs). Autotrophs make food (sugar, which is stored energy) through two different processes. The primary method (most efficient and prevalent) is **photosynthesis**. All photosynthetic organisms contain a pigment called chlorophyll. This pigment absorbs sunlight (the color is green, so all colors of sunlight are absorbed except green, which is reflected and is what we see). The chlorophyll absorbs the sunlight so that it can be present as an energy source during photosynthesis. For **oxygenic photosynthesis**, water and carbon dioxide molecules are combined using energy from the sunlight. A sugar molecule is produced from this combination, along with a waste gas, oxygen, which is released to the environment. **Nonoxygenic photosynthesis** uses light energy to combine molecules available in the environment to produce a sugar molecule, depositing minerals such as iron oxides or sulfides as byproducts (no oxygen gas). **Chemosynthesis** happens when there is no sunlight. Instead of using solar energy, these unique autotrophs capture the energy of gases, such as methane and hydrogen sulfide. This energy is used to combine molecules available in the environment to produce a sugar molecule, with byproducts such as sulfuric acid (no oxygen gas).

Heterotrophs can't make their own food. They ingest other organisms and take the sugars in those organisms and burn them for energy. *(Note: autotrophs must also burn their sugars to produce energy when they need it for growth, reproduction, and motion.)* The burning of sugar to release its stored energy is called **respiration**. All organisms perform respiration when they need energy. During respiration, sugar is burned in the presence of oxygen, and water, carbon dioxide, and heat energy are produced.

Dead organisms and organic matter (like fecal pellets and discarded exoskeletons) will, over time, decompose thanks to the efforts of bacteria and other organisms. This **decomposition** is effectively the same process as respiration in that the sugar in the organic material is ingested by the bacteria and broken down in the presence of oxygen to release its original components.

**OXYGENIC PHOTOSYNTHESIS**

$6\ CO_2 + 6H_2O + \text{LIGHT ENERGY} \rightarrow C_6H_{12}O_6 + 6\ O_2$

carbon dioxide + water + sunlight → sugar + oxygen

**RESPIRATION or DECOMPOSITION**

$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6H_2O + \text{HEAT ENERGY}$

sugar + oxygen → carbon dioxide + water + heat

**CHEMOSYNTHESIS** $6\ CO_2 + 6H_2O + 3H_2S \rightarrow C_6H_{12}O_6 + 3H_2SO_4$

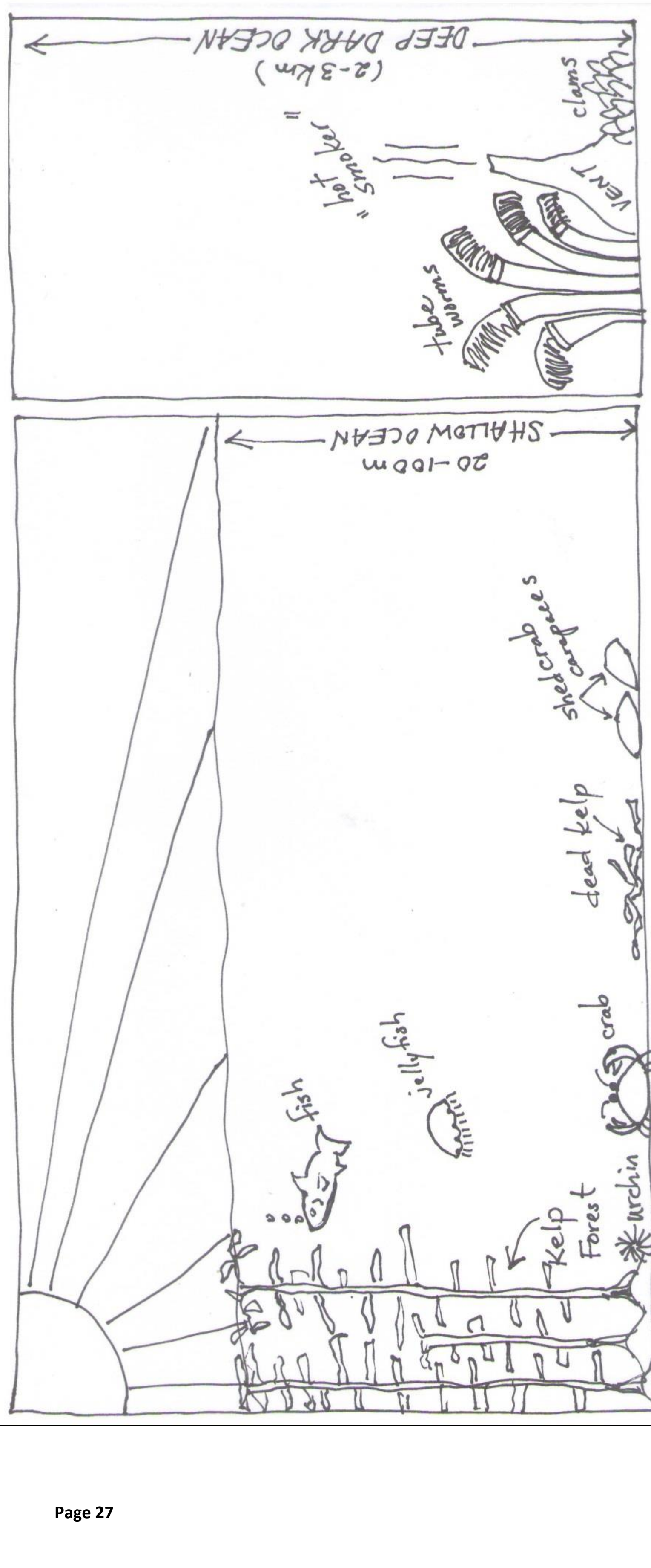
carbon dioxide + water + hydrogen sulfide → sugar + sulfuric acid

Each of these processes uses up some ingredients and produces others. When an ingredient is used up or removed from the environment in order to make the process move forward, the process is called a **SINK** for the ingredient. *Example: chemosynthesis is a SINK for hydrogen sulfide.* When an ingredient is produced at the end of the process, the process is called a **SOURCE** for that ingredient. *Example. Chemosynthesis is a SOURCE for sulfuric acid.*

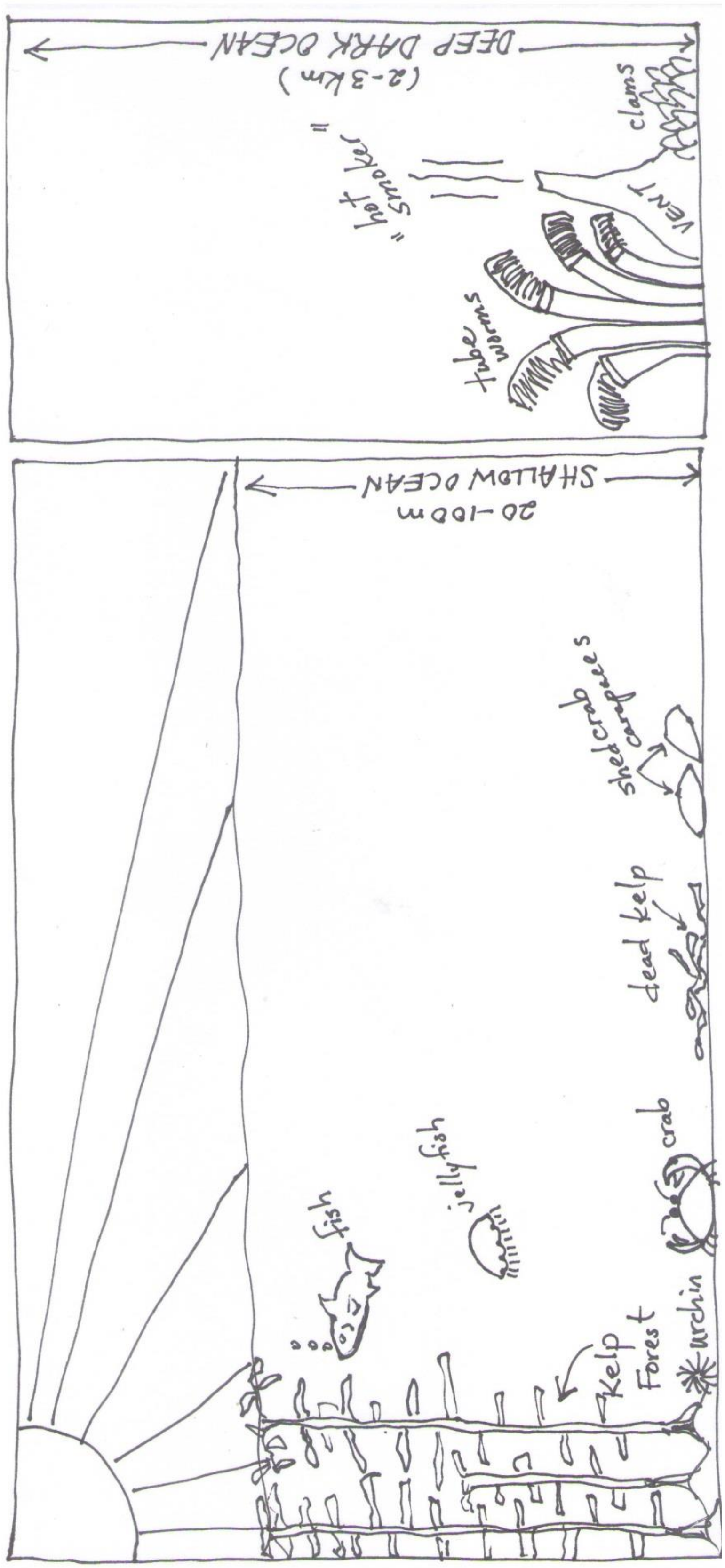
*Image used with permission: © hayes roberts 2016*

| | |
|---|---|
| 1. | Which process **is a SOURCE for oxygen** in the environment?<br>CIRCLE: Atmospheric Diffusion \| Chemosynthesis \| Decomposition \| Oxygenic Photosynthesis \| Respiration |
| 2. | Which process **is a SOURCE for carbon dioxide** in the environment?<br>CIRCLE: Atmospheric Diffusion \| Chemosynthesis \| Decomposition \| Oxygenic Photosynthesis \| Respiration |
| 3. | Which process **is a SINK for oxygen** in the environment?<br>CIRCLE: Atmospheric Diffusion \| Chemosynthesis \| Decomposition \| Oxygenic Photosynthesis \| Respiration |
| 4. | Which process **is a SINK for carbon dioxide** in the environment?<br>CIRCLE: Atmospheric Diffusion \| Chemosynthesis \| Decomposition \| Oxygenic Photosynthesis \| Respiration |
| 5. | Which organisms perform **photosynthesis**? Circle: autotrophs \| heterotrophs |
| 6. | Why? |
| 7. | Where does this process mostly occur in the oceans and why? |
| 8. | Which organisms perform **chemosynthesis**? Circle: autotrophs \| heterotrophs |
| 9. | Why? |
| 10. | Where does this process mostly occur in the oceans and why? |
| 11. | Which organisms perform **respiration**? Circle: autotrophs \| heterotrophs |
| 12. | Why? |
| 13. | Where does this process mostly occur in the oceans and why? |
| 14. | Where does **decomposition** mostly occur in the oceans? How and why? |
| 15. | Which process is used by organisms to convert environmentally available chemical energy (from energy gasses like $CH_4$ or $H_2S$) to combine water and gases and produce sugar for storage?<br>CIRCLE: Chemosynthesis \| Decomposition \| Photosynthesis \| Respiration |
| 16. | Which process **sucks up energy** (takes energy away from an environment)?<br>CIRCLE: Chemosynthesis \| Decomposition \| Photosynthesis \| Respiration |
| 17. | Which process **releases energy** into the organisms or environment?<br>CIRCLE: Chemosynthesis \| Decomposition \| Photosynthesis \| Respiration |

18. Turn the following image into a concept sketch/map that shows where all four processes (chemosynthesis, decomposition, photosynthesis, and respiration) are found in the oceans and how they relate. Use arrows to show the direction of flow of **<u>carbon dioxide</u>** (arrows point out of **sources** and into **sinks**).

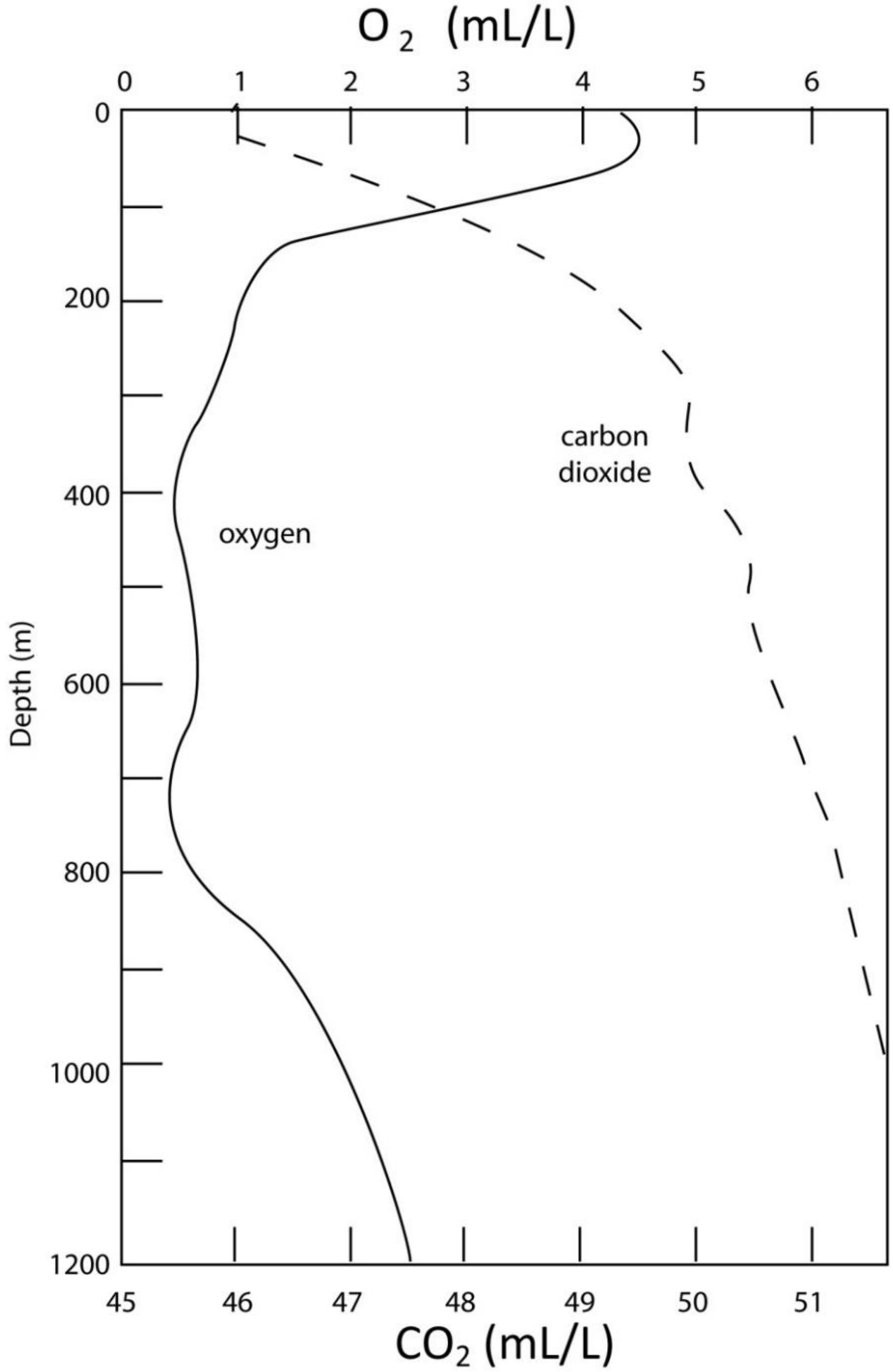


19. Turn the following image into a concept sketch/map that shows all four processes (chemosynthesis, decomposition, photosynthesis, and respiration) and how they contribute to the **oxygen cycle**. Use arrows to show the direction of flow of oxygen (arrows point out of **sources** and into **sinks**).



20. Now look at the Oxygen and Carbon Dioxide depth profiles shown to the right. Referencing the sources and sinks listed below, provide an explanation for what you see. Use text and arrows and circles, whatever you need!

- Atmospheric Diffusion
- Decomposition
- Oxygenic Photosynthesis
- Respiration




*General variations of the concentrations of carbon dioxide and oxygen with depth in the world's oceans.*

# Weekly Reflection

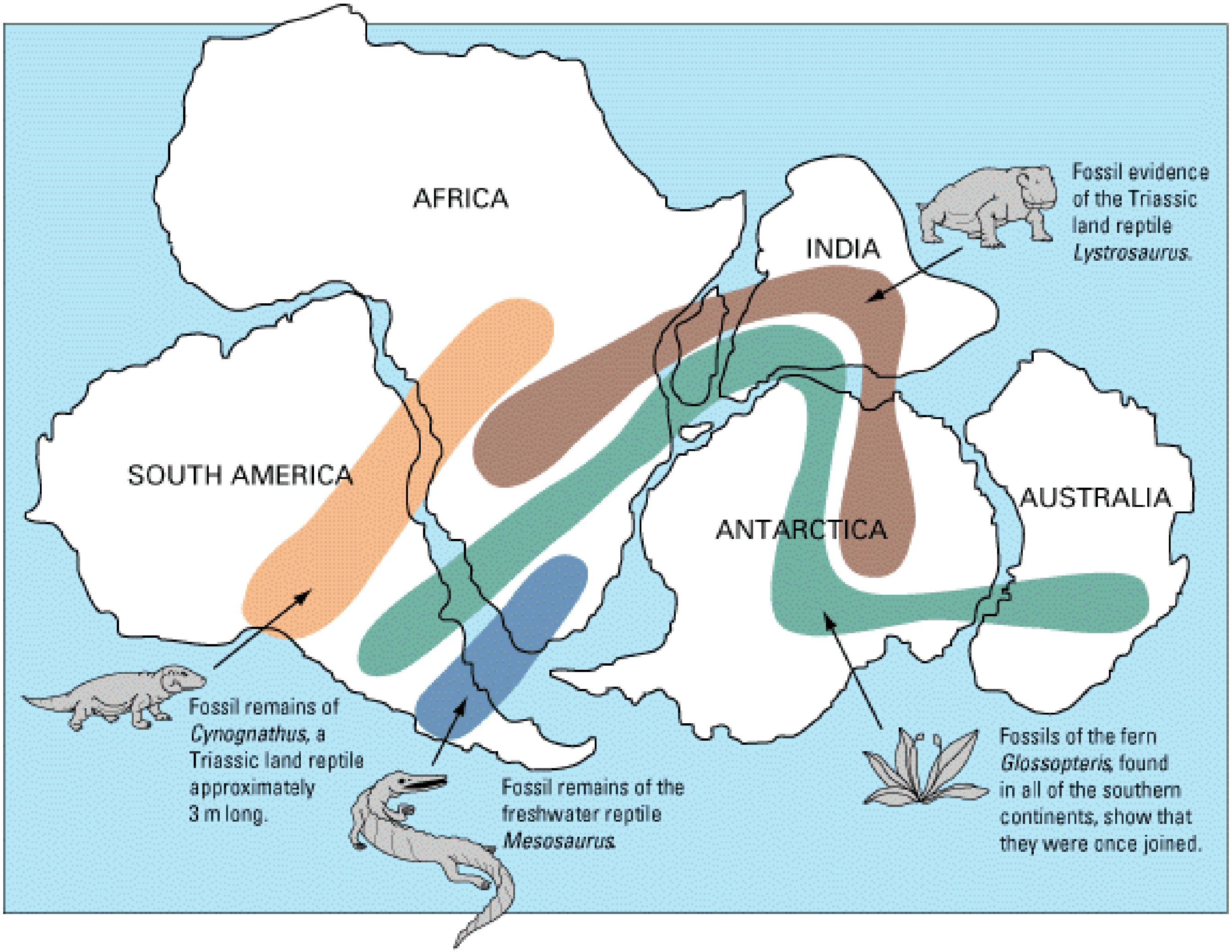
Take a moment to reflect on your comfort level and mastery of the week’s objectives and describe an action plan for how you will practice or improve on anything that challenged you.

| **Weekly objective** | **Self-assessment of mastery level** | **Action plan for improvement** |
|---|---|---|
| Describe how **Earth's oceans formed** and evaluating the evidence that supports it. | A \| B \| C \| D \| F | |
| Evaluate the **role the oceans have played** in the evolution of Earth's atmosphere and life. | A \| B \| C \| D \| F | |
| Identify **basic ocean geography and landforms** and interpreting their formation. | A \| B \| C \| D \| F | |
| Compare and contrast the various elements of the **Hydrologic Cycle**. | A \| B \| C \| D \| F | |
| Use **latitude and longitude** to identify location on Earth's surface. | A \| B \| C \| D \| F | |
| Compare and contrast **scales for time**. | A \| B \| C \| D \| F | |

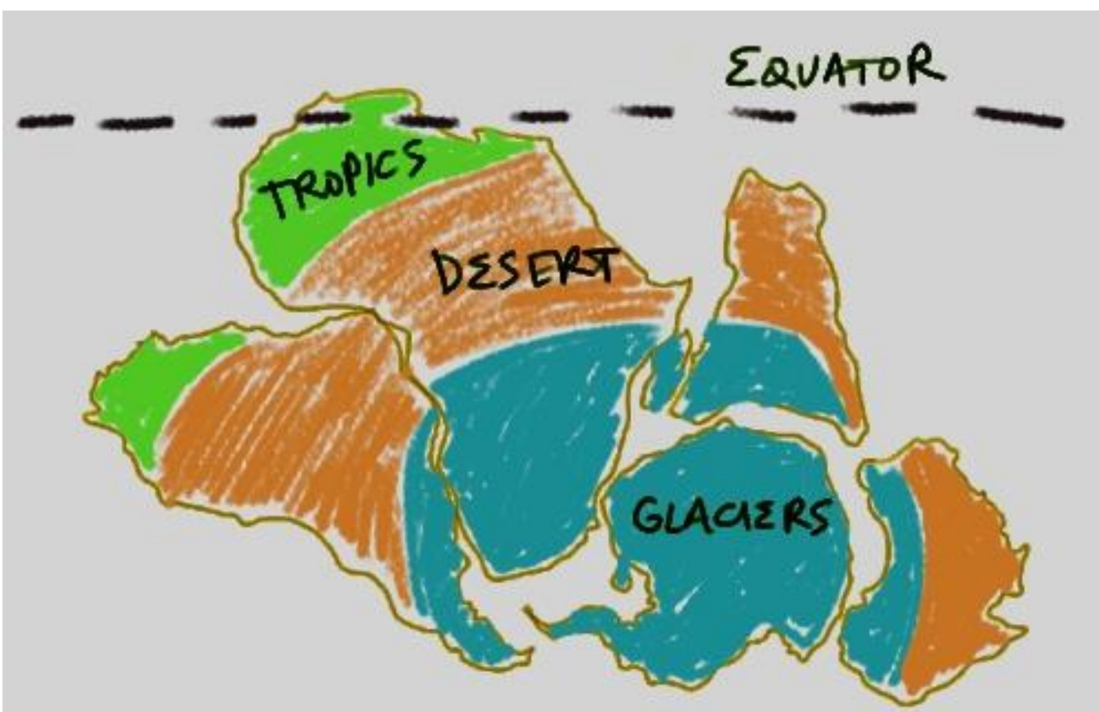
## AHA! Moments

What content from this week really resonated with you, helped you understand something you’ve always wondered about, or made you think about the world with new eyes?

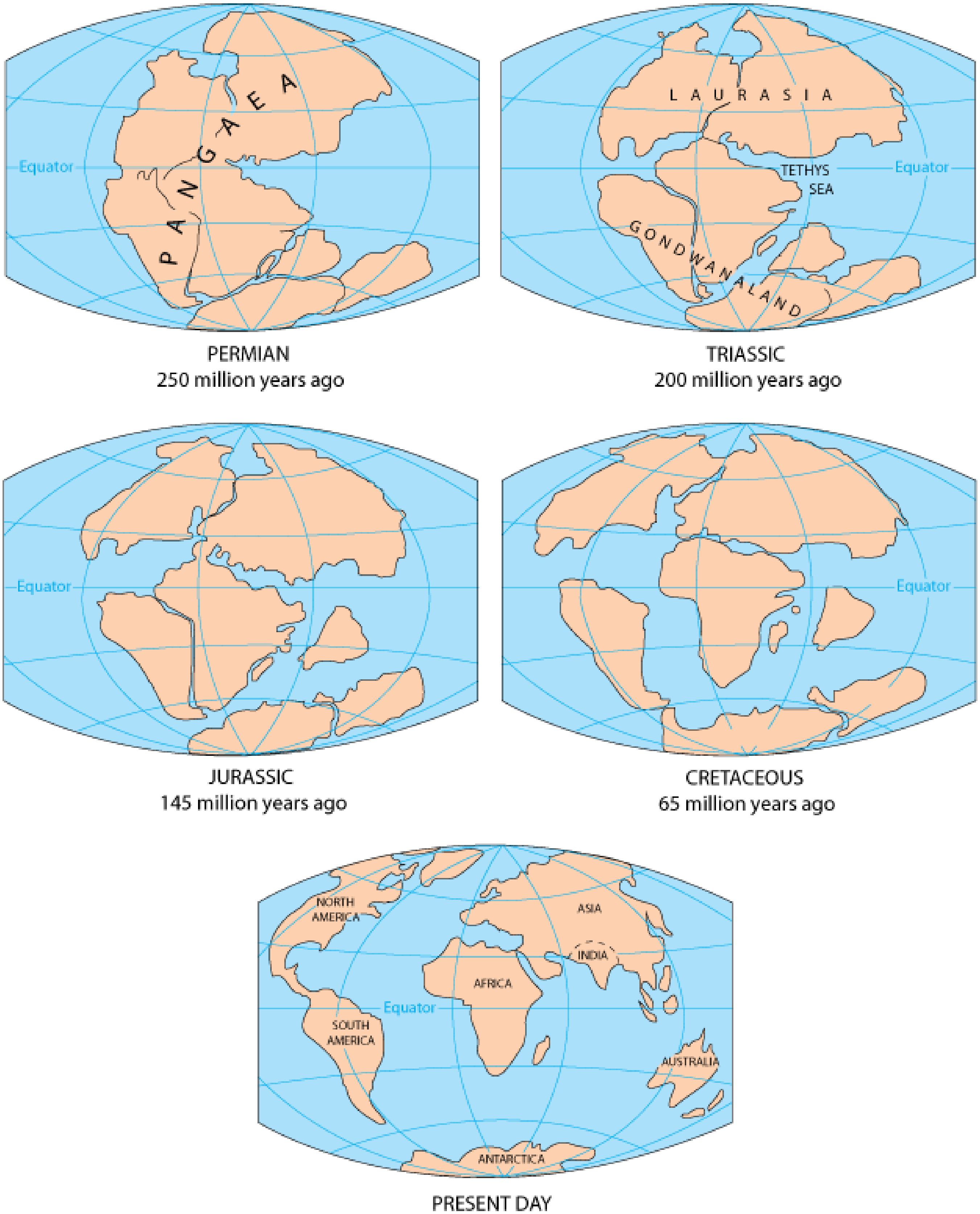
# PLATE TECTONICS



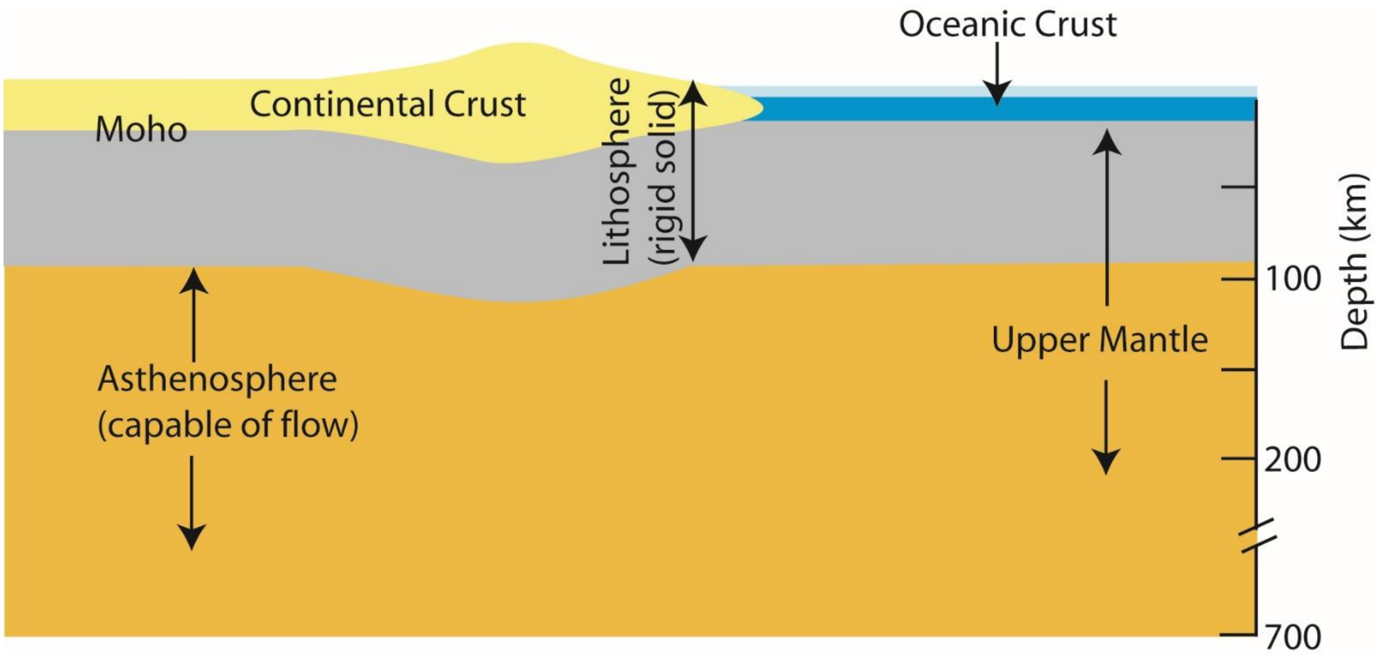

*Fossil evidence for continental drift since the time of during the time of Pangaea, about 250 Ma. USGS.*



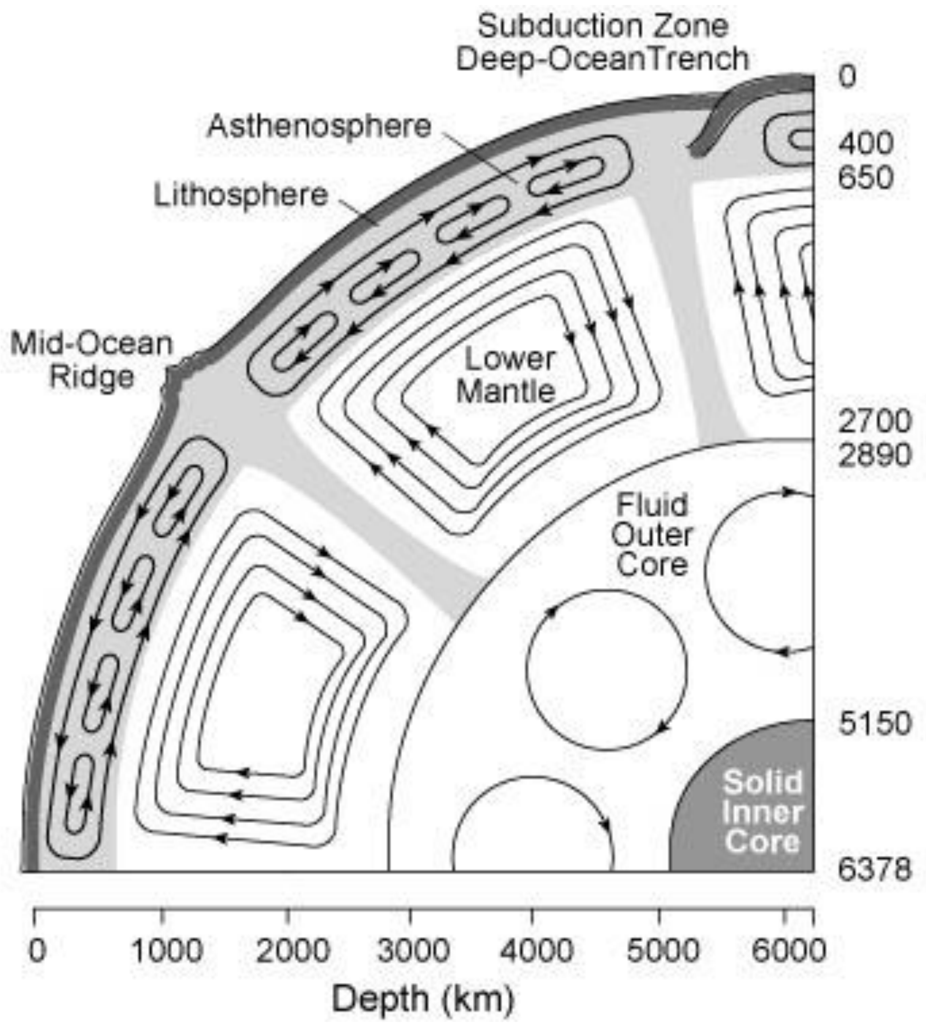

*Fossil and rock evidence of single polar ice cap during the time of Pangaea, about 250 Ma.*
*Eliza Richardson Creative Commons BY-SA-NC-3.0.*



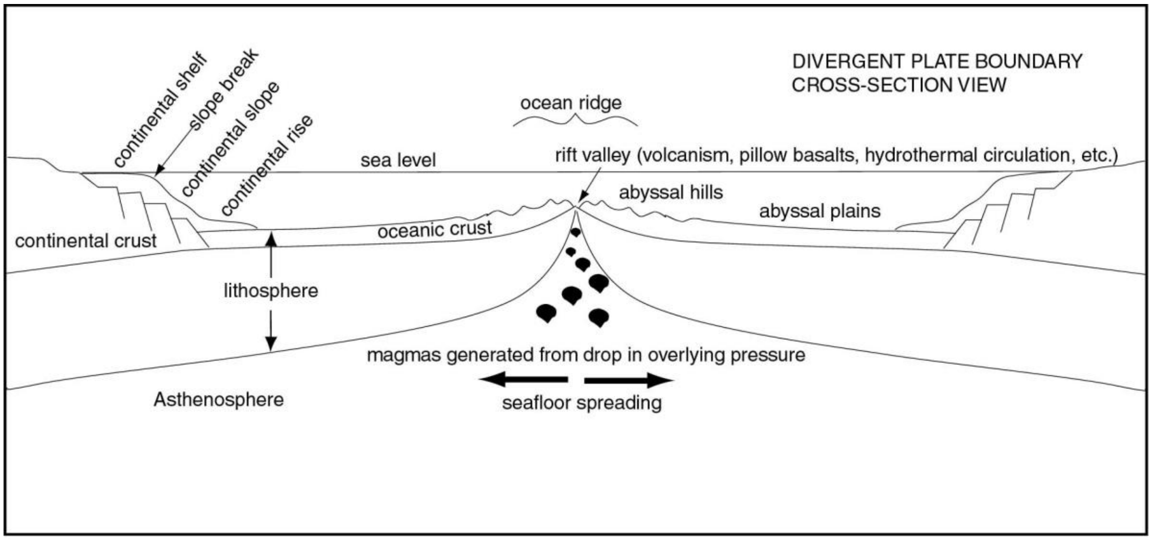

*Pangaea breakup. USGS.*




*Close-up view of the Earth layers involved in plate tectonics. The lithosphere contains ALL the crust plus the uppermost portion of the mantle; it is solid and breaks into pieces called plates, which then move around atop the underlying plastic mantle layer known as the asthenosphere. Convection of the hot plastic asthenosphere directs the motion of the plates above. The MOHO is the boundary between the crust and the mantle underneath. NOTE: The grey layer above has no name.*




*Convection of Earth's mantle, in asthenosphere and lower mantle. Also note the convection of the outer iron core. Note: the convection shown in the lower mantle is different from the rest because the material there is considered solid. The arrows represent the fact that lithospheric plates in subduction zones can descend all the way to the core-mantle boundary and that hotspot plumes can rise up from the core to the crust.*
*Image from Kenneth R. Lang's book The Cambridge Guide to the Solar System, Second Edition 2011.*

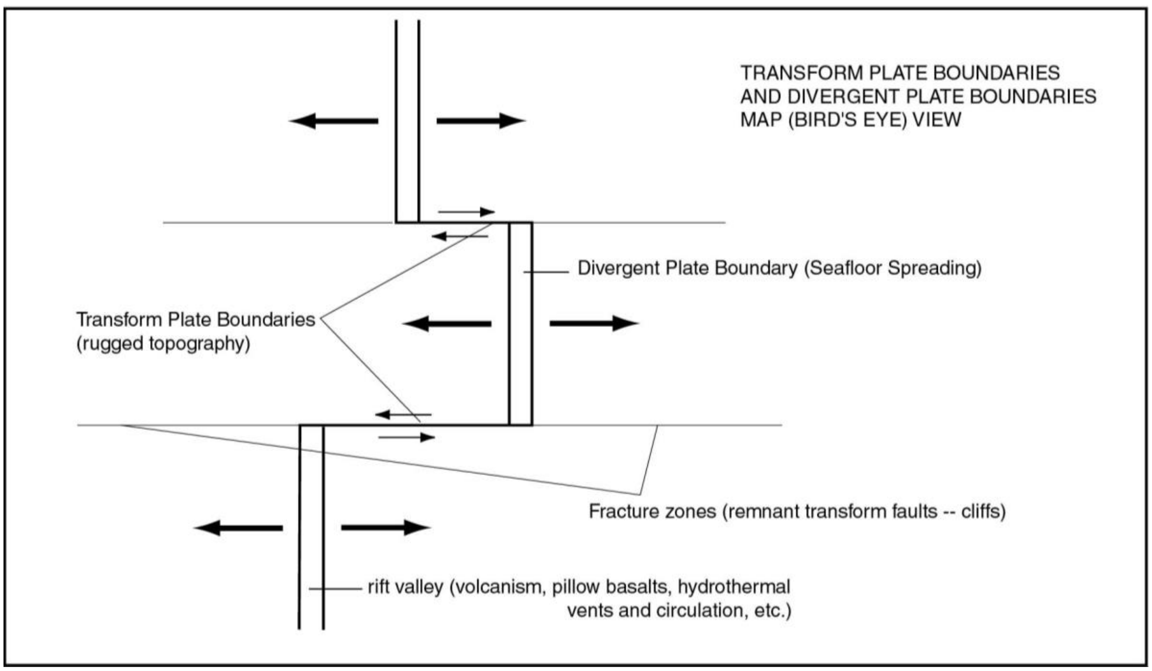



**DIVERGENT**

**MOTION:** Apart

**FEATURES:** Oceanic ridges. Seafloor spreading. Melted mantle rock due to reduced overlying pressure. Rift valleys with volcanism, pillow basalts, hydrothermal vents, and hydrothermal circulation. Serpentinites form at depth in mantle rocks that are undergoing hydrothermal alteration. Transform faults (associated with transform plate boundaries) break up divergent boundaries into small sections offset from one another.

WORLD EXAMPLES: Mid-Atlantic Ridge, Iceland.

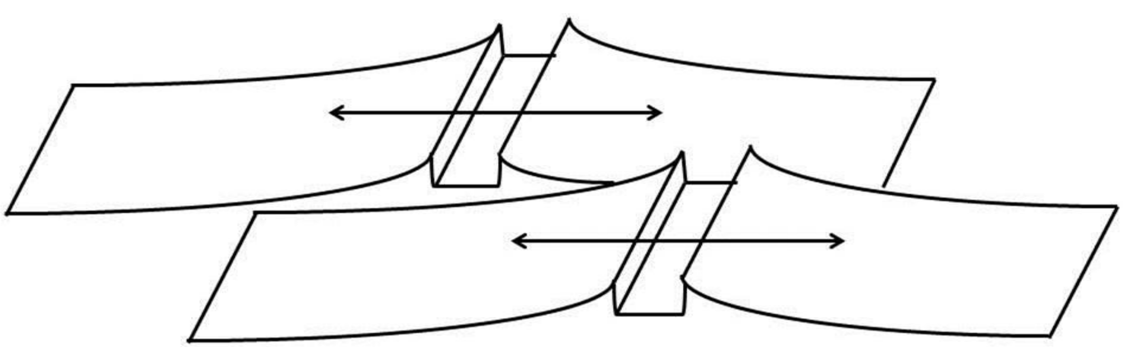



**TRANSFORM**

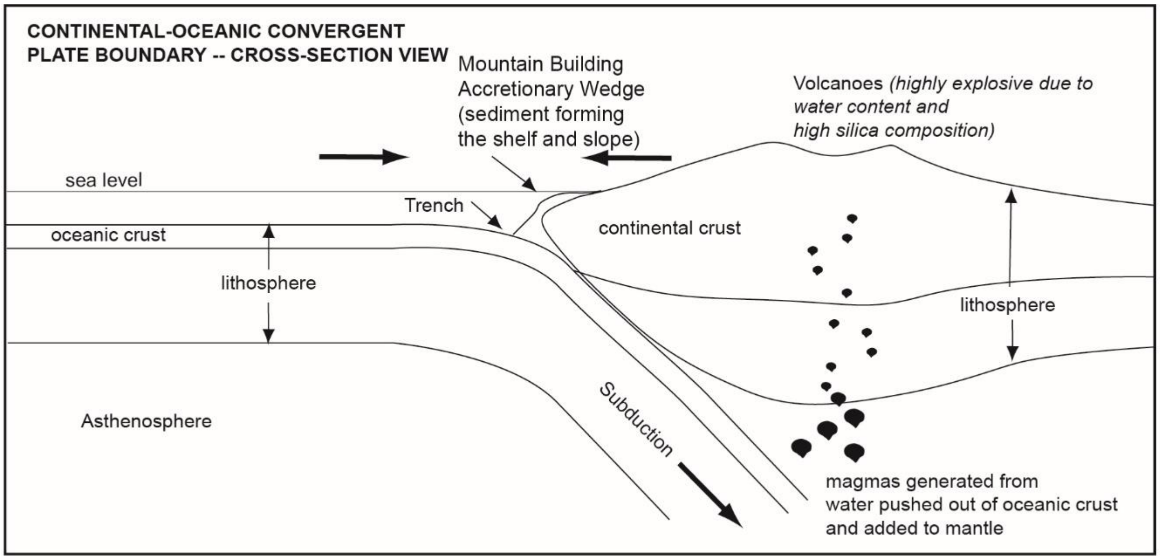
**MOTION:** side by side

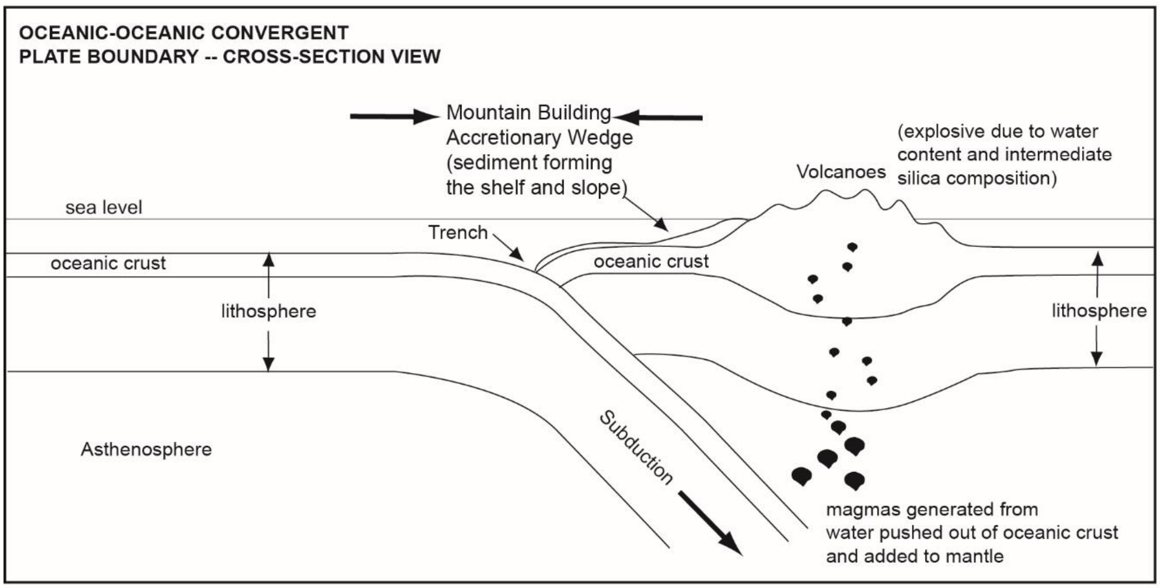
**FEATURES:** Fracture zones (old transform faults, no longer active, because lithosphere on both sides are part of the same plate). Rough topography (cliffs where ridges offset. Oceanic ridges and spreading centers on both sides.

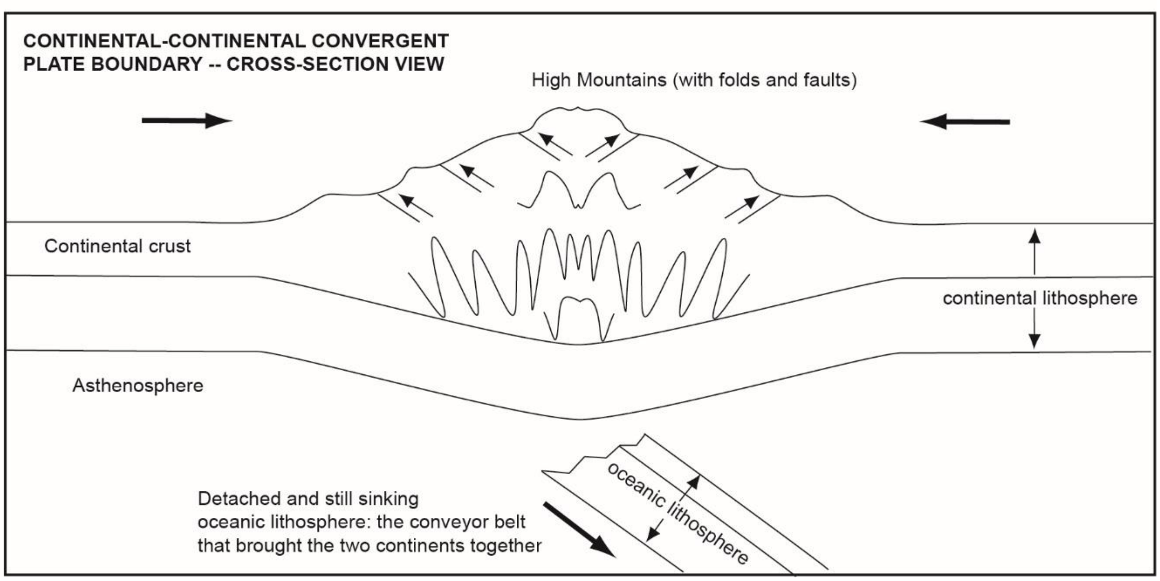
WORLD EXAMPLES: California, Iceland



Oblique view of seafloor spreading centers and transform boundaries.




**CONVERGENT**

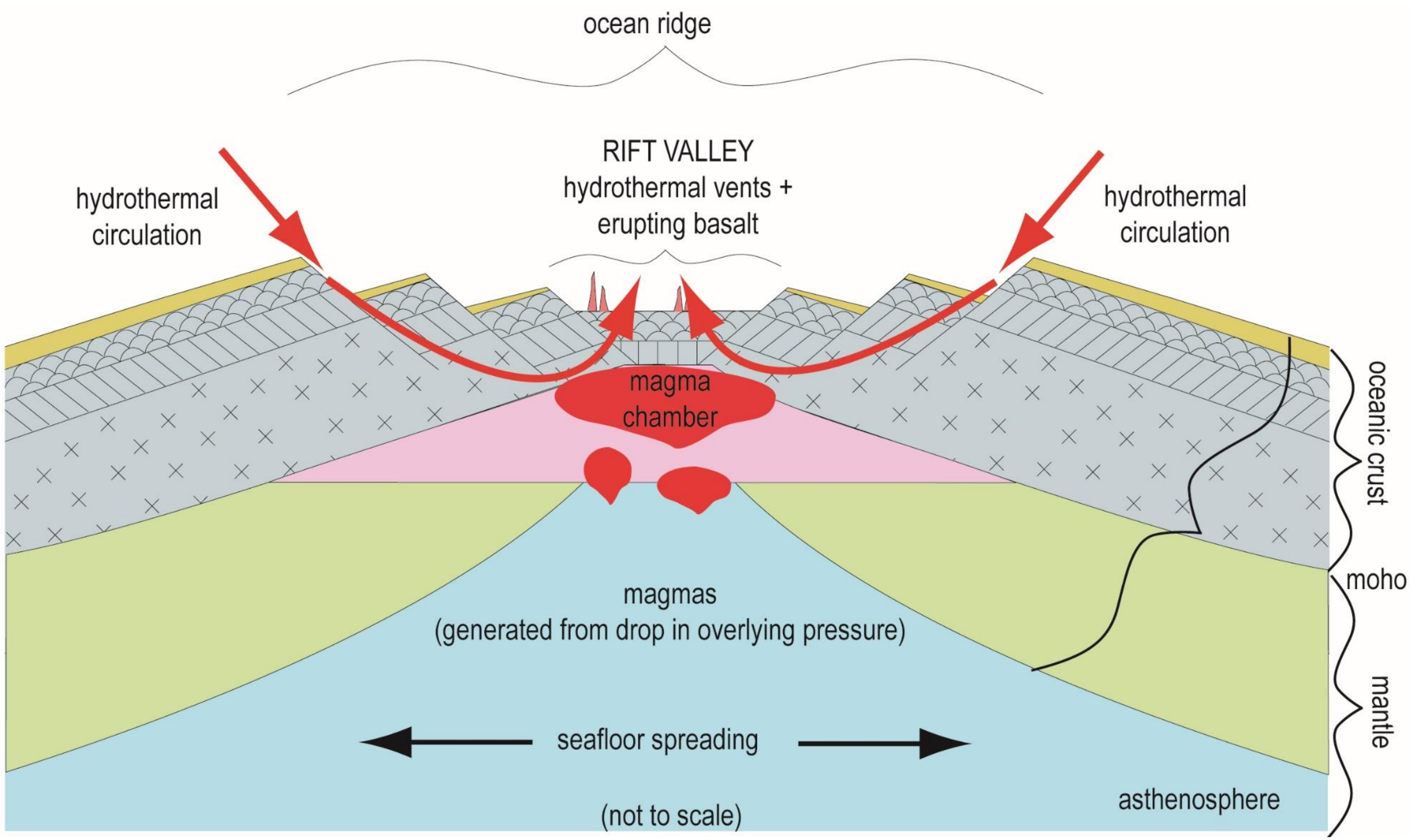
**MOTION:**
Towards each other

**FEATURES:**

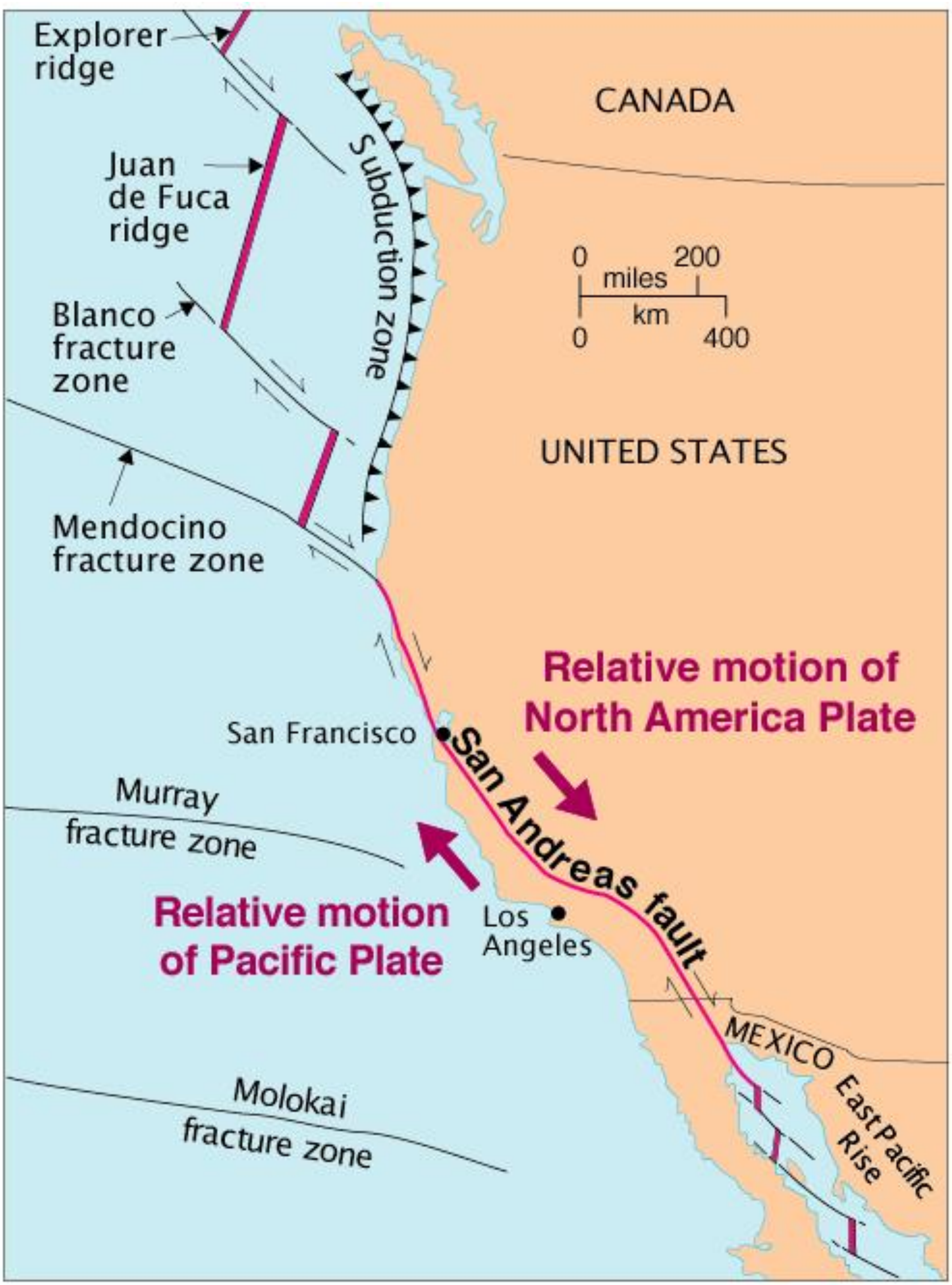
**Continent-Ocean**
Subduction zones (ocean crust sinks back into mantle). Melted mantle rock due to addition of water, which drops the melting point of the underlying mantle. Volcanoes above subduction zone. Trenches on ocean floor where ocean crust begins subducting. Accretionary wedge mountains (made up of terranes: sediments, islands, crustal blocks)
WORLD EXAMPLES:
W. coast S. America
Pacific Northwest

**Ocean-Ocean**
Subduction zones (ocean crust sinks back into mantle). Melted mantle rock due to addition of water, which drops the melting point of the underlying mantle. Volcanoes above subduction zone. Trenches on ocean floor where ocean crust begins subducting. Accretionary wedge mountains (made up of terranes: sediments, islands, crustal blocks)
WORLD EXAMPLES:
Japan, Philippines, Aleutian Islands

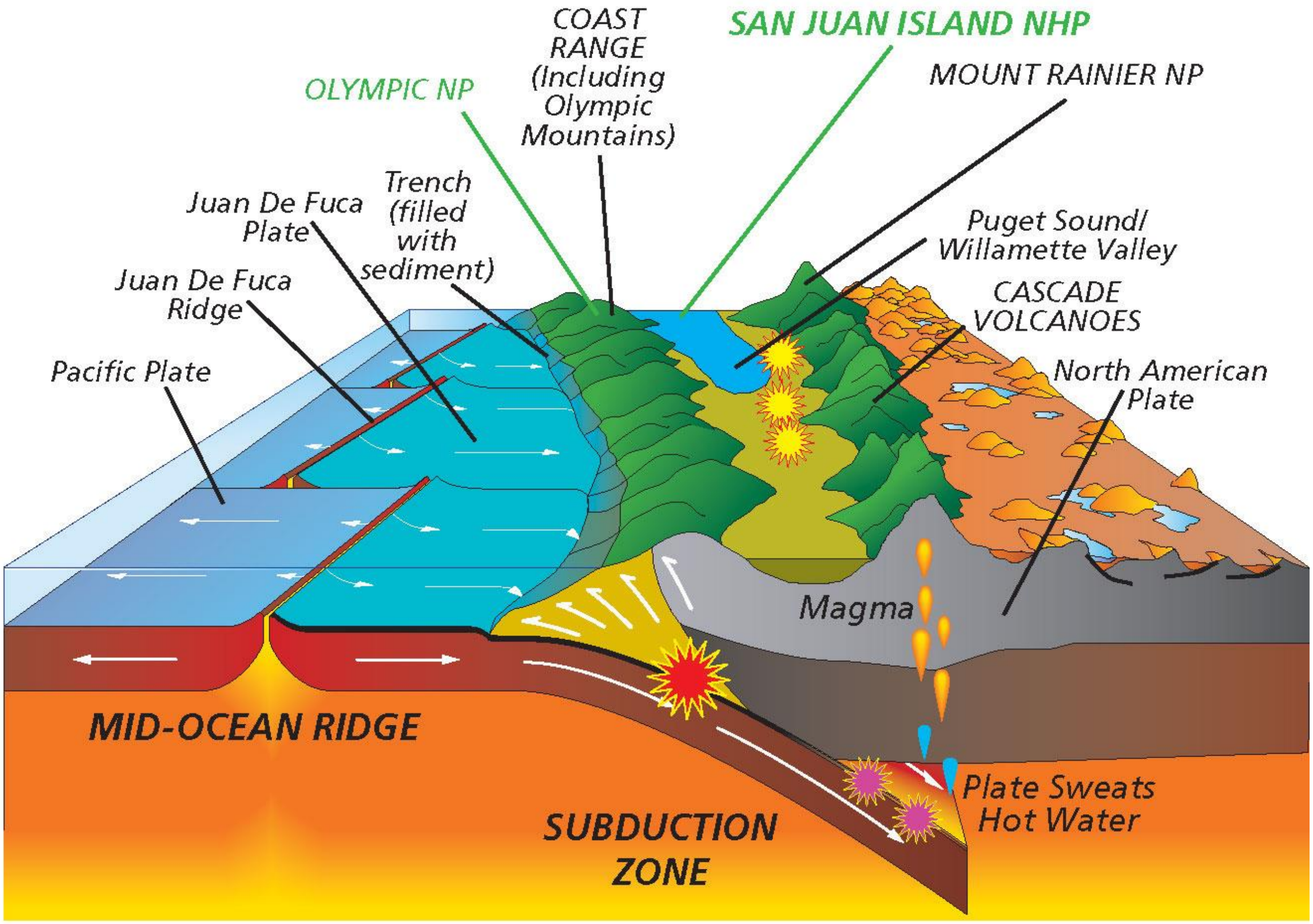
**Continent-Continent**
Fold and thrust mountains, thickened lithosphere.
WORLD EXAMPLES:
Himalayas (India)
Alps (Europe)




*At seafloor spreading centers, magmas form as mantle melts under the thinned crust (a drop in pressure causes melting). Magmas rise to the surface and erupt under water as pillow basalts. The vertical cracks that formed between the top of the magma chamber and the bottom of the seafloor to allow the basalt through will then solidify under the pillows and form basalt dikes. Both of these are spread aside to make room for the next series of pillow basalts and dikes, and as they spread away from the rift valley, they collect sediment on their top and beneath, the edges of the magma chambers cool slowly underground to form gabbro. Seawater will descend through the cracks formed from spreading, leach elements from the ocean crust, get heated by the magma chamber and rise back up in the center of the rift valleys producing hydrothermal vents made of chimneys of metal sulfides precipitated from the hot fluids as they exit the ground and enter the cold ocean (much like mineral deposits that form on the inside of plumbing pipes).*



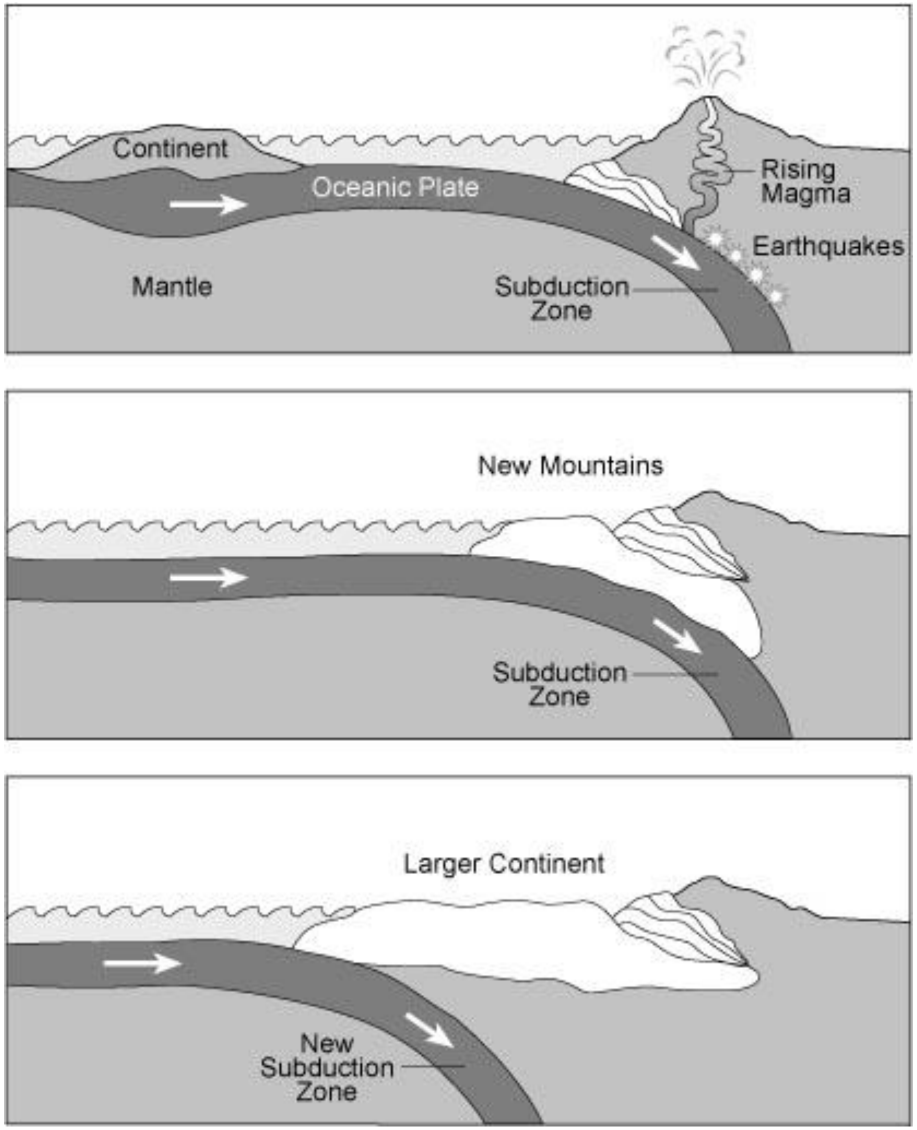

*Map view showing plate boundaries along the western margin of North America, with subduction in northern California, Oregon, and Washington; seafloor spreading off the coast of this same area and in the Sea of Cortez; transform motion between northern California and Los Angeles. Image from USGS modified from This Dynamic Earth by Stoffer, 2006.*



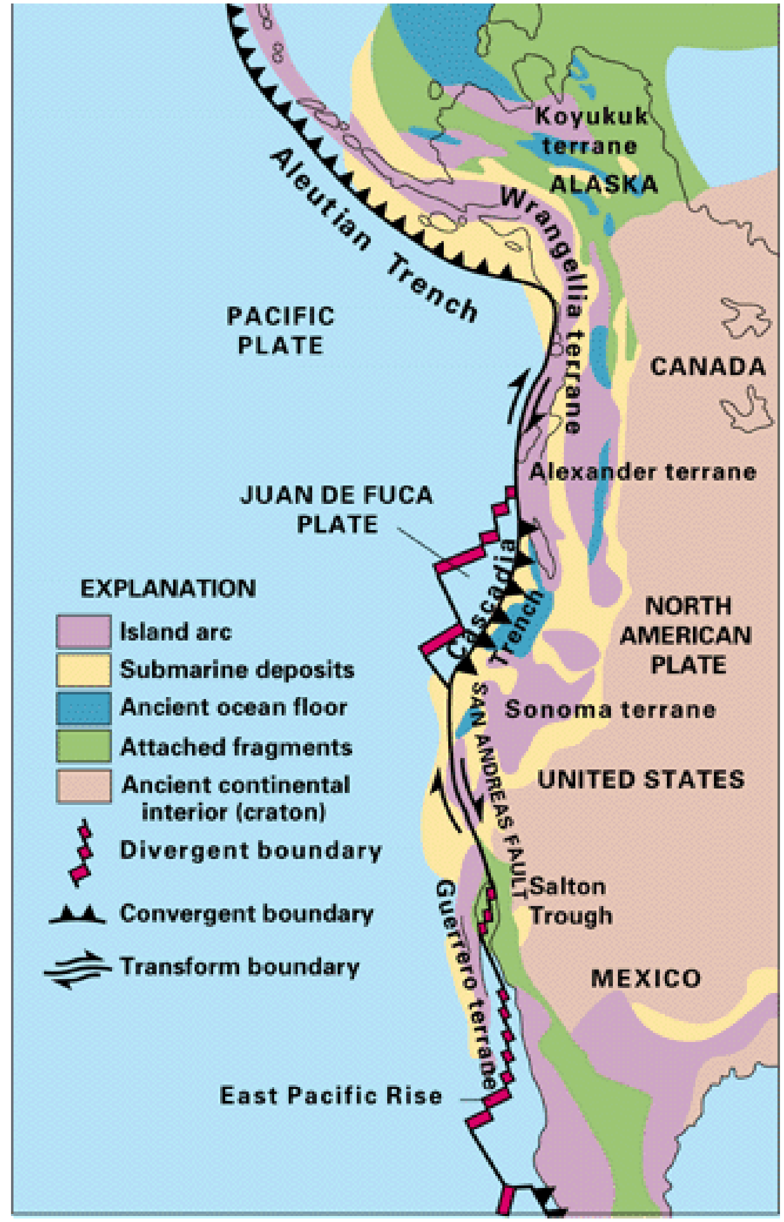

**Cascadia earthquake sources**

| *Source* | *Affected area* | *Max. size* | *Recurrence* |
|---|---|---|---|
| Subduction Zone | West. WA, OR, CA | M 9 | 500-600 years (1700) |
| Deep Juan De Fuca Plate | West. WA, OR | M 7+ | 30-50 years (1949, 1965, 2001) |
| Crustal faults | WA, OR, CA | M 7+ | hundreds of years? (CE 900, 1872) |

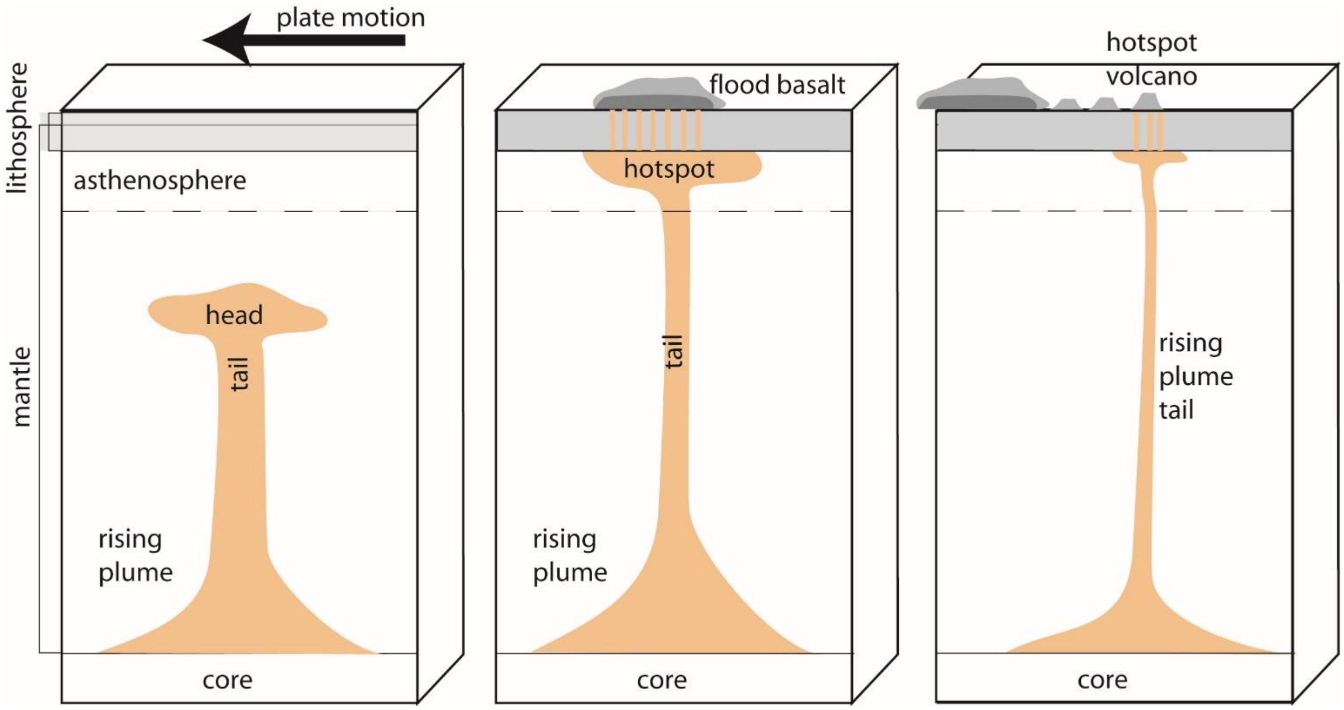
*Cross-section through the western margin of North America in the region of the Pacific Northwest – Washington, Oregon, and Northern California. Image from National Park Service*



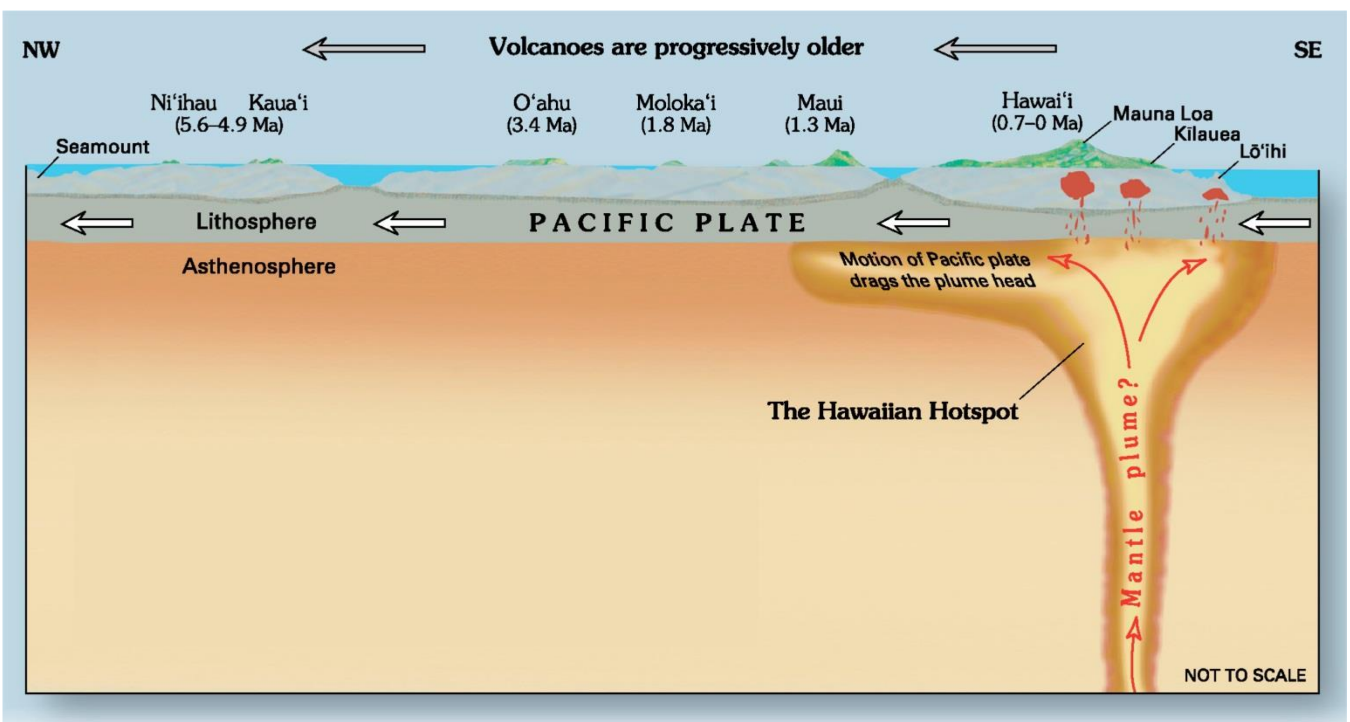

*Terrane accretion. Image from Kenneth R. Lang's book The Cambridge Guide to the Solar System, Second Edition 2011.*



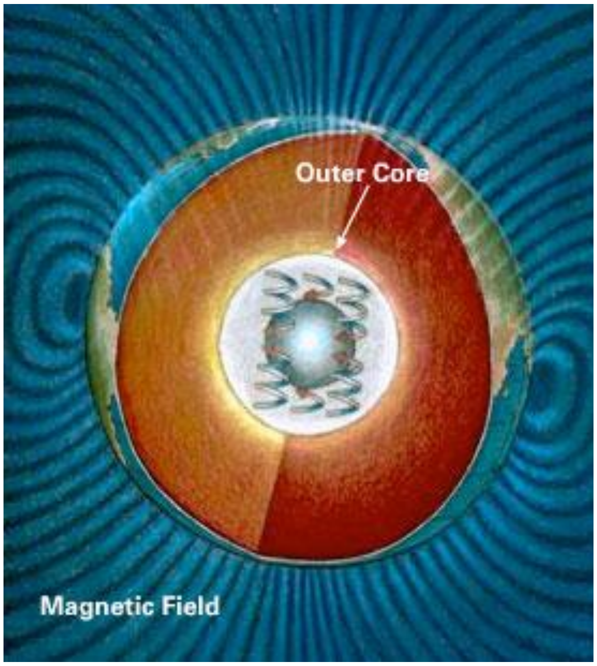

*Terrane accretion along the western margin of North America. USGS.*



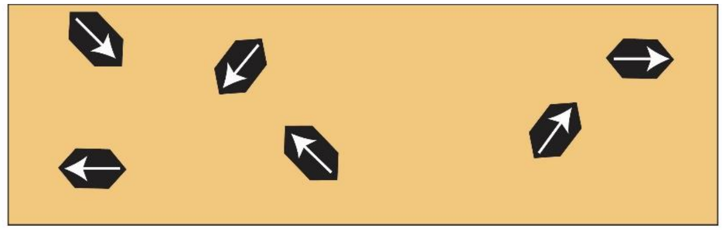

*Depiction of the formation of a particular type of deeply formed hotspot, from when it first rises from the base of the mantle, to when it breaks through the lithosphere with a massive eruption of flood basalts, to its continued eruption over time as plate tectonics moves the older volcanic structures away and new volcanoes form .*



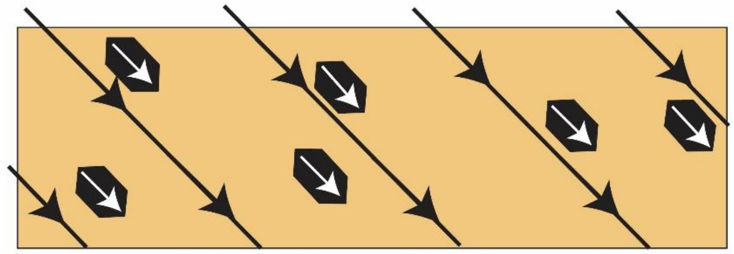

*Cross-section through Hawaiian Hotspot – USGS.*



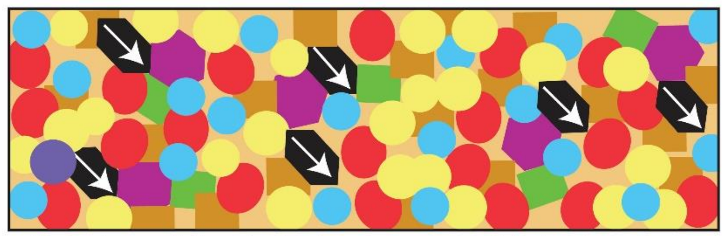

*Earth's magnetic field and the proposed source: a magnetic dynamo created by convection of liquid iron in the outer core. This convecting iron acts like a current moving in a loop and creates a magnet. Image from Smithsonian National Museum of Natural History*



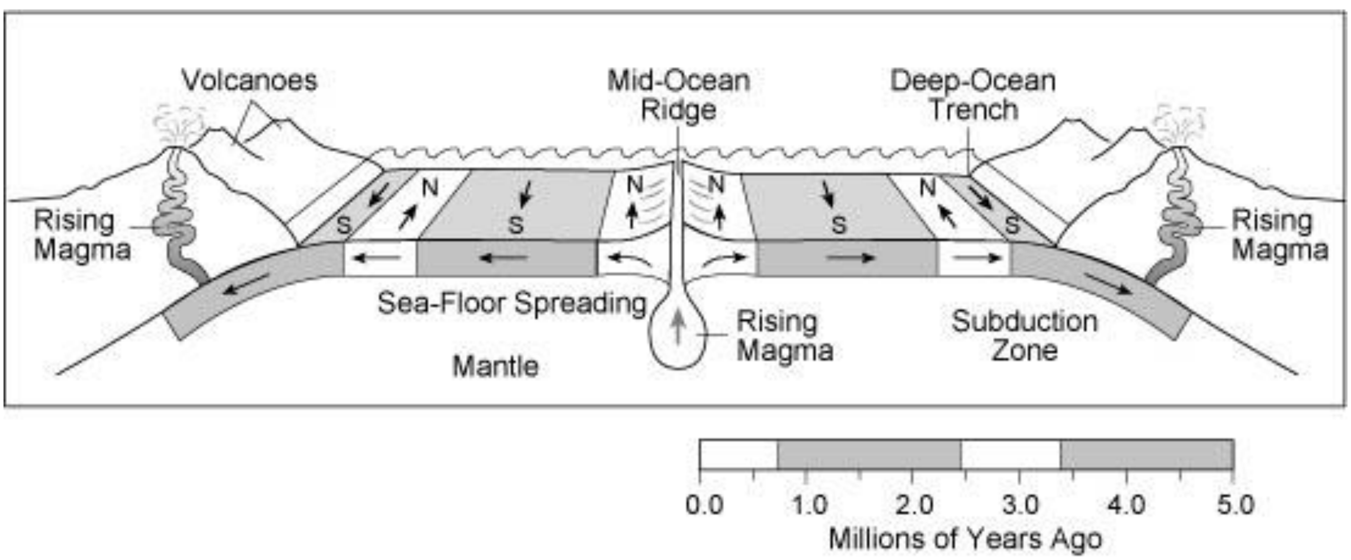
Magnetite crystals randomly aligned and moving in magma or suspended in waves



Magnetite crystals aligned under magnetic field while moving and then frozen in place in rocks or compacted in place in sand layers



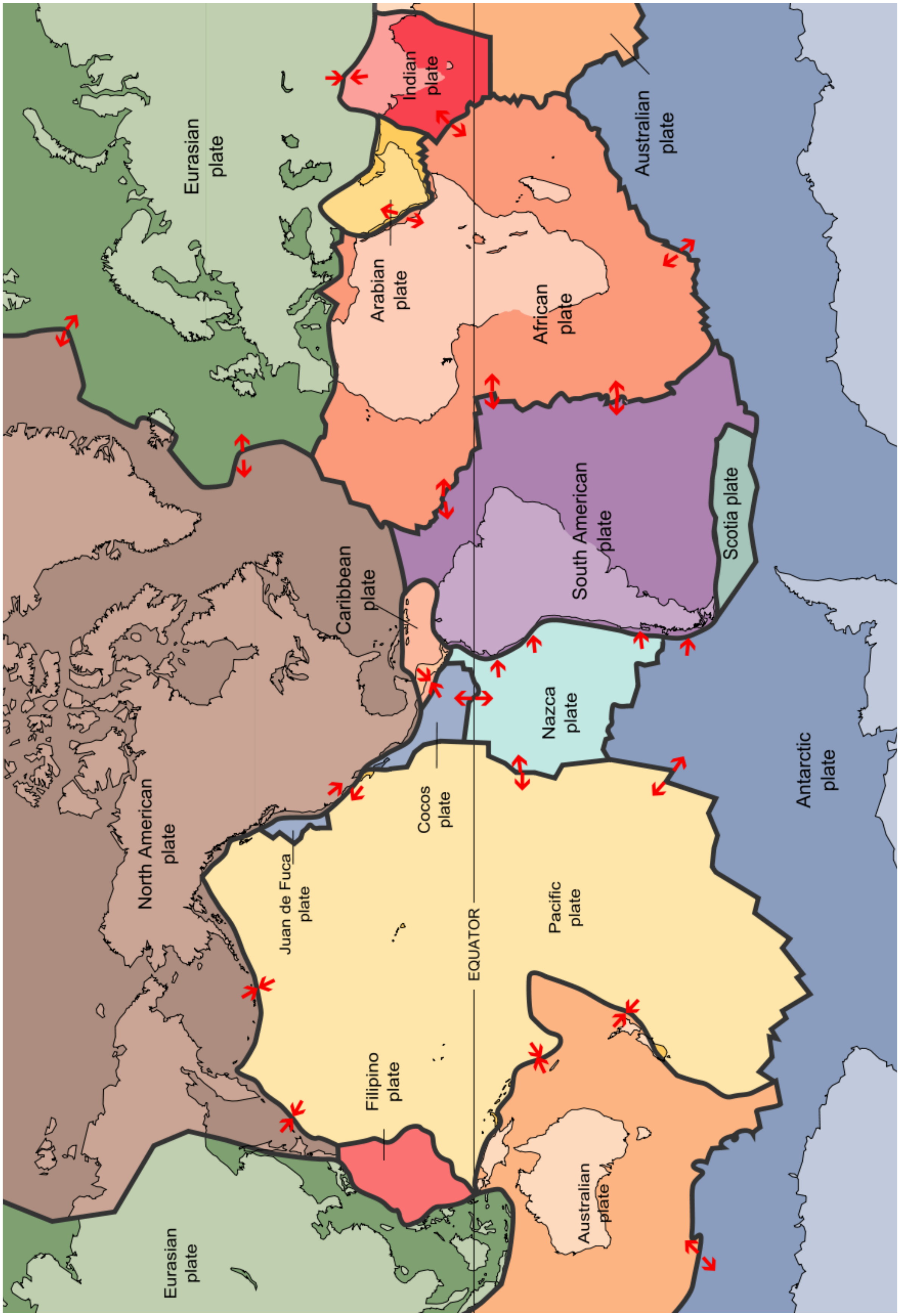
Magnetite crystals frozen in place in rocks or compacted in place in sand layers




*Magnetic Anomalies.*
*Image from Kenneth R. Lang's book The Cambridge Guide to the Solar System, Second Edition 2011.*

*Satellite image showing relief of India and surroundings. NOAA*

# PLATE BOUNDARY REFERENCE




*Global Plate Boundaries, USGS*

# Plate Tectonics Chapter Worksheet

1. **<u>OCEAN CRUST</u>** CIRCLE most appropriate terms:
NEW ROCKS FORMING
OLDEST ROCKS ON PLANET
NEVER OLDER THAN 200 Ma
BASALT | GRANITE
THICKNESS: 3-10 km | THICKNESS: 30-50 km
DENSEST | LEAST DENSE | SUBDUCTS

2. **<u>CONTINENTAL CRUST</u>** CIRCLE appropriate terms:
NEW ROCKS FORMING
OLDEST ROCKS ON PLANET
NEVER OLDER THAN 200 Ma
BASALT | GRANITE
THICKNESS: 3-10 km | THICKNESS: 30-50 km
DENSEST | LEAST DENSE | SUBDUCTS

3. CIRCLE: Which of the following natural processes would cause the lithosphere to **rise** isostatically?
*Basalt lava flows | Continental collision and accretion*
*Deposition of sediment | Erosion of rock and sediment*
*Glacial advance (more glaciers) | Glacial retreat*
*Transform plate motion | Divergent plate motion*

4. CIRCLE: Which of the following natural processes would cause the lithosphere to **sink** isostatically?
*Basalt lava flows | Continental collision and accretion*
*Deposition of sediment | Erosion of rock and sediment*
*Glacial advance (more glaciers) | Glacial retreat*
*Transform plate motion | Divergent plate motion*

5. Which of the following characteristics of a fluid that is free to move make it rise relative to the objects around it?
CIRCLE ALL THAT APPLY: *Density | Temperature | Salinity | Viscosity*

6. The Moho is the boundary between which two layers?

7. How does the Moho relate to the asthenosphere, lithosphere?

*8.* In what parts of the planet is the Moho deepest (closest to the center of the Earth)?
CIRCLE: *Mountains | Mid-Ocean Ridge | Coastal Plains*

*9.* In what parts of the planet is the Moho shallowest (furthest from the center of the Earth)?
CIRCLE: *Mountains | Mid-Ocean Ridge | Coastal Plains*

10. What happens to oceanic lithosphere over time, as it ages? (Be specific and thorough.)

11. The continents are ~20 times older than the oldest ocean basins – Why?

12. What is a **terrane**? What are different types of terranes, and how do they contribute to the growth of continents?

13. Stack the following layers found in ocean lithosphere vertically as they'd be found in a hole drilled through the ocean crust and describe how each is formed:
BASALTIC DIKES | DEPLETED MANTLE (PERIDOTITE) | GABBRO | PILLOW BASALT | SEDIMENT

14. Draw arrows in map-view boxes below to indicate directions of plate motion at these **plate boundaries**: (| is boundary)

| **Divergent** | **Transform** | **Convergent (ocean-ocean)** | **Convergent (ocean-cont)** | **Convergent (cont-cont)** |
|---|---|---|---|---|
| | | | | |

15. Which of the following plate boundaries produces **earthquakes**? CIRCLE ALL THAT APPLY:
Convergent (Ocean-Ocean) | Convergent (Cont-Ocean) | Convergent (Cont-Cont) | Divergent | Transform

16. Which of the following plate boundaries produces **volcanism**? CIRCLE ALL THAT APPLY:
Convergent (Ocean-Ocean) | Convergent (Cont-Ocean) | Convergent (Cont-Cont) | Divergent | Transform

17. Which of the following plate boundaries produces a **fracture zones**?
Convergent (Ocean-Ocean) | Convergent (Cont-Ocean) | Convergent (Cont-Cont) | Divergent | Transform

18. Which of the following plate boundaries produces a **mid-ocean ridge**?
Convergent (Ocean-Ocean) | Convergent (Cont-Ocean) | Convergent (Cont-Cont) | Divergent | Transform

19. Which of the following plate boundaries produces **mountains (of any size)**?
Convergent (Ocean-Ocean) | Convergent (Cont-Ocean) | Convergent (Cont-Cont) | Divergent | Transform

20. Where does all new ocean crust form?
CIRCLE: trenches | passive continental margins | abyssal plains |mid-ocean ridges | varies (no one place)

21. What is the age of the oldest ocean crust currently found in the world's oceans?
Where in general in the world's oceans are the oldest rocks?
CIRCLE: trenches | passive continental margins | abyssal plains |mid-ocean ridges | varies (no one place)

22. What kind of plate boundary do we live
on or near in San Francisco?

23. Which of the following is true of **hotspots**? CIRCLE: *Can originate from as deep as core-mantle boundary | produce flood basalts and mass extinctions when first break through crust | can last over 200 million years | move with the plate | found in Iceland |found in Yellowstone | found in Hawaii*

*24.* If a 5-my-old island that formed at a hotspot is now 500 km northwest of the hotspot, how fast has the plate been moving since its formation? And what direction has the plate been moving?
*(Note: calculate as km/my then convert to cm/yr by dividing by 10.)*

*25.* Which of the following is true of **Earth's Magnetic Field**? CIRCLE ALL THAT APPLY: *Poles reverse | Poles wander | Strength changes with time | Has four poles | Attracts magnets | Direction fluctuates based on latitude*

*26.* If a 10-my-old pillow basalt is 1200 km west of the nearest seafloor spreading center, how fast has its plate been moving since its formation? And what direction has the plate been moving?
*(Note: calculate as km/my then convert to cm/yr by dividing by 10.)*

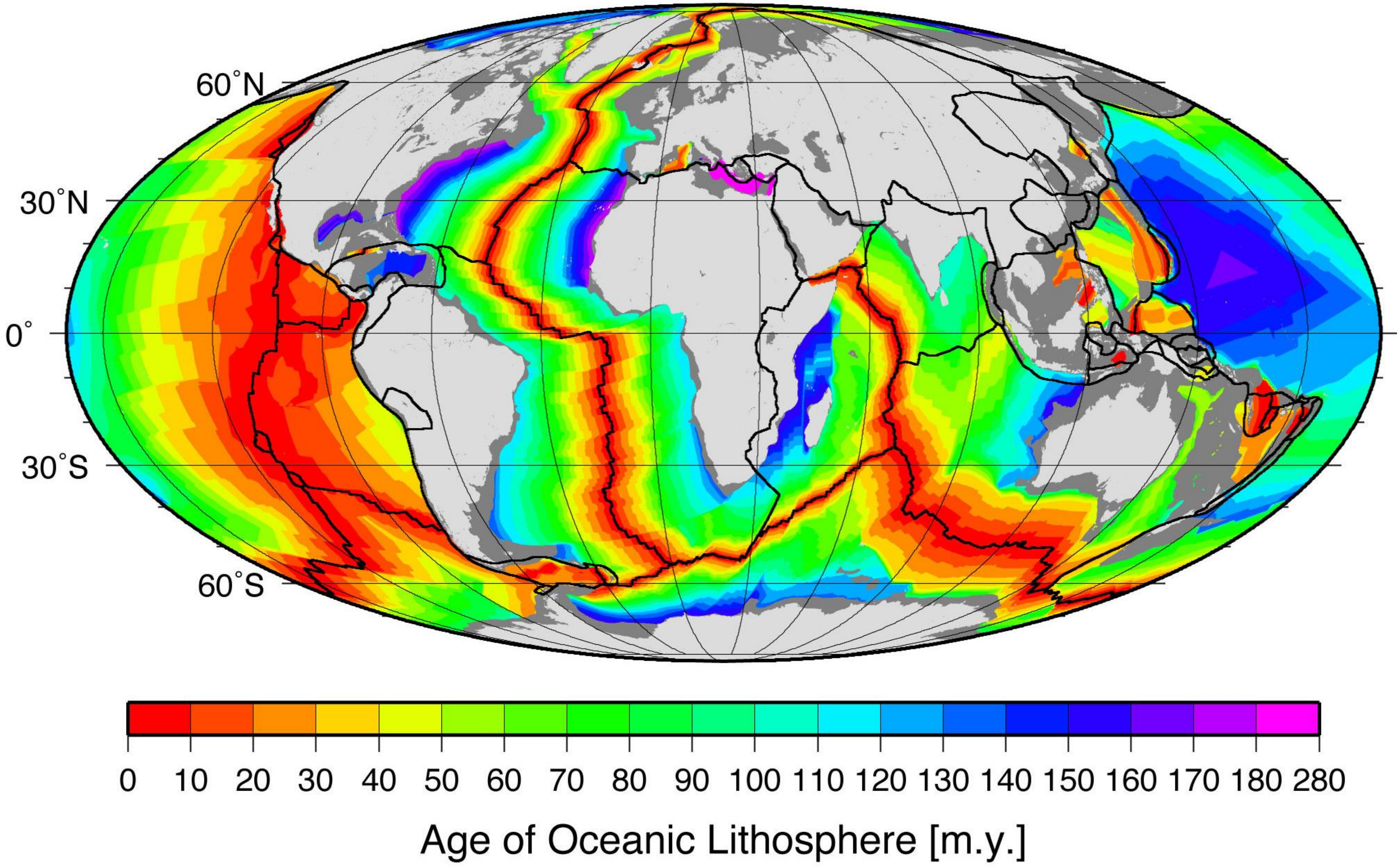
*27.* Which of the following is TRUE of **paleomagnetism**? CIRCLE: *ancient record of magnetic pole locations| requires magnetic material to align and freeze in place in a rock | can form from magnetite crystals forming from lava | can form with magnetite grains settling on a beach and being buried | can be used to determine latitude of original rock | can be used to see the symmetry of seafloor spreading | can be studied only in rocks found on the seafloor | can be studied only in rocks found on land | can be studied in ALL rocks found anywhere*

28. Review the figure that shows the **<u>age of the ocean crust beneath ocean sediments</u>**: Which of the following was required to create this map? CIRCLE: *Magnetic signature of rocks on seafloor | Timeline of when Earth's magnetic field has switched polarities historically (gathered by land-based volcanic rock layers)| Sampling of individual rocks collected from the seafloor | Dating seafloor rock samples in a laboratory | Ships travelling back and forth across the sea surface dragging a magnetometer | Satellites*

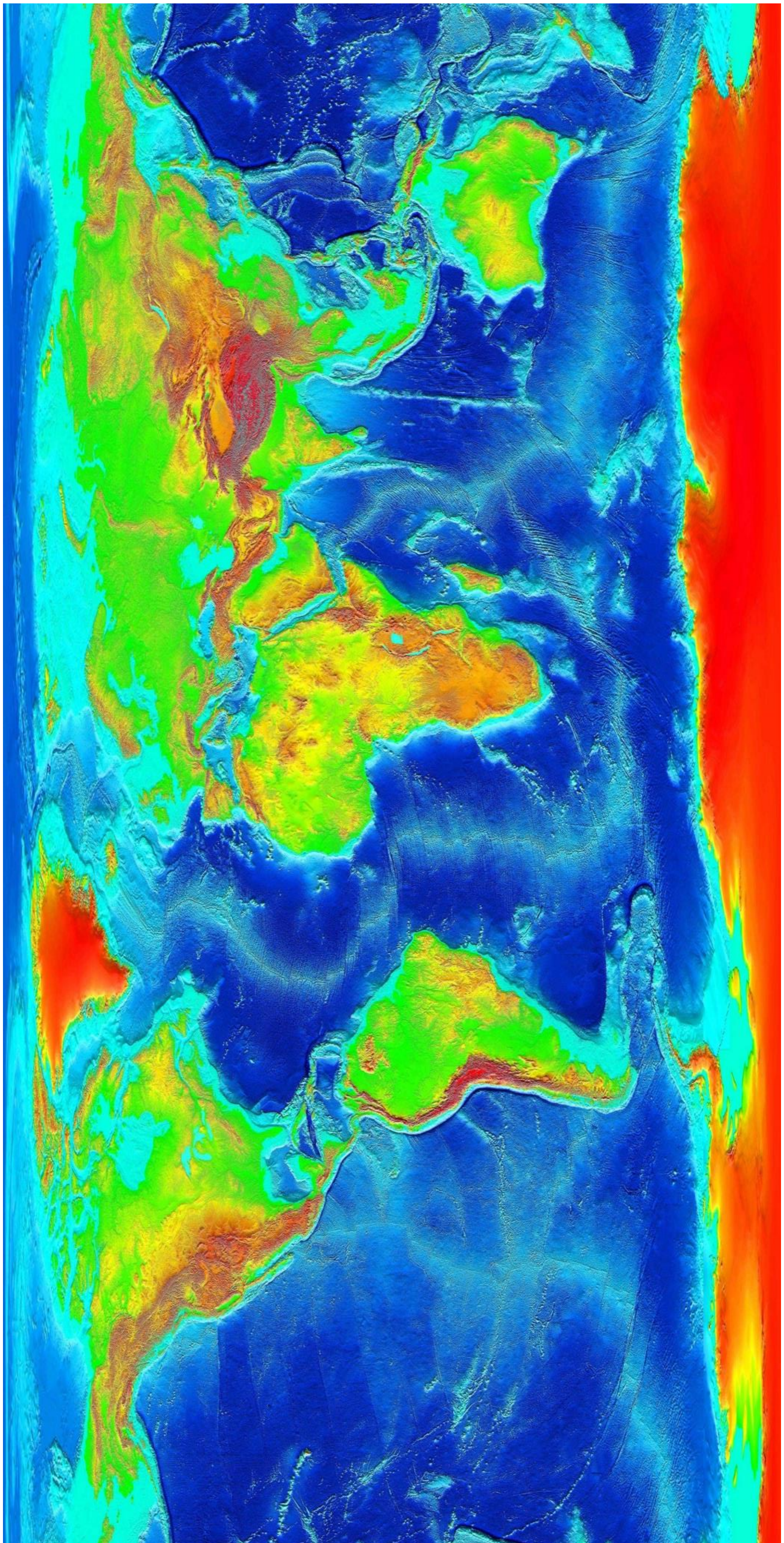
29. Which types of chemical, physical, and biological processes occur at or under hydrothermal vents? CIRCLE:
CHEMOSYNTHESIS | PHOTOSYNTHESIS | DISSOLUTION | PRECIPITATION |
CHALLENGING ECOSYSTEMS | ALTERED OCEAN CRUST | PILLOW BASALTS | EARTHQUAKES |
HOT AND COLD WATERS MIXING | SUBDUCTION | SPREADING | TRANSFORM MOTION

30. How hot is the water coming out of a
hydrothermal vent?

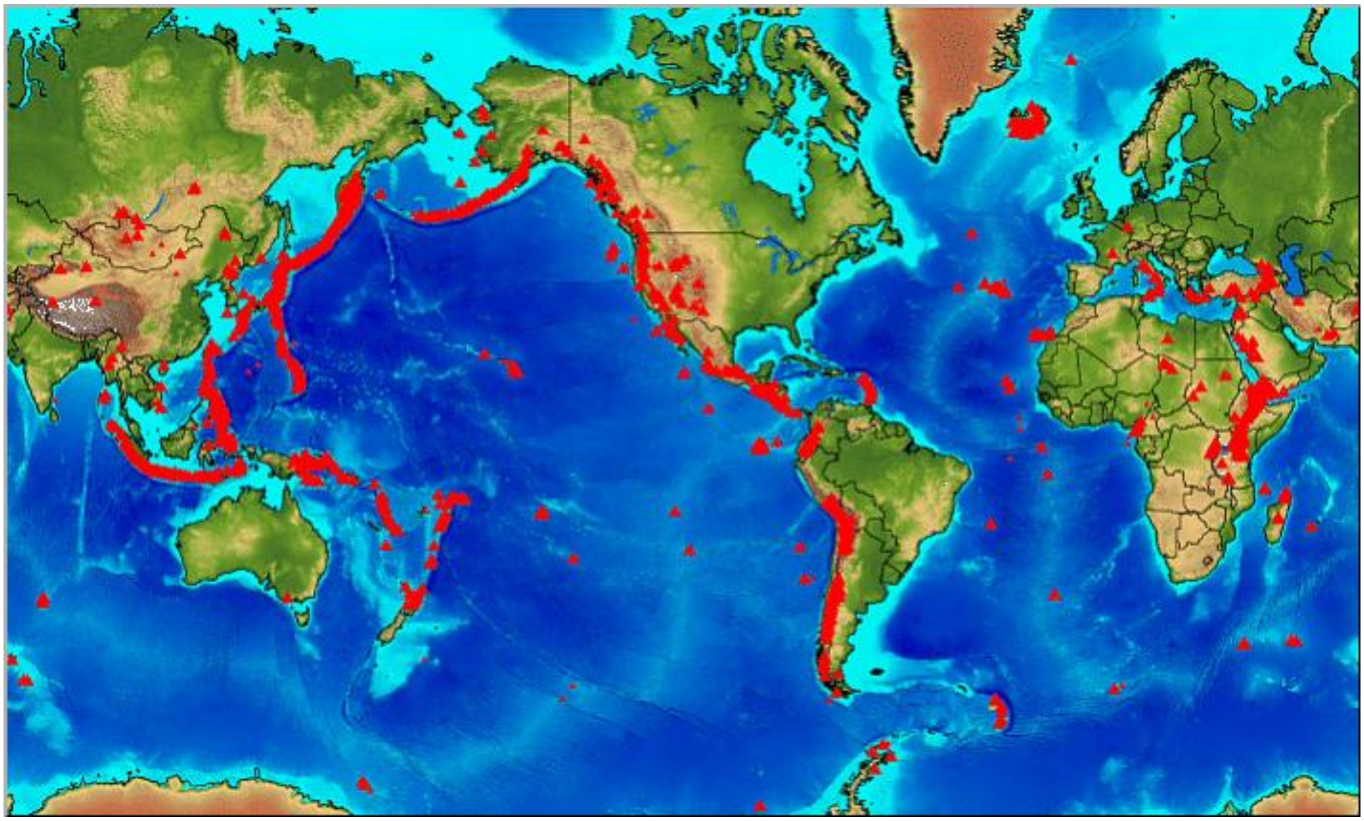
31. Where do the water and associated dissolved ions in a hydrothermal vent come from?



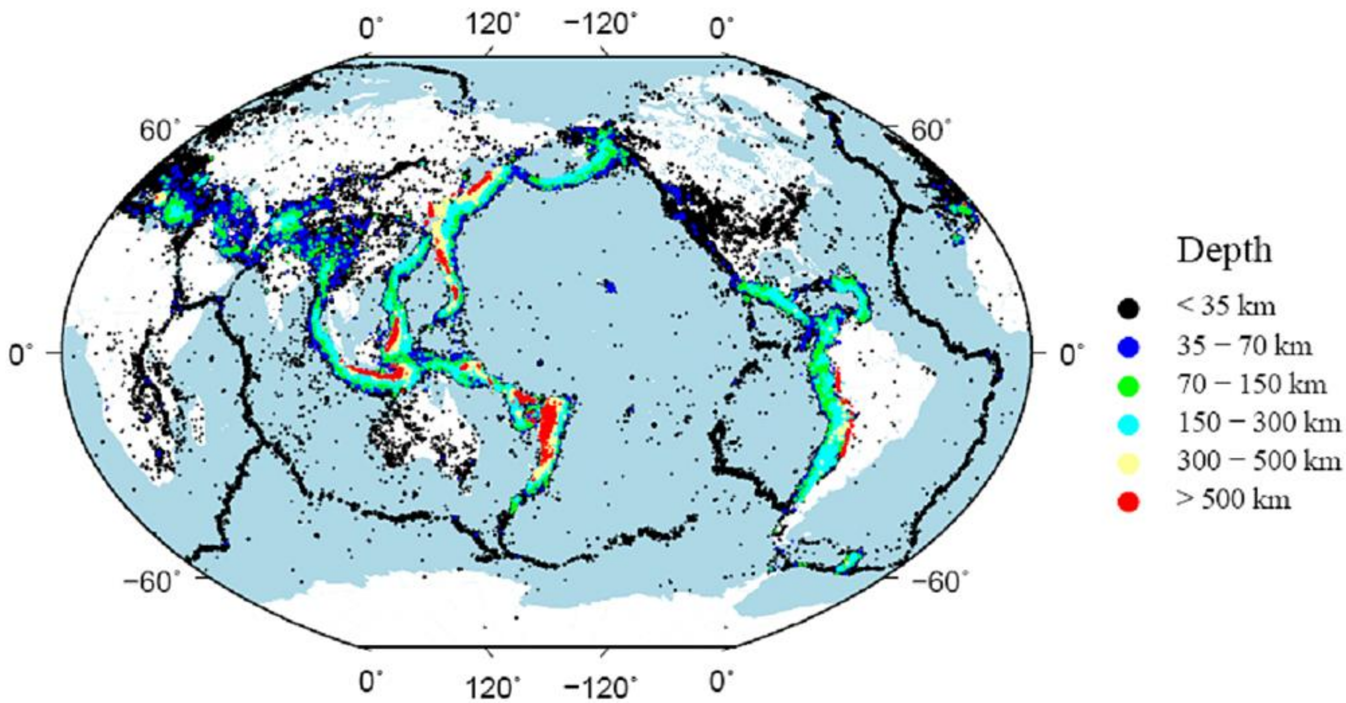

*ISOCHRON Map (lines of a particular color represent equal lithosphere age ranges) For example. All areas in yellow are lithosphere from 40 to 50 million years old. NOAA*



*Seafloor Bathymetry and Continental Topography – World Relief Map – NOAA*



*Location of the world's primary active volcanic centers. Image from Smithsonian Institution Global Volcanism Project*




*Earthquakes around the world color coded by depth (Image produced by NORSAR using USGS data.*

# Plate Motions Activity

Use the preceding Isochron Map (age of seafloor rocks), Global Ocean Bathymetry and Land Topography Map (relief of Earth's surface), Volcanoes Map, and Earthquakes Map to answer these questions. Use support discussion board in CANVAS to seek help and share ideas about these questions.

| |
|---|
| 1. Observe known **divergent plate boundaries** across all four of the preceding maps. What landforms are associated with these boundaries? What patterns in earthquakes, volcanoes, and isochrons? (Think about shapes and patterns!) |
| 2. Observe known **transform plate boundaries** across all four of the preceding maps. What landforms are associated with these boundaries? What patterns in earthquakes, volcanoes, and isochrons? (Think about shapes and patterns!) |
| 3. Observe known **subduction zone plate boundaries** across all four of the preceding maps. What landforms are associated with these boundaries? What patterns in earthquakes, volcanoes, and isochrons? (Think about shapes and patterns!) |
| 4. Observe known **continent-continent convergent plate boundaries** across all four of the preceding maps. What landforms are associated with these boundaries? What patterns in earthquakes, volcanoes, and isochrons? (Think about shapes and patterns!) |

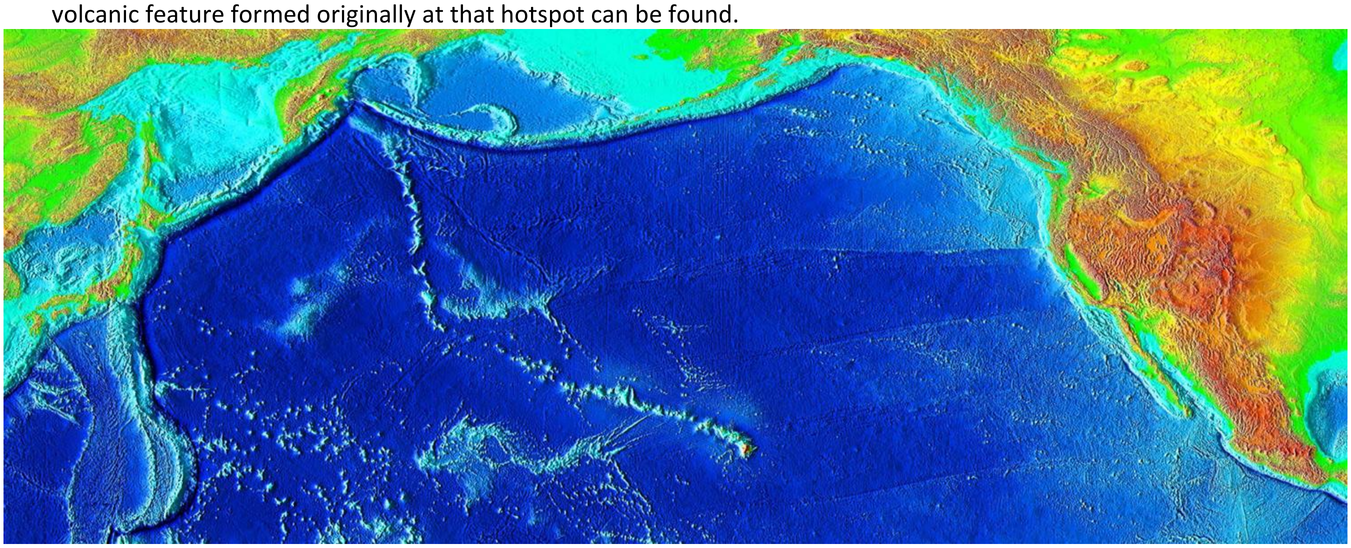
**World Ocean Comparison (Isochron Map)**

| | |
|---|---|
| 5. | The fastest spreading center in the world spreads at a rate of 18 cm/yr.<br>How do you recognize it? Where is it located? |
| 6. | The slowest spreading center in the world spreads at a rate of 2 cm/yr.<br>How do you recognize it? Where is it located? |
| 7. | What are some possible reasons for the differences? |

**Atlantic Ocean (Isochron Map)**

| | |
|---|---|
| 8. | What is the age of the youngest rock<br>in the Atlantic Ocean? Where is it? |
| 9. | What is the age of the oldest rock<br>in the Atlantic Ocean? Where is it? |
| 10. | When and where did the Atlantic<br>Ocean first start to open? |
| 11. | Did the entire Atlantic Ocean open at the same time? What's the evidence? |

12. Hotspot volcanic islands are prominent topographic features on the seafloor that do not occur at plate boundaries. Isolated volcanic islands and seamounts (undersea mountains) form a linear chain as magma rises under one location and the plate moves these volcanoes away to erode while new ones form. On the map below, locate and label the HAWAIIAN hotspot track. Draw an arrow indicating plate motion (remember: plates take volcanoes away from active hotspot after which they become extinct), and label "NEW" where the new rock is forming and "OLDEST" where oldest volcanic feature formed originally at that hotspot can be found.



*NOAA – Northern Pacific (**Note: to draw on this image, use white colored pencil or SHARPIE or stickers. **)*

13. How do the volcanic landforms that are produced vary among the three geologic settings for volcanism? (How can you recognize which is which?) Give world examples of each.

| | **Volcanic Landforms (shapes and behaviors)** | **World Examples** |
|---|---|---|
| **Hotspots** | | |
| **Subduction Zone Volcanic Arcs** | | |
| **Divergent Plate Boundaries** | | |

# Weekly Reflection

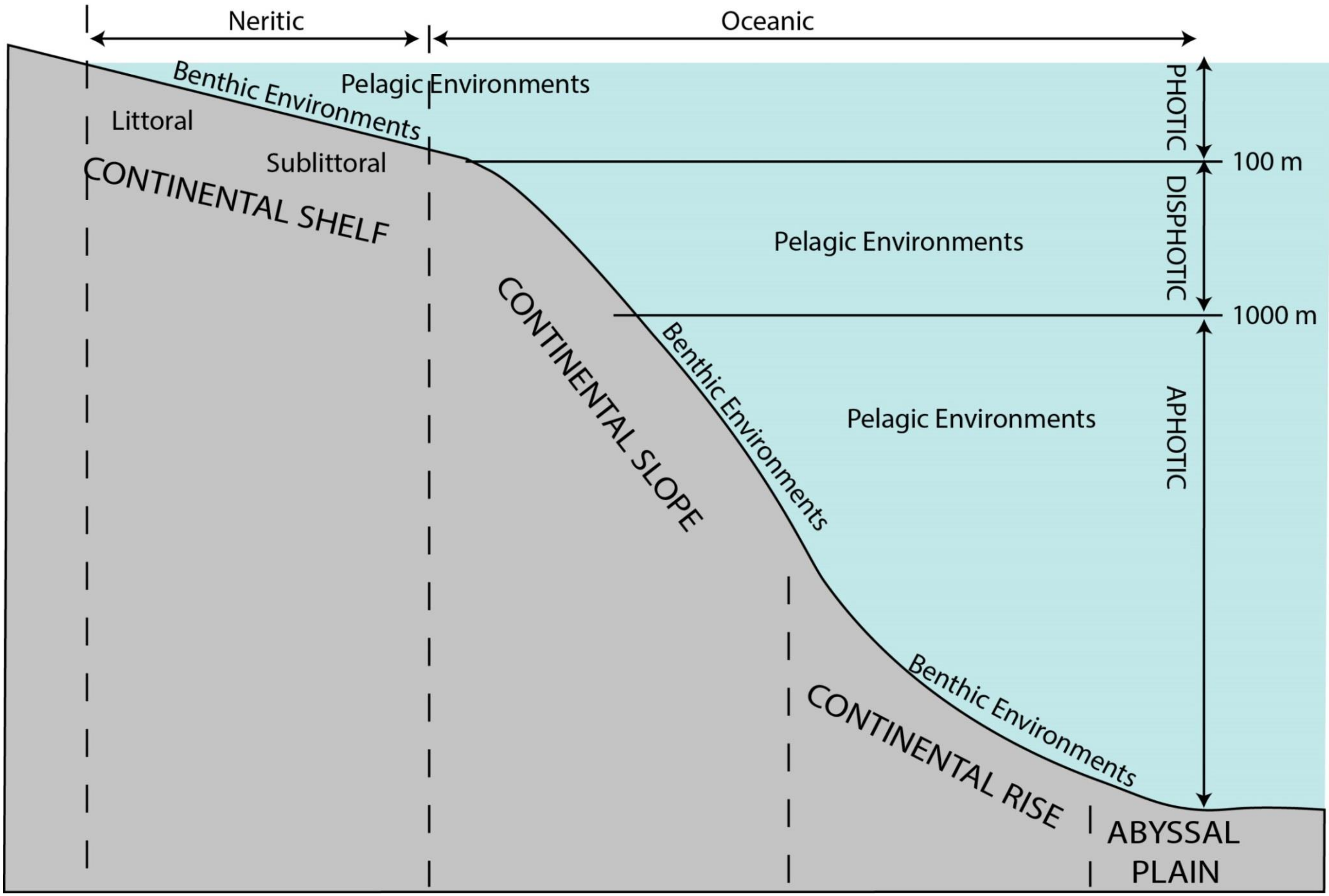
Take a moment to reflect on your comfort level and mastery of the week's objectives and describe an action plan for how you will practice or improve on anything that challenged you.

| **Weekly objective** | **Self-assessment of mastery level** | **Action plan for improvement** |
|---|---|---|
| Evaluate the **evidence for plate tectonics**. | A \| B \| C \| D \| F | |
| Analyze the **cause of earthquakes, volcanism, and mountain building** globally. | A \| B \| C \| D \| F | |
| Compare and contrast **plate boundaries and the landforms** and processes found associated with them. | A \| B \| C \| D \| F | |
| Apply plate tectonics theory to the **origin and evolution of ocean margins, basins, and crust**. | A \| B \| C \| D \| F | |

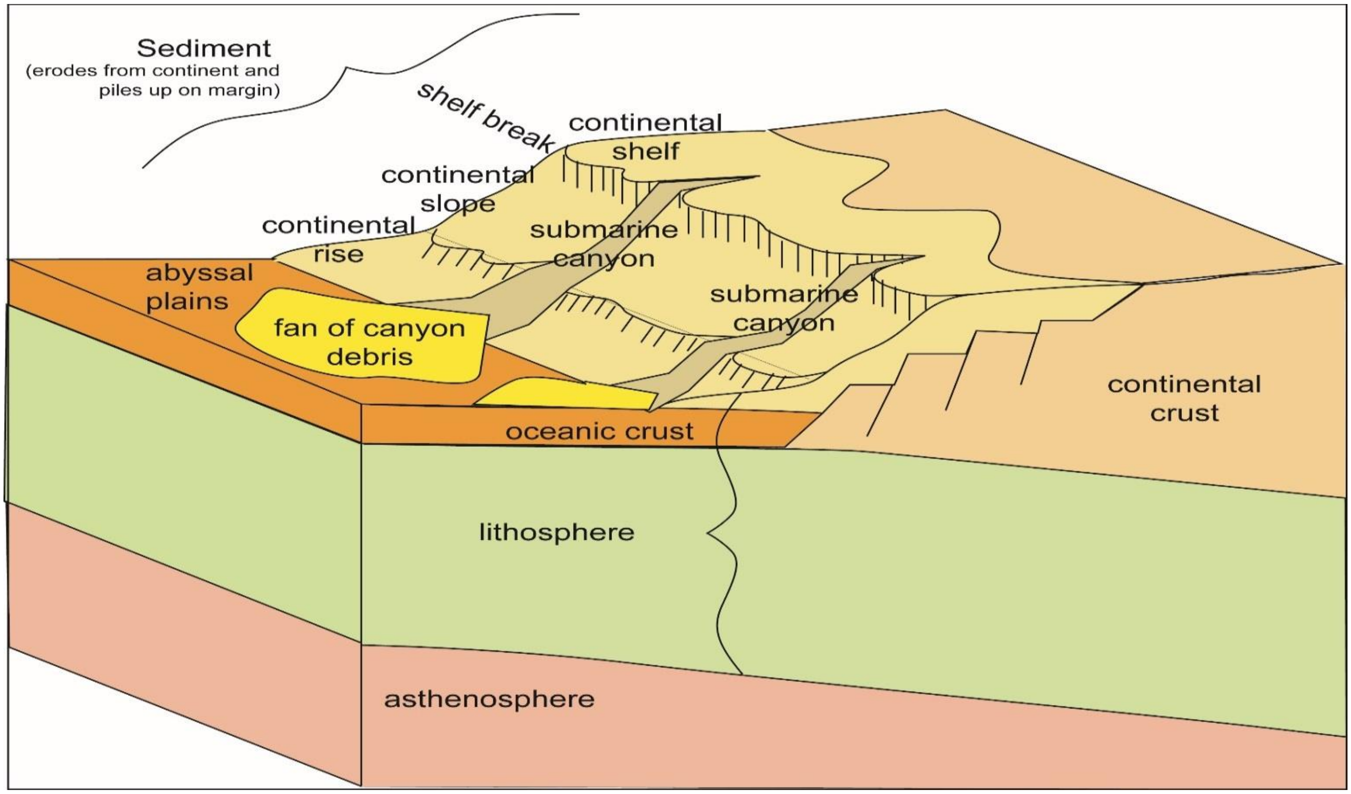
## AHA! Moments

What content from this week really resonated with you, helped you understand something you've always wondered about, or made you think about the world with new eyes?

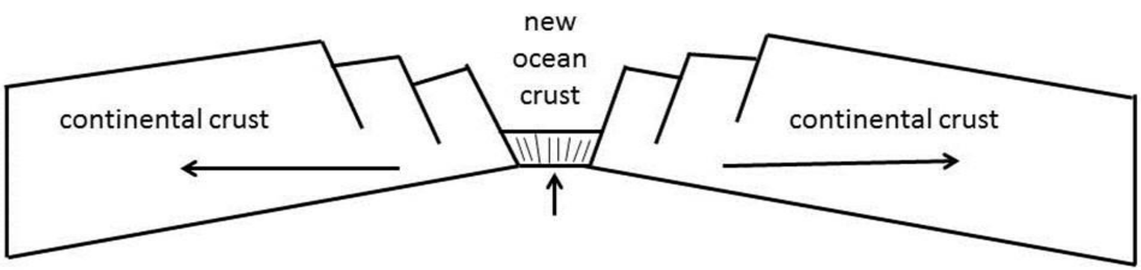
# SEAFLOOR & SEDIMENTS



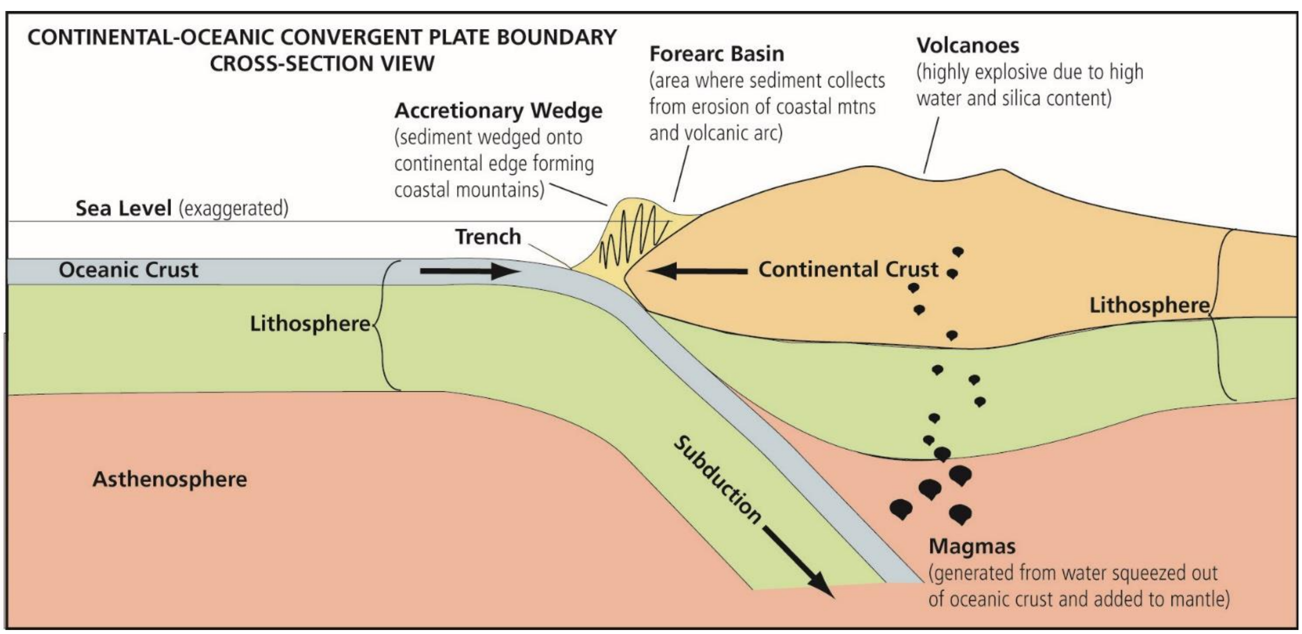

*Comparison of Benthic (seafloor) and Pelagic (water column) environments and the Neritic (near shore – over the continental shelf) and Oceanic (offshore – deeper than the continental shelf) provinces. Photic zone is depths where sunlight is still available at least 1% of surface values. Dispohotic zone is where available light is between zero and 1% of surface light. The Aphotic zone has no light available.*




*Continental Shelf – not to scale. Submarine canyons carved out of shelf by turbidity currents (avalanches of sediment).*

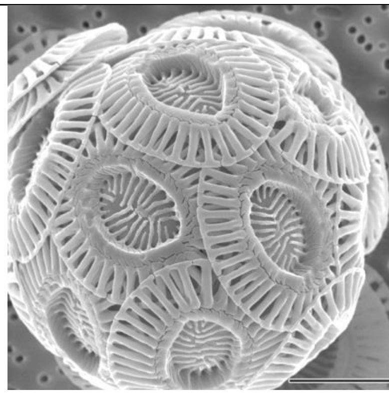
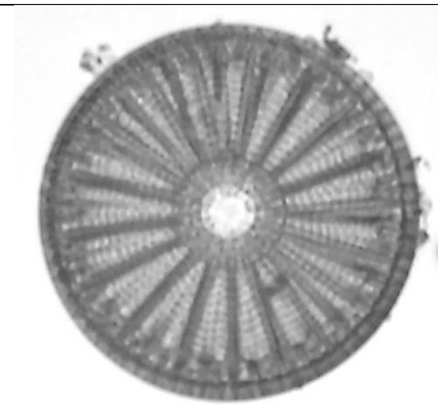
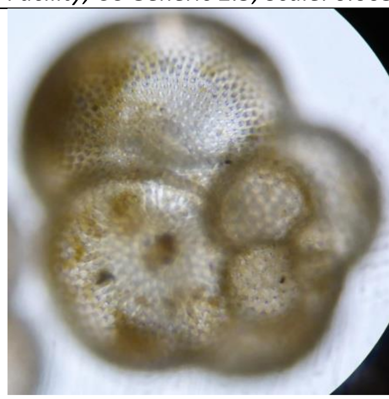
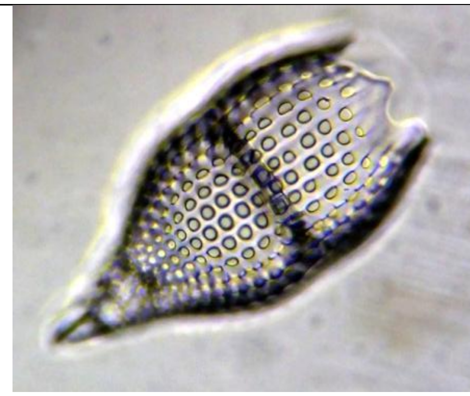


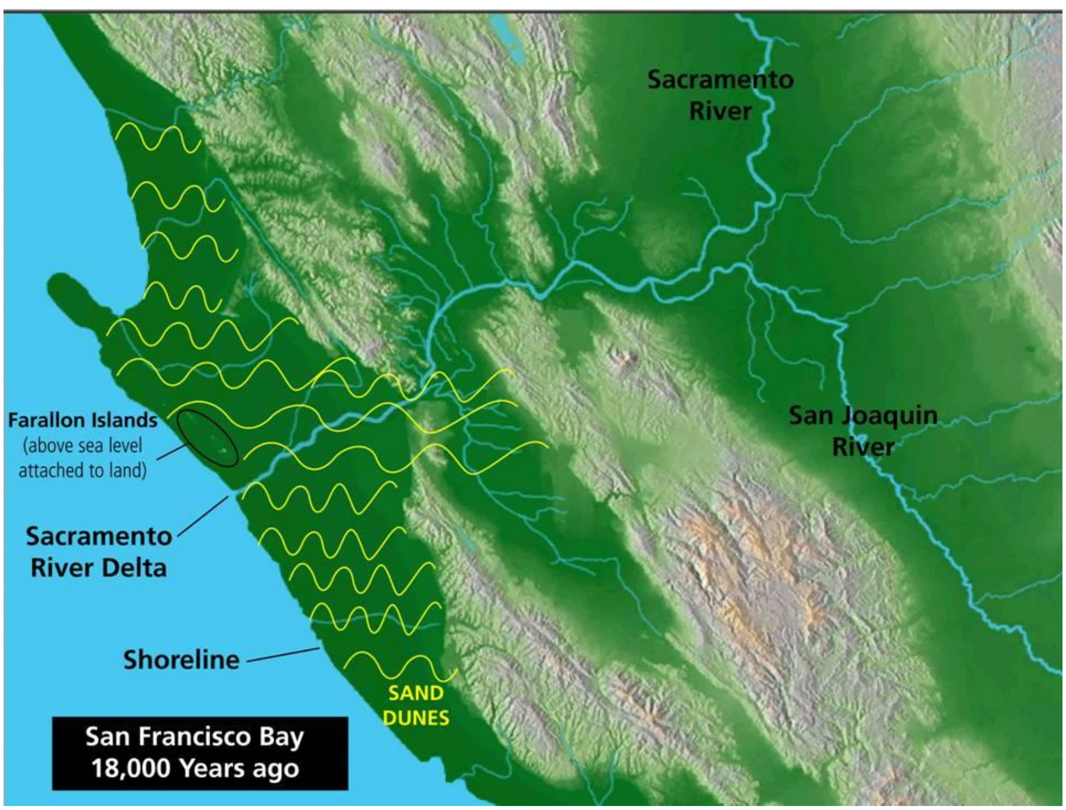

*Rift valley in the center of a divergent plate boundary where the continental crust is ripping apart.*



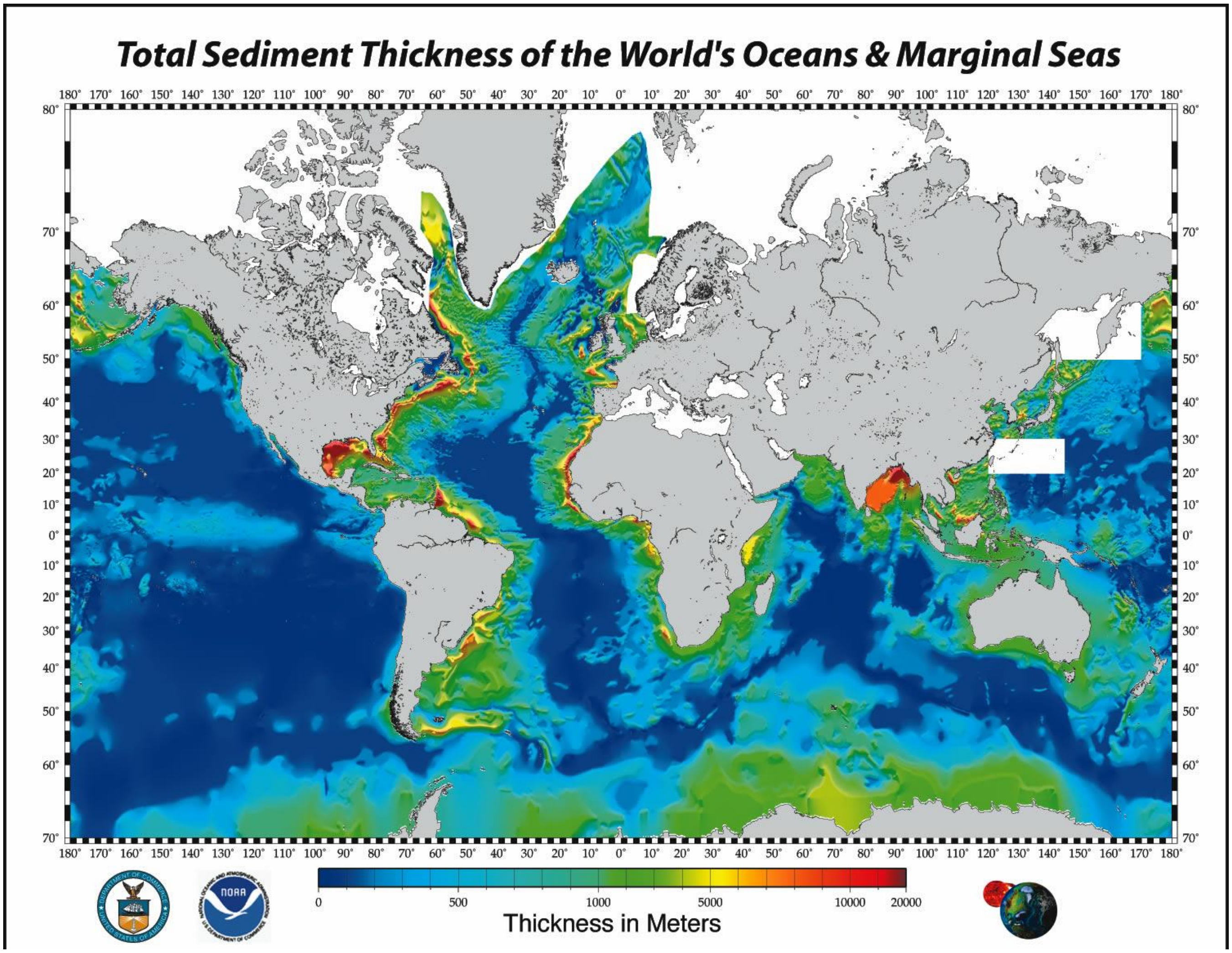

*Trench forming above a subduction zone.*

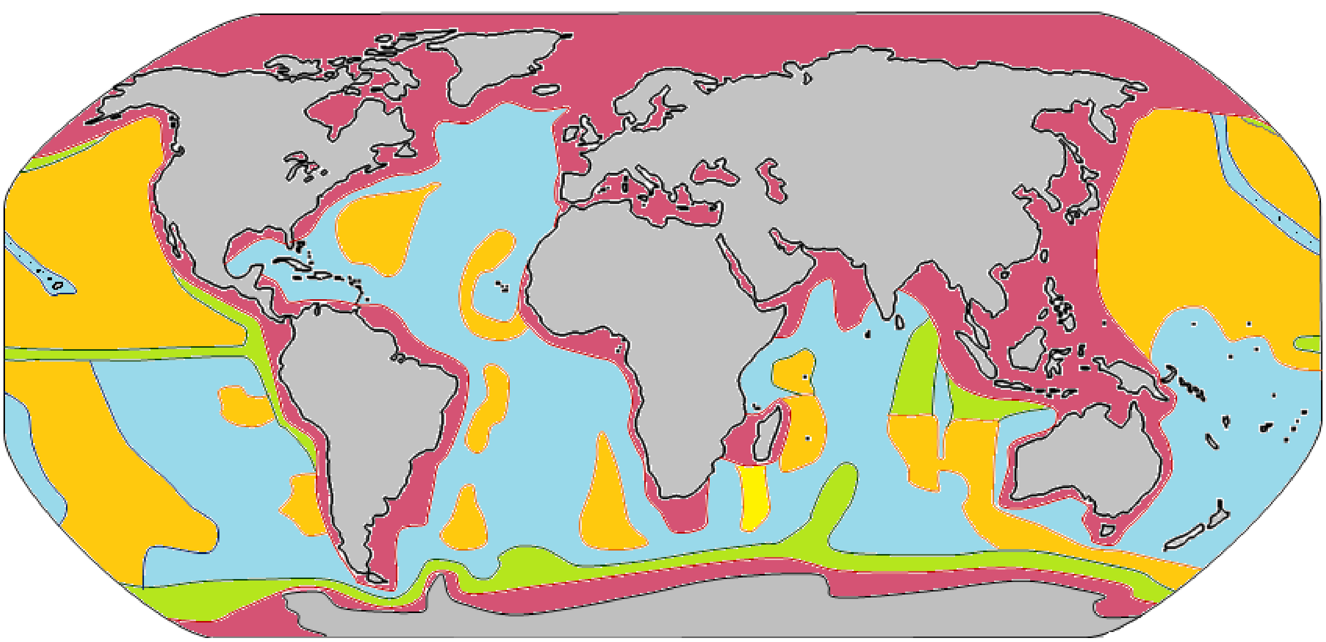
**Plankton whose shells contribute to deep-sea oozes**

| | $CaCO_3$ shell | $SiO_2$ shell |
|---|---|---|
| **AUTOTROPHS** |  **COCCOLITHOPHORE** *(image: Alison R. Taylor, UNC Wilmington Microscopy Facility, CC Generic 2.5; Scale: 0.005 to 0.1 mm)* |  **DIATOM** *(image: M. Dubose; Scale: 0.005 to 1 mm)* |
| **HETEROTROPHS** |  **FORAMINIFERA** *Scale: 0.1 to 1 mm* |  **RADIOLARIA** *Scale: 0.1 to 1 mm* |




*San Francisco Bay Area coastline (and sea level) at the height of the last ice age, 18,000 years ago. Yellow curved lines represent extent of sand dunes covering continental shelf. Modified from work by Tanya Atwater – UC Santa Barbara*



Generalized map of global sediment distribution. PINK = lithogenous sediment that includes quartz, clay, and other rock and mineral fragments. BLUE = calcareous ooze. GREEN = siliceous ooze. YELLOW = abyssal clay. Based on image from Creative Commons Licensed Online Textbook: Physical Geology by Steven Earle: https://opentextbc.ca/geology/chapter/18-3-sea-floor-sediments/

| Feature | Depth | Shape | Location & Cause |
|---|---|---|---|
| Rift Valley | 1-2 km | Linear valley. Square cross section | At the center of divergent plate boundaries (usually atop ocean ridges, unless in center of continent), caused by divergence. |
| Submarine Canyon | 20 m to 2 km | V-shaped cross-section. Sinuous canyon, like river canyons in the mountains. | Carved out of continental shelves by **turbidity currents** – extend out perpendicular to the shoreline. |
| Deep-sea trench | > 2 km (6-11 km) | Arc-shaped from above. Deep, wide depression, with steep sides and a flat floor (covered with sediment). | Above subduction zones, caused by subducting oceanic lithosphere. |

| | Lithogenous or Terrigenous | Biogenic | Hydrogenous | Cosmogenous |
|---|---|---|---|---|
| **Source** | LAND – dumped by rivers, coastal erosion, wind, and glaciers. | Dead shelled organisms | Precipitation from supersaturated water | Extra-terrestrial |
| **Examples** | Quartz, clay (mature materials) + any rock and mineral debris from land (immature materials). | $CaCO_3$ or $SiO_2$ shells of microscopic plankton. (Minor amounts from coral reefs and coastal creatures.) | Manganese (Mn) and Phosphate nodules. Metal sulfides at hydrothermal vents. Evaporites (salt and gypsum). | Meteorites and tektites |
| **Distribution** | Continental margins; Continental rises where turbidity currents deposit; Deep-sea floor where surface waters do not support a large plankton community. | Deep-sea floor where surface waters support a large plankton community. Near coral reefs. | Hydrothermal vents; areas of deep seafloor with locally high amounts of Mn or P; inland or shallow seas where evaporation rates are high. | Scattered |
| **% seafloor coverage** | ~45% | ~55% | <1% | <<<1% |

| Region | % of ocean floor | % of total volume of marine sediments | Sediment thickness | Sedimentation rate |
|---|---|---|---|---|
| **Neritic** | 22% | 87% | 2.5 to 9 km | Deltas 800 m/1000 yr \| Quiet bays 500 cm/1000 yr<br>Shelves/slopes 10-40 cm/1000 yr |
| **Oceanic** | 78% | 13% | 0 to 0.6 km | 0.1 to 1 cm/1000 yr (abyssal clay) |

**DEEP-SEA, OCEANIC MUDS**

| Sediment type | Source | Global distribution | % |
|---|---|---|---|
| **Calcareous ooze** (>30% $CaCO_3$ shells) | Foraminifera (hetero)<br>Coccolithophores (auto) | Beneath warm surface water that is filled with marine plankton (and on seafloor that is less than 4 km deep).<br>Accumulation rate: 0.5 to 1 cm/1000 yr. | 47% |
| **Siliceous ooze** (>30% $SiO_2$ shells) | Radiolaria (hetero)<br>Diatoms (auto) | Dominates beneath high-nutrient, cold surface water or plankton-filled water where the seafloor is deeper than 4 km. Common in polar and eastern equatorial oceans. Accumulation rate: 0.5 to 1 cm/1000 yr. | 15% |
| **Abyssal or red clay** | Deserts: wind-blown clay, sand, dust; Rivers: clays; Volcanic ash | Deep ocean floor near major rivers or deserts, or where surface waters are devoid of plankton.<br>Accumulation rate: 0.1 cm/1000 yr (higher off rivers). | 38% |

| Characteristic | Immature (near source or carried by glaciers) | Mature (usually long travelled by river) |
|---|---|---|
| **Grain composition** | ALL POSSIBLE | Only chemically stable minerals like quartz and clay |
| **Grain size** | All sizes (gravels, sands, muds) | Fine sands and muds |
| **Sorting** | Very poor | Very good |
| **Grain shape** | Angular | Rounded |

| Sediment size | Particle diameter | Where deposits are found in ocean |
|---|---|---|
| **Gravel** | X > 2 mm | Where rock is breaking down. Where water energy is high (and smaller sediments are held in suspension). Coastline. |
| **Sand** | 1/16 < X < 2 mm | Where water energy is low. Inner shelf; submarine canyons and their deposits (slope and rise) |
| **Mud** | 0.0002 < X < 1/16 mm | Where water is still. Outer shelf, estuaries, lagoons (still or slack water); deep-oceans. (EVERYWHERE!) |

# The Seafloor and its Sediments Chapter Worksheet

1. What methods have been used in the past (and are in use today) to measure the depth to the seafloor so we can create bathymetric maps of the seafloor?

2. **SEAFLOOR FEATURES:** Circle the relevant characteristics in the appropriate boxes below.

| RIFT VALLEY | TRENCH | SUBMARINE CANYON |
|---|---|---|
| *Caused by subduction* | *Caused by subduction* | *Caused by subduction* |
| *Caused by seafloor spreading* | *Caused by seafloor spreading* | *Caused by seafloor spreading* |
| *Caused by turbidity currents* | *Caused by turbidity currents* | *Caused by turbidity currents* |
| *Found only along coasts* | *Found only along coasts* | *Found only along coasts* |
| *Can be found in middle of ocean* | *Can be found in middle of ocean* | *Can be found in middle of ocean* |
| *Seafloor depression* | *Seafloor depression* | *Seafloor depression* |
| *Deepest spot in ocean* | *Deepest spot in ocean* | *Deepest spot in ocean* |
| *Cross-section = square shape* | *Cross-section = square shape* | *Cross-section = square shape* |
| *Cross-section = V shape* | *Cross-section = V shape* | *Cross-section = V shape* |
| *Map view = linear shape* | *Map view = linear shape* | *Map view = linear shape* |
| *Map view = arc shape* | *Map view = arc shape* | *Map view = arc shape* |
| *Map view = branching shape* | *Map view = branching shape* | *Map view = branching shape* |

3. **CONTINENTAL MARGINS:** Circle the relevant characteristics in the appropriate boxes below.

| ACTIVE MARGIN | PASSIVE MARGIN |
|---|---|
| *Edge of the continent (where meets ocean)* | *Edge of the continent (where meets ocean)* |
| *Subduction* | *Subduction* |
| *Plate boundary* | *Plate boundary* |
| *Uplifting* | *Uplifting* |
| *Sinking* | *Sinking* |
| *Large earthquakes* | *Large earthquakes* |
| *Volcanism* | *Volcanism* |
| *Found in Arctic ocean* | *Found in Arctic ocean* |
| *Found in Indian ocean* | *Found in Indian ocean* |
| *Found in Atlantic ocean* | *Found in Atlantic ocean* |
| *Found in Pacific ocean* | *Found in Pacific ocean* |

4. Circle the locations below that represent ACTIVE margins:

EAST COAST US | NORTHWEST COAST US | SOUTHWEST COAST US | EAST COAST SOUTH AMERICA | WEST COAST SOUTH AMERICA | EAST COAST AFRICA | WEST COAST OF AFRICA | AUSTRALIA | INDIA | ALEUTIAN ISLANDS | PHILIPPINES | JAPAN | INDONESIA

5. **Abyssal Plains:** CIRCLE ALL THAT APPLY: *flattest place on Earth | rough topography | the deepest parts of the ocean (after trenches) | shallowest parts of ocean | most of ocean seafloor*

6. Circle which of the following are considered **nutrients**: CALCIUM | SILICA | CARBONATE | SUGAR OXYGEN GAS | CARBON DIOXIDE GAS | WATER | SUNLIGHT | NITRATES | PHOSPHATES | SULFIDE

7. How do autotrophs get nutrients?

8. How do heterotrophs get nutrients?

9. What is the **calcium carbonate compensation depth** (CCD)? How can it explain why calcareous biogenous deposits are rare on the deepest parts of the ocean floor?

10. **DEEP-SEA MUDS:** Circle the relevant characteristics in the appropriate boxes below.

| ABYSSAL or RED CLAY | SILICEOUS OOZE | CALCAREOUS OOZE |
|---|---|---|
| *Foraminifera* | *Foraminifera* | *Foraminifera* |
| *Radiolaria* | *Radiolaria* | *Radiolaria* |
| *Coccolithophore* | *Coccolithophore* | *Coccolithophore* |
| *Diatom* | *Diatom* | *Diatom* |
| *Lithogenous* | *Lithogenous* | *Lithogenous* |
| *Biogenous* | *Biogenous* | *Biogenous* |
| *High near volcanoes* | *High near volcanoes* | *High near volcanoes* |
| *High near rivers* | *High near rivers* | *High near rivers* |
| *High near deserts* | *High near deserts* | *High near deserts* |
| *High under zones of upwelling* | *High under zones of upwelling* | *High under zones of upwelling* |
| *Abundant above CCD* | *Abundant above CCD* | *Abundant above CCD* |
| *Most abundant below CCD* | *Most abundant below CCD* | *Most abundant below CCD* |
| *Collects the slowest* | *Collects the slowest* | *Collects the slowest* |
| *Abundant on seafloor where surface waters are warm* | *Abundant on seafloor where surface waters are warm* | *Abundant on seafloor where surface waters are warm* |
| *Abundant on seafloor where surface waters are cold* | *Abundant on seafloor where surface waters are cold* | *Abundant on seafloor where surface waters are cold* |
| *Dominates mid-ocean ridges* | *Dominates mid-ocean ridges* | *Dominates mid-ocean ridges* |
| *Dominates abyssal plains* | *Dominates abyssal plains* | *Dominates abyssal plains* |

**SEDIMENT TYPES:** Circle the relevant characteristics in the appropriate boxes below.

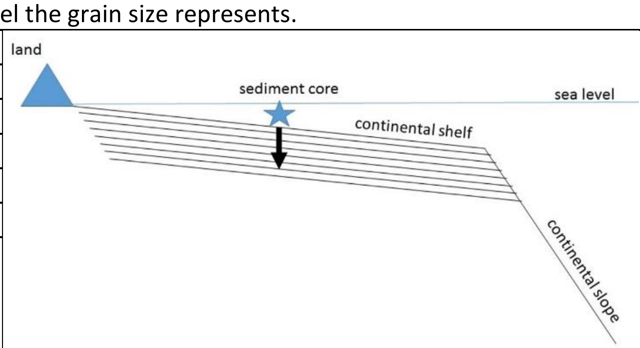
| Lithogenous | Biogenous | Hydrogenous | Cosmogenous |
|---|---|---|---|
| *Largest volume in oceans* | *Largest volume in oceans* | *Largest volume in oceans* | *Largest volume in oceans* |
| *Largest surface area coverage of seafloor* | *Largest surface area coverage of seafloor* | *Largest surface area coverage of seafloor* | *Largest surface area coverage of seafloor* |
| *Quartz and clay* | *Quartz and clay* | *Quartz and clay* | *Quartz and clay* |
| *Tektites and meteorites* | *Tektites and meteorites* | *Tektites and meteorites* | *Tektites and meteorites* |
| *Shells and bones* | *Shells and bones* | *Shells and bones* | *Shells and bones* |
| *Precipitates (nodules/salts)* | *Precipitates (nodules/salts)* | *Precipitates (nodules/salts)* | *Precipitates (nodules/salts)* |

11. What happens to global sea level when average ocean temperature warms? CIRCLE: Rises | Drops
12. What happens to global sea level when average ocean temperature cools? CIRCLE: Rises | Drops
13. What happens to global sea level when ocean basin size increases? CIRCLE: Rises | Drops
14. What happens to global sea level when ocean basin size decreases? CIRCLE: Rises | Drops
15. What happens to global sea level when glaciers expand on land? CIRCLE: Rises | Drops
16. What happens to global sea level when glaciers melt on land? CIRCLE: Rises | Drops
17. What is the lowest sea level would drop during an ice age?
18. What feature is exposed at that depth?
19. What size of sediment deposits at a **beach**? CIRCLE: Gravel | Sand | Mud
20. What size of sediment deposits at a **rocky headland**? CIRCLE: Gravel | Sand | Mud
21. What size of sediment deposits at the **edge of the continental shelf**? CIRCLE: Gravel | Sand | Mud
22. During an **Ice Age**, what sediment deposits where the **shelf break** is today? CIRCLE: Gravel | Sand | Mud
23. Below you will find layers of a core of sediment recovered from drilling through the top layer of sediment in the middle of the continental shelf. For each layer, circle the sea level the grain size represents.

Top

| | |
|---|---|
| Mud | HIGH sea level, MODERATE sea level, LOW sea level |
| Sand | HIGH sea level, MODERATE sea level, LOW sea level |
| Gravel | HIGH sea level, MODERATE sea level, LOW sea level |
| Sand | HIGH sea level, MODERATE sea level, LOW sea level |
| Mud | HIGH sea level, MODERATE sea level, LOW sea level |

Bottom




24. Which of the above layers is the oldest? Youngest? Label above layers accordingly.

# Scale Activity

1 kilometer = 1000 meters 1 meter = 100 centimeters

| | |
|---|---|
| 1. 5000 meters = how many kilometers? | |
| 2. 11 kilometers = how many meters? | |
| 3. 5000 meters = how many centimeters? | |
| 4. What, on your body, is 1 cm wide? (Pick something you can regularly reference.) | |
| 5. What, on your body, is 10 cm wide or long or tall? (Pick something you can regularly reference.) | |
| 6. What, on your body, is 100 cm or 1 m wide or tall or long? (Pick something you can regularly reference.) | |
| 7. If you travelled 1000 meters or 1 km west from the CCSF Science Building, where would you be? ***(Use* Google Maps *and note the scale bar in the lower right corner. Click on it to change it to kilometers) https://www.google.com/maps*** | |
| 8. What is the length/distance in kilometers of some key landmarks in the surroundings? *(Use Google Maps)* | |
| 9. How **tall is the CCSF Science Building**? *Try to reason this out for yourself. Think about how many floors it has (5) and how tall one floor is. See tips on website for more suggestions.* | |
| 10. What is the **radius** of planet Earth (in km)? | |
| 11. What is the **circumference** of planet Earth (in km)? | |
| 12. What is the **deepest hole** ever drilled (in km)? *Follow website link in the resources section for this answer.* | |
| 13. What is the **average thickness of continental crust** (in km)? | |
| 14. What is the **average thickness of oceanic crust** (in km)? | |
| 15. What is the depth of the ocean's **deepest trench** (in km)? | |
| 16. What is the elevation of the continents' **tallest mountain** (in km)? | |
| 17. What is the **average depth of the oceans** (in km)? | |
| 18. The lowest sea level would drop during an ice age is about 120 m, which exposes the currently flooded edges of the continents, known as the c**ontinental shelves**. 120m is what percent of the average depth of the oceans? | |
| 19. What is the **average elevation of the land** (in km)? | |

*Continue on to next page…*

20. Draw **Earth's layers** to scale (include asthenosphere, crust, core (inner + outer), lithosphere, mantle, and moho).

# Weekly Reflection

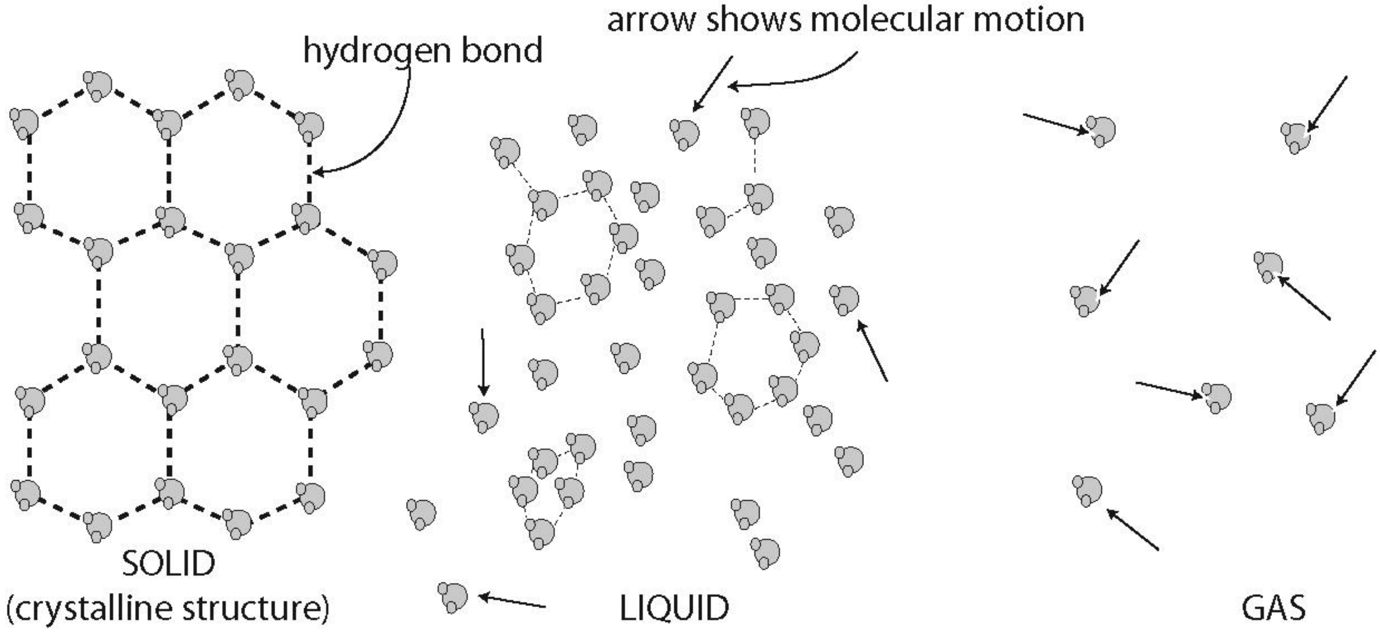
Take a moment to reflect on your comfort level and mastery of the week's objectives and describe an action plan for how you will practice or improve on anything that challenged you.

| **Weekly objective** | **Self-assessment of mastery level** | **Action plan for improvement** |
|---|---|---|
| Compare and contrast the origins and distributions of **abyssal plains, trenches, rift valleys, and submarine canyons**. | A \| B \| C \| D \| F | |
| Compare and contrast the causes, behaviors, and global distribution of **active and passive margins**. | A \| B \| C \| D \| F | |
| Analyze and interpret the origin, distribution, and evolution of **ocean sediment**. | A \| B \| C \| D \| F | |
| Recognize the major causes and impacts of **global (eustatic) sea level rise and fall**. | A \| B \| C \| D \| F | |
| Compare and contrast **scales for distance**. | A \| B \| C \| D \| F | |

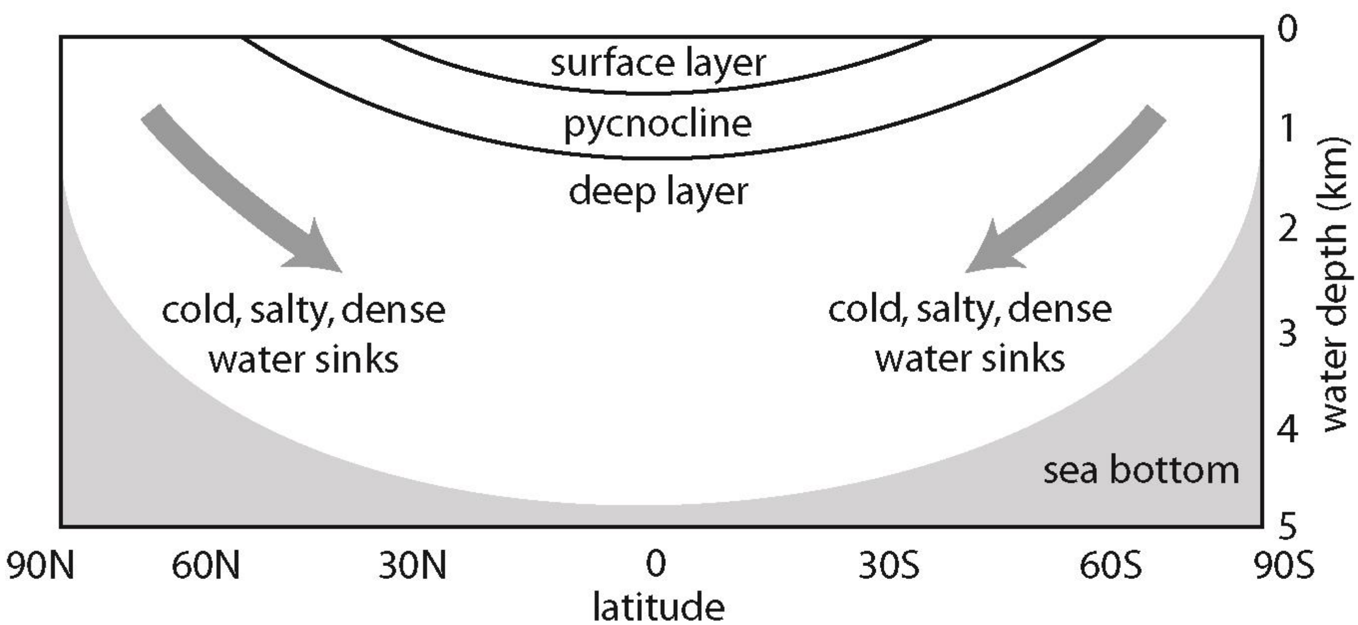
## AHA! Moments

What content from this week really resonated with you, helped you understand something you've always wondered about, or made you think about the world with new eyes?

# SEAWATER – PHYSICAL PROPERTIES



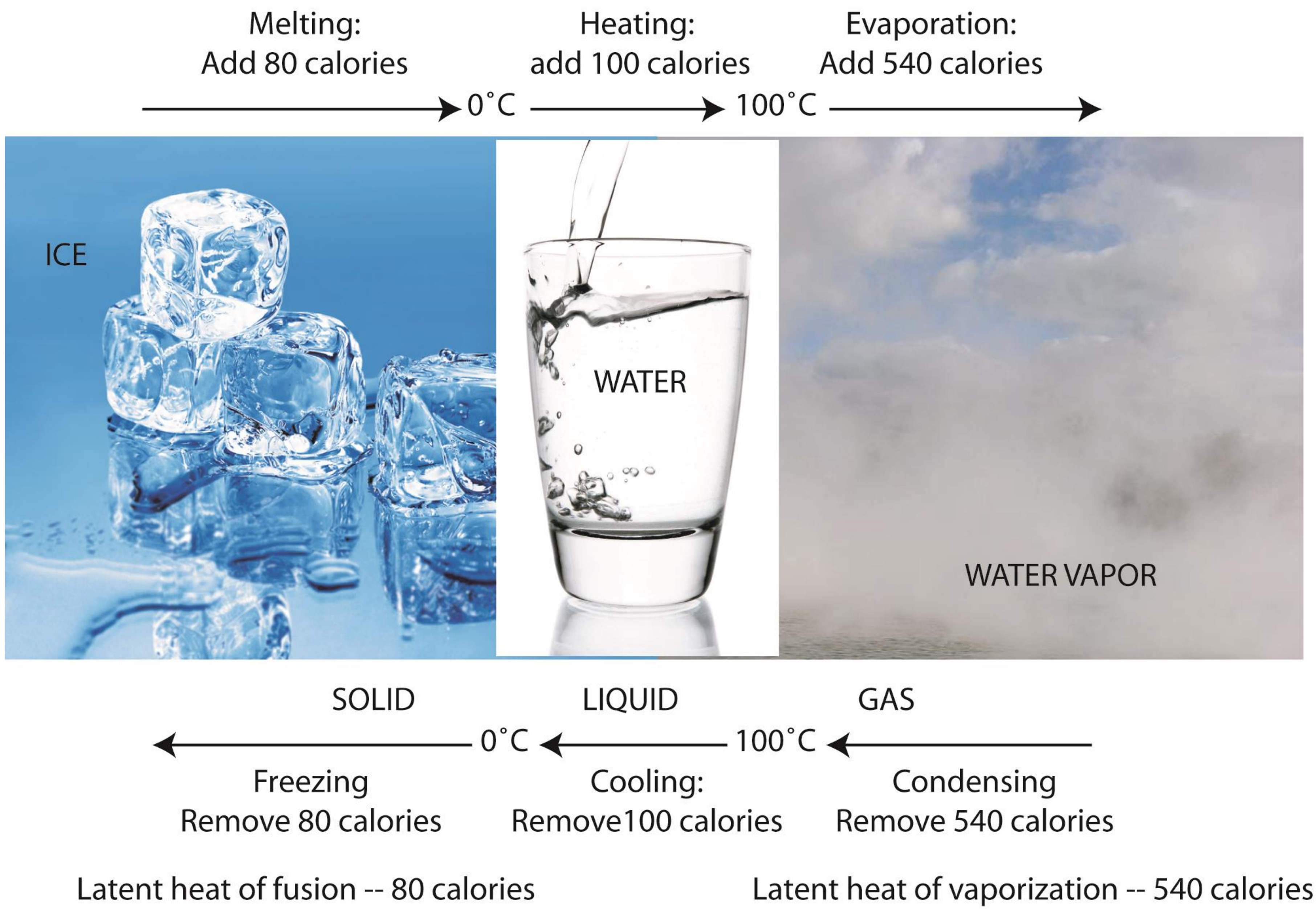

*Atomic structure of water in its solid, liquid, and gaseous forms. Note the increased volume of water in the solid state.*



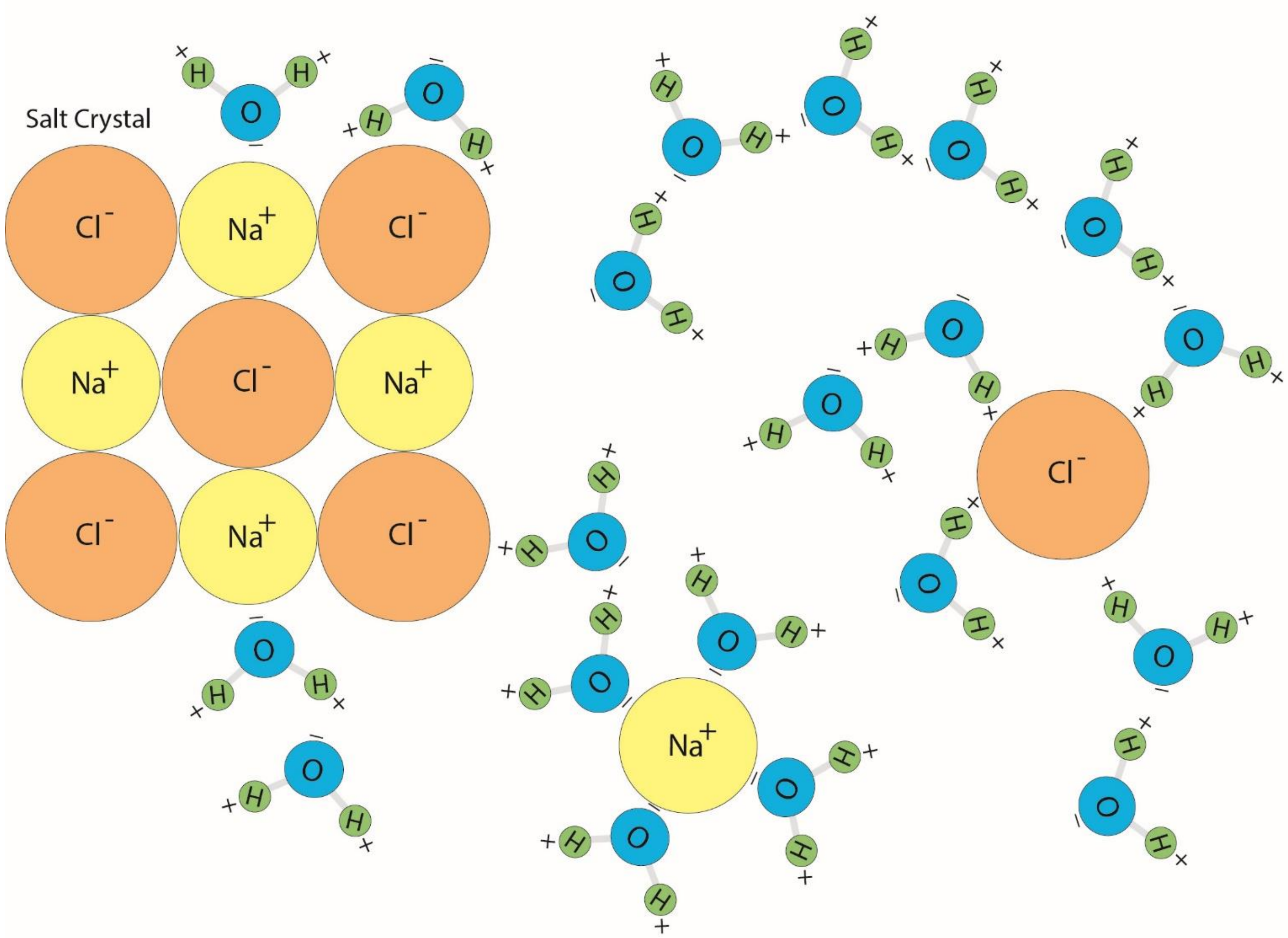

*Generalized water-layer structure of the oceans.*

**SPECIFIC HEAT OF COMMON SUBSTANCES**

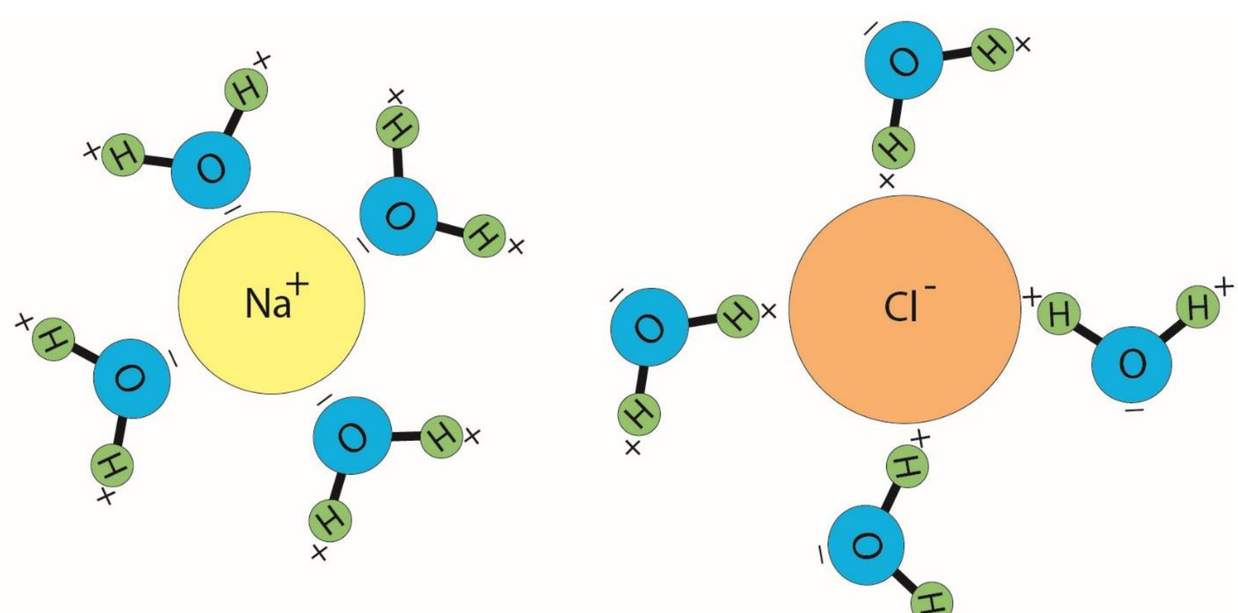
| | |
|---|---|
| Water | 1 cal/g°C |
| Air | 0.25 cal/g°C |
| Sandstone | 0.47 cal/g°C |
| Shale | 0.39 cal/g°C |
| Basalt | 0.20 cal/g°C |
| Limestone | 0.17 cal/g°C |



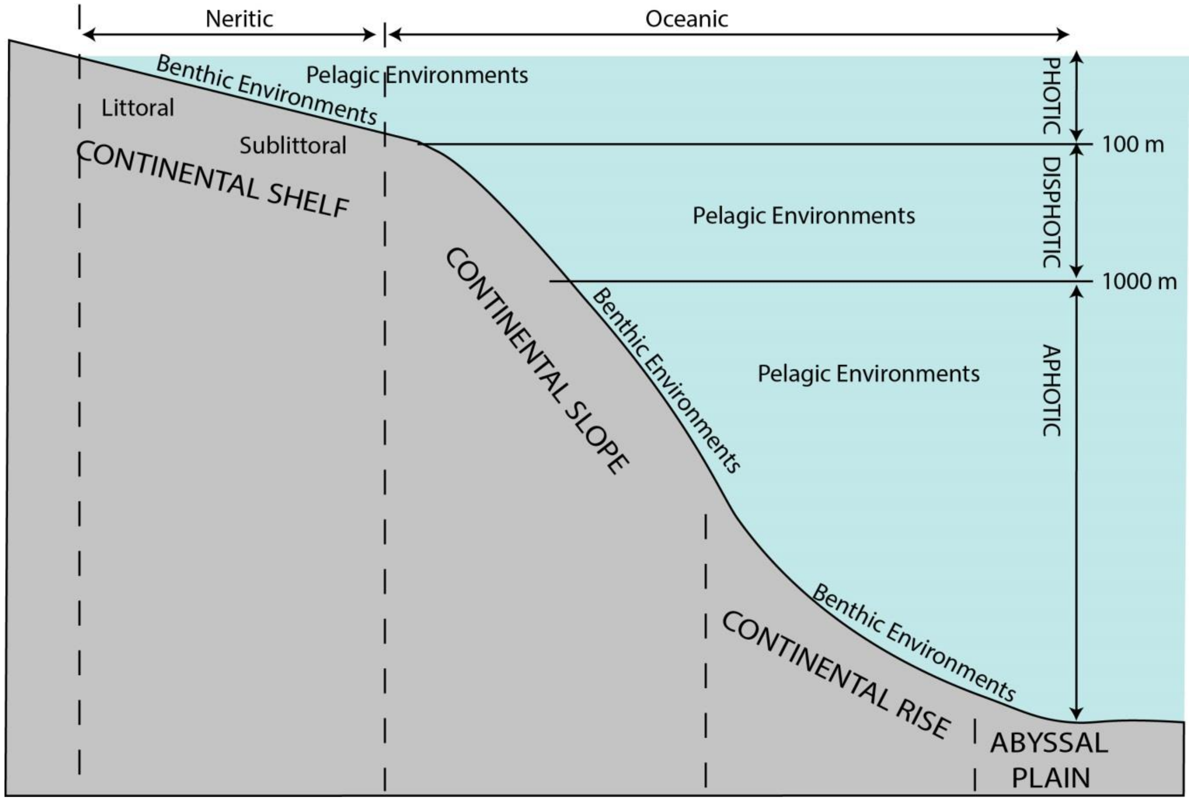

*Heat required to be taken out of environment and provided to the water molecule for it to move from solid to liquid to vapor, including latent heat (for breaking bonds) and specific heats (changing temperatures) and the heat loss from the water molecule (return back to the environment) to return vapor back to ice.*



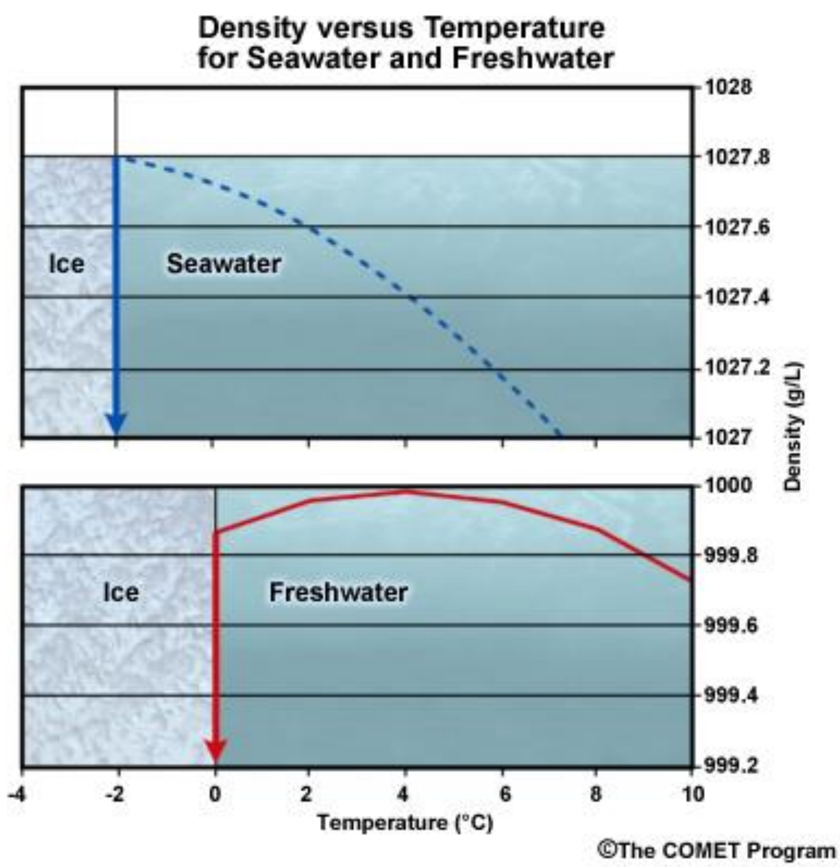

*Dissolution of salt (NaCl)*




*Hydration spheres – what dissolved ions look like when held in water. Example here is for the dissolution of salt (NaCl).*




*Comparison of Benthic (seafloor) and Pelagic (water column) environments and the Neritic (near shore – over the continental shelf) and Oceanic (offshore – deeper than the continental shelf) provinces. Photic zone is depths where sunlight is still available at least 1% of surface values. DIspohotic zone is where available light is between zero and 1% of surface light. The Aphotic zone has no light available.*



# Physical Properties of Seawater Chapter Worksheet

1. Draw **two** water molecules and label with:
   *H | O | + | - | Covalent bond | Hydrogen bond*

2. This bug is walking on water because of what property of water? *Image: David J. Ringer (CC BY-NC-ND 3.0)*

3. Which phase of water has the largest distance between water molecules? CIRCLE: gas | liquid | solid
4. Which phase of water has the smallest distance between water molecules? CIRCLE: gas | liquid | solid
5. Which side of a water molecule sticks to a $Ca^{2+}$ ion?
6. Which side of a water molecule sticks to a $CO_3^{2-}$ ion?
7. When water turns from liquid to gas, what do we call it?
8. When water turns from gas to liquid, what do we call it?
9. When water turns from liquid to solid, what do we call it?
10. When water turns from solid to liquid, what do we call it?

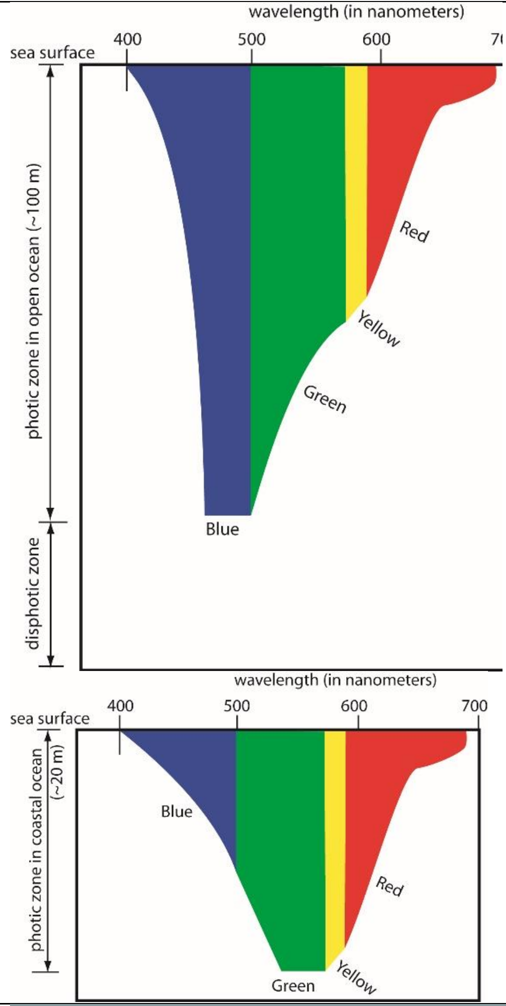
**Kinetic Energy (KE) = ½ $mv^2$ where m=mass and v=velocity.** Objects with greater mass and velocity have higher KE. Velocity can be the actual speed of motion of individual atoms or molecules OR it can be vibrational motion of these same atoms within a solid crystal structure. A solid with high kinetic energy has a lot of internal vibrational motion. A solid within which the atoms have NO vibrational motion – no kinetic energy – means that substance is at ABSOLUTE ZERO = 0 degrees Kelvin = -273 degrees Celsius).

11. TERM for the average kinetic energy of molecules in a system:
12. TERM for the total kinetic energy of molecules in a system:
13. TERM for the amount of HEAT required to raise 1 g of water by 1° C:
14. If the velocity of molecules within a solid slows down (kinetic energy drops), what happens to the temperature of the substance?
15. At the beach, on a hot day, in which substance are molecules moving with the highest internal velocity? (Circle: *Sand | Water | Asphalt*)
16. What happens to freshwater Density when temperature rises from 10 to 20C?
17. What happens to freshwater density when temperature descends from 20 to 10C?
18. What happens to freshwater density when temperature rises from 1to 4C?
19. What happens to freshwater density when temperature cools from 4 to 1C?
20. What happens to seawater density when temperature rises from 1to 4C?
21. What happens to seawater density when temperature cools from 4 to 1C?
22. What is the **freezing point** of freshwater?
23. What is the **boiling point** of freshwater?
24. What happens to water's **freezing point** when salinity increases?
25. What happens to water's **boiling point** when salinity increases?
26. **If <u>HEAT</u> is added to a system, and the system's <u>TEMPERATURE</u> increases as a result, we call that type of heat:**
27. **If heat is added to a system, and molecular bonds are broken to allow a solid to melt and form a liquid, we call that type of heat:** __________________________.
    What happens to the temperature during this change of state?
28. If heat is added to a system, and molecular bonds are broken to allow a liquid to become a gas, we call that type of heat: __________________________.
    What happens to the temperature during this change of state?
29. What is the specific heat of water?
30. What is the **latent heat of evaporation** of freshwater?

31. What is the **latent heat of fusion of** freshwater?

32. What happens to the heat of the surroundings during **evaporation**?

33. What happens to the heat of the surroundings during **precipitation**?




34. Based on these pictures, what color of light is absorbed first in the open ocean?

35. What color of light lasts the longest in the open ocean and thus gives this water its color?

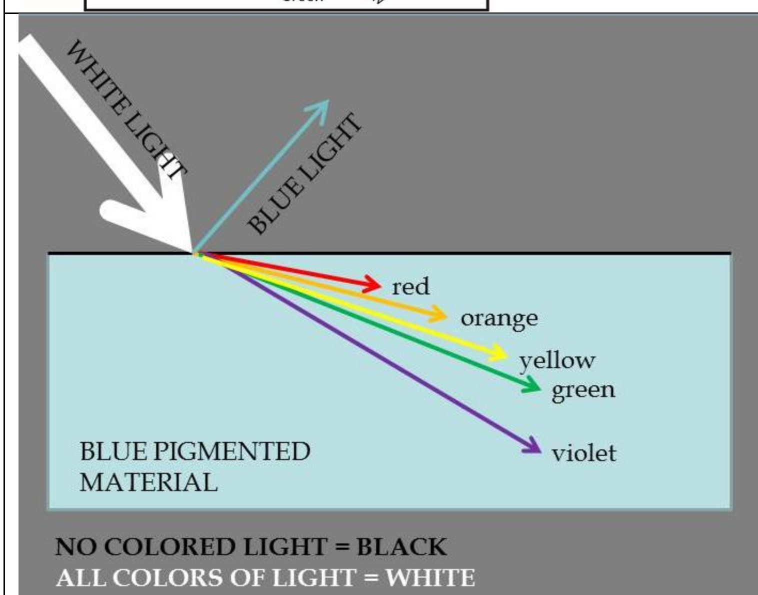
36. White light contains all colors of the spectrum (Red, Orange, Yellow, Green, Blue, Indigo, Violet).
What color(s) does green pigment (chlorophyll) **absorb**?

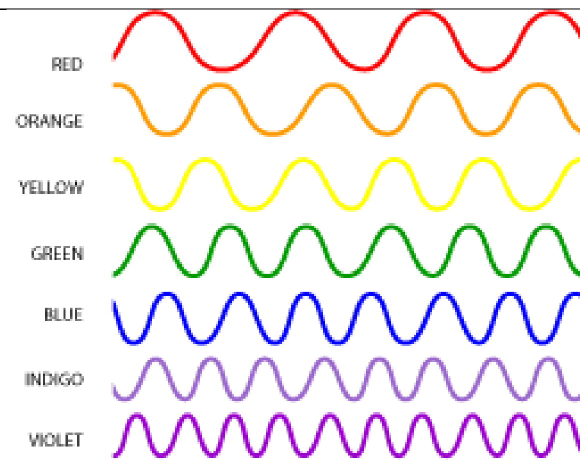
37. What color does green pigment (chlorophyll) **reflect?**

38. What color would a red shrimp appear to be if you could look at it at the bottom of the photic zone?

39. What color would a green organism appear to be if you could look at it at the bottom of the photic zone in the near shore? In the far shore/open ocean?

*Colors of light and their attenuation with depth.*



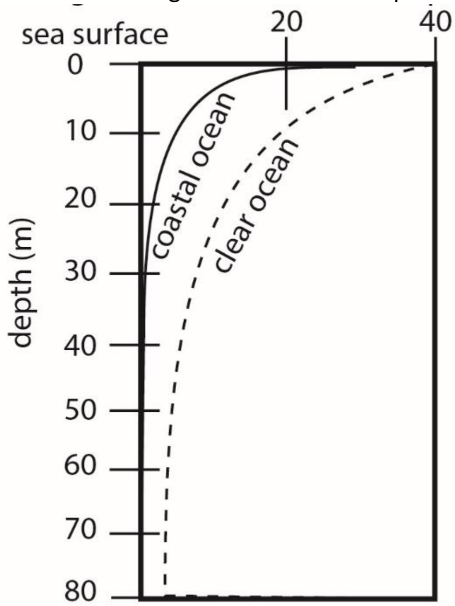




*Relative wavelengths of the different colors of light. Image: NASA*

Graph shows the % of light remaining with 100% hitting surface and decreasing amounts

**40. Which of these water types has the deepest photic zone (light travels deepest)?**

of that light available with depth.




CIRCLE: Hot water | Cold water | No difference
CIRCLE:
Water with lots of sediment | Clear of sediment | No difference
CIRCLE:
Water with lots of plankton | Desert water (no life) | No difference

41. **Attenuation** is the term used to describe the amount of light absorbed by water in a particular area (not the color but how MUCH). What is the attenuation at the base of the photic zone?

42. **VISCOSITY means**:

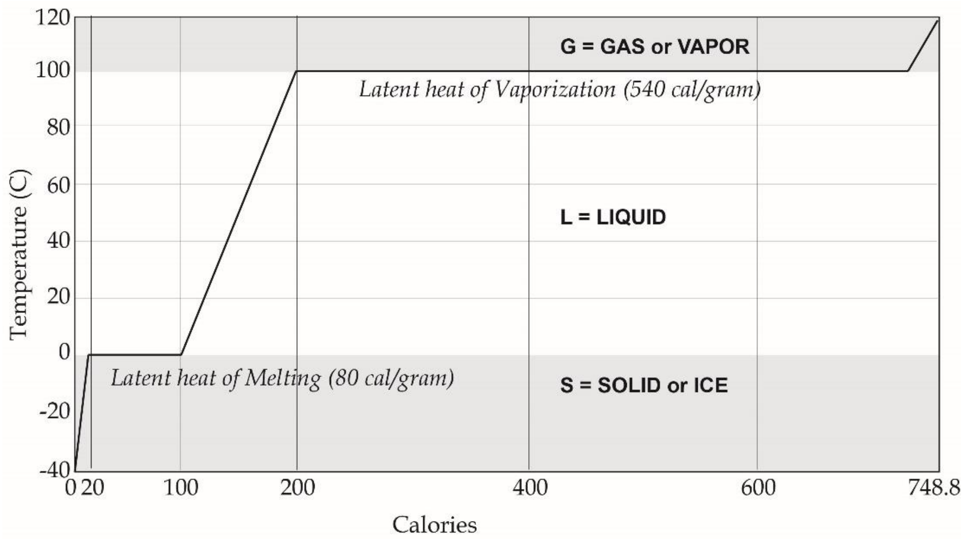
43. **Which is most viscous?** CIRLE: *Honey or Water*

44. Pressure increases by 1 atm for every 10 meters of descent in the ocean; the pressure at the surface is 1 atm

| | | |
|---|---|---|
| What is the pressure at 100 meters depth? | What is the pressure at 1000 meters depth? | What is the pressure at 10,000 meters depth? |

45. Label the picture below of heat/energy transfer with these terms:
*Conduction | Convection | Radiation*

# Phase Changes Activity




**Specific heat of water:**
1 calorie/gram°C
**Specific heat of water vapor:**
0.44 cal/gram°C
**Specific heat of ice:**
0.5 calorie/gram°C
**Latent heat of melting:**
80 calorie/gram
**Latent heat of vaporization:**
540 calorie/gram
*Note: specific heat has also be called heat capacity, though technically they are not synonyms.*

Heat is moved around our natural world through three processes: radiation (think of solar radiation), conduction (think of heat transfer from an iron skillet to your hand), and convection (think of boiling water).

In addition to how heat is transferred, we can also classify heat by how it's used by the object to which it is transferred. If heat is used to break bonds to change the phase of a material, we call it **LATENT heat**. If it's used to raise temperature of a substance, we call it **SPECIFIC HEAT**. ANALOGY: If you took the money you bring in each week and classified it by how you used it, you could have *services money* and *goods money* depending on how you choose to spend it. Same concept as heat categories. Heat goes to accomplish different needs.

Determining how much heat is transferred to the water system matters greatly to our understanding of natural processes. Why? The heat that is used to raise the temperature of ice in the mountains (or at the poles), break its bonds to melt it, and then raise its temperature and then evaporate it, so it's part of the air, is the SAME AMOUNT OF HEAT that is then returned to the system when that same water molecule travels to a new location and cools and precipitates and cools more and freezes. Heat added to the system in one location (equator and tropics where most of the evaporation happens) is later released to another location (think the midlatitudes during rain storms or the poles during ice formation).

Through this process of evaporation in one place followed by precipitation in another, heat is redistributed on our planet and keeps our planet from becoming colder each day at the poles (where solar energy is low) and hotter each day at the equator (where solar energy is high).

Example: On a hot summer day, how much heat does the air have to transfer to an open bowl with **1,000 grams of solid ice at -2°C** to change it into **1,000 grams of water vapor at 105°C?** And how much would the temperature of the surrounding air drop as a result?

**STEP 1: Use specific heat to change temperature of SOLID ICE from -2°C to 0°C**
1000g x 2°C x 0.5cal/g°C = 1000 cal
**STEP 2: Use latent heat to break bonds of SOLID ICE and turn it to LIQUID WATER**
1000g x 80 cal/g = 80,000 cal
**STEP 3: Use specific heat to change temperature of LIQUID WATER from 0°C to 100°C**
1000g x 100°C x 1cal/g°C =100,000 cal
**STEP 4: Use latent heat to break bonds of LIQUID WATER and turn it to WATER VAPOR**
1000g x 540cal/g = 540,000 cal
**STEP 5: Use specific heat to change temperature of WATER VAPOR from 100°C to 105°C**
1000g x 5°C x 0.44cal/g°C=2,200 cal
**TOTAL heat removed from surrounding air: 723,200 calories**

The heat capacity and density of air vary by composition and temperature, but for our purposes we use 0.24 cal/g°C. and 1300 g/m$^3$. If we imagine we're in a room that is 9x9x9 meters (729 m$^3$), there would be 1300 g/m$^3$ x 729 m$^3$ = 947,700 grams of air.

947,700 grams x 0.24 cal/g°C = 227,448 cal/°C

723,200 calories x 1°C/227,448 cal = 3.2°C.

**RESULT: The temperature of the air in the room goes down 3.2°C or 5.7°F.**

*You'd notice that (however, in reality, the heat transfer is happening from the bowl and the table as well, not just the air. And heat is continually transferred among all the objects in the room as well, so to get the entire room to go down 3.2 ℃, you'd need more ice!*

TOTAL HEAT TRANSFER for 1000 grams of material:

| | Change | Heat ratio | Required heat |
|---|---|---|---|
| **STEP 1** | -2° to 0°C (ice) | 0.5 cal/g°C | 1000g x 2°C x 0.5cal/g°C = 1000 cal |
| **STEP 2** | 0°C Solid → Liquid | 80 cal/g | 1000g x 80 cal/g = 80,000 cal |
| **STEP 3** | 0° to 100°C (liquid) | 1 cal/g°C | 1000g x 100°C x 1cal/g°C =100,000 cal |
| **STEP 4** | 100°C Liquid → Gas | 540 cal/g | 1000g x 540cal/g = 540,000 cal |
| **STEP 5** | 100° to 105°C (gas) | 0.44 cal/g°C | 1000g x 5°C x 0.44cal/g°C=2,200 cal |
| | | **Total** | **723,200 calories** |

1. **How much heat does desert air give up if heat is used to melt ice in a cup and evaporate the water?**

START: 1 gram of solid ice at -10°C

END: 1 gram of water vapor at 120°C

| Change | Heat ratio | Required heat |
|---|---|---|
| -10° to 0°C (ice) | 0.5 cal/g°C | |
| 0°C Solid → Liquid | 80 cal/g | |
| 0° to 100°C (liquid) | 1 cal/g°C | |
| 100°C Liquid → Gas | 540 cal/g | |
| 100° to 120°C (gas) | 0.44 cal/g°C | |
| | **Total** | |

2. **How much heat do your hands give up if heat is used to melt a snowball and evaporate the water?**

START: 10 gram of solid ice at -10°C

END: 10 gram of water vapor at 120°C

| Change | Heat ratio | Required heat |
|---|---|---|
| -10° to 0°C (ice) | 0.5 cal/g°C | |
| 0°C Solid → Liquid | 80 cal/g | |
| 0° to 100°C (liquid) | 1 cal/g°C | |
| 100°C Liquid → Gas | 540 cal/g | |
| 100° to 120°C (gas) | 0.44 cal/g°C | |
| | **Total** | |

3. **How much heat does your stove use up to melt ice and evaporate the water in a skillet?**

START: 10 gram of solid ice at -8°C

END: 10 gram of water vapor at 110°C

| Change | Heat ratio | Required heat |
|---|---|---|
| -8°C to 0°C (ice) | 0.5 cal/g°C | |
| 0°C Solid → Liquid | 80 cal/g | |
| 0° to 100°C (liquid) | 1 cal/g°C | |
| 100°C Liquid → Gas | 540 cal/g | |
| 100° to 110°C (gas) | 0.44 cal/g°C | |
| | **Total** | |

4. **How much heat does the ocean and air give up if heat is used to melt and evaporate an iceberg?**

START: 5 gram of solid ice at -2°C

END: 5 gram of water vapor at 119°C

| Change | Heat ratio | Required heat |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |
| | **Total** | |

5. **How much heat does your skin give up if that heat is used to evaporate sweat?**

START: 3 gram of water at 20°C

END: 3 gram of water vapor at 110°C

| Change | Heat ratio | Required heat |
|---|---|---|
| | | |
| | | |
| | | |
| | **Total** | |

6. **How much heat does your window/air give up if heat is used to melt frost on the pane and then raise the temperature of the melted water?**

START: 5 gram of solid ice at -12°C

END: 5 gram of water at 89°C

| Change | Heat ratio | Required heat |
|---|---|---|
| | | |
| | | |
| | | |
| | **Total** | |

7. If the amount of sunlight that arrives at the surface on a particular day is 1.8 calories/$cm^2$•min, and directly hits 1 gram of 15°C water in a 1 square centimeter space, what would the new temperature be after 1 minute?

8. The amount of sunlight that arrives at the surface on a particular day at a particular location with a glacier present is 1.6 calories/$cm^2$•min. The air temperature is 0°C or warmer. The sunlight directly hits a 1 $cm^2$ surface of a glacier. How many minutes would it take to melt 4 grams of 0°C ice in this glacier?

# Weekly Reflection

Take a moment to reflect on your comfort level and mastery of the week's objectives and describe an action plan for how you will practice or improve on anything that challenged you.

| **Weekly objective** | **Self-assessment of mastery level** | **Action plan for improvement** |
|---|---|---|
| Diagram and analyze the **shape and physical and chemical behaviors of the water molecule**. | A \| B \| C \| D \| F | |
| Compare and contrast **heat and temperature** and the methods for transferring the former and raising or lowering the other. | A \| B \| C \| D \| F | |
| Analyze the **heat and physical changes** that occur externally and internally when water changes phase. | A \| B \| C \| D \| F | |
| Evaluate how the **color and intensity of light** we see is affected by differences in water clarity and depth; and the impacts these effects have on marine life. | A \| B \| C \| D \| F | |
| Evaluate how **density, viscosity, and pressure change** in a variety of ocean conditions and thereby impact on marine life. | A \| B \| C \| D \| F | |

## AHA! Moments

What content from this week really resonated with you, helped you understand something you've always wondered about, or made you think about the world with new eyes?

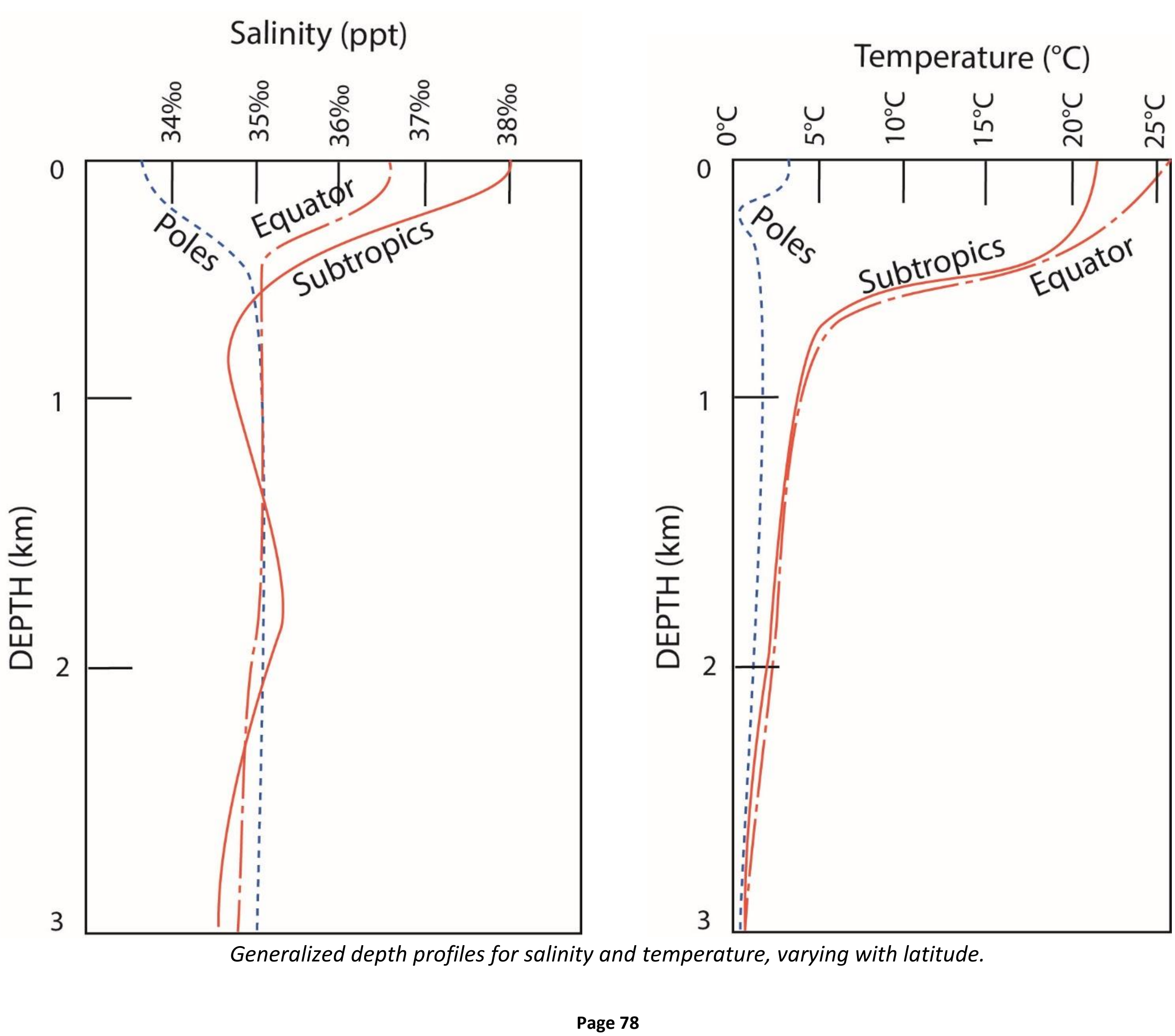
# SEAWATER CHEMISTRY

**Comparison of the concentration of major dissolved ions in the oceans and in the rivers that act as their primary source to the oceans (by volume or frequency, NOT by weight)**

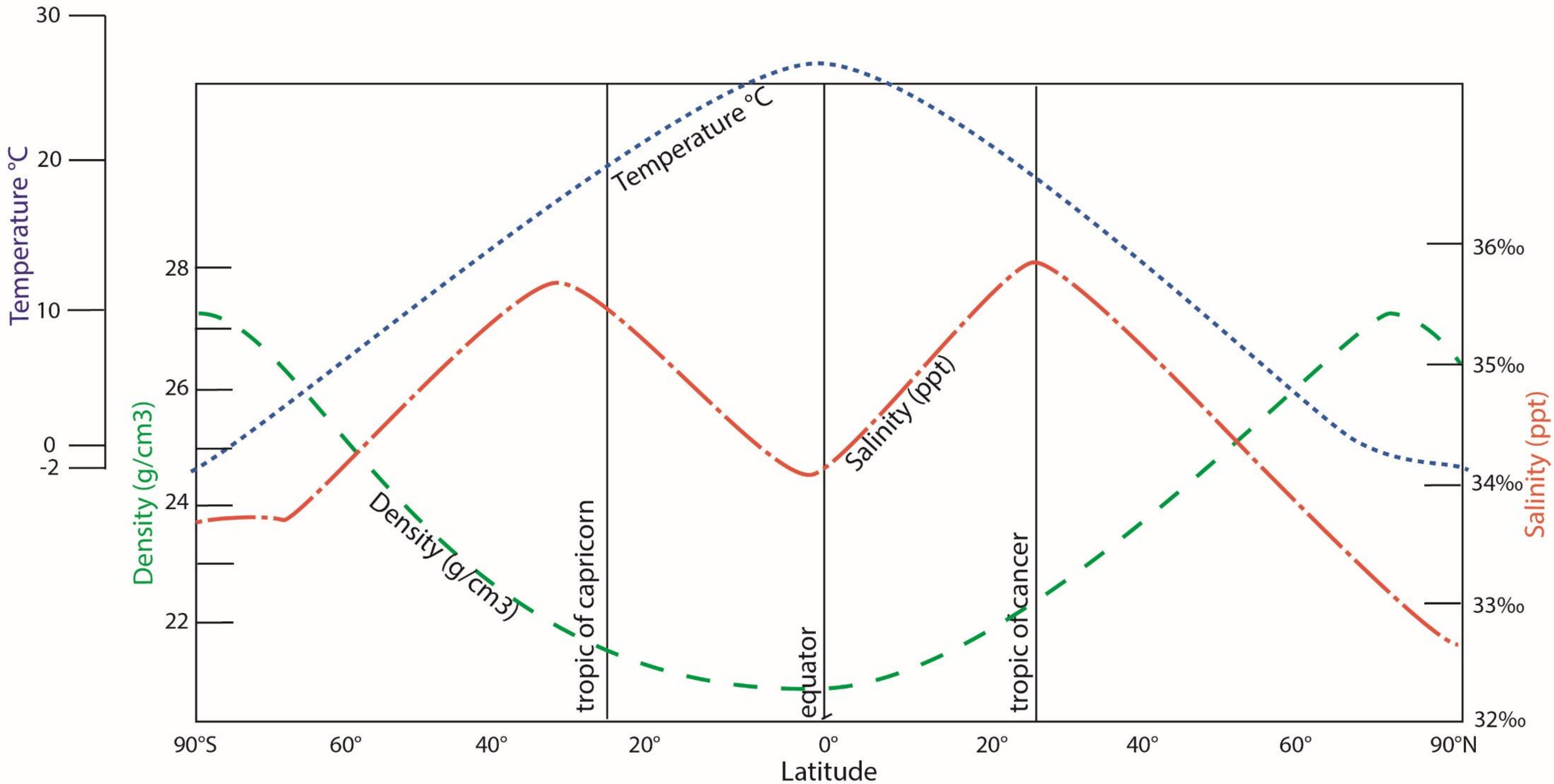
| | Oceans (mol/L) | Residence time (yr) | Ocean input from rivers ($10^{10}$ mol/yr) | Rivers (mol/L) |
|---|---|---|---|---|
| $Cl^-$ | 0.55 | 87 million | 720 | 0.00022 |
| $Na^+$ | 0.46 | 55 million | 900 | 0.00027 |
| $Mg^{2+}$ | 0.054 | 13 million | 550 | 0.00017 |
| $SO_4^{2-}$ | 0.028 | 8.7 million | 380 | 0.00012 |
| $K^+$ | 0.01 | 12 million | 190 | 0.000059 |
| $Ca^{2+}$ | 0.01 | 1.1 million | 1220 | 0.00038 |
| $HCO_3$- | 0.0023 | 83,000 | 3200 | 0.00095 |

**Comparison of the concentration of gases in the atmosphere and dissolved in the ocean (by volume or frequency, NOT by weight)**

| Gas | % in atmosphere by volume | % in ocean surface by volume | % in total ocean by volume |
|---|---|---|---|
| Nitrogen ($N_2$) | 78 | 48 | 11 |
| Oxygen ($O_2$) | 21 | 36 | 6 |
| Carbon dioxide ($CO_2$) | 0.04 | 15 | 83 |



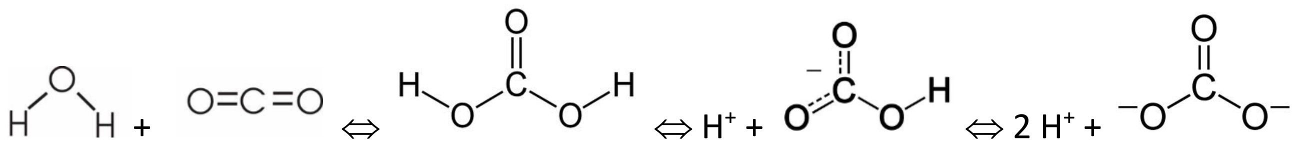

*Generalized depth profiles for salinity and temperature, varying with latitude.*




*Generalized variations in surface water temperature, salinity, and density across latitude in the world's oceans.*

Carbon dioxide + water ⇔ carbonic acid ⇔ hydrogen ion + bicarbonate ion ⇔ hydrogen ion + carbonate ion

$CO_2 + H_2O \Leftrightarrow H_2CO_3 \Leftrightarrow H^+ + HCO_3^- \Leftrightarrow 2H^+ + CO_3^{-2}$



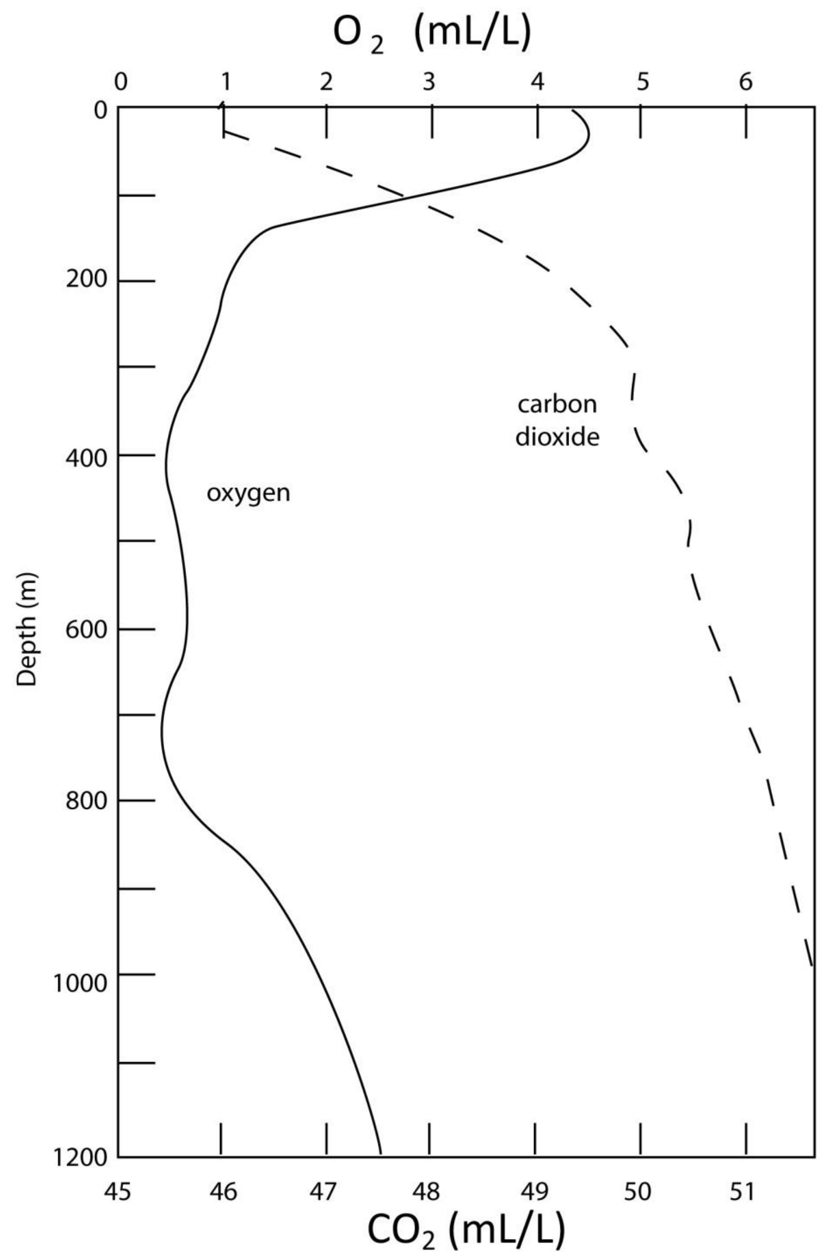
**This equation maintains EQUILIBRIUM in the oceans, which means:**
Whenever you try to change the ocean's $H^+$ or $CO_2$ content, the above equation will work in whatever directions UNDOES the change, so the system goes back to being in balance.

**pH** = measurement of the activity (concentration) of $H^+$ ion.

BUT scale is a negative log function:
high pH = low H+ ion concentration;
low pH = high H+ ion concentration.

$H_2O \leftrightarrow H^+ + OH^-$

If $H^+$ and $OH^-$ do NOT balance, then the system will be **<u>acidic</u>** (if more $H^+$ than $OH^-$) or **<u>basic</u>** (if more $OH^-$ than $H^+$).




*General variations of the concentrations of carbon dioxide and oxygen with depth in the world's oceans.*

# Seawater Chemistry Chapter Worksheet

1. What specifically does **salinity** measure? (definition)

2. What is the **average salinity** of the oceans? (be sure to include number + FULL units)

3. Circle which of the following objects would be part of the above calculation of salinity:
*Suspended clay minerals | Cl- |Na+ | Water molecules | plankton | feces | dissolved oxygen gas | nitrates ($NO_3^{2-}$) | foraminifera and diatoms | $SiO_2$ shells | $SO_4^{2-}$*

4. List the major ions dissolved in seawater in decreasing order (highest on left – least on right):

5. For the list above, circle the ions that are CATIONS and underline the ones that are ANIONS.

6. List the 3 types of bonds discussed in this class below the appropriate circumstances in which they are found:
**WITHIN a single water molecule | BETWEEN water molecules | BETWEEN Na+ and Cl- in a salt crystal**

7. Rank the above bonds (specific to the examples) in order from strongest to weakest **(1=strongest | 3 = weakest).**

*8.* What is the term used to describe the opposite of dissolution**?** *(when dissolved ions get back together and bond to make a solid )*

9. If the concentration of Cl- in a body of water is 4.5 mol/L, and the saturation concentration is 4 mol/L, what term do we use to describe this system?

**10.** Common evaporite minerals found under shallow seas in warm climates include: Gypsum ($CaSO_4$-$2H_2O$), Salt (NaCl), and Calcite ($CaCO_3$). What kind of bonds exist between the atoms in these minerals?

11. Make a list below of ALL the things **conservative constituents** have in common:

12. Make a list below of ALL the things **nonconservative constituents** have in common:

13. Circle the **conservative constituents** from the following materials dissolved in the oceans.
*$Na^+$ | Cl- | $CO_2$ gas | $O_2$ gas | $N_2$ gas | Nitrates ($NO_3^{2-}$) | Phosphates ($PO4^{3-}$) | $H^+$ | $HCO_3^-$ | $SO_4^{2-}$*

14. REVIEW: What is a nutrient and which of the above are considered **nutrients**?

**15.** What is the **PRIMARY** SOURCE of dissolved ions to the oceans? (what brings ions to the ocean)

16. List as many other SOURCES of dissolved ions to the oceans as you can:

17. How are **nutrients** transported through the oceans?

Ions are removed from the ocean when they bond with each other. Solid surfaces can accelerate that bonding. It is for that reason that PEARLS form – as $Ca^{2+}$ and $CO_3^{2-}$ find each other on the surface of a sand grain and bond to grow a mineral. When solid surfaces collect and facilitate bonding of seawater ions, we call that **adsorption.**

18. In addition to adsorption, what are other ways to remove ions from the oceans?

19. How is **chlorinity** related to salinity? Why?

20. Describe these main methods used to measure salinity. Are they directly measuring salinity or indirectly measuring it? How does each work?

| Method | CIRCLE: | How does it work? Provide full explanation of how each of these parameters tells us about salinity. |
|---|---|---|
| Conductivity (current meter) | Direct Indirect | |
| Density (hydrometer) | Direct Indirect | |
| Chlorinity | Direct Indirect | |
| Taste | Direct Indirect | |
| Evaporation and scales | Direct Indirect | |
| OTHER: | | |

21. What happens to local salinity when **evaporation** rates increase? CIRCLE: *rises* | *lowers*

22. What happens to local salinity when **ice formation** rates increase? CIRCLE: *rises* | *lowers*

23. What happens to local salinity when **rain** increases? CIRCLE: *rises* | *lowers*

24. What happens to local salinity when **river input** increases? CIRCLE: *rises* | *lowers*

25. Where is surface salinity **highest** in the world ocean (in general)? Why?

26. Where is surface salinity **lowest** in the world ocean (in general)? Why?

27. Describe how and why salinity varies with depth in the oceans (poles vs subtropics). *(Observations and Evaluations – see graph showing depth profile for salinity in the images that precede this assignment.)*

28. Where is surface temperature **highest** in the world ocean (in general)? Why?

29. Where is surface temperature **lowest** in the world ocean (in general)? Why?

30. Describe how and why temperature varies with depth in the oceans (poles vs subtropics). *(Observations and Evaluations – see graph showing depth profile for temperature in the images that precede this assignment.)*

31. What happens to gas solubility when **pressure** increases? CIRCLE: *rises | lowers*

32. What happens to gas solubility when **temperature** increases? CIRCLE: *rises | lowers*

33. What happens to gas solubility when **salinity** increases? CIRCLE: *rises | lowers*

34. Which gas is highest in abundance in the **atmosphere**?

35. Which gas is highest in abundance in the **oceans**? Why?

36. Which of the following processes increases **oxygen** in the oceans? SOURCES -- CIRCLE:
*atmospheric interaction | decomposition | photosynthesis | respiration | volcanic outgassing*

37. Which of the following processes increases **carbon dioxide** in the oceans? SINKS -- CIRCLE:
*atmospheric interaction | decomposition | photosynthesis | respiration | volcanic outgassing*

38. Describe how and why oxygen varies with depth in the oceans. *(Observations and Evaluations – see graph showing depth profile for oxygen in the images that precede this assignment. And note that you've answered this question before in Week 1 What is Science activity and Week 2 Photosynthesis activity so I'm expecting you to get this one 100% correct now!)*

39. Describe how and why carbon dioxide varies with depth in the oceans. *(Observations and Evaluations – see graph showing depth profile for salinity in the images that precede this assignment. And note that you've answered this question before in Week 1 What is Science activity and Week 2 Photosynthesis activity so I'm expecting you to get this one 100% correct now!))*

40. What chemical does **pH** measure?
Be specific! (include definition)

41. In 1 liter of water, there are 3.3 x $10^{25}$ atoms of water, 6.022x$10^{16}$ of $H^+$, and 6.022x$10^{16}$ of $OH^-$.
What kind of solution is it? **CIRCLE:** *Acidic | Neutral | Basic*

42. If, in that same liter of water, there is more H+ than OH- (NOT equal), what kind of solution is it?
**CIRCLE:** *Acidic | Neutral | Basic*

43. If, in that same liter of water, there is more OH- than H+ (they are NOT equal), what kind of solution is it?
**CIRCLE:** *Acidic | Neutral | Basic*

44. What is the pH range for **basic solutions?** **CIRCLE:** 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14

45. What is the pH range for **neutral solutions?** **CIRCLE:** 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14

46. What is the pH range for **acidic solutions?** **CIRCLE:** 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14

47. What is the average pH of **the oceans?** **CIRCLE:** 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14

48. What is the average pH of **coffee?** **CIRCLE:** 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14

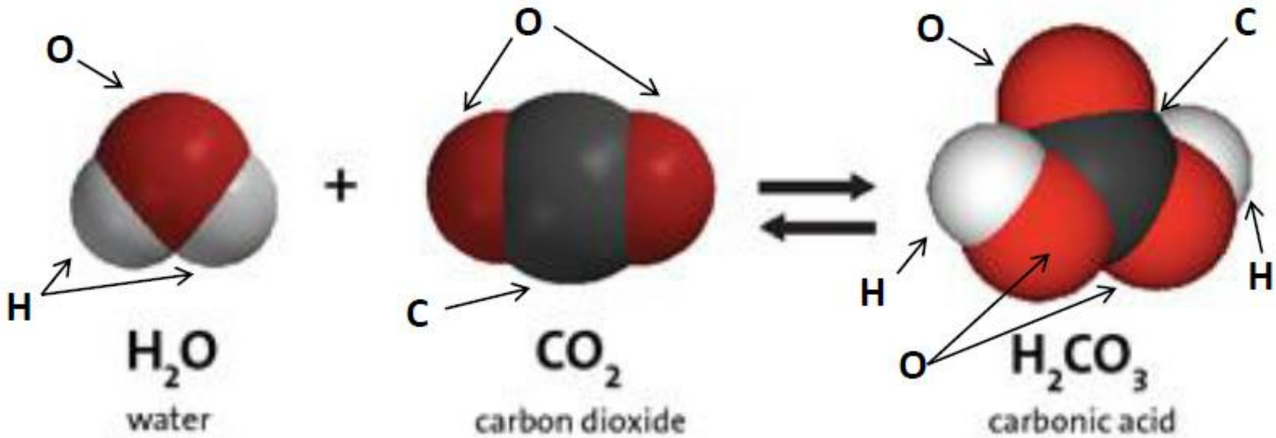
49. What is the average pH of **orange juice?** **CIRCLE:** 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14

# Carbonate Buffering and Seawater Salinity Activity

**BUFFERING** is the action of maintaining pH at a set level. It is a main process at work in the oceans due to the high concentrations of carbon dioxide gas. The chemical equation in balance at the heart of buffering is this one:

carbon dioxide + water ⇔ carbonic acid ⇔ hydrogen ion + bicarbonate ion ⇔ hydrogen ion + carbonate ion

$$CO_2 + H_2O \Leftrightarrow H_2CO_3 \Leftrightarrow H^+ + HCO_3^- \Leftrightarrow 2H^+ + CO_3^{-2}$$




This equation maintains EQUILIBRIUM in the oceans, which means:
Whenever you try to change the ocean's $H^+$ or $CO_2$ content, the above equation will work in whatever directions UNDOES the change, so the system goes back to being in balance. The balance point creates an average pH for the oceans, which is, currently 8.1.

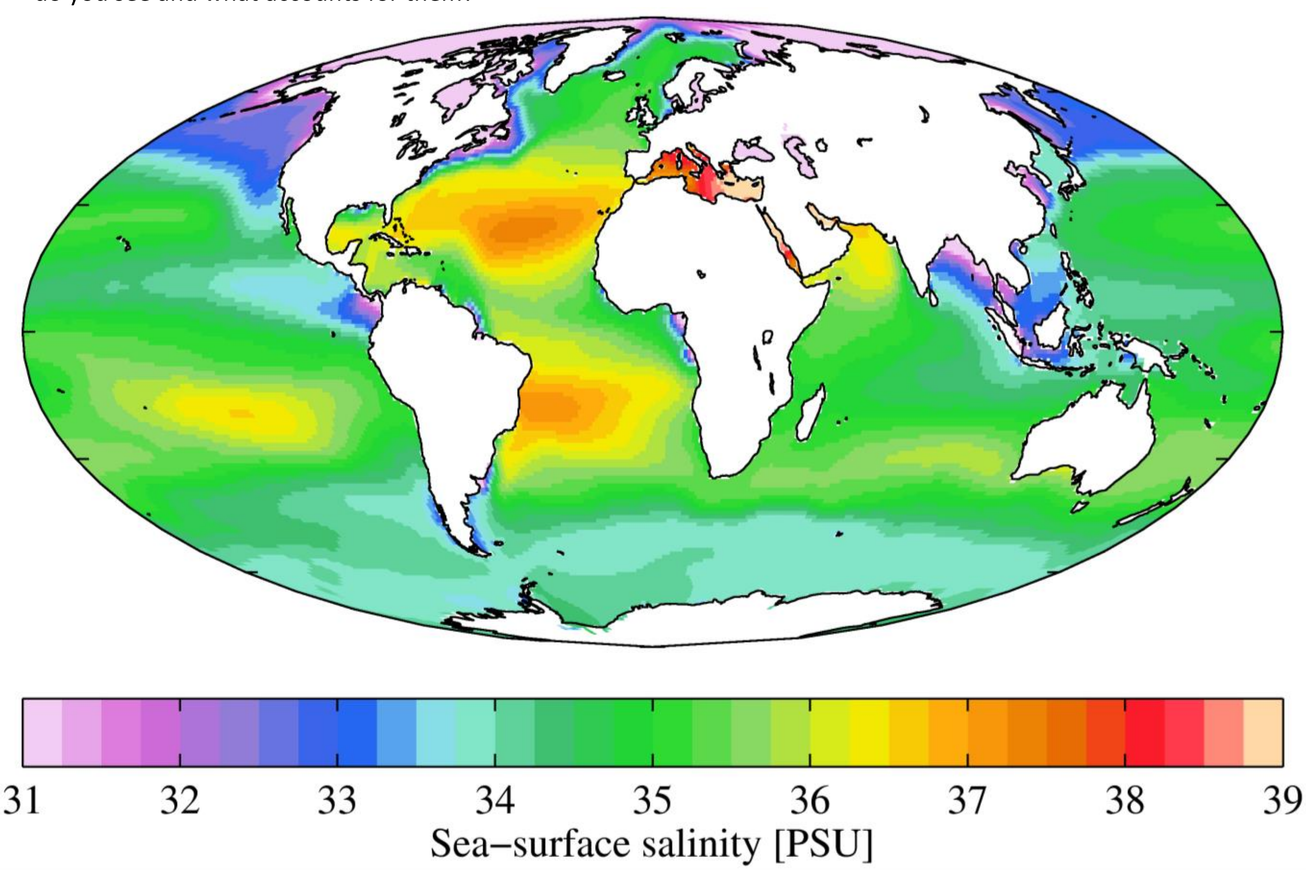
1. **In the equation on the top of the page, circle the ions that are CATIONS and underline the ANIONS.**
2. What direction would the above equation move if we added acid ($H^+$) to the oceans?
3. What direction would the above equation move if we removed (H+) from the oceans (which happens when we add base ($OH^-$) to the oceans)?
4. How does the above behavior contribute to ocean buffering? What's the net result?
5. As long as there's enough carbonate and bicarbonate in the oceans (defined as total alkalinity), will this buffering always happen?
6. What would stop ocean buffering?
7. What's the only thing that could change the balance point (average ocean pH) to which this equation equilibrates?
   - Specifically, what could lower the pH of the oceans? Why?
   - What could raise the pH of the oceans? Why?

**SALINITY**

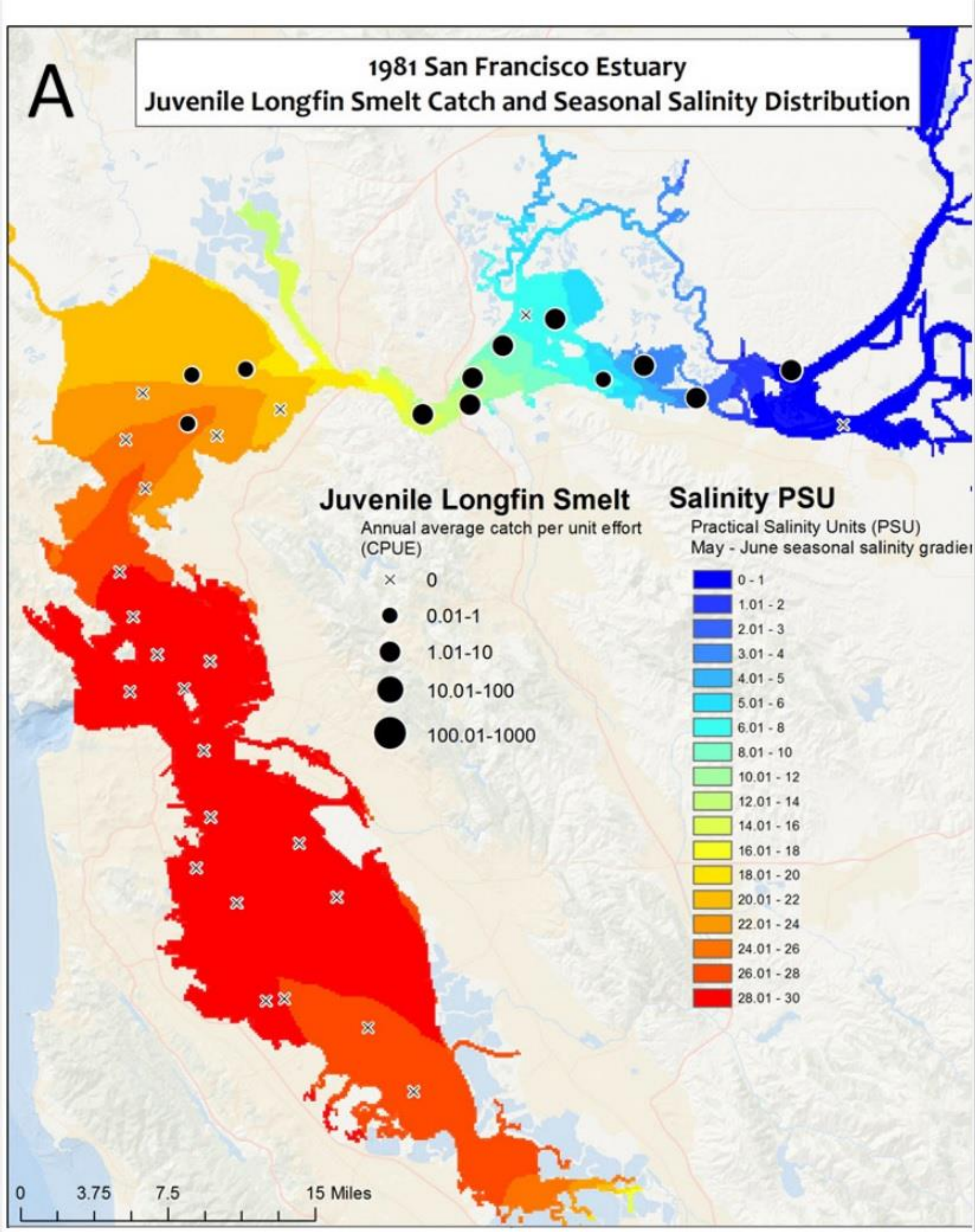
8. **Seawater salinity** is a ratio of dissolved ions per unit of water. Where do the ions and water come from that make salinity higher in some places and lower in others? *(*Refer to Photosynthesis activity from Water Planet chapter for review of the definition of sources and sinks.*)*

| | |
|---|---|
| Ion SOURCES (what brings ions to the ocean) | Ion SINKS (what takes ions from the oceans) |
| Water SOURCES | Water SINKS |
| Salinity is HIGH where what is happening? | Salinity is LOW where what is happening? |

9. Review figure below of the global distribution of seawater surface salinity. Describe what the data show. What patterns do you see and what accounts for them?




*Annual mean sea surface salinity for the World Ocean. Data from the World Ocean Atlas 2009. Plumbago - CC BY-SA 3.0*




Predicted average salnity (PSU or PPT) between May 1 and June 30 1981 with annual average catch per unit effort (CPUE) of Juvenile Longfin Smelt. From [MacWilliams, Bever, and Foresman, 2016](). CC-BY 4.0

| | |
|---|---|
| 10. **REVIEW:** What is the salinity of river water? | 11. **REVIEW:** What is the average salinity of seawater? |

12. Review figure on previous page of the distribution of seawater surface salinity for San Francisco Bay. What patterns in seawater surface salinity do you see and what accounts for them? (Ignore the fish data)

13. Would you expect to see changes in these values at the end of winter and spring rain storms? If so describe those changes here:

# Weekly Reflection

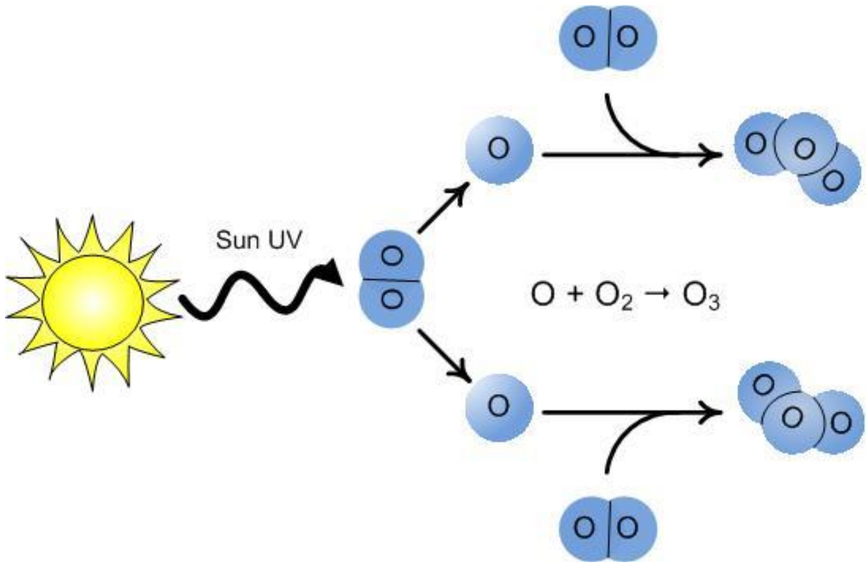
Take a moment to reflect on your comfort level and mastery of the week's objectives and describe an action plan for how you will practice or improve on anything that challenged you.

| Weekly objective | Self-assessment of mastery level | Action plan for improvement |
|---|---|---|
| Evaluate the definition, components, sources, sinks, and causes for global and local **variations of seawater salinity**. | A \| B \| C \| D \| F | |
| Compare and contrast a variety of methods for **measuring seawater salinity**. | A \| B \| C \| D \| F | |
| Evaluate the definition, components, sources, sinks, and distribution of **dissolved ions, including nutrients, in the oceans**. | A \| B \| C \| D \| F | |
| Compare and contrast the **main gases dissolved in the ocean** -- their solubilities, sources, sinks, and distribution. | A \| B \| C \| D \| F | |
| Evaluate the impacts of **dissolved carbon dioxide on ocean pH and marine life**. | A \| B \| C \| D \| F | |

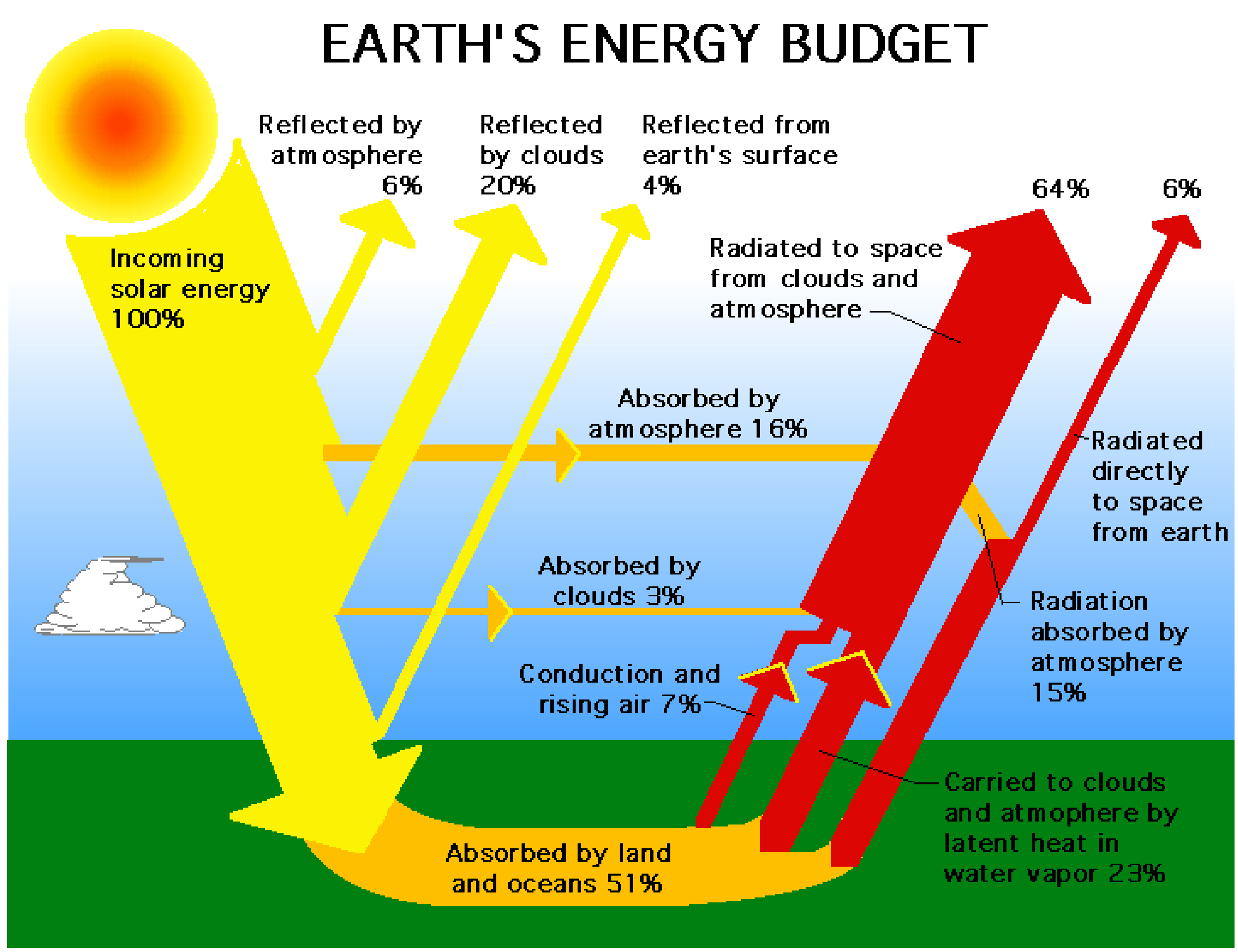
## AHA! Moments

What content from this week really resonated with you, helped you understand something you've always wondered about, or made you think about the world with new eyes?

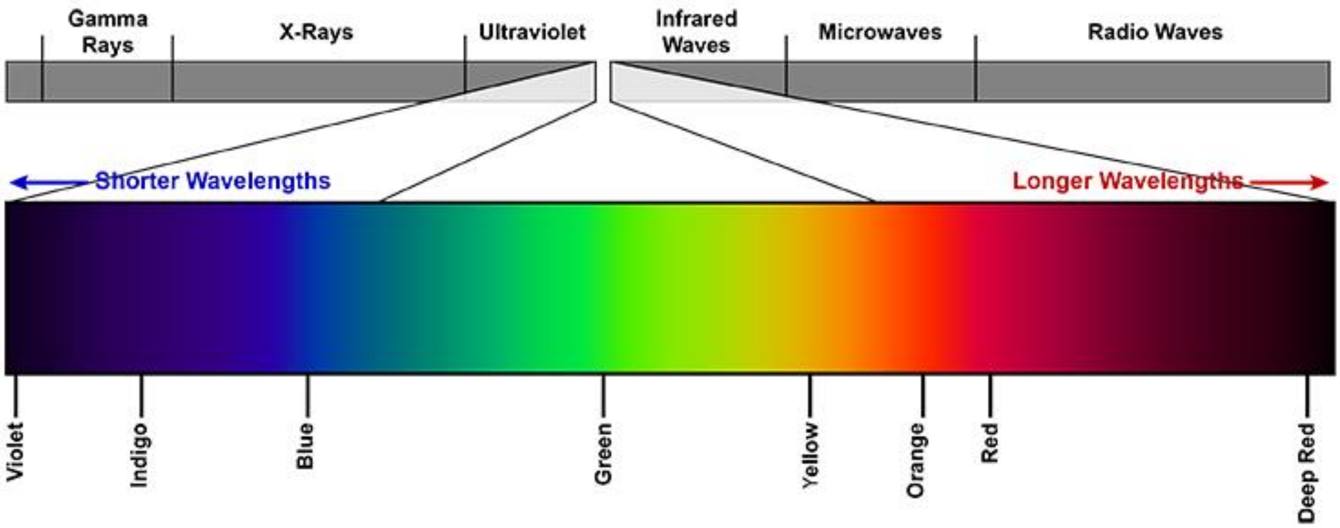
# ATMOSPHERE & SEASONS



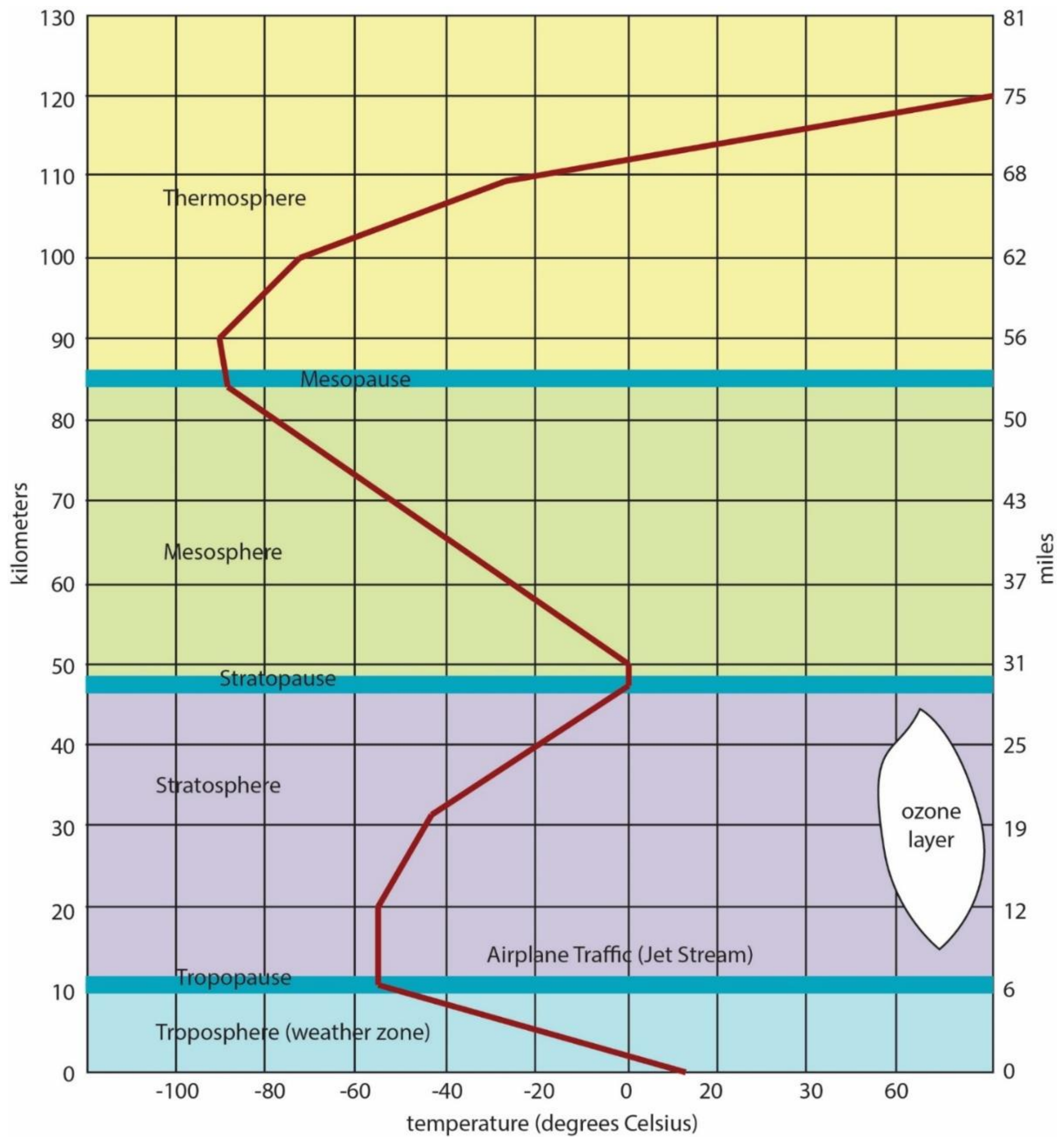

*Ozone formation in the stratosphere.*
*Image from Environment Canada.*
*http://www.ec.gc.ca/*



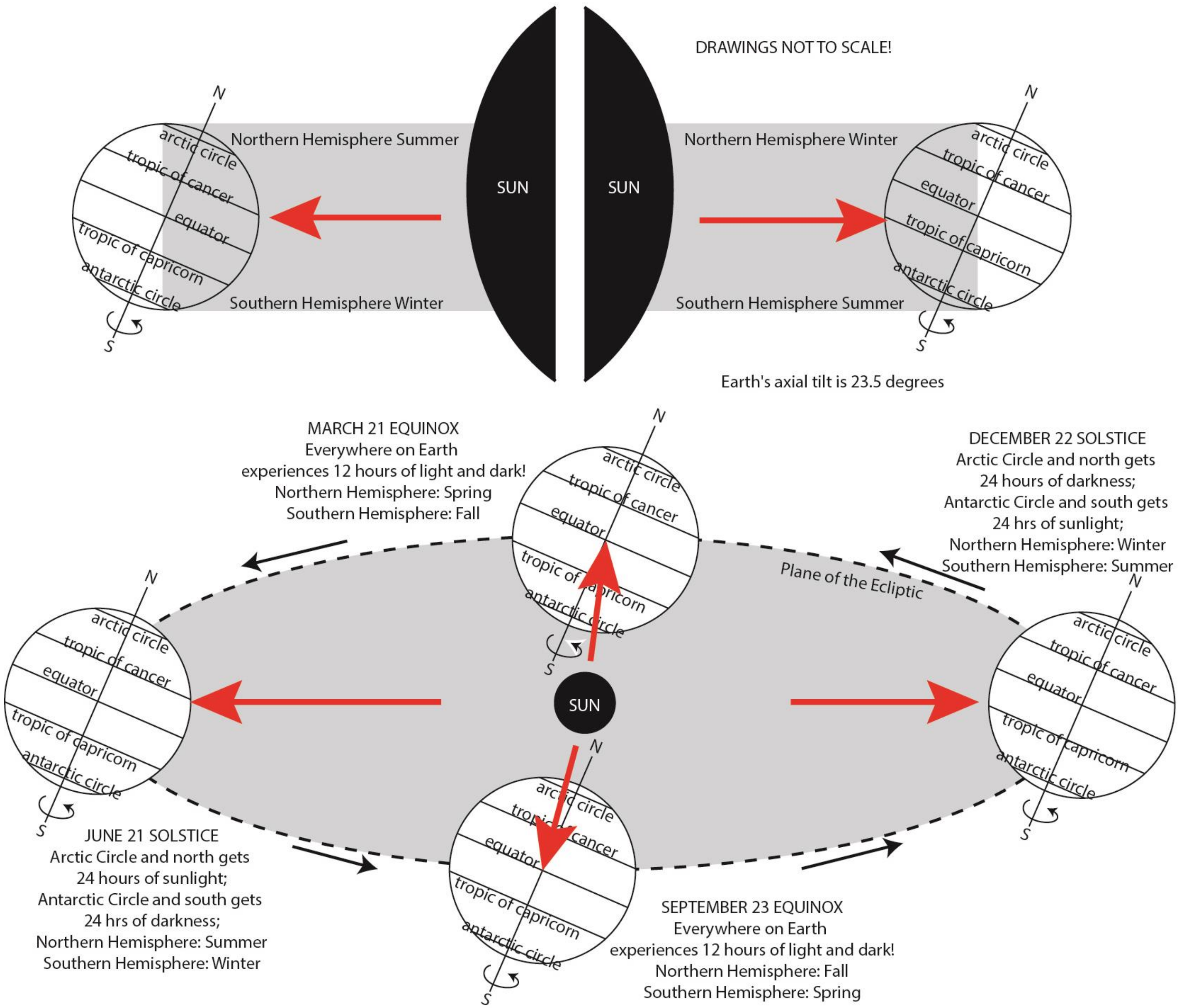

*Generalized heat budget of Earth's atmosphere assuming the only source is incoming solar radiation. (Image: NASA) % values are all relative to a 100% original input of solar energy (UV, visible, IR radiation). 30% of this energy is reflected by atmosphere, clouds, and earth's surface. 19% is absorbed by the atmosphere, leaving 51% to be absorbed by Earth's surface. Assuming an unchanging global surface temperature, all of this heat absorbed by Earth's surface is released back upwards into the atmosphere and escapes to space. (If it didn't Earth's surface temperatures would increase.) 7% transfers through conduction and rising air. 23% transfers through the latent heat of water vapor. 21% through direct IR radiation (15% is absorbed by the atmosphere en route). The 33% total that is absorbed by the atmosphere (both during incoming path and outgoing path) is also a steady amount that is balanced by equal loss outward through radiation, so with an unchanging Earth temperature, the net energy gain by Earth is 0.*



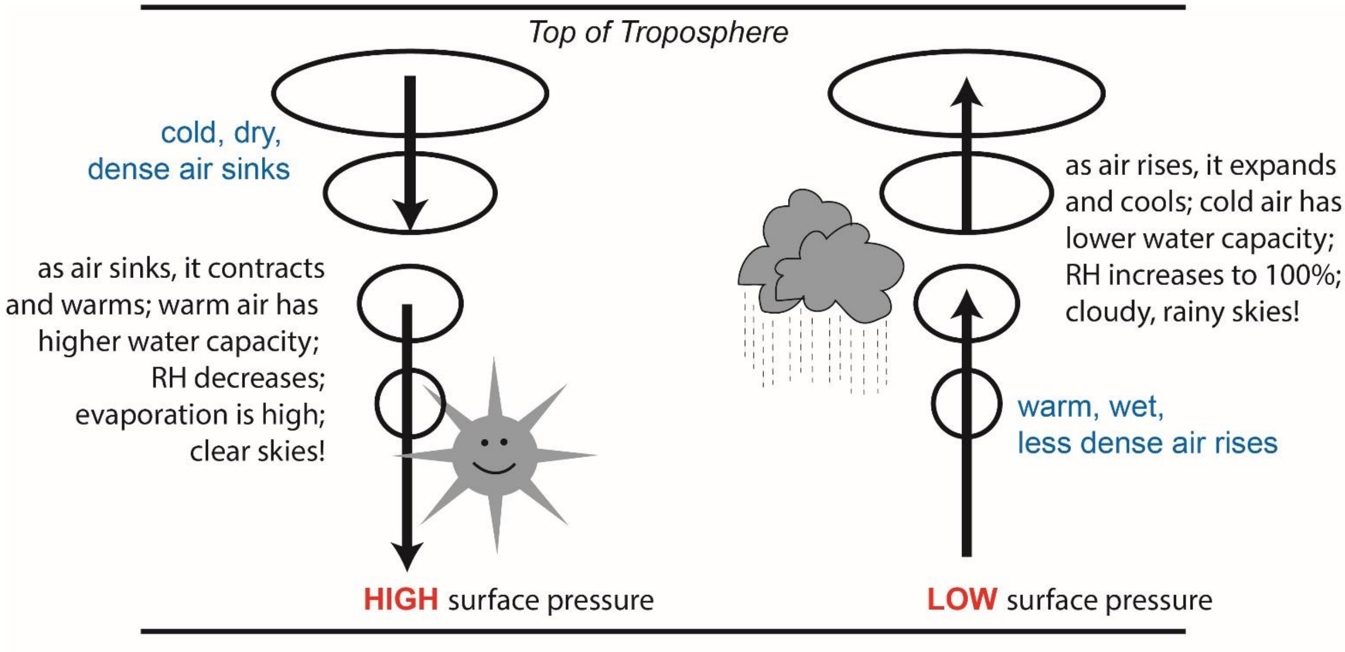

*Colors of Visible light, and their place within the electromagnetic spectrum – NOAA*
*Gamma rays have a wavelength of $10^{-12}$ m; Ultraviolet (UV) rays: $10^{-8}$ to $10^{-9}$ m (nanometers); Visible light: $10^{-6}$ to $10^{-7}$ m; Infrared (IR): $10^{-4}$ to $10^{-5}$ m; Microwaves: centimeters and millimeters; Radio waves: 1-100 m.*



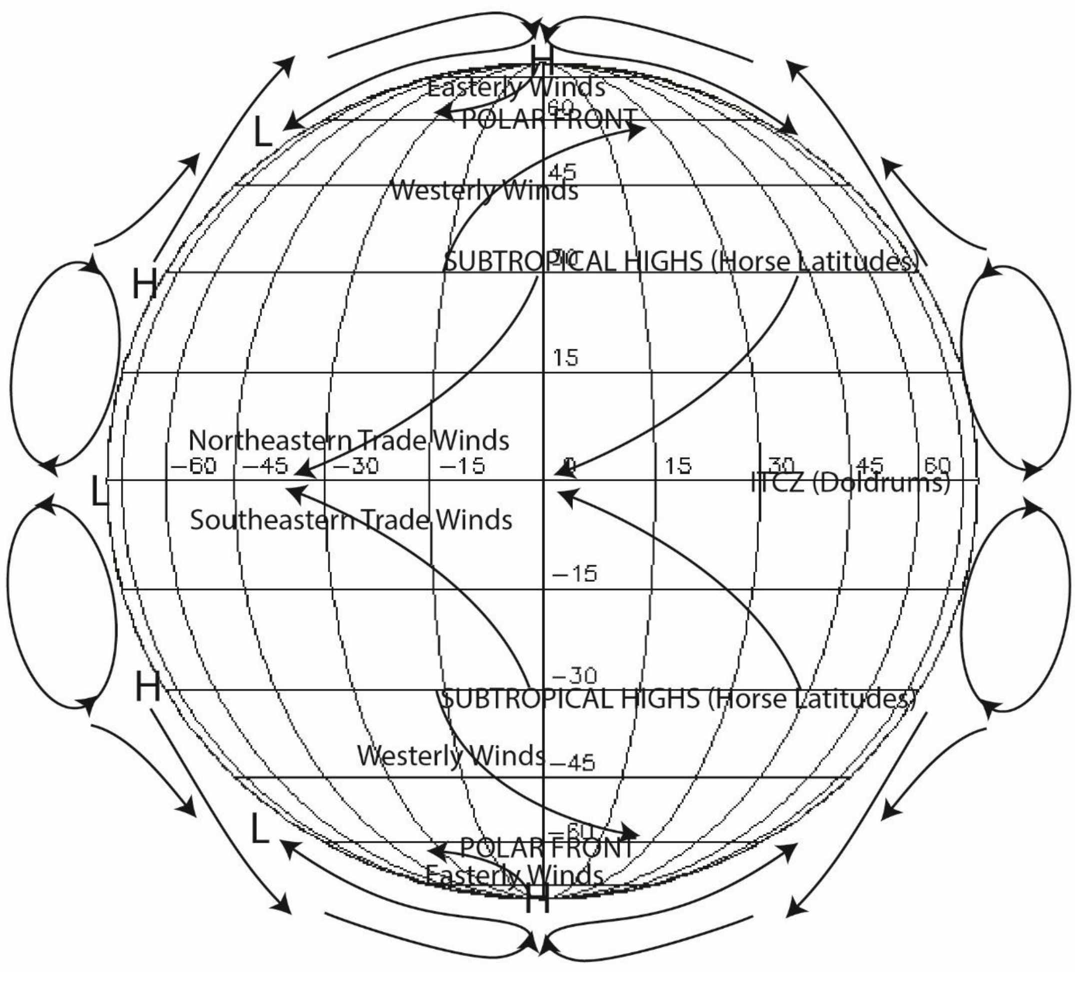

*Layers of Earth's atmosphere. Based on image from NOAA.*



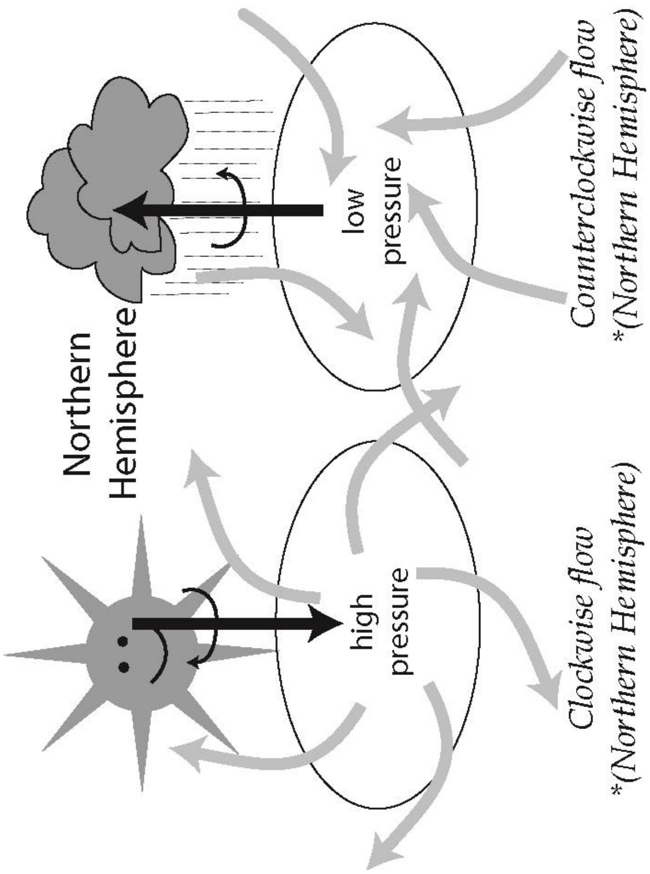

*Earth's orbit around the sun and the relationship between its tilted rotational axis and the seasons.*



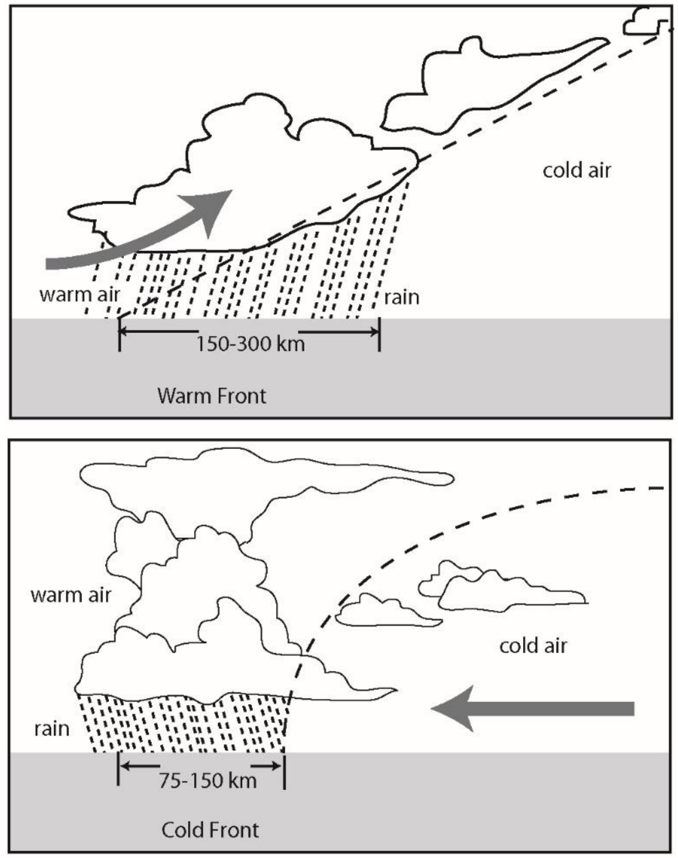

*The relationship of air rising and falling in the troposphere and the consequent surface air pressures experienced.*




*Generalized pattern of tropospheric air motion during an equinox*
*(vertically shown along edges and horizontally shown across surface).*




*Comparison of air motion and associated weather for low pressure versus high pressure systems in the northern hemisphere. Note that high pressure produces clockwise flow and clear skies; low pressure, the opposite.*




*Comparison of warm and cold fronts and the intensity of rains associated with their rising air masses.*

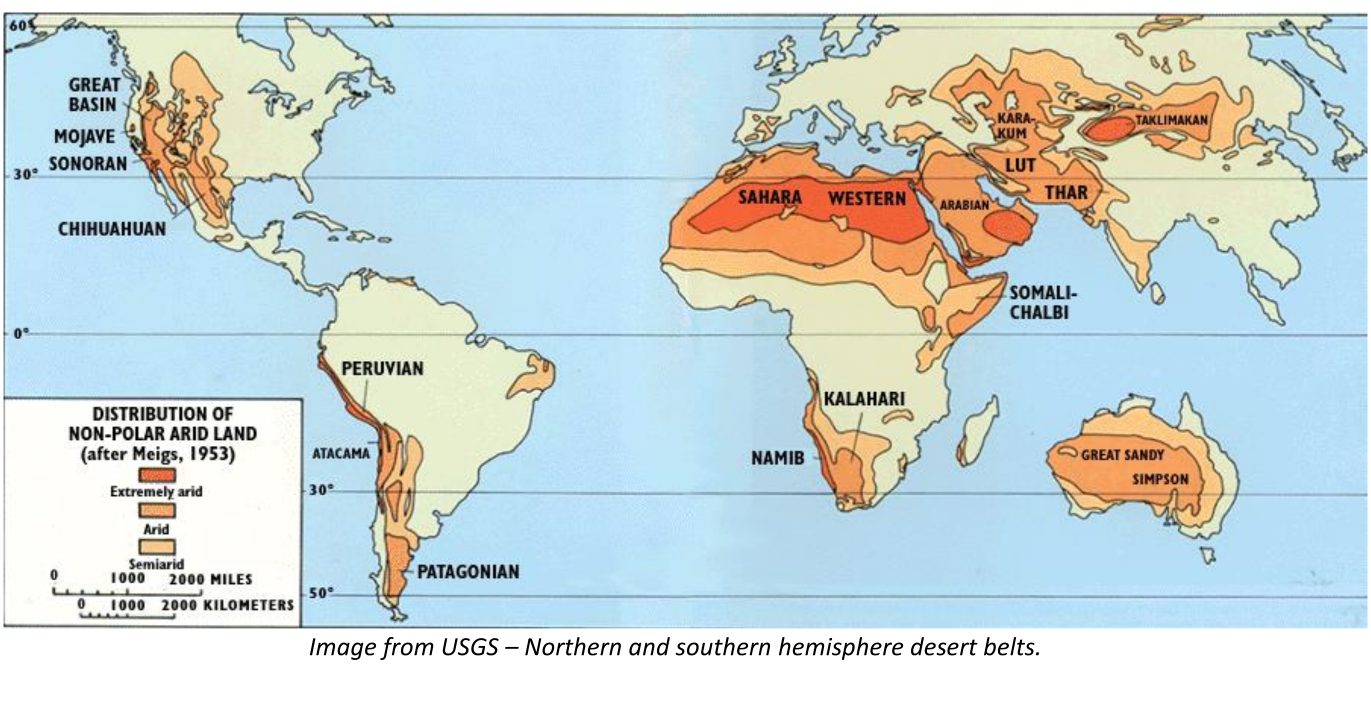
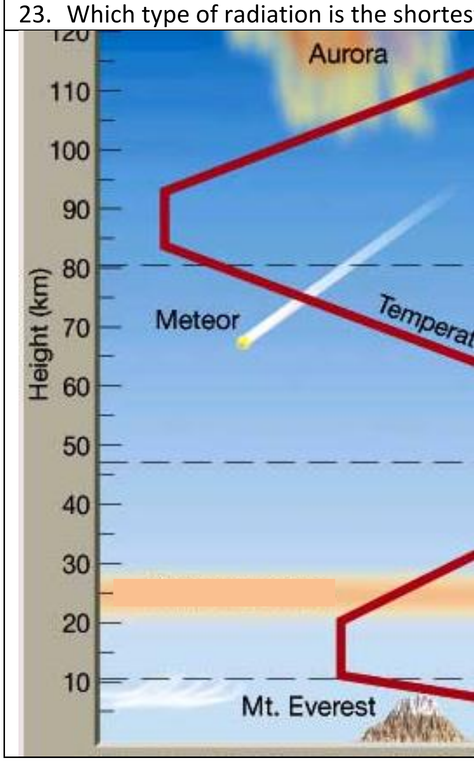



*Image from USGS – Northern and southern hemisphere desert belts.*

# Atmosphere Chapter Worksheet

| | |
|---|---|
| 1. What do we call the time it takes the Earth to rotate once around its axis? | 2. What do we call the amount of time it takes the Earth to orbit the Sun? |
| 3. What do we call the amount of time it takes the Moon to orbit the Earth? | 4. At what time of the year is the sun directly overhead at the equator? |
| 5. At what time of year is the sun directly overhead at the tropic of cancer? | |
| 6. How much sunlight is received at the Arctic Circle on the September Equinox? | |
| 7. What is the latitude of the Tropic of Capricorn? | 8. What is the latitude of the Arctic Circle? |
| 9. At what time of year does the area inside the Antarctic Circle receive no sunlight? | |
| 10. Which latitude on Earth's surface receives the most sunlight year round? | |
| 11. What causes the seasons? | |
| 12. At what time of the year are the Earth and the Sun closest together? | 13. What is the angle of axial tilt? |
| 14. Which corresponds to the **midlatitudes**? CIRCLE: equatorial \| tropics \| subtropics \| temperate \| subpolar \|polar | |
| 15. What percentage of solar radiation is reflected back to space? | 16. What percentage of solar radiation is absorbed by Earth's surface? |
| 17. What are the primary mechanisms for redistributing heat on Earth's surface? (Between the equator and poles) | |
| 18. Which type of radiation comes from the Sun? | CIRCLE: infrared \| visible \| ultraviolet |
| 19. Which type of radiation comes from Earth? | CIRCLE: infrared \| visible \| ultraviolet |
| 20. Which type of radiation is absorbed by the ozone layer? | CIRCLE: infrared \| visible \| ultraviolet |
| 21. Which type of radiation is absorbed by greenhouse gases? | CIRCLE: infrared \| visible \| ultraviolet |
| 22. Which type of radiation is the longest wavelength? | CIRCLE: infrared \| visible \| ultraviolet |
| 23. Which type of radiation is the shortest wavelength? | CIRCLE: infrared \| visible \| ultraviolet |




| |
|---|
| 24. In which atmosphere layer does most weather occur? CIRCLE: stratosphere \| troposphere \| ozone layer |
| 25. What is the temperature at the top of that layer? |
| 26. What is the thickness of that layer? |
| 27. What is the chemical reaction that occurs to produce ozone? |
| 28. In addition to the ozone layer, ozone is produced near Earth's surface by combustion. This ozone does what? CIRCLE: *migrates to ozone layer \| stays at surface as smog* |
| 29. How does the ozone layer interfere with radiation? CIRCLE: *reduces incoming solar radiation \| reduces outgoing thermal radiation* |
| 30. In the image on the left, label the: **Stratosphere, Troposphere, Ozone layer** |

31. What is the average composition
of the atmosphere (with no water)
-- give percentages?
(Look back at images in Water Planet chapter.)

32. What is the range in % that water
can contribute to atmospheric gases?

33. List all known greenhouse gases in decreasing order of importance (most important first):

34. What is the value of the
solar constant?

35. What are the conditions necessary to get that solar constant to exist somewhere on Earth?

**36.** Are there any locations on planet Earth where those conditions are true? CIRCLE: *Yes | No*

**37.** What is average **air pressure** on Earth's surface
at sea level in ***pounds per square inch*** AND in ***atmospheres***?

38. How does atmospheric pressure change as you go up a mountain? CIRCLE: *Increases | Decreases | No change*

39. What happens to a bag of potato chips, bagged at sea level, when it moves up a mountain? CIRCLE:
*Puffs up (expands) | Shrinks down (contracts) | No change*

40. What is the ultimate cause of vertical air motion? CIRCLE: *density | viscosity | temperature | pressure*

41. What happens when the
relative humidity of air equals 100%?

42. The maximum amount of water vapor that can exist within air is dependent on temperature.
**What happens to the maximum "allowable" amount of water vapor as an air mass cools?**

43. When air reaches the temperature at which the maximum amount of
water vapor within = the actual amount of water within, we call that temperature: ________________________
What happens at this point?

44. What happens to relative humidity
of air when the air **warms**?

45. What happens to relative humidity
of air when the air **cools**?

46. What are clouds made of?

47. What do we call clouds on the ground?

48. How does atmospheric pressure change on Earth's surface when air is **rising**?
CIRCLE: *Increases | Decreases | No change*

49. We call those areas on the surface? CIRCLE: *High pressure | Low pressure*

50. When air **rises**, what happens to its temperature? CIRCLE: *Warms | Cools | No change*

51. When air **rises**, what happens to its water capacity? CIRCLE: *Increases | Decreases | No change*

52. When air **rises**, what happens to its relative humidity? CIRCLE: *Increases | Decreases | No change*

53. In what way does atmospheric pressure change on Earth's surface when air is **sinking**?
CIRCLE: *Increases | Decreases | No change*

54. We call those areas on the surface? CIRCLE: *High pressure | Low pressure*

55. When air **sinks**, what happens to its temperature? CIRCLE: *Warms | Cools | No change*

56. When air **sinks**, what happens to its water capacity? CIRCLE: *Increases | Decreases | No change*

57. When air **sinks**, what happens to its relative humidity? CIRCLE: *Increases | Decreases | No change*

58. Which surface pressure system is associated with clear cloudless skies? CIRCLE: *High | Low | Depends*

59. All winds move FROM areas of? CIRCLE: *High pressure | Low pressure*
TO areas of? CIRCLE: *High pressure | Low pressure*

60. Which air is the densest? CIRCLE: *Cold and Dry | Cold and Wet | Warm and Dry | Warm and Wet*
Why?

61. In the southern hemisphere, the coriolis effect makes objects that move independent of the ground (like winds, currents, and airplanes) appear to deflect to the (CIRCLE: *right | left | depends*) of a straight path.

62. At what latitude is the **polar front**?

63. What meet there?

64. What happens to the latitude of the Polar front during the northern hemisphere summer?
*(*Remember: the figure of Earth's Tropospheric Circulation is idealized for the equinox.)*

65. Which is greater? CIRCLE: *heat capacity of the oceans | heat capacity of the land*

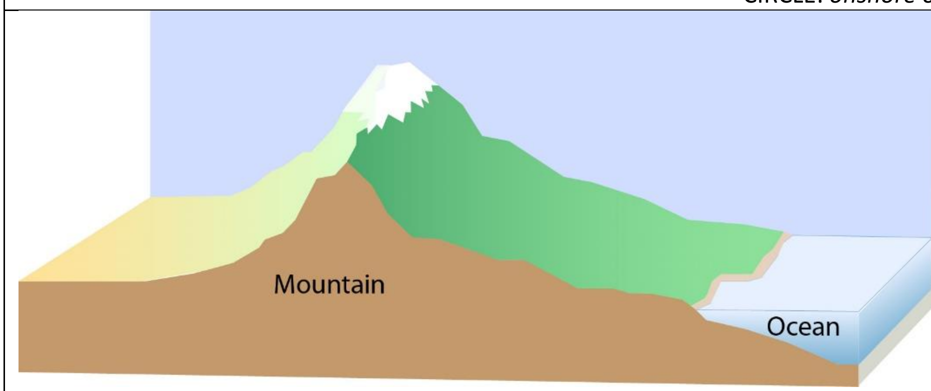
66. Which is true for land near large bodies of water? CIRCLE: *cold winters | mild winters | hot summers | mild summers | big temperature differences between night and day | big temperature differences between summer and winter |*

*67.* Winds that move from the ocean onto the shore are called? CIRCLE: *onshore breezes | offshore breezes*

68. They form because the pressure over the ocean is (CIRCLE: *Higher | Lower*) than the pressure over land.

69. In the San Francisco Bay Area in summer, which happen during the **day**?
CIRCLE: *onshore or sea breezes | offshore or land breezes*

70. In the San Francisco Bay Area in summer, which happen during the **night**?
CIRCLE: *onshore or sea breezes | offshore or land breezes*



**Rainshadow Deserts** *(image from Cort Benningfield)*

71. In this image of a mountain range next to the water, use arrows to show winds moving onshore and creating a **rainshadow**.

72. Indicate the high surface pressure area with an H and the low pressure with an L. *(Note: the H and L that result from the wind moving over a mountain, not the H and L that caused the original winds blowing off the ocean).*

73. Write RAIN where rain will be high and EVAP, where evaporation will be high.

74. Most of the air that reaches eastern California comes off the Pacific Ocean. What happened to its water to create the deserts of the Mojave and Owens Valley?

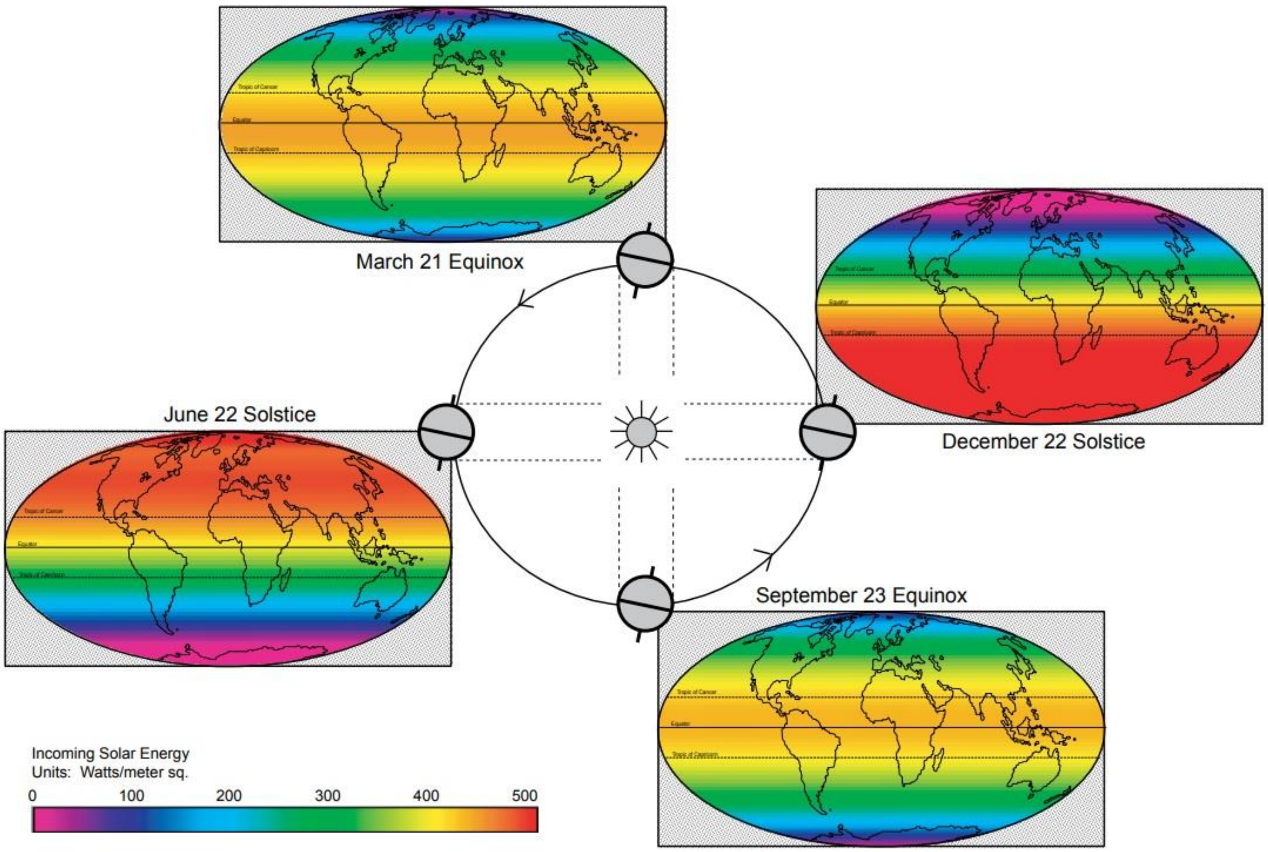
75. Based on all you've learned about rising air masses, rainshadows, and more, what do you think is the evolutionary benefit to the California Coastal Redwoods being so tall?

76. **HURRICANES:** Created by: (CIRCLE: *High pressure | Low pressure*)
Found at: (CIRCLE: *all latitudes | only mid latitudes | only low latitudes – near equator*)
In Northern Hemisphere, hurricane winds move: (CIRCLE: *clockwise | counterclockwise | depends*)
In Southern Hemisphere, hurricane winds move: (CIRCLE: *clockwise | counterclockwise | depends*)
Travel path: (CIRCLE: *Can cross the equator | can't cross the equator*); gets (CIRCLE: *stronger | weaker*) on land.
Is accompanied by a dome of water, called a ___________________, which floods land when hurricane arrives.

# Seasons and Relative Humidity Activity (4 pages)

**SOLAR CONSTANT** = 2 calories/cm$^2$/min. This is the theoretical maximum amount of sunlight that would hit the surface of the Earth if the sun's rays were direct and there were no atmosphere to reflect or absorb any incoming solar radiation. Let's solve a few problems to help us understand:

1. At what time of the year does solar radiation hit directly (at right angles to the surface) at the Tropic of Cancer?
2. At what time of the year does solar radiation hit directly (at right angles to the surface) at the equator?
3. Incoming sunlight changes throughout the year, but has a big impact on which of the following processes (circle): chemosynthesis | decomposition | photosynthesis | respiration.
4. Review figure below of the global distribution of incoming sunlight with the seasons. What patterns do you see and what accounts for them?




*Incoming solar energy throughout the seasons. From Globe.gov*

**Patterns:**

**Explanation:**

5. How would you expect variations in surface sunlight to impact marine life?

# RELATIVE HUMIDITY

**ABSOLUTE HUMIDITY (**OR **WATER VAPOR PRESSURE**) = amount of water vapor present in a unit volume of air, usually expressed in kilograms per cubic meter or in units of pressure like millibars (mb) or kilopascals (kPa) (the pressure produced by that number of water molecules at that temperature).

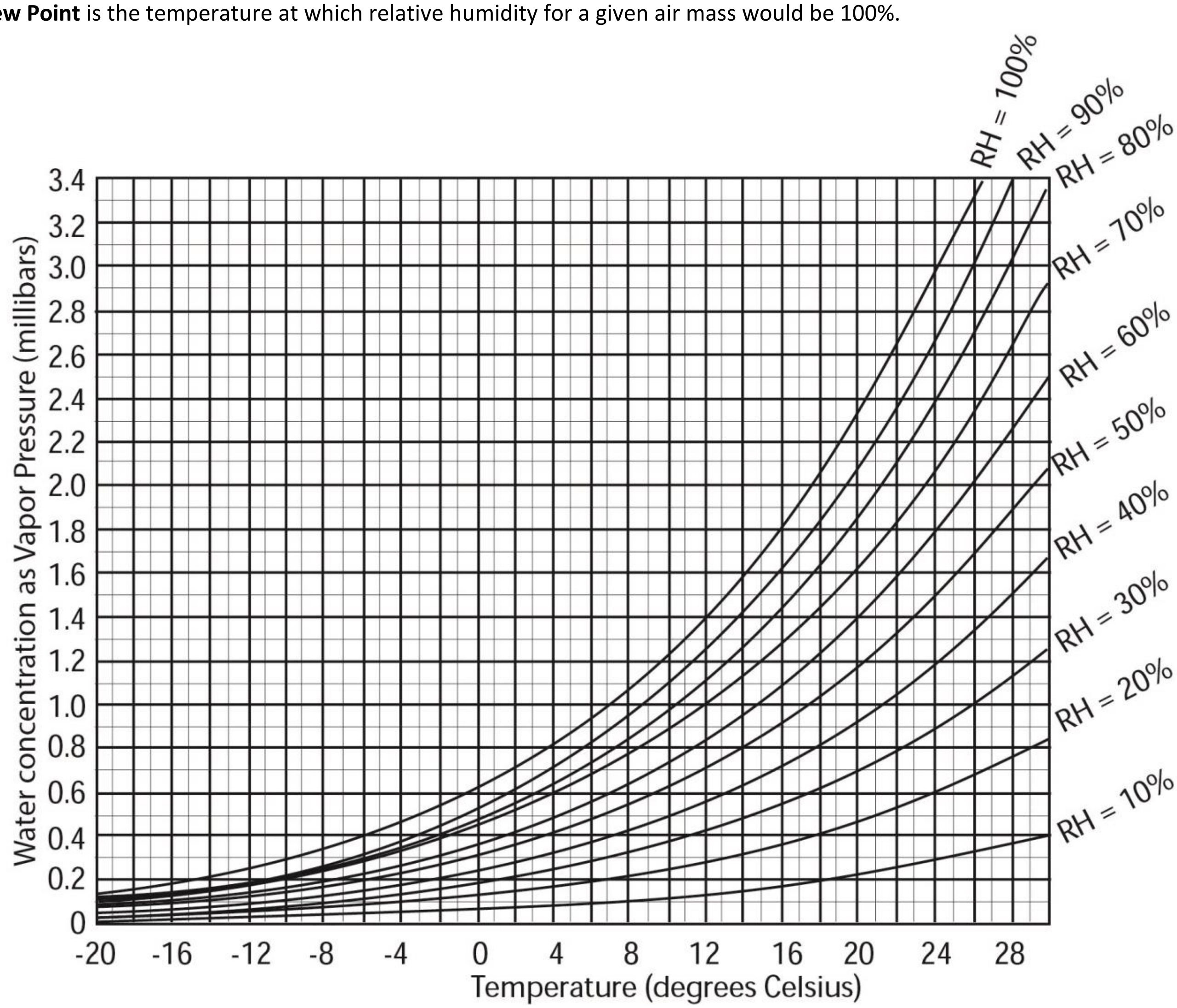
**SATURATION ABSOLUTE HUMIDITY (**OR **SATURATION WATER VAPOR PRESSURE** or **CAPACITY**) is the maximum amount of water vapor that *could be* present in a unit volume of air (similar units as above) – it is almost entirely dependent on temperature.

**RELATIVE HUMIDITY** (R.H.) = 100 x amount of water present as a gas in a unit volume of air / total amount of water that *COULD* be present as a gas in a unit volume of air at that temperature

**RELATIVE HUMIDITY** (R.H.) = 100 x Actual Water Vapor Content in air. / Capacity (max that can be in air)

R.H. is a measurement of what percentage of that maximum has been reached by actual water vapor in the air. In the graph below, you can see that that the top line indicates air at 100% R.H. – the content or pressure of water vapor in the air is at its maximum and usually won't rise further. Saturation Vapor Pressure = Actual Water Vapor Pressure. Condensation usually begins at 100% R.H. (*see note). When R.H. is low, like 20%, the air is relatively empty of water. Liquid water that's available in the area will evaporate, R.H. (think of this as "closeness to capacity") will rise.

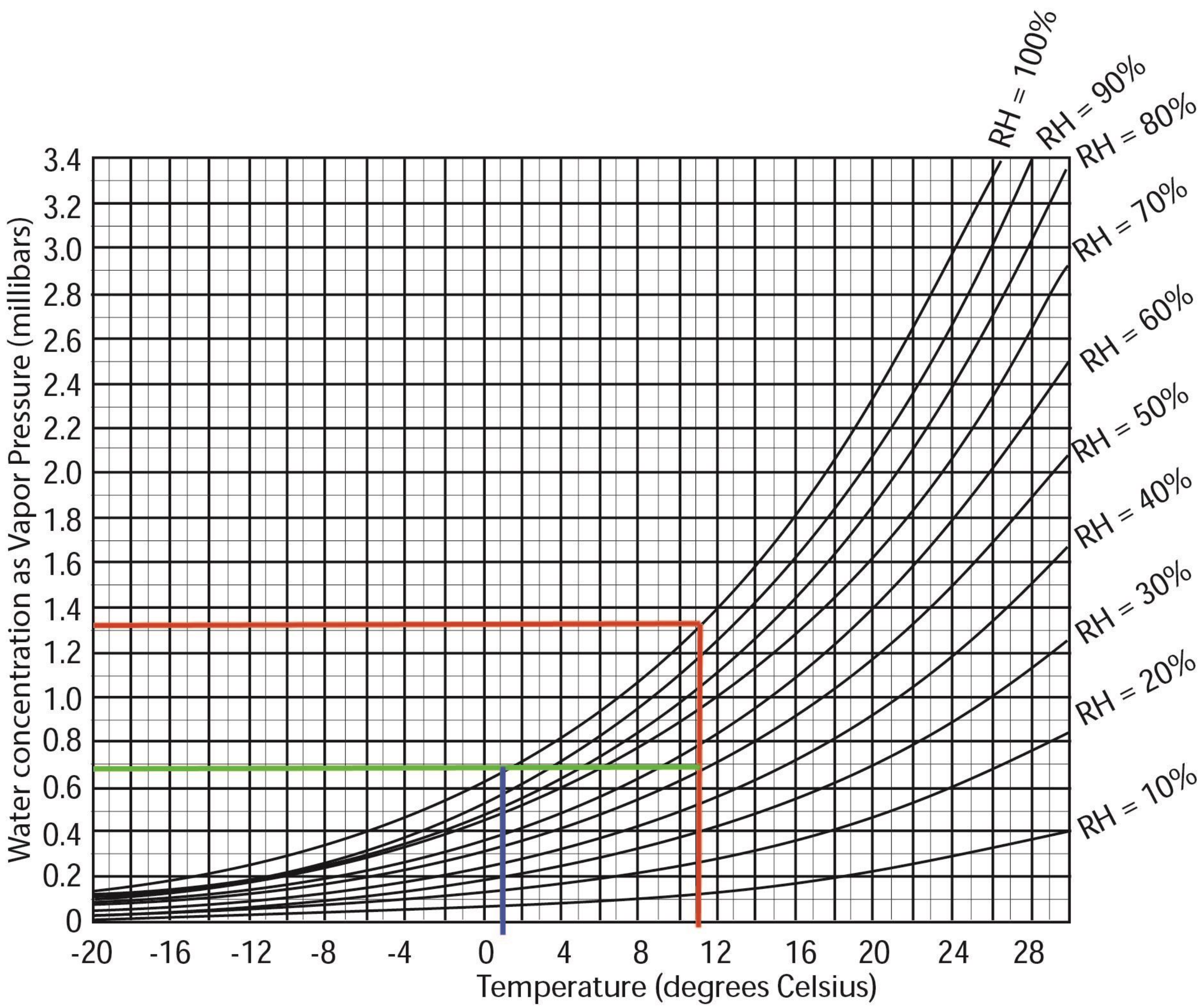
**Dew Point** is the temperature at which relative humidity for a given air mass would be 100%.




*Temperature and water vapor concentration for a range of relative humidities.*

As the temperature of air rises (gets hotter), the thermal energy of the molecules increases. That means it's now more likely that water molecules **could be** present as a gas. *(If thermal energy is low, most of the water will be moving too slowly to break the hydrogen bonds and will be present only as a liquid.)* So as air warms, more water *CAN* be present as a vapor *(increased capacity)*; as air cools, less water *CAN* be present as a vapor (decreased capacity). Assuming that the water vapor is slow to adjust or can't adjust, the R.H. will change. Remember: R.H. does NOT measure how much water is present in the air, rather how close the air parcel is to its maximum content for water vapor. An increase in temperature usually means a decrease in R.H. (water capacity is much higher than the actual content). And vice versa.
**NOTE: Although condensation begins at R.H.=100%, it takes a lot of condensation before there's enough water to create visible droplets and clouds. When these droplets fall faster than rising air, it rains.*

*As air rises and cools, R.H. will increase to 100%, and condensation will begin. As air continues to rise and cools more, R.H. continues to drop, and more water condenses, until enough rising has caused enough cooling to case enough of a drop in R.H. to create enough condensation to produce clouds and rain.*




*Example: an air mass at* 11°C, it has a saturation absolute humidity (maximum water vapor content) of 1.3 mbars (red lines). IF it is currently at 50% relative humidity, then it contains half that: 0.65 mbars (green lines).
Such an air mass (50% RH at 11°C) would reach its Dew Point at 1°C.
That's when actual water content = maximum or 100% RH.

# RELATIVE HUMIDITY EXERCISES

| | |
|---|---|
| 1. What is the maximum water vapor content possible for a unit volume of air at 20°C. | |
| 2. If the actual water vapor content of that same air parcel at 20°C is 1.3865 mbar, what is the relative humidity? | |
| 3. What does that relative humidity mean for your life if you're walking around in that air? | |
| 4. What is the Dew Point Temperature for this same air mass? | |
| 5. If the air temperature overnight will reach 10°C, what does that mean you'll find in the morning on the plants, windows, and outside surfaces? | |
| 6. What is the maximum water vapor content possible for a unit volume of air at 4°C? | |
| 7. What happens to the maximum water vapor content possible as temperature drops? | |
| 8. If the relative humidity of air at 4°C is 20%, what is the actual water vapor content? | |
| 9. What is the Dew Point Temperature for this same air mass? | |
| 10. If the air temperature overnight will reach -4°C, what does that mean you'll find in the morning on the plants, windows, and outside surfaces? | |
| 11. What is the maximum water vapor content possible for a unit volume of air at 25°C? | |
| 12. What happens to the maximum water vapor content possible as temperature increases? | |
| 13. If the relative humidity of air at 25°C is 80%, what is the actual water vapor content? | |
| 14. What is the Dew Point Temperature of this 25°C air at 80% RH? | |
| 15. If the air temperature overnight will reach 20°C, what does that mean you'll find in the morning on the plants, windows, and outside surfaces? | |
| 16. If we cooled this air parcel from 25°C to 23°C, how would the maximum possible water vapor content (saturation pressure) change? | |
| 17. How would relative humidity ("fullness") change? | |
| 18. If we warmed this air parcel from 25°C to 28°C, how would the maximum possible water vapor content (saturation pressure) change? | |
| 19. How would relative humidity ("fullness") change? | |
| 20. What is the relative humidity of an air mass at 20°C that has a Dew Point Temperature of 5°C | |
| 21. What is the relative humidity of an air mass at 26°C that has a Dew Point Temperature of 17.5°C | |
| 22. What is the relative humidity of an air mass at 12°C that has a Dew Point Temperature of -14°C | |
| 23. Which of the above air masses is going to feel the driest to you (evaporating fluids from your skin, eyes, and mouth?) | |

# Weekly Reflection

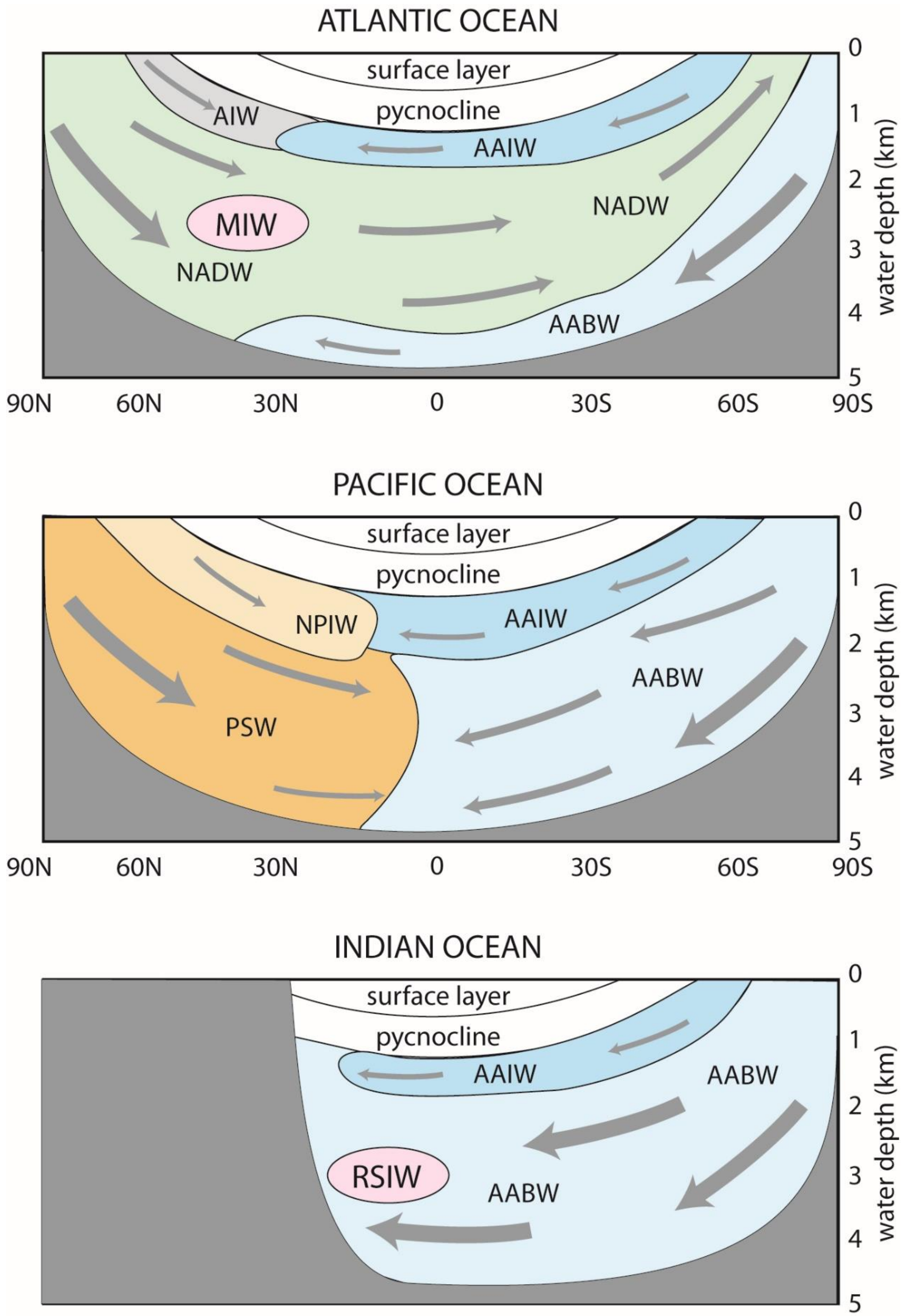
Take a moment to reflect on your comfort level and mastery of the week's objectives and describe an action plan for how you will practice or improve on anything that challenged you.

| Weekly objective | Self-assessment of mastery level | Action plan for improvement |
|---|---|---|
| Evaluate the variations in **solar input latitudinally and seasonally** and the natural mechanisms for **redistributing this heat**. | A \| B \| C \| D \| F | |
| Analyze the causes of **Earth's greenhouse effect and its impact on global warming**. | A \| B \| C \| D \| F | |
| Evaluate the location, cause, and impact of **Earth's ozone layer**. | A \| B \| C \| D \| F | |
| Apply an understanding of the causes of vertical and horizontal air movement to generate a generalized picture of **general global air circulation and pressure systems**. | A \| B \| C \| D \| F | |
| Analyze the relationships among air **density, temperature, and water content, including relative humidity and dew point**. | A \| B \| C \| D \| F | |
| Interpret the causes and effects of ocean-specific weather and climate phenomena such as **rainshadow deserts, hurricanes, and fluctuating directions of coastal breezes**. | A \| B \| C \| D \| F | |

## AHA! Moments

What content from this week really resonated with you, helped you understand something you've always wondered about, or made you think about the world with new eyes?

# CURRENTS




*Generalized intermediate currents found in the three main oceans.*
*AABW = Antarctic Bottom Water; AAIW = Antarctic Intermediate Water; AIW = Arctic Intermediate Water;*
*MIW = Mediterranean Intermediate Water; NADW = North Atlantic Deep Water;*
*PIW = Pacific Intermediate Water; PSW = Pacific Subarctic Water; RSIW = Red Sea Intermediate Water.*

| | When pycnocline best developed? Why? |
|---|---|
| Polar seas | Never – always vertical mixing – doesn't warm up enough in summer. |
| Temperate seas | Summer – sun produces warm surface layer with no vertical mixing. In winter, surface water and deep water mix. |
| Tropical and equatorial seas | Always – constant supply of sun keeps warm surface layer year-round. No vertical mixing. |

| | Definition | Cause/location | Biological effects | Climate effects |
|---|---|---|---|---|
| **Upwelling** | Deep water moving upward to replace surface water | **GENERAL CAUSE:** Surface water moved away.<br>**LOCATIONS:**<br>**Coastal:** Where wind direction, coriolis effect, and/or shape of coast conspire.<br>**Submerged Seamounts:** Where surface currents are forced to rise up over these mountains.<br>**Equatorial:** Eastern edge of equatorial oceans<br>**Surface current divergence:** Central equatorial oceans and around Antarctica. | Increased nutrients and hence increased biologic productivity (more biomass). | Cool water cools air, so that it can hold less water. Can cause rain or fog. |
| **Down-welling** | Surface water sinking down to become deep water | **GENERAL CAUSE:** Surface water piled up in an area.<br>**LOCATIONS:**<br>**Coastal:** Where wind direction, coriolis effect, and/or shape of coast conspire.<br>**Equatorial:** Western edge of equatorial oceans<br>**Surface current convergence:** Subpolar and subtropical convergence zones. | Plankton, oxygen, and surface toxins carried to deep benthic region. | |

| | Definition | Cause | Depth | Location |
|---|---|---|---|---|
| **Antarctic Bottom Water or Oceanic Common Water (AABW)** | Cold (-1 to 1 C)<br>Salty (34.7 ppt) | Cold Antarctic climate (colder than the arctic due to West Wind Drift) Ice formation | Deepest | All oceans |
| **North Atlantic Deep Water (NADW)** | Cold (2.5 to 3.5 C)<br>Salty (34.9 ppt) | Cold Arctic climate<br>Ice formation | On bottom, above ABW | North Atlantic |
| **Antarctic Intermediate Water (AAIW)** | Cold (3 to 6 C)<br>Low salinity (34.1 ppt) | Antarctic Convergence – piling up and sinking of water where surface current converge | 500-1500 m, above deep and bottom water | All oceans |
| **Mediterranean Intermediate Water (MIW)** | Warm<br>(8.5 to 12.5 C)<br>Salty! (36 ppt) | Evaporation in hot Mediterranean Sea | 1000 to 2500 m | Central Atlantic Ocean |
| **Red Sea Intermediate Water (RSIW)** | Warm! (23 C)<br>Salty! (40 ppt) | Evaporation in hot Red Sea | 2000 to 3000 m | Indian Ocean |

| | Location | Travel direction | Temp | Speed | Width | Depth | Volume | World examples |
|---|---|---|---|---|---|---|---|---|
| **Eastern boundary current** | Eastern edge of the ocean (western continental margin) | Away from poles; toward equator | Cold | < 0.3 m/s<br>or 10 km/d | >1000 km | <0.5 km | 10-15 Sv | California, Canary |
| **Western boundary current** | Western edge of the ocean (eastern continental margin) | Away from equator; toward poles | Warm | > 1.5 m/s<br>or 100 km/d | <100 km | 1-2 km | > 50 Sv | Gulf Stream [3-10 km/hr; 100 Sv], Kuroshio |

- Gulf Stream: max speed usually ~9 km/hr; 30-150 Sv, average water temperature of at least 24°C in winter; ~100 km wide, ~ 1 km deep.
- West Wind Drift (Antarctic Circumpolar Current): max speed usually ~3.7 km/h; 100-150 Sv; -1 to 5°C; ~200 km wide, ~4km deep.
- California Current: <1 km/hr; 1.1 Sv; temperature varies based on El Niño/La Niña; > 1000 km wide; ~100 m deep
- *[Sv = Sverdrup = 1 million cubic meters flowing past a point per second. Transport rate of freshwater in all the world's rivers is 1 Sv]*

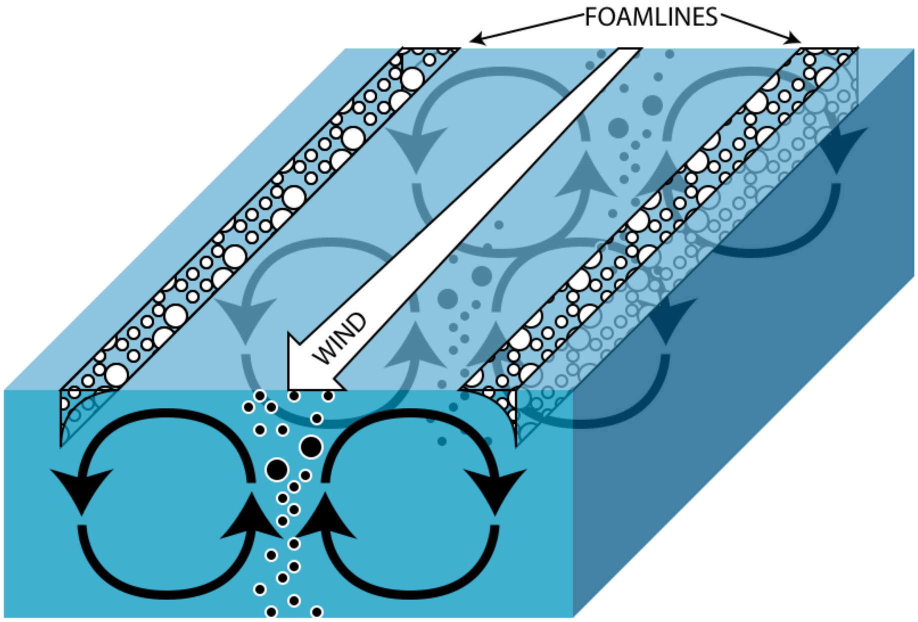



*Image of Langmuir cells, affecting the top 10 meters of the ocean surface (when winds blow in a continual direction over a body of water). (Image is from public domain.)*

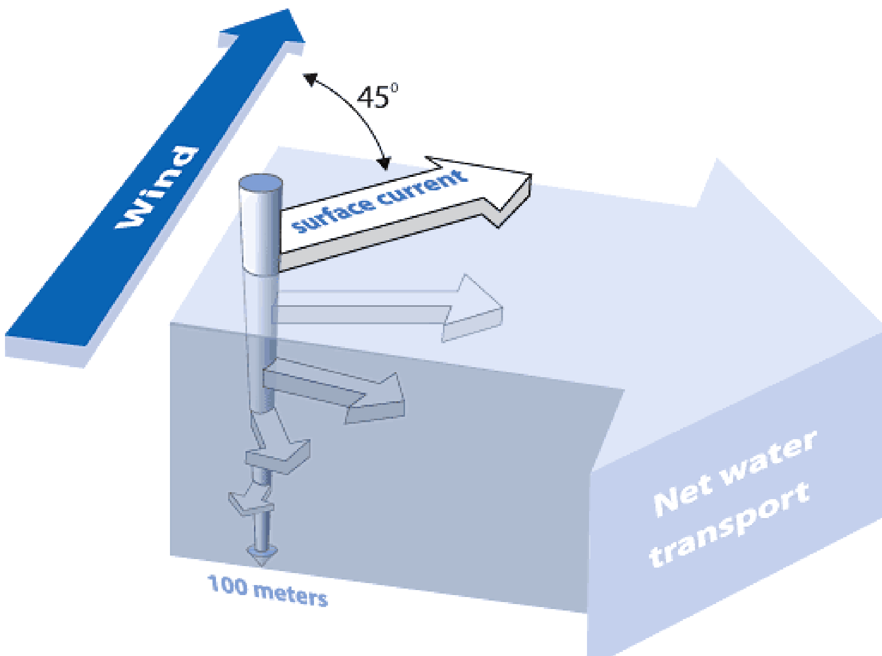
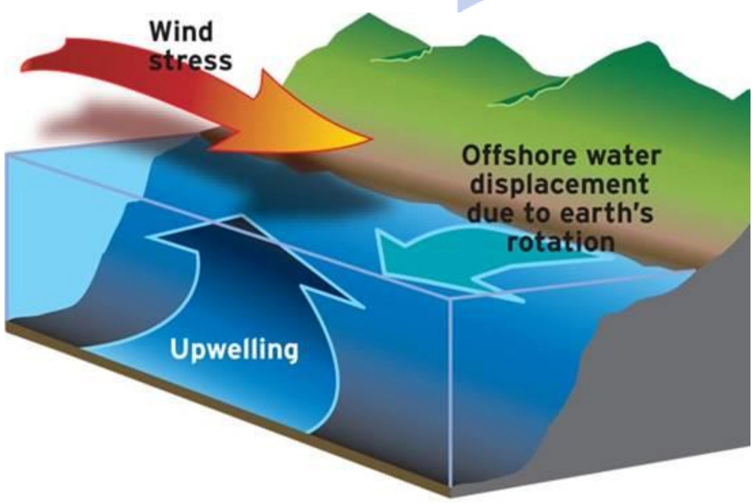



*Image of Ekman Transport in the Northern Hemisphere affecting the top 100 meters of the ocean surface. (NOAA)*




*Northern Hemisphere Ekman Transport-induced Coastal Upwelling (NOAA)*

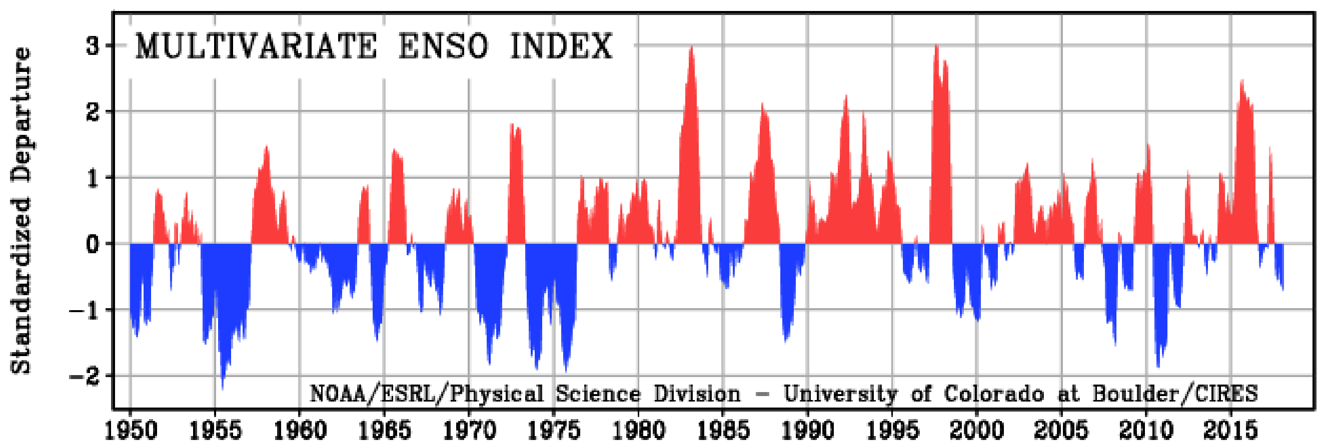
# ENSO (El Niño Southern Oscillation)

ENSO – (El Niño Southern Oscillation) is the term for the shift in winds, ocean currents, sea surface temperatures, and surface air pressure patterns in the Pacific Ocean. Most commonly observed and reported aspect of ENSO is the change in sea surface temperature in the central and east Pacific Ocean. ENSO changes lead to major shifts in global weather patterns which effect the weather in several locations around the world. The maps below show where significant changes occur, relative to normal, due to the influence of ENSO. (NOAA)

**El Nino Characteristics:**

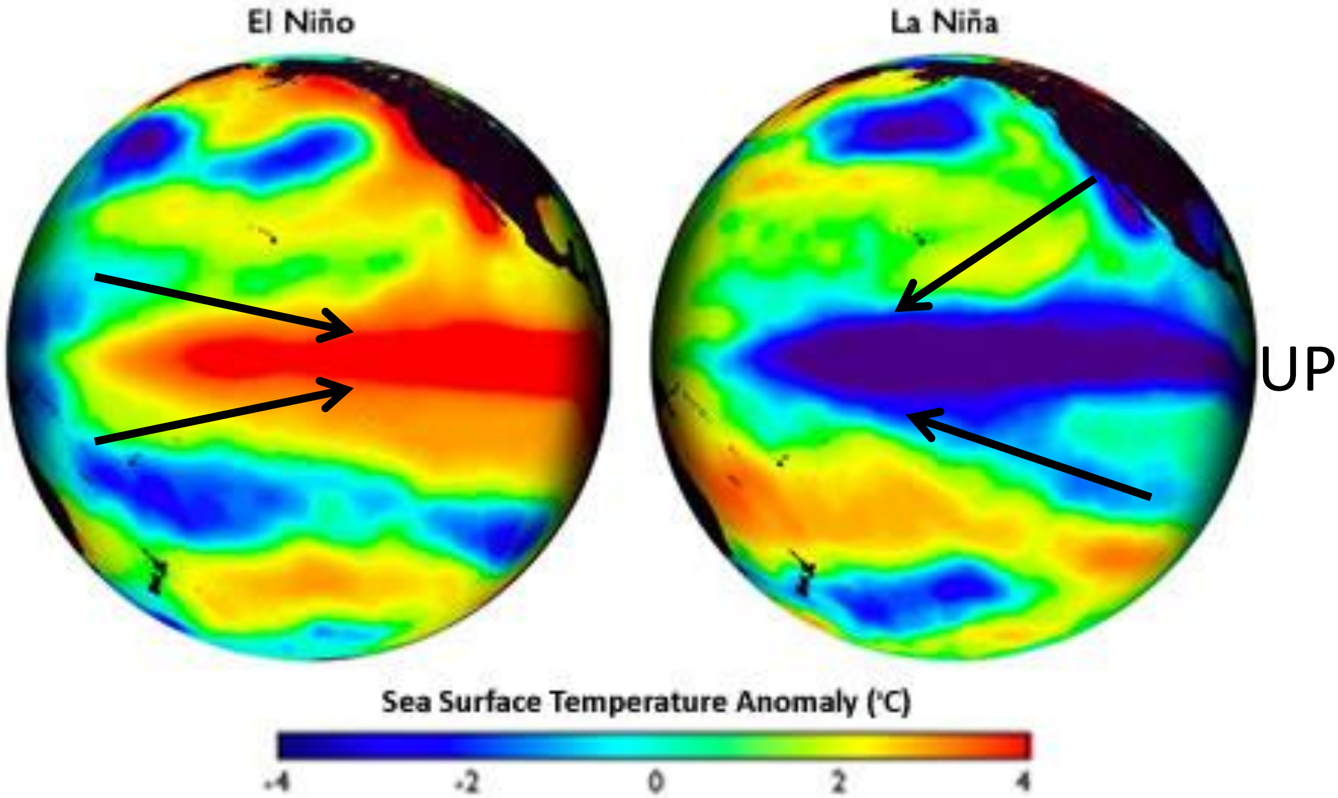
- Reversing or weakening of trade winds (Walker Cell convection shifts eastward in equatorial Pacific): Weather patterns reverse: water-laden air masses reach North America's west coast (hurricanes and storms – causing flooding – *where normally deserts*); dry air reaches Australia and Asia's east coasts (causing fires and droughts – *where normally rainforest*)
- Thermocline along the equator flattens:
  - Equatorial currents weaken *(normally strongest)* while equatorial countercurrents strengthen *(normally weakest) – cold tongue of upwelled water disappears and is replaced by warm tongue*
  - Upwelling off Eastern Equatorial Pacific stops; hence low nutrients and warmer waters; low nutrients causes biological productivity to drop; combined with warmer waters, many organisms migrate or die.
  - Downwelling off Western Equatorial Pacific stops; water gets slightly colder, sea level drops; reefs destroyed.

El Nino Frequency




**Multivariate ENSO index, 1950s to present.** ENSO index values are calculated using 6-7 different atmospheric and oceanic indicators. Values greater than zero (red areas) indicate El Nino while those less than zero (blue areas) indicate La Nina. The greater the value is from zero, the stronger the event.

For updates, see: https://www.esrl.noaa.gov/psd/enso/mei/




*These global maps centered on the Pacific Ocean show patterns of sea surface temperature during El Niño and La Niña episodes. The colors along the equator show areas that are warmer or cooler than the long-term average. Images courtesy of Steve Albers, NOAA and modified by K. Wiese. Arrows represent trade wind direction. UP = upwelling.*

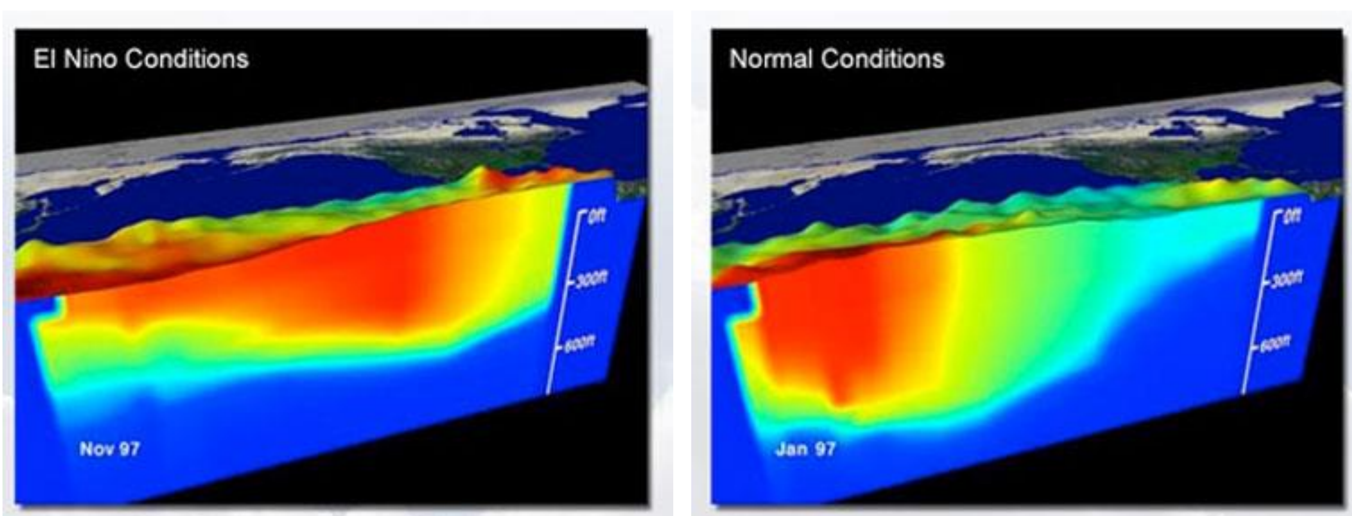
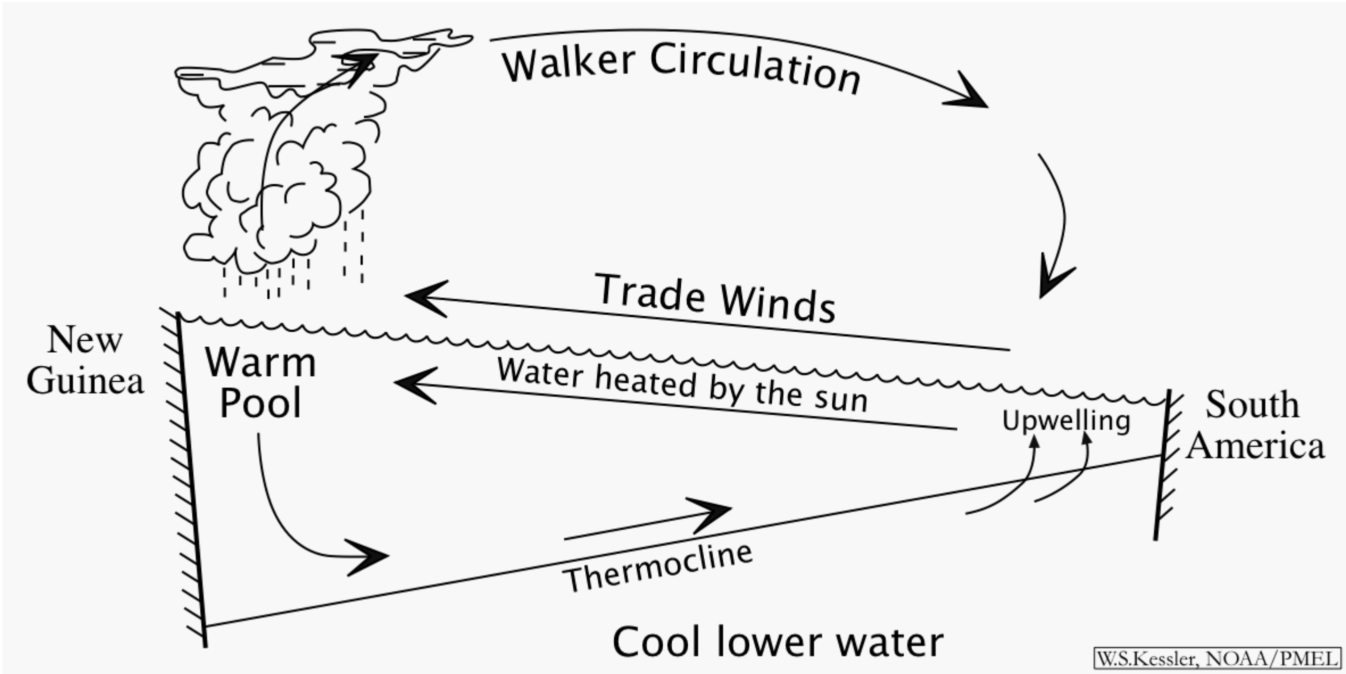
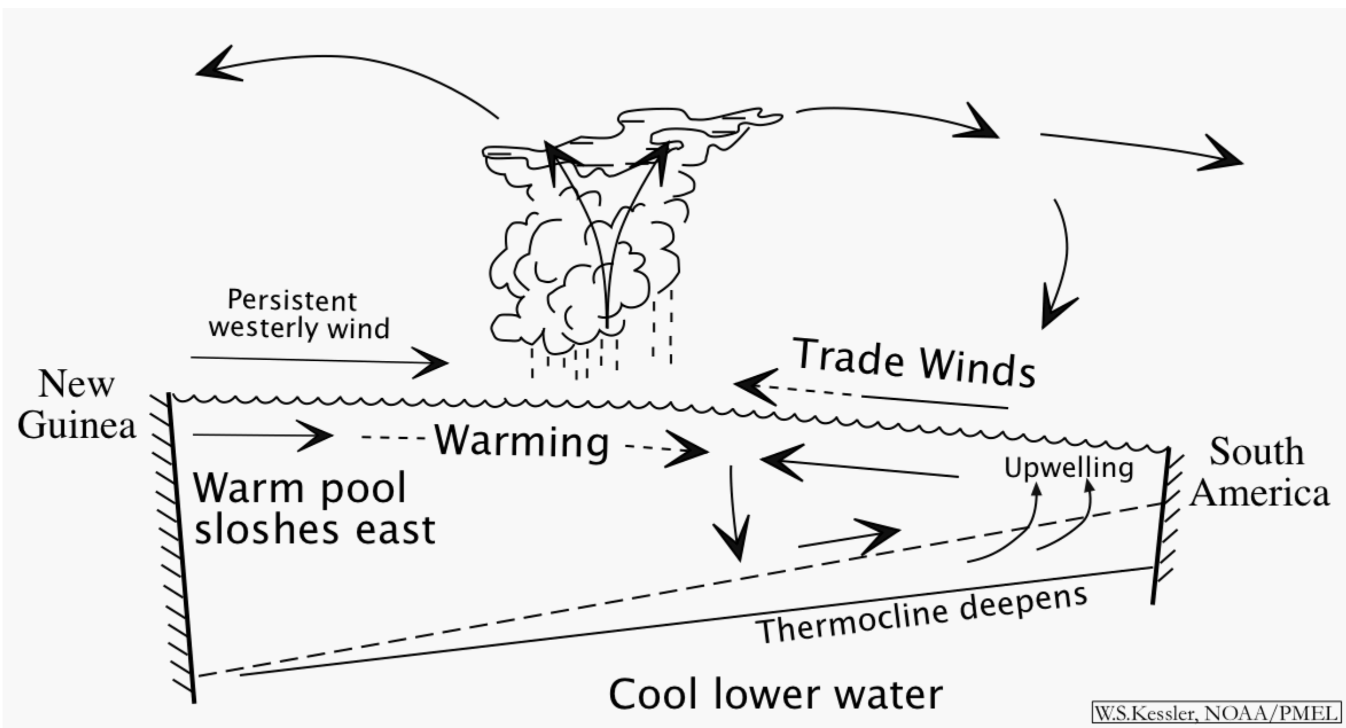
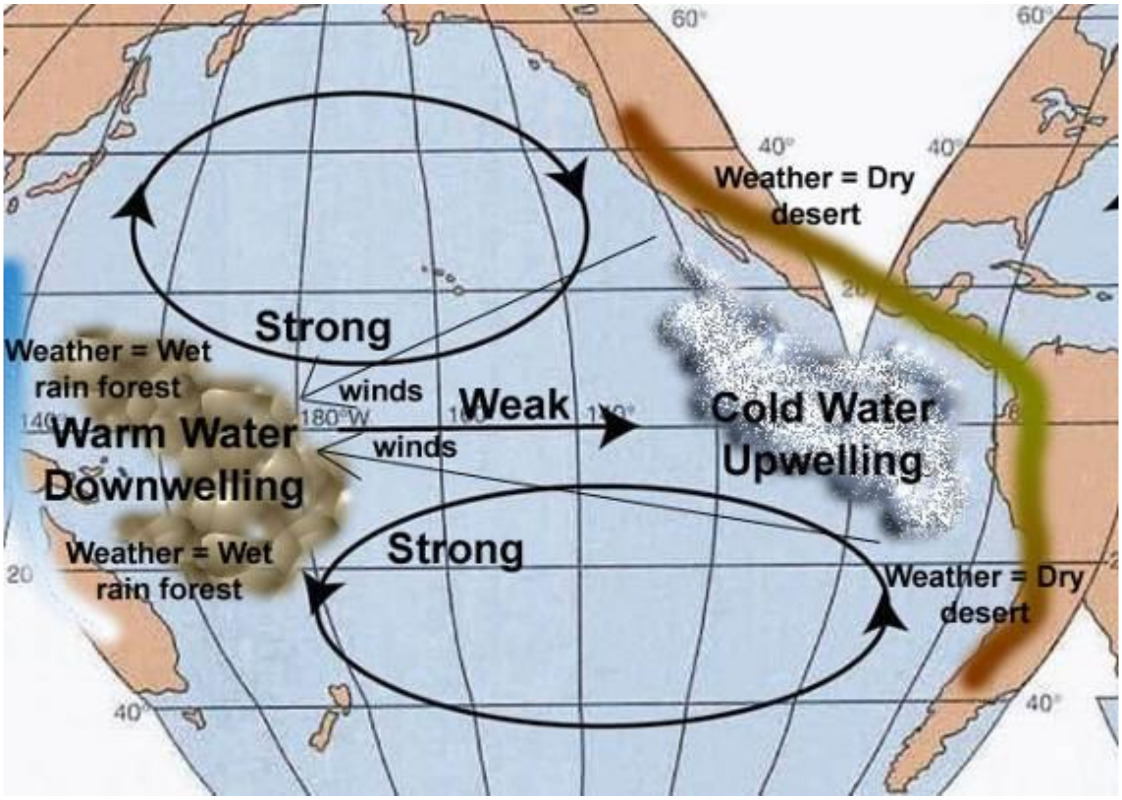



*Image: NOAA – These images show sea surface topography and upper ocean temperature data from satellites and buoys. The height of the sea is represented by hills and valleys. Water temperature is shown in color, ranging from 30°C as red to 8°C, shown in dark blue. The image on the right represents "normal" conditions in the equatorial Pacific during January 1997. Notice the lack of a thermocline in the east – as cold water upwells to surface and is pulled from east to west (cold tongue). The image on the left shows El Niño conditions from November 1997. Notice the much warmer waters present in the eastern equatorial Pacific and the deep sharp thermocline. Final note: "Normal" conditions are intermediate between El Niño and La Niña. During a full La Niña, the thermocline in the eastern equatorial ocean would become even less visible and the cold tongue on the surface would become even stronger as globe images above show.*

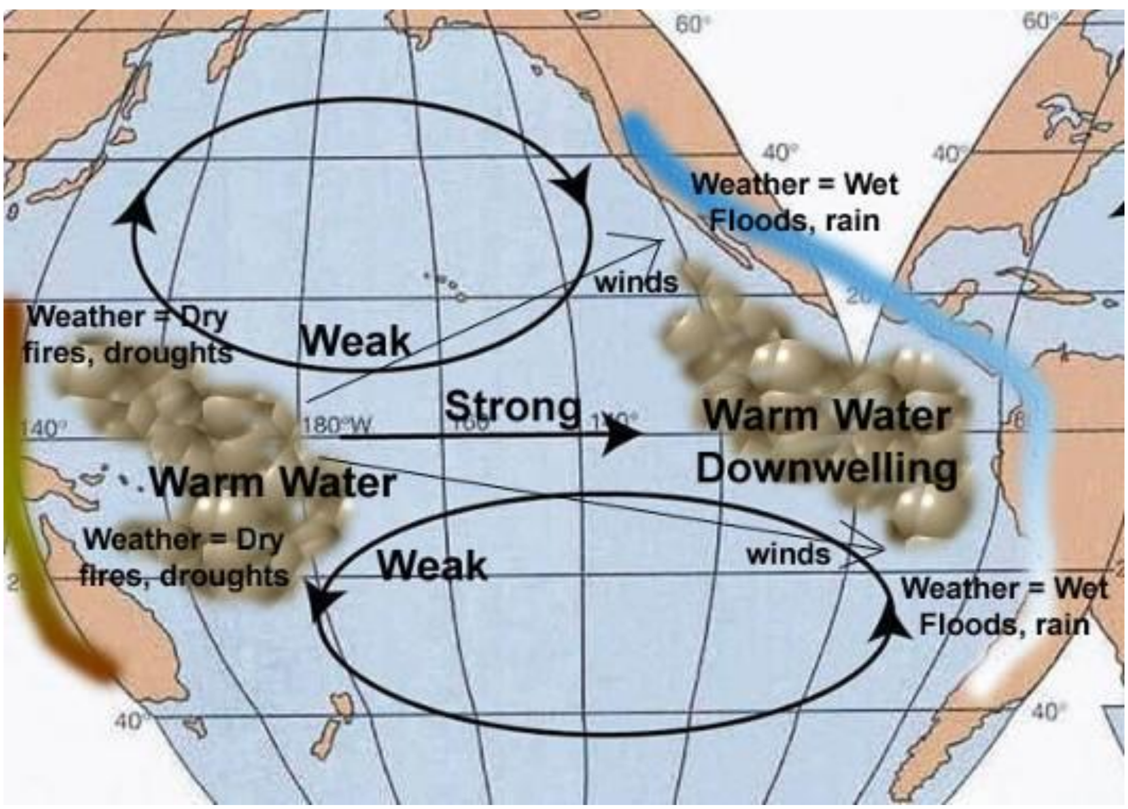


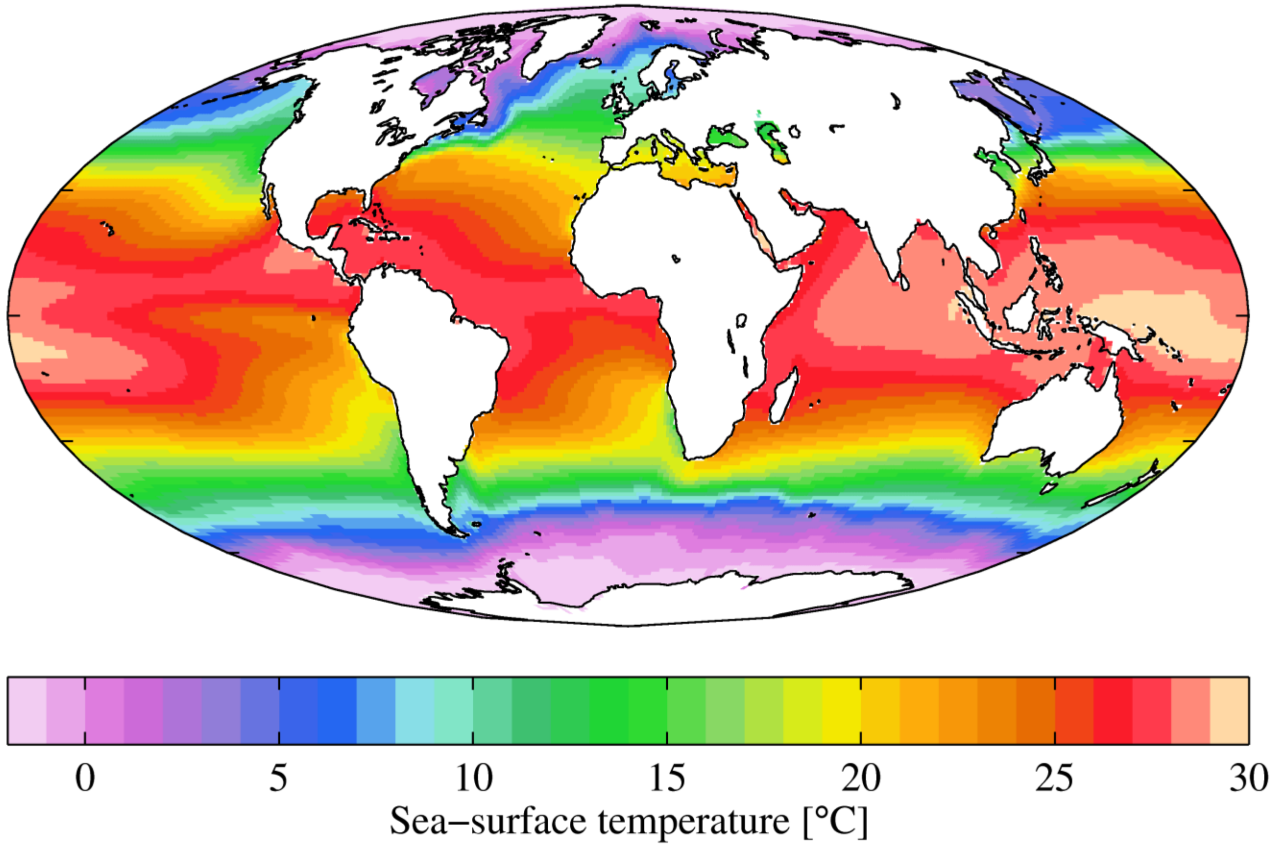

*Schematic of normal and El Niño conditions in the equatorial Pacific (ocean currents and atmospheric circulation systems). Image: NOAA Schematic of normal and El Niño conditions in the equatorial Pacific. Image: NOAA*
*This image illustrates the connection between atmospheric conditions and ocean currents. Notice during La Niña, high pressures in Peru and low pressures in the western equatorial Pacific produce convection that causes the disappearance of a thermocline in the east and the cold tongue of surface water moving west. During El Niño, atmospheric convection shifts eastward, and the warm dome of water normally covering the western equatorial Pacific also shifts eastward, flattening the thermocline, shutting down upwelling, and creating a warm tongue of water pushing east.*

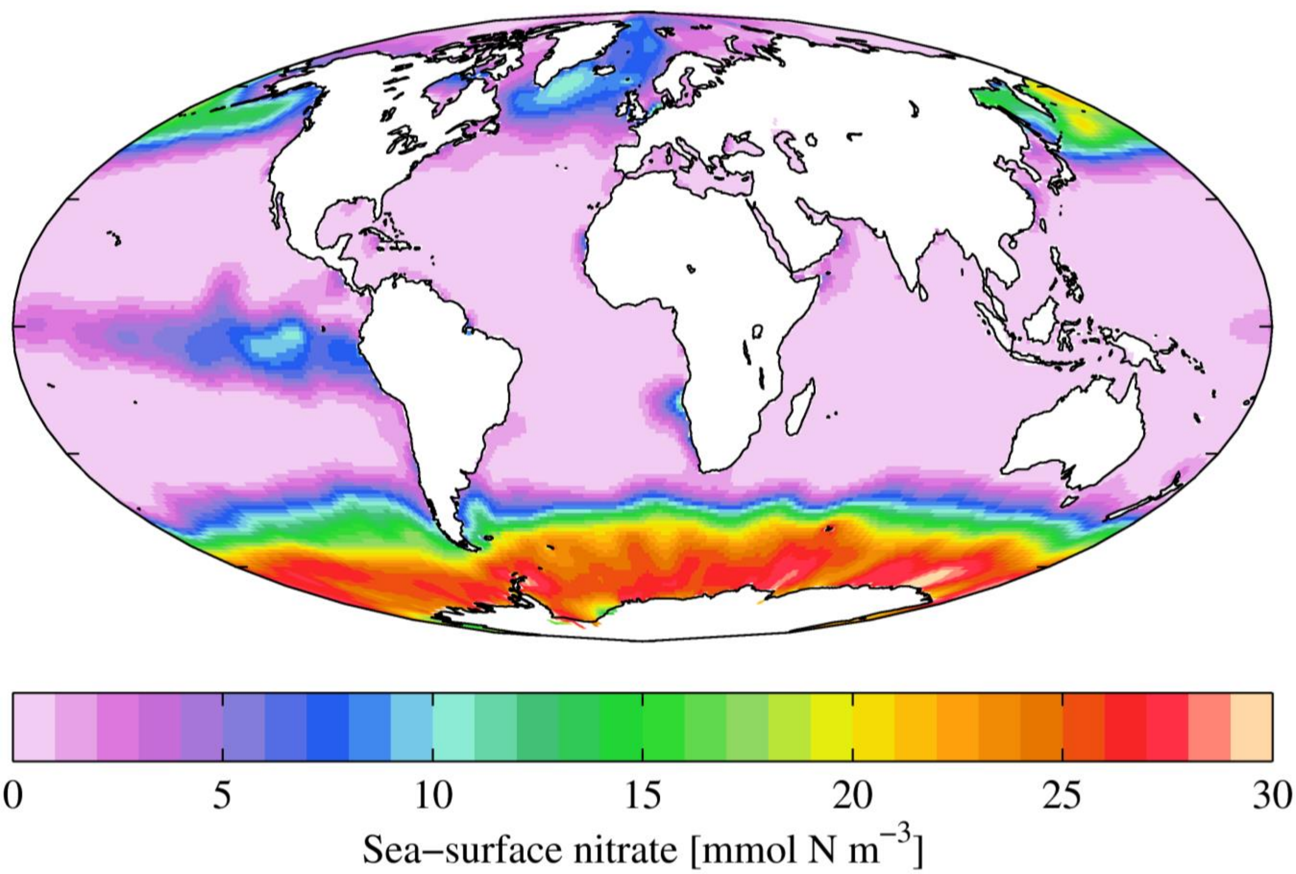



***La Niña*** *(eastern equatorial zone: ocean = upwelling, cold water, atmosphere = dry high pressure; western equatorial zone: ocean= warm pile of water with downwelling, atmosphere = wet low pressure; equatorial currents STRONG; equatorial countercurrent is WEAK.)*




***El Niño*** *(eastern equatorial zone: ocean = NO upwelling, warm water, atmosphere = wet, low pressure; western equatorial zone: ocean = reduced pile of warm water, atmosphere = dry, high-pressure; equatorial currents WEAK; equatorial countercurrent is STRONG.)*

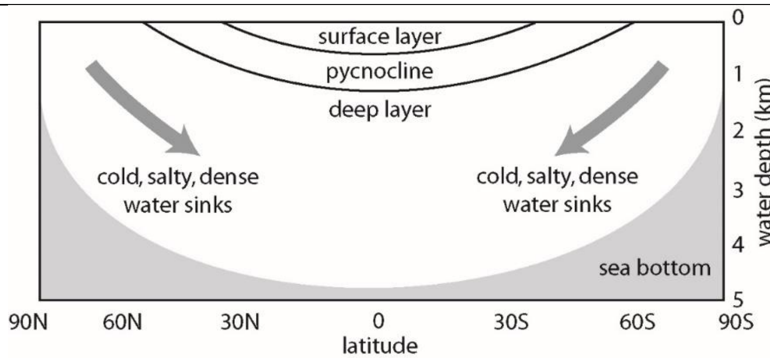



Both of the above world maps were produced by Plumbago (CC BY-SA 3.0), Wikipedia, based on data from World Ocean Atlas 2009

# Currents Chapter Worksheet

| | | | |
|---|---|---|---|
| 1. Thermohaline currents are caused by: (CIRCLE all that apply: *wind \| coriolis effect \| gravity \| density*) | | | |




2. How do water characteristics change with depth as you cross the pycnocline in these general locations? CIRCLE.

| | Poles | Subtropics | Equator |
|---|---|---|---|
| **Density** | *increases \| decreases \| no change* | *increases \| decreases \| no change* | *increases \| decreases \| no change* |
| **Salinity** | *increases \| decreases \| no change* | *increases \| decreases \| no change* | *increases \| decreases \| no change* |
| **Temperature** | *increases \| decreases \| no change* | *increases \| decreases \| no change* | *increases \| decreases \| no change* |
| Pycnocline also = | *halocline \| thermocline* | *halocline \| thermocline* | *halocline \| thermocline* |

3. When is there a pycnocline in the Poles? CIRCLE: *spring | summer | fall | winter | never*
4. When is there a pycnocline in the midlatitudes? CIRCLE: *spring | summer | fall | winter | never*
5. When is there a pycnocline from the equator to the subtropics? CIRCLE: *spring | summer | fall | winter | never*
6. Where does all **deep water** in the world's oceans originate? CIRCLE: *poles | mid latitudes | equator | depends*
7. Why?

Use the following **thermohaline currents** to answer these questions:
Antarctic Bottom Water (ABW) | Antarctic Intermediate Water (AAIW) | Mediterranean Intermediate Water (MIW) |
North Atlantic Deep Water (NADW) | Red Sea Intermediate Water (RSIW)

8. Which current is the **densest**? CIRCLE: AABW | AAIW | MIW | NADW | RSIW
9. Which current is the **least dense**? CIRCLE: AABW | AAIW | MIW | NADW | RSIW
10. Which current is the **coldest**? CIRCLE: AABW | AAIW | MIW | NADW | RSIW
11. Which current is the **warmest**? CIRCLE: AABW | AAIW | MIW | NADW | RSIW
12. Which current is the **freshest**? CIRCLE: AABW | AAIW | MIW | NADW | RSIW
13. Which current is the **saltiest**? CIRCLE: AABW | AAIW | MIW | NADW | RSIW
14. Does cold water sit over warm water anywhere? Where and why?

*15.* **Upwelling causes**: CIRCLE all that apply: *surface current convergence | surface current divergence*
*islands blocking a surface current |seamounts blocking a bottom current*
*Ekman transport INTO coastline | Ekman transport AWAY from coastline*

*16.* **Downwelling causes**: CIRCLE all that apply: *surface current convergence | surface current divergence |*
*islands blocking a surface current |seamounts blocking a bottom current*
*Ekman transport INTO coastline | Ekman transport AWAY from coastline*

17. What happens to the following surface water characteristics when upwelling is happening?
**Temperature** – CIRCLE: increases | decreases | no impact || **Nutrient content** – CIRCLE: increases | decreases | no impact
**Density** – CIRCLE: increases | decreases | no impact || **Oxygen content** -- CIRCLE: increases | decreases | no impact
**Marine life activity** – CIRCLE: increases | decreases | no impact || **Fog** -- CIRCLE: increases | decreases | no impact

18. What percentage of wind speed (10 m or 30 ft above the surface) is transferred to water to produce surface currents?

19. **The Ekman spiral** is caused by: (CIRCLE all that apply: *wind | coriolis effect | gravity*)

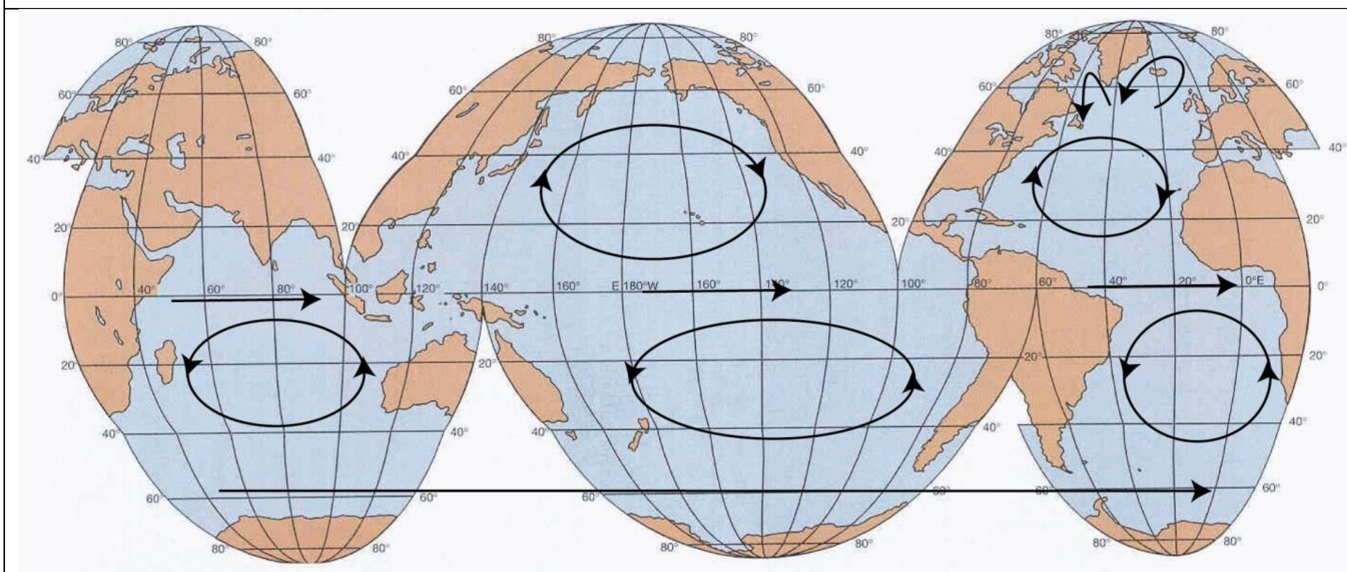
20. **The Ekman spiral** affects what portion of the ocean's surface water? (How deep?)

21. **Ekman transport** in the **northern hemisphere** is what angle to the wind and what direction?

22. **Ekman transport** in the **southern hemisphere** is what angle to the wind and what direction?

23. What are the 5 circulation circles in the 3 main oceans called (generic term)?

24. What causes them to form?




*Map of the world's oceans with the main five gyres, equatorial countercurrents, and major polar currents (both hemispheres).*

25. Label these **surface currents** in the above map: *Calif. Current | Equatorial countercurrent | Gulf Stream |West Wind Drift*

26. From the list above, and consulting the sea surface temperature graphs that precede this assignment, which current is the **warmest**?

27. From the list above, which current is the **coldest**?

28. In comparison with **western boundary currents**, **EASTERN boundary currents** are:
(CIRCLE: *faster | slower*) (CIRCLE: *colder | warmer*) (CIRCLE: *deeper | shallower*)
(CIRCLE: *moving poleward | moving equatorward*)

29. Along the equator in each major ocean, there are countercurrents. Why?

30. What happens to these countercurrents during El Niño? Why?

31. **El NIÑO/LA NIÑA:** Trade Winds stronger than normal. CIRCLE: *El Niño/La Niña*
Trade Winds weaken and possibly reverse. CIRCLE: *El Niño/La Niña*
Warm equatorial ocean currents move east. CIRCLE: *El Niño/La Niña*
Eastern equatorial oceans have high upwelling (surface waters pulled away). CIRCLE: *El Niño/La Niña*
Western equatorial oceans experience dry weather, fires, and drought. CIRCLE: *El Niño/La Niña*
Eastern equatorial oceans experience wet weather, flooding, and coastal erosion. CIRCLE: *El Niño/La Niña*

32. **Langmuir cells** include zones of: (CIRCLE *convergence | divergence | eddies | Ekman spirals*)

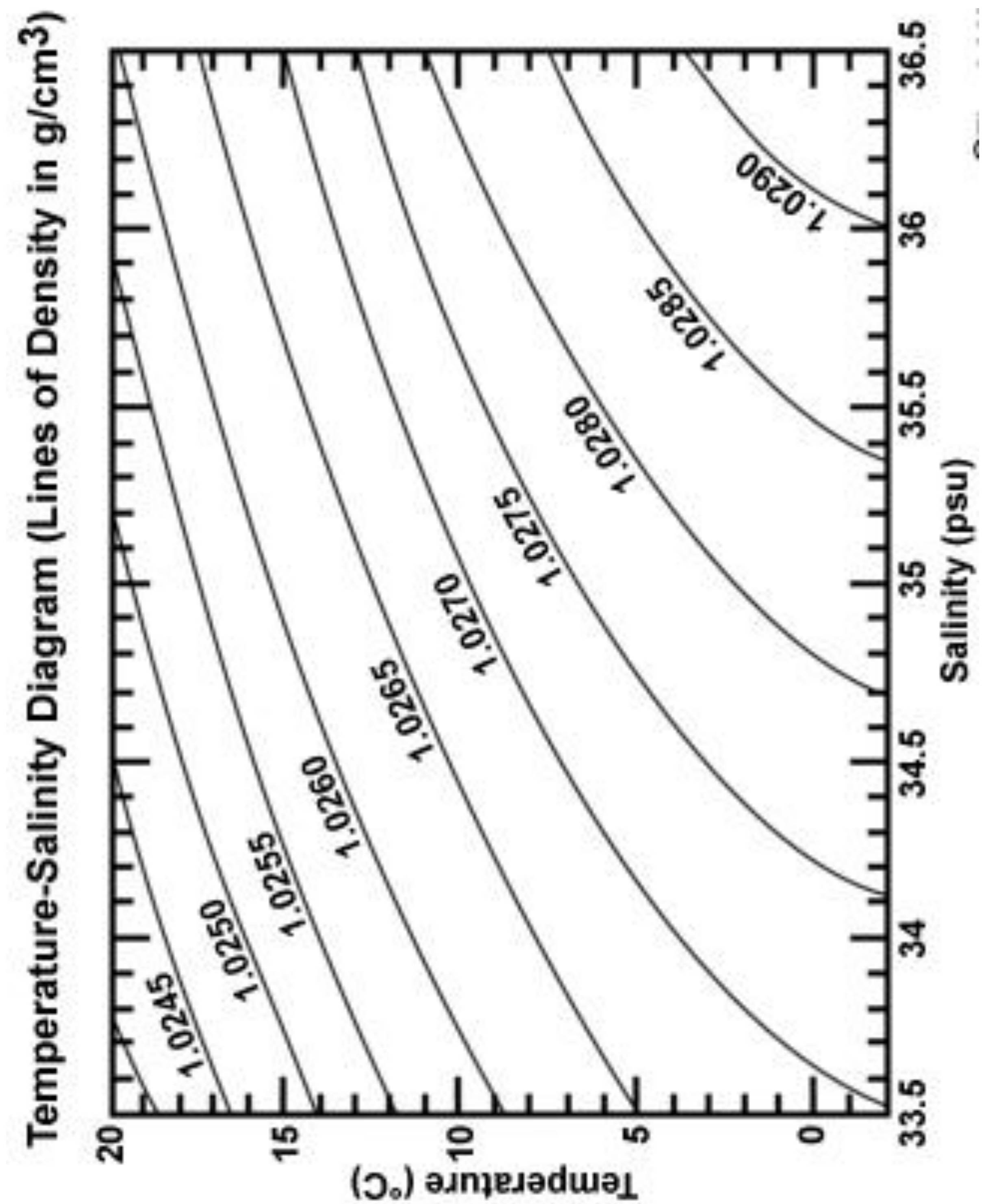
33. **Langmuir cells** affect what portion of the ocean's surface water? (How deep?)

34. *On the graph below, map the values of the thermohaline currents from the table that appears on the second page of images for this chapter of the workbook. Where values are range, create a bar (where both X and Y values are a range, create a rectangle). Label: AABW, NADW, AAIW, MIW, RSIW.*

Note: Salinity units in graph below are PPT. *(Image below is from the Comet Program.)*

35. Based on the location each appears on the graph, determine density. *(You can also use the calculator on class website for more numeric accuracy.)*

| | Freshwater at 4°C | AABW | NADW | AAIW | MIW | RSIW |
|---|---|---|---|---|---|---|
| **Density** | 1.000 g/cm$^3$ | | | | | |



# Lost at Sea – Where Am I? Activity

You are left in adrift in a dinghy after a fishing excursion gone awry somewhere near Hawaii over spring break. How can you use your knowledge to find your location and to make your way back to land? Use the following clues to identify the **your location on the following maps** (mark with an X), and the **direction you would paddle to find land** (mark the location you would travel to with another X and draw an arrow between the two). Clues:

- Sun rises at **stern** (back) of your vessel and sets at **bow** (front) and you are keeping your vessel oriented this way throughout the day.
- Currents are moving towards the sunset (direction your bow is facing).
- Water temperatures are on the warm side.
- Frigate birds are flying from the sunrise direction in morning and the sunset direction in evening;
- Albatross and Arctic Tern are flying from **starboard** (right side of vessel when facing bow) to **port** (left side).
- At night, Polaris is on starboard side of boat and appears at angle of 10 degrees from horizon.
- Winds are from starboard **stern**.
- Swell is approaching from multiple directions but no local storm and no clouds in sky.
- When on dry land in Hawaii, your clock read 12 noon at close to solar noon. Now it reads 1 pm at solar noon.

**To learn more about how to use the clues above and how to use them, refer to the exercises that follow then return here to answer the question!**

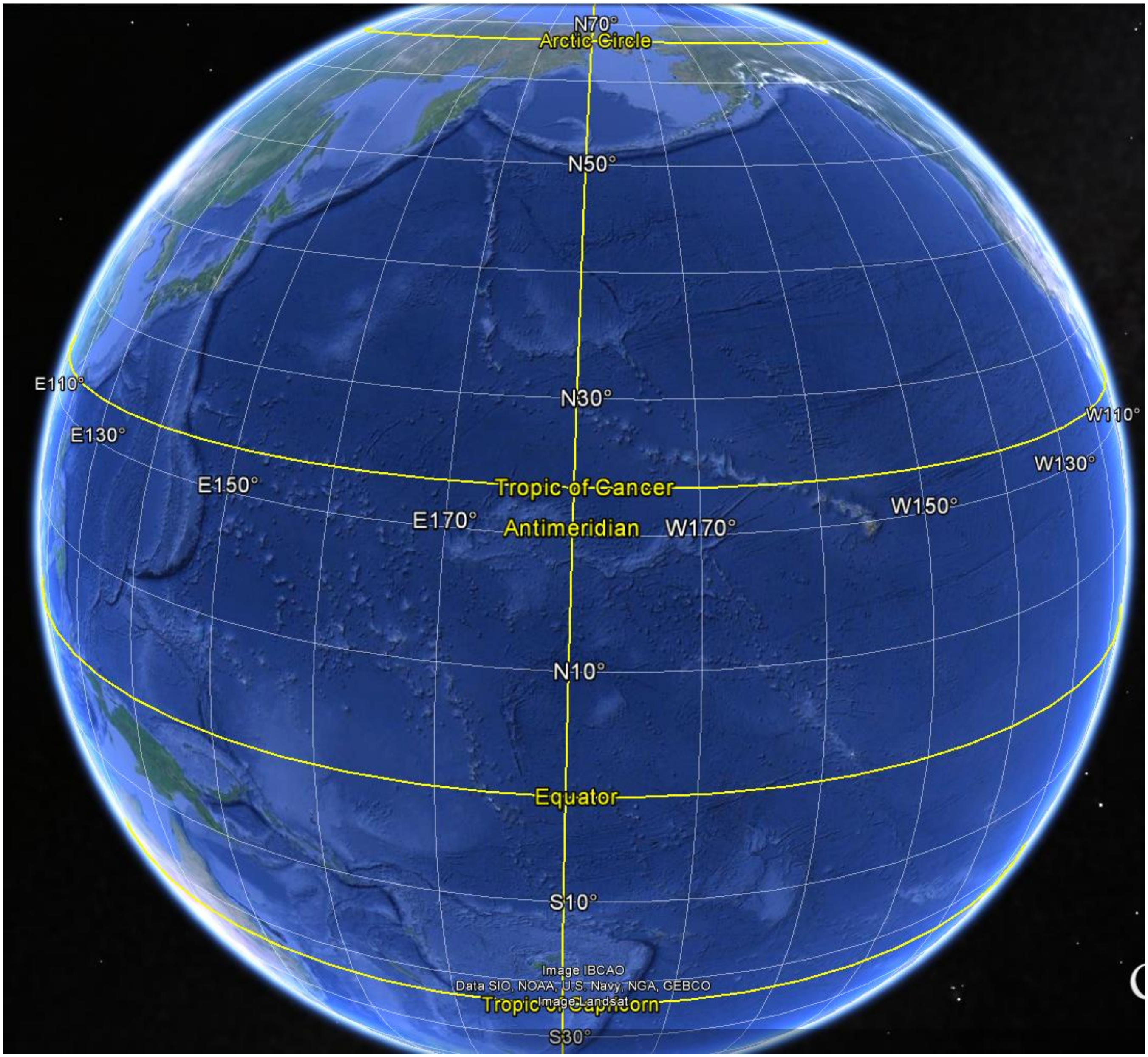



*Image: Google Earth*

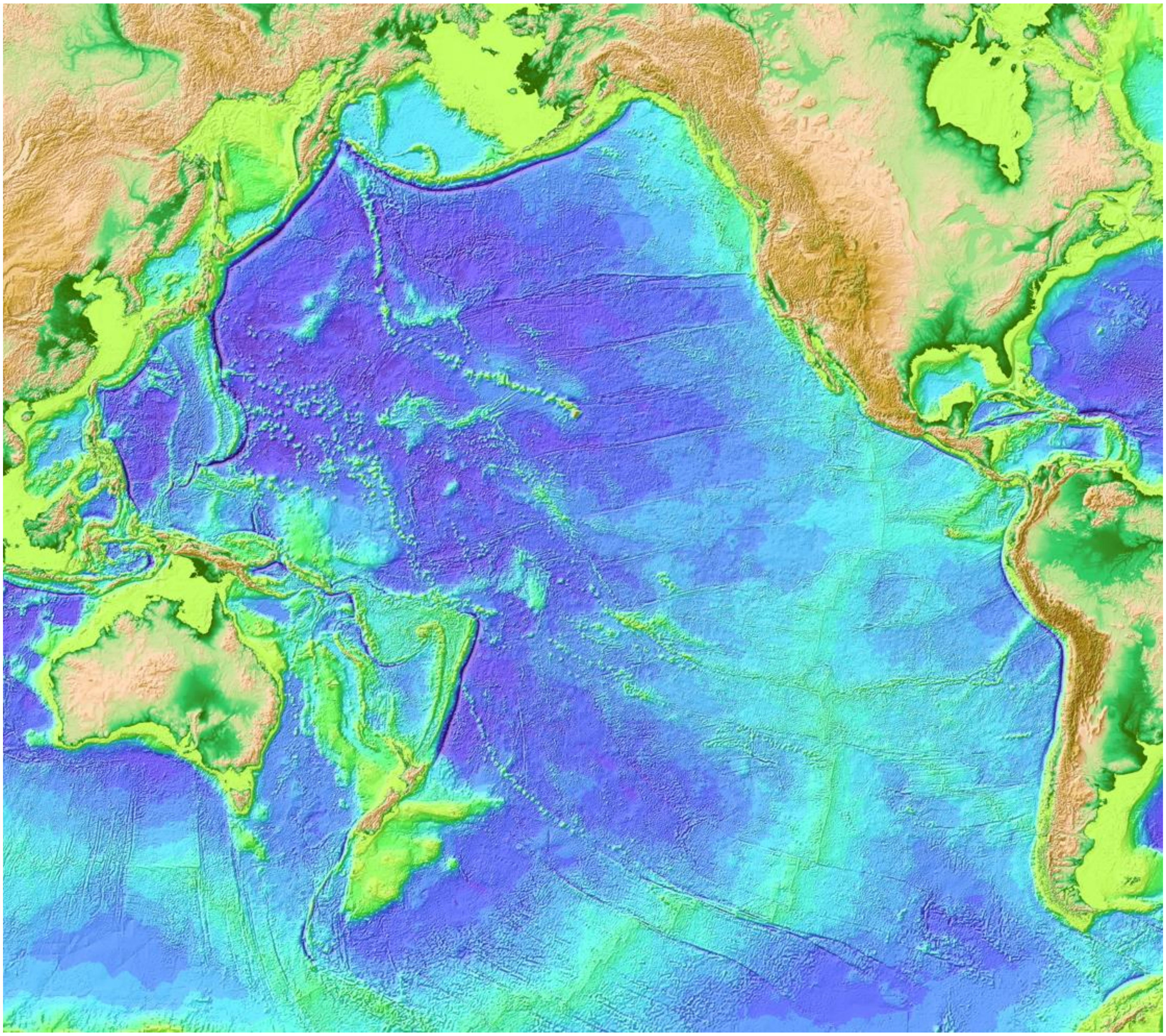


*Image: NOAA*

**Which clues did you use and how did you use them to answer the questions: Where am I? Where do I go to get to land?**

**MARINE TRADITIONAL NAVIGATION WAYFINDING --** Text below is from www.exploratorium.edu:
For thousands of years, group of explorers from a variety of indigenous cultures have set out on canoes for points unknown, possibly never to return, leaving behind loved ones and the safety of terra firma. What made them do it? No written record preserves much of this history, but speculations abound. They may have been driven by population pressures, a famine caused by a period of drought, or a lost battle. Or they may have been led by an ambitious chief, bent on glory or expansion. Some voyages may not have been driven by necessity at all, but instead by curiosity and a spirit of adventure.

This much is certain: Traditions of seafaring ran deep in the peoples of Pacific Coastal and Island nations, and often those who voyaged left their homes with no intention of returning, bringing with them the plants and animals they would need to start their lives afresh in a new land.

Today, with the rebirth of traditional voyaging in Hawai'i and elsewhere, we can ask the same question: Why set out for a weeks-long journey on a pitching canoe, risking the dangers of the open sea, and leaving behind loved ones and the comforts of home?

When the navigation renaissance began in the early 1970s, native peoples voyaged to prove a point, to refute the claim being advanced by some that their land was settled accidentally by the hapless drifting of rafts or by fishing boats blown off course. Now, with the tradition of traditional canoe navigation revived and thriving, the voyages allow new generations to connect with their native histories.

Of course, traveling thousands of miles by canoe without navigation aids has appeal in modern times, especially to people who love challenges as much as they love the ocean. But those voyagers who have mastered observation-based navigation techniques agree that it isn't really about the sailing, nor is it about the mental feat of getting from one tiny speck in the vast Pacific to another. These canoe voyages are really about preserving and celebrating culture—knowledge, traditions, and values that were very nearly lost.

*Hokule'a Sailing 2009 (Honolulu, Hawaii) – Image by Kohuroa CC BY 2.0.*

**PACKING FOR THE JOURNEY**
"Packing for a modern canoe voyage is a weighty matter, and the packing list looks much the same as for a long backpacking trip into the wilderness: water, nonperishable meals (think pasta and canned beans), a sleeping bag, a select and sturdy set of clothing, first aid and medications, a light source, and any of the things you can't imagine going a few weeks without—books, music, a journal, and yes, fishing gear. (Fresh sashimi is one of the delights of ocean travel.)

Water is the heaviest burden—a gallon of water per day per person. It must be stored and used in a carefully balanced arrangement, lest it disturb the steering and tracking of the canoe. When it rains, the crew uses tarps to catch the rainwater and refill empty bottles. Meals are also packed systematically, in bins marked "Day 1" and "Day 2," etc., for easy access" and to ensure there's enough food to last the voyage.

In a broader sense, preparing for a voyage has to do with not only what you bring, but also what you leave behind. Navigators counsel their crew members to make whatever arrangements are necessary to take care of responsibilities at home so that they can set out to sea untroubled." -- Exploratorium's *Never Lost*

| |
|---|
| What would YOU bring or most like to have with you if out in the middle of the Pacific Ocean? (Pick your top 5.)<br>*Answers will vary. Suggestions: water (or tarp to collect water); warm clothing, watch, compass, fishing line/hook and/or food, maps!, flares.* |
| What would be the biggest challenges you'd face?<br>*Answers will vary. Suggestions: hunger and thirst; communication, staying warm, staying dry* |

**WHICH WAY IS HOME?**

"If there is a golden rule among marine navigators, it is this: **Keep track of where you've been, and you will never be lost.** Traditional marine navigation is home-centered, meaning that the navigator keeps a mental and even a written log of every step of the voyage, starting from the moment the canoe is launched. What was the bearing? How far did the canoe travel? How did the wind and currents affect the canoe's path? By tracking direction and distance throughout the journey, the navigator maintains a mental roadmap of the canoe's path that establishes the location of both the destination and the home island. The payoff for such careful observation is that at any given moment during the voyage, you should always be able to point both to the destination and back to home. Even if the winds or currents put the canoe off track, even if the destination island never appears, returning home is still just a matter of retracing the journey, relying on the same clues that brought you. In this sense, you are never lost, because you always know the way home." -- Exploratorium's *Never Lost*

To make the above possible, there has to be a constant knowledge of how the boat is situated relative to north, south, east, and west. Use the rising sun in the east and the setting sun in the west to get your bearings first, then be sure you never lose them. Always know which direction your bow is facing at any particular time.

| |
|---|
| If no compass or map, how would you keep track of where you've been and where you're going?<br>*You'd want some kind of writing device, so you could keep a record – create a map as you travel. AND FIRST AND FOREMOST figure out North South East and West directions from setting sun. Keep these always aligned.* |
| If no compass, how do you orient yourself relative to north, south, east, west and keep your orientation (know the direction you're moving or facing?<br>*Pick a location on the boat and use that as your guide (measure everything relative to that one location). Then at night check orientation of north stars or ecliptic against that location. During day check sun's path. Remember that sun sets in west and rises in east. When no land in sight, and no stars or sun, you can keep your orientation by direction the waves are coming from.* |

**HOW FAR?**

"A voyaging canoe lacks two things that most people have come to expect in a moving vehicle: a speedometer and a trip odometer. So how do you know how far you've gone?

A straightforward way of measuring speed is by what's called dead reckoning. If you time the progress of bubbles and froth as they pass along the length of the canoe, it's possible to get a rough calculation of speed using simple algebra. To calculate canoe speed by dead reckoning, you can use a very simple formula: speed = distance / time.

So, for example, if it takes a bubble 4 seconds to travel 20 feet along the canoe, you know you are traveling at 5 feet per second. Divide by 6,077 feet per nautical mile, and multiply it by 3,600 seconds per hour, and you'll have your answer in nautical miles per hour, or knots—in this case, 3 knots.

Sometimes navigators prefer to simply estimate the distance traveled using "canoe days," the average distance a particular canoe covers over the course of a full day. For example, a voyaging canoe might average 120 miles (193 km) per day when sailing in tropical latitudes. So after sailing three days, you can assume you've traveled roughly 360 miles (579 km), although variations in winds and currents can alter this number dramatically." -- Exploratorium's *Never Lost*

| |
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| If you paddle at the same rate every day, what are some reasons you would actually cover more ground (be moving faster) on a particular day? Moving slower on a particular day? *If you're paddling WITH the current, you'll be moving faster. If you're paddling AGAINST the current, you'll be moving slower.* |
| •How fast are you travelling if your boat is 10 feet long, and you paddle past a floating log in 10 seconds? How far could you travel paddling at this speed for 8 hours?<br>*10 feet/10 seconds = 1 foot per second*<br>$\frac{1\ foot}{1\ \cancel{sec}} \times \frac{60\ \cancel{sec}}{1\ \cancel{min}} \times \frac{60\ \cancel{min}}{1\ \cancel{hr}} \times 8\ \cancel{hr} = 28{,}800\ feet$ SO $\frac{28{,}800\ \cancel{feet}}{1} \times \frac{1\ nautical\ mile}{6{,}077\ \cancel{feet}} = 4.7\ n.\ mi$<br>*You could travel 4.7 nautical miles or ~5 degrees of longitude at the equator.* |

**SEAMARKS**

"Seamarks can help track progress and indicate location. Seamarks are natural mid-ocean signposts that tend to appear at certain specific places along the way, including sea life, flocks of birds, free-floating seaweed or driftwood, or other natural phenomena. A particular zone might always host a swarm of jellies, say, or a school of porpoises. Seamarks reassure the navigator that he or she is on track.

Locating a small island in the middle of the Pacific might seem a nearly impossible feat, but navigators get help from a variety of sources. First, most islands occur in groups. This makes the navigator's target more of a zone than a dot. Find any island in the group, and you can use it to find the one you're looking for." -- Exploratorium's *Never Lost*

| |
|---|
| What are some reasons that areas would regularly have floating material?<br>*Zone of converging currents and downwelling and/or center of gyre* |
| What are some reasons that areas would regularly have high sea life?<br>*Zone of upwelling due to diverging currents or an underwater seamount intersection a bottom current or bottom feature.* |
| How are the island chains and areas of active sea life related (especially areas with no visible islands)?<br>*Typically we find upwelling happening on one side of an island (if winds from NE, then upwelling happens on NW side of island). And if island chains continue under water, then upwelling will happen over these seamounts.* |
| Refer to map below. In the areas around Hawaii, what direction has the highest amount of seamounts?<br>*West of Hawaii there are a LOT of seamounts/island chains. – MOST are southwest.* |
| If you connected these island chains and seamounts with lines, what directions would they run? (Example: a line parallel to the equator would be east-west. A line parallel to a meridian would be north-south. What are the geometries of the lines of seamounts? (If you follow them in your boat, what two directions might you be traveling<br>*Many line up northwest-southeast; some are almost north-south* |

**USING WINDS AND CURRENTS**

"Most navigators plan their routes using a technique known as downwind sailing. The strategy is to set a course to a point at a given latitude upwind of the target island. Then, when you reach the correct latitude, you turn and let the wind carry you to your destination.

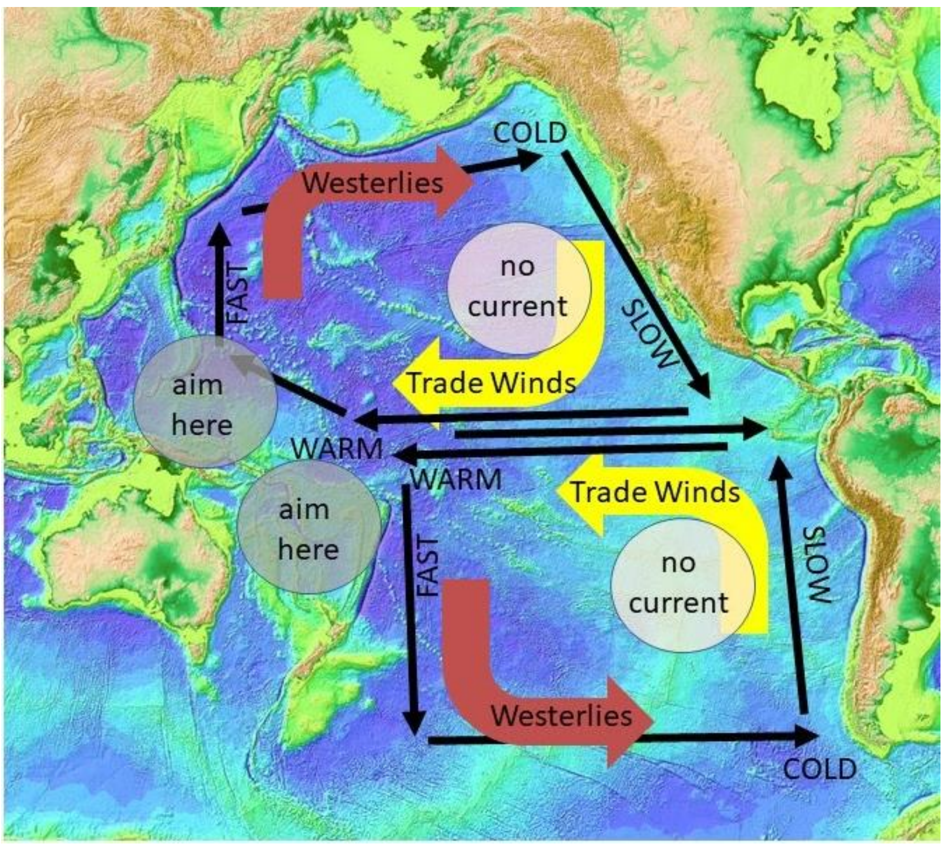
Downwind sailing helps simplify the challenge of locating the target island. If you sail directly toward your target and somehow miss it, you may not know which way to turn. Was it to the left or right? But if you deliberately sail to a point to one side (that is, east or west) and upwind of your target, you can then turn downwind and trust that the island is in front of you. Fortunately, many islands are part of a group of islands, presenting a larger target that is easier to locate than a single, lone island.

Another advantage to downwind sailing: It guarantees that the final leg of the journey will be relatively easy, giving the crew a break when they are likely to need it most.

Any successful sailing voyage requires intimate knowledge of wind patterns and currents. A strong current can be friend or foe, helping to carry you where you want to go or rapidly carrying you off course. Winds and currents vary widely from place to place and from season to season, and storms frequently disrupt the typical patterns. A good navigator takes careful consideration of the winds and currents likely to be in play at the time of a voyage.

Clouds can be a sign of land. Clouds accumulate over islands, and an isolated pile of clouds on the horizon often signals the presence of land. Reflected light on clouds can be another clue. When sunlight (or moonlight) shines on white sand and shallow bays, the light can reflect upward, illuminating the base of low clouds with a silver or greenish glow." -- Exploratorium's *Never Lost*

| |
|---|
| On the map on the first page of this assignment, draw in the typical currents found in the Northern and Equatorial Pacific. Label them with speeds (fast, slow) and temperature (cold, warm). |
| On the same map, in another color, draw arrows indicating the dominant wind directions (and names). |
| Circle on the same map the largest islands that would be good targets for navigation (based on wind and current directions and not wanting to miss the island…) |
| How could you decide which current you were in if you found yourself in a current? Give example. *Size of current, temperature, and direction it's going. For example, if warm current travelling westward, probably in the equatorial currents. If warm and going eastward, probably in equatorial countercurrent.* |
| Where would you be if you noticed NO current? Put a big 0 mark there in the map on the previous page and indicate no current. *In center of Gyre! **NOTE: This is the only place where there is no current, also where the "garbage patches"are.* |
| What happens to the location of currents and winds with the seasons? *At June solstice, they've all migrated north so equatorial currents and ITCZ is around tropic of cancer. At December solstice, they've all migrated south so equatorial currents and ITCZ are around tropic of capricorn. At equinoxes, equatorial currents and ITCZ are at equator!* |

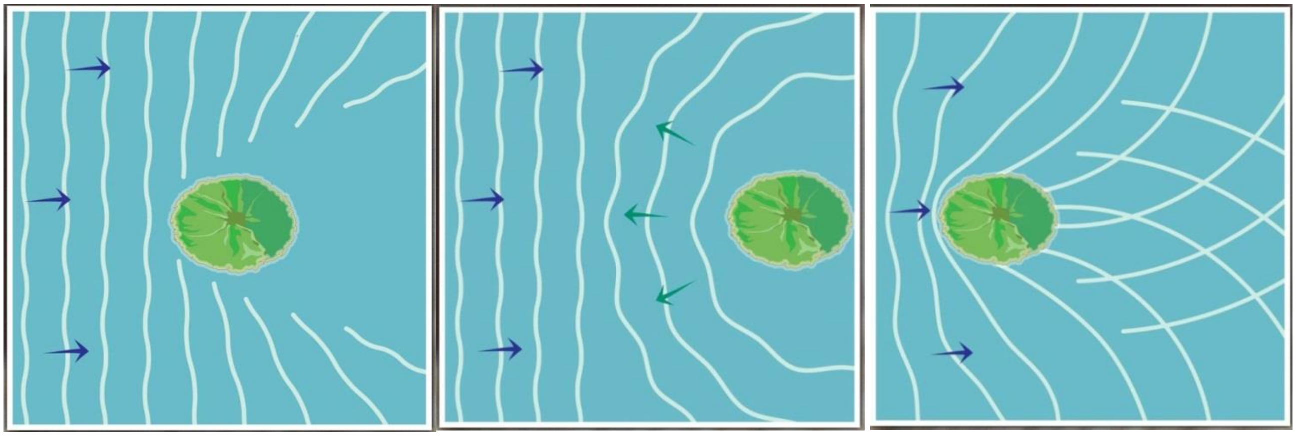



**SWELL**

"Night and day, ocean swells can fill in as a rough guide to direction. Ocean swells are waves that have traveled far from the winds or storms that generated them. With practice, you can feel their subtle roll as they pass under the canoe and sense the direction the swells are coming from. If you note the direction from which the swells are coming at a time when the stars or other celestial guides are available, those same swells can guide you when the celestial guides disappear.

Unlike other guides to direction, swells are almost always present, which makes them especially important during the day, when other clues are absent. But swell patterns can and do shift, so a navigator can't rely on them indefinitely. When all else fails, and there's no way to keep a correct bearing, a good navigator "heaves to"; that is, takes down the sail and waits until he or she can set the course again.

Wave patterns, too, can be altered by the presence of land. Islands block, reflect, and refract ocean swells, creating distinct wave patterns that can help steer a seasoned navigator to land—especially helpful at night or when visibility is low. Bits of land vegetation such as seed pods or driftwood floating on the waves are yet another sign of land nearby." -- Exploratorium's *Never Lost*



*Wave refraction around islands. Images reproduced with permission from the Exploratorium*

| |
|---|
| Where do swell originate? (And can that help you find your location at sea?)<br>*Distant storms – so wherever swell is coming FROM is where there's a low pressure. Winds also likely moving in that direction.* |
| How can you use swell direction to keep your direction/bearing constant during the day?<br>*If you can't see sun or stars, and swell have been pretty consistent, you can keep yourself moving at same angle to swell.* |
| What do you do if you have lost your direction and no longer trust the swell direction?<br>*Stop and wait until you can find something you can measure.* |
| If you are traveling in the opposite direction of the swell (against the swell) and notice an area of interference (where waves suddenly seem to be coming from multiple directions, what might that represent? (Put an X in the pictures above that mark that location.) *Island ahead! You can see this in the right-most image above – X goes in the center of the right half.* |

**BIRDS**

Birds can be helpful to a navigator in search of an island. Certain land-nesting birds fly out to hunt for fish in the morning and return to their nests in the evening, supplying a useful pointer to land. Not all birds make this daily commute between land and sea, however, so it's important to know one species from another.

A typical Pacific island can be sighted on a clear day from about 10 miles (16 km) away. Birds can significantly extend this detection zone. Some birds range only 30 miles (50 km) from land, while others, such as frigate birds can range much farther, up to 100 miles (160 km) from land. But don't trust every bird you see. Behaviors are general and many juveniles can be unpredictable.

**Frigatebirds** are found over tropical oceans and ride warm updrafts. Therefore, they can often be spotted riding weather fronts and can signal changing weather patterns. These birds do not swim and cannot walk well, and cannot take off from a flat surface. Having the largest wingspan to body weight ratio of any bird, they are essentially aerial, able to stay aloft for more than a week, landing only to roost or breed on trees or cliffs. Because they cannot swim or take off from a flat surface, they will never set down in the water. They mostly steal their food from other birds mid-flight.

The **Arctic Tern** travels the farthest of any bird, crossing the equator in order to spend the Austral summer in Antarctica. They thus travel from pole to pole, maximizing their food sources – summer in the Arctic and then summer in Antarctica, and back again.

*Image: Malene Thyssen, Wikimedia Commons*

**Albatrosses** usually spend 80 to 90 percent of their time at sea flying, day and night. They return to islands once a year to breed. If you can recognize the species and know its breeding time, you should be able to determine whether it's heading to land or open sea.

*Image: Laysan Albatross, Kauai, Hawaii by Dick Daniels (Wikimedia Commons)*

**Shorebirds** or land birds are those that must stay close to land and/or rely on freshwater. These include penguins, cormorants, coots (a few migrating species migrate only at night), eagles, herons, osprey, ducks, sanderlings, oyster catchers, ruddy turnstones, plovers, red- and blue-footed boobies, and more.

Coot

Cormorant

Penguin

Osprey

Sanderlings

Snowy Plover

*(images from Wikipedia Commons)*

| |
|---|
| Which birds provide no indication of the proximity of land?<br>*Arctic tern, Albatross, Frigate birds (mostly),* |
| Which birds indicate land is nearby?<br>*Frigate birds (somewhat – but can be out for a week!) – shorebirds – like coots, hawks, oyster catchers, etc.* |
| Which birds can be used to indicate time of year? How?<br>*Migrating birds, like arctic tern. If we see them moving North to South, we know that it's the end of the Northern Hemisphere summer.* |

**CALCULATING YOUR LATITUDE**

"The North Star, known as Polaris or Hōkūpa'a (Hawaiian), is an especially useful star. Situated at the north celestial pole, it is fixed in the sky and reliably marks due north. In the Southern Hemisphere, where the North Star can't be seen, there is no fixed pole star. But there is a constellation in the southern sky—called the Southern Cross, or Hānaiakamalama in Hawaiian—that points to the south. Draw a line from the top of the cross through the bottom, and this line points toward due south on the horizon.

Of course, stars aren't visible all the time. That's when the sun and moon can help. At dawn, as the stars are fading, you can note the position of the rising sun relative to the canoe and use the sun as a guide while it's low in the sky. At night, if clouds or fog pass in front of your guiding stars, the moon may still be visible and a good bearing marker when it is near the horizon.

Stars can also give clues about location. The height of a star as it passes through its highest point in the sky depends directly on the latitude of the observer. So you can measure the height of stars above the horizon to figure out your latitude.

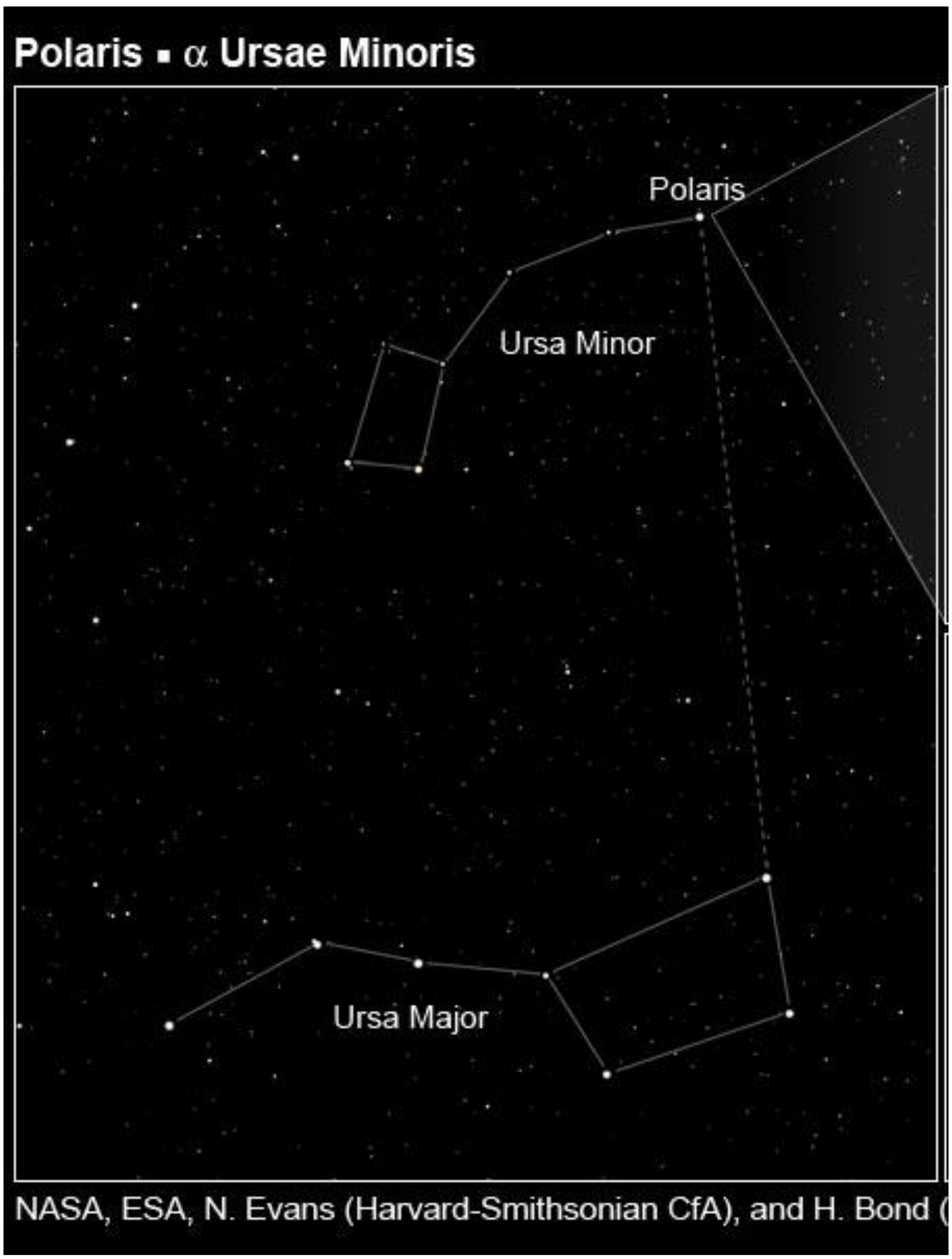
The North Star, or Hōkūpa'a, is a useful latitude marker when you're in the northern hemisphere. The angular height of the North Star above the horizon, in degrees, is equal to your latitude. For example, in Hawai'i, the North Star is 20° above the horizon. That tells you that your latitude in Hawai'i is 20°.

Measuring the angular height of a star in degrees may sound complicated, but it's something you can do easily, using your own body as a measuring tool. Stretch your hand out in front of you, as far as it will go. The width of your pinky is about 1°. Make a fist, and the width of your fist is about 10°. For greater accuracy, you'll want to "calibrate" your own hand as a measuring tool.

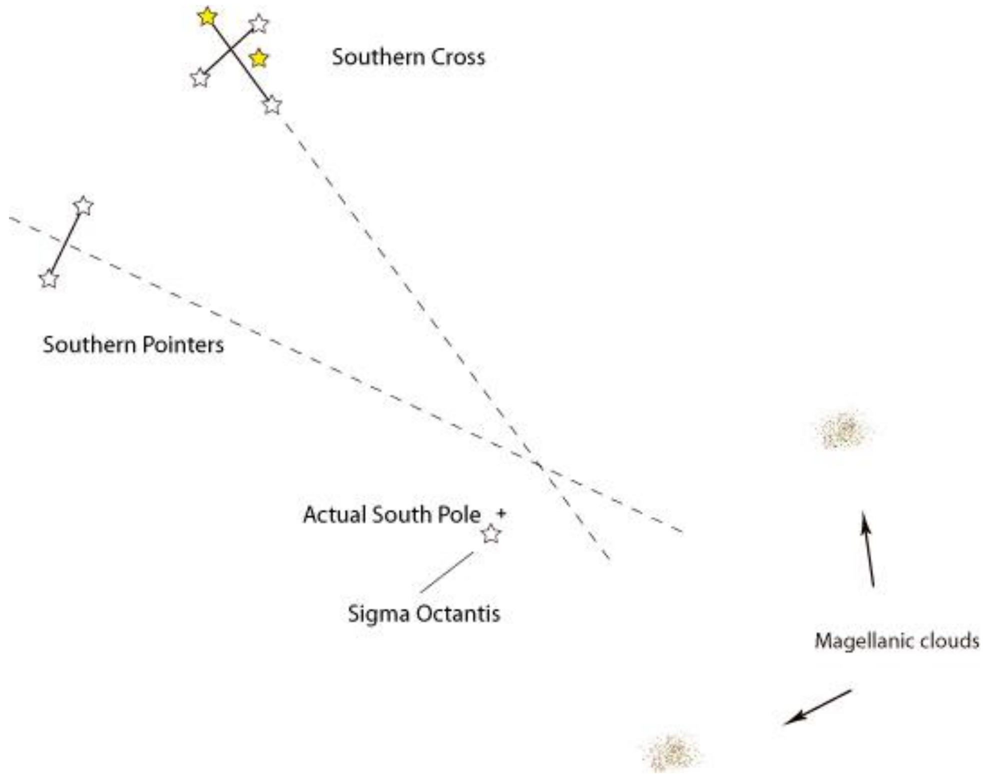
The Southern Cross, or Hānaiakamalama, is another useful constellation for finding your latitude, especially near Hawai'i. When the Southern Cross is upright above the horizon, and the distance between the top star and the bottom star is equal to the distance between the bottom star and the horizon, then you know you are at 20° north, the latitude of Hawai'i. Travel south from Hawai'i and the Southern Cross rises higher in the sky, to 30° above the horizon (about three fists) at the equator." -- Exploratorium's *Never Lost*

Hold your hand in front of you, as far as you can. Line up your outstretched hand with distant objects to measure their angular width or height. Various parts of your hand span different angles. These "rules of thumb" work for most people, but if you want to make your "handy" measuring tool even more personal and precise, try calibrating your hand.

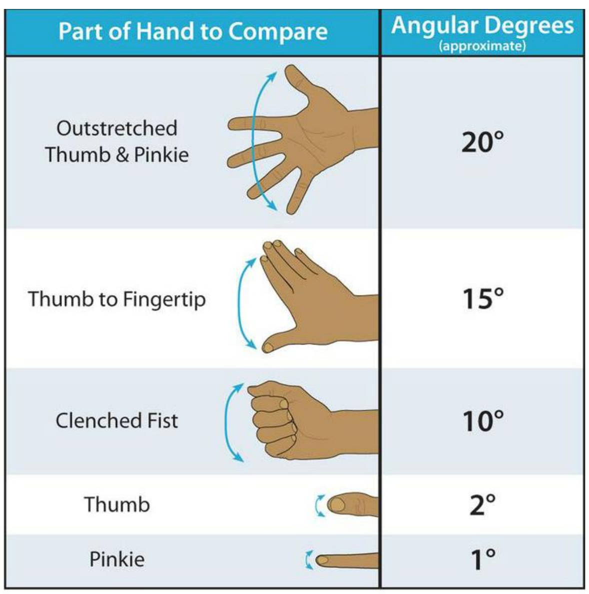
- Find a wall that you can stand back from at least 2 meters.
- Get your meter stick and put a bright sticker or piece of tape at the following positions: 3.5 cm (1°), 17.5 cm (5°), 35.3 cm (10°), and 72.8 cm (20°). Write the degree measurement on top of each sticker.
- Use the clear tape to attach the meter stick to the wall. Orient the meter stick vertically and put the center of the meter stick roughly at eye level.
- Put your measuring tape on the floor and measure a distance of 2 meters from the wall. Use colored tape or a sticker to mark the spot on the floor.
- Stand on the spot and look toward the meter stick. Use the markings on the meter stick to figure out exactly what positions your hand must take to span the distance to each sticker. Memorize these and you'll have a handy measurement tool to take with you wherever you go!"



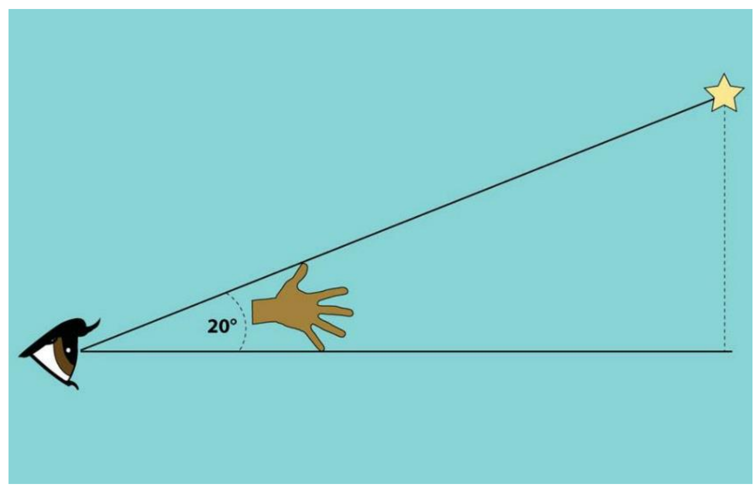

*Polaris Image from NASA |*




*Southern Cross Image by Michael Millthorn (Creative Commons Share Alike 3.0)*



| Part of Hand to Compare | Angular Degrees (approximate) |
|---|---|
| Outstretched Thumb & Pinkie | 20° |
| Thumb to Fingertip | 15° |
| Clenched Fist | 10° |
| Thumb | 2° |
| Pinkie | 1° |




*Images reproduced with permission from the Exploratorium*

LATITUDE: YOUR TURN FOR SOUTHERN HEMISPHERE:

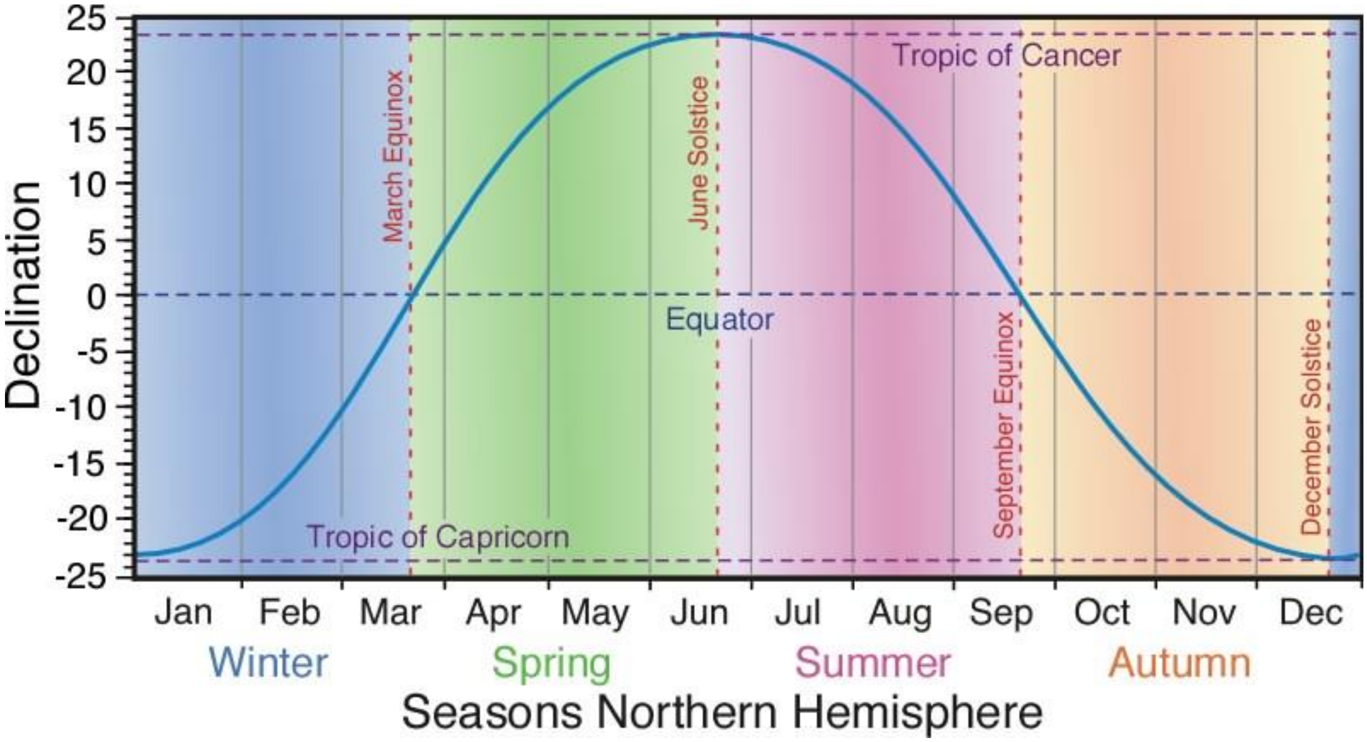
**What's your latitude if you measure the sun's altitude at solar noon to be 53.5°, and it is Dec 21st?**
Dec. 21 = summer in southern hemisphere
A = 53.5 degrees, D = 23.5 degrees, L = 90 degrees – 53.5 degrees + 23.5 degrees = 60 degrees S latitude

**What's your latitude if you measure the sun's altitude at solar noon to be 20°, and it is March 22?**
A = 20 degrees, D = 0 degrees, L = 90 degrees – 20 degrees = 70 degrees S latitude

**What's your latitude if you measure the sun's altitude at solar noon to be 5°, and it is July 1st?**
July 1st is winter in southern hemisphere and it sits between D=23.5° (June Solstice) and D=0° (September Equinox). From the graph, I get that D on July 1 day is ~23°.
Latitude = 90° - (5° - 23°) = 62°S (This answer is only as good as D was measured)

**FINDING LONGITUDE DURING THE DAY:**
Go outside at solar noon and measure the angle between the horizon and the sun. What is **solar noon**? Solar noon is the moment at which the sun is at its maximum height above the horizon. If you are at the Tropic of Cancer on the June Solstice in the Northern Hemisphere, the sun would be DIRECTLY over your head. If you are at a latitude further north from 23N (the tropic), the sun will always make its transit south of you, and you will have to look south to find it. North of 23N (and south of 23S), the sun will never be DIRECTLY overhead.

The rest of this section is based on information and uses images produced by Dr. Michael Pidwirny, University of British Columbia Okanagan. http://www.physicalgeography.net



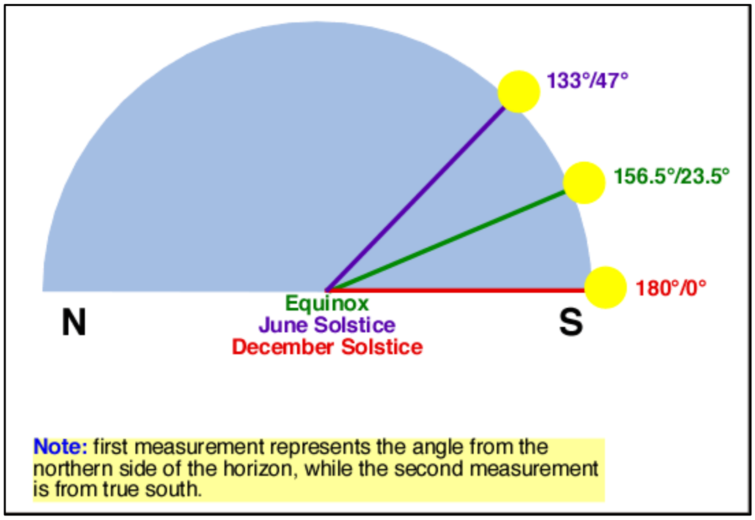

June solstice D=23.5°, December solstice D=23.5°, March equinox D=0°, and September equinox D=0°.
Declination = the latitudinal angle at which the sun is directly overhead (depends on season).

Maximum Sun altitudes for selected latitudes during the two solstices and equinoxes.

| **Location's Latitude** | **March Equinox March 20/21** | **June Solstice June 21/22** | **September Equinox September 22/23** | **December Solstice December 21/22** |
|---|---|---|---|---|
| 90 N | 0° | 23.5° | 0° | - 23.5° |
| 70 N | 20° | 43.5° | 20° | -3.5° |
| 66.5 N | 23.5° | 47° | 23.5° | 0° |
| 60 N | 30° | 53.5° | 30° | 6.5° |
| 50 N | 40° | 63.5° | 40° | 16.5° |
| 23.5 N | 66.5° | 90° | 66.5° | 43° |
| 0° | 90° | 66.5° | 90° | 66.5° |
| 23.5 S | 66.5° | 43° | 66.5° | 90° |
| 50 S | 40° | 16.5° | 40° | 63.5° |
| 60 S | 30° | 6.5° | 30° | 53.5° |
| 66.5 S | 23.5° | 0° | 23.5° | 47° |
| 70 S | 20° | -3.5° | 20° | 43.5° |
| 90 S | 0° | - 23.5° | 0° | 23.5° |

(winter in a hemisphere)
Latitude = 90 – sun altitude – sun declination
(L = 90° – (A – D))

(summer in a hemisphere)
Latitude = 90 – sun altitude + sun eclination
(L = 90° – (A + D))




Solar noon Sun angles for 66.5° N.

In this equation, latitude (L) is in degrees as is declination (D). Sun altitudes (A) are measured relative to True North for southern latitudes and True South for northern latitudes. When using the above equation in tropical latitudes, Sun altitude values greater than 90° may occur for some calculations. When this occurs, the noonday Sun is actually behind you when looking towards the equator. Under these circumstances, Sun altitude should be recalculated as follows:

$A_{new} = 180° - A_{original}$

EXAMPLES FOR NORTHERN HEMISPHERE:

| | |
|---|---|
| **What's your latitude if you measure the sun's altitude at solar noon to be 63.5°, and it is June 22?** | |
| On June 21 or 22 (solstice) D=23.5°. | |
| **FROM TABLE** | From the table above, on June Solstice, a 63.5° altitude means I'm at 50°N latitude! |
| **EQUATION** | Latitude = 90° – (63.5°-23.5) = 50°N |

| | |
|---|---|
| **What's your latitude if you measure the sun's altitude at solar noon to be 20°, and it is September 23?** | |
| On September 21 or 22 is equinox, D=0°. | |
| **FROM TABLE** | From the table above, on September Solstice, a 20° altitude means I'm at 70°N latitude! |
| **EQUATION** | Latitude = 90° – (20°) = 70°N |

| | |
|---|---|
| **What's your latitude if you measure the sun's altitude at solar noon to be 50°, and it is March 1st?** | |
| **What is D?** March 1st sits between D=0° (at March 20/21) and D=23.5° (December 21/22). From the above graph, I get that D on that day is ~10°. **(An estimate…if you needed to be really accurate, you would use this equation where δ = declination angle (rads); n = the day number, such that n = 1 on the 1st January.** $\delta = 23.45\frac{\pi}{180}\sin\left[2\pi\left(\frac{284+n}{36.25}\right)\right]$ | |
| **EQUATION** | Latitude = 90° – (50° + 10°) = 30°N **(This answer is only as good as D was measured)** |

**MAKING A SEXTANT.**

MATERIALS: Protractor, jumbo paper clip, 20 cm string, clear plastic straw, tape, scissors, metric ruler.

1. Tape the straw to the protractor so that the straw goes through 90 degrees and the center hole.
2. Tie the string to the paper clip. Making sure that the string hangs freely, tape it to the center mark. (Note: the string should go through the O degree mark if the straw is held parallel to the ground.)
3. Pick an object high on the ceiling or outdoors above ground. Sight this object through the straw. Press the string against the protractor when it stops swinging and read the scale on the protractor. (Read the scale that ranges between O to 90 degrees.) This is the angle of the object above ground.

**CALCULATING LONGITUDE *(nontraditional, but useful!)***
Although traditional ocean voyagers didn't have a pocket watch, modern mariners do. We can use these clock to help us determine longitude by seting it to keep track of what time it is at the Prime Meridian (Greenwich, England). On the day you want to know your latitude, go outside at solar noon with your watch.

EXAMPLE:

| **When it is solar noon in your location, your Greenwich clock says its 3:53 pm. What is your longitude?** | |
|---|---|
| **How many hours and what direction away from Greenwich are you?** | We are 3 hrs and 53 minutes west of Greenwich |
| **Convert 53minutes to hours** | 53 ~~minutes~~ x 1 hr = 0.883 hr TOTAL=3.883 hr<br>1 60 ~~minutes~~ |
| **Convert hours to° of longitude** | 3.883 ~~hr~~ x 15° of longitude = 58.25° of longitude W of PM<br>1 1 ~~hr~~ |

| **When it is solar noon in your location, your Greenwich clock says its 6:26 am. What is your longitude?** | |
|---|---|
| **How many hours and what direction away from Greenwich are you?** | 12:00 – 6:26 = 5:34<br>We are 5 hrs and 34 minutes East of Greenwich |
| **Convert minutes to hours** | 34 ~~minutes~~ x 1 hr = 0.566 hr TOTAL=5.566 hr<br>1 60 ~~minutes~~ |
| **Convert hours to° of longitude** | 5.566 ~~hr~~ x 15° of longitude = 83.5° of longitude E of PM<br>~~1~~ 1 ~~hr~~ |

YOUR TURN

| When it is solar noon in your location, your Greenwich clock says its 9:51 pm. What is your longitude? | |
|---|---|
| **How many hours and what direction away from Greenwich are you?** | *It's later in Greenwich, so they must be east of us. We're west of Greenwich by 9 hours and 51 minutes.* |
| **Convert minutes to hours** | *51 ~~minutes~~ x 1 hr = 0.85 hr TOTAL=9.85 hr*<br>*1 60 ~~minutes~~* |
| **Convert hours to° of longitude** | *9.85 ~~hr~~ x 15° of longitude = 147.75° of longitude E of PM*<br>*1 1 ~~hr~~* |

| When it is solar noon in your location, your Greenwich clock says its 11:55 am. What is your longitude? | |
|---|---|
| **How many hours and what direction away from Greenwich are you?** | *It's earlier in Greenwhich, so we're east.*<br>*12:00 – 11:55 = 0:05 We are 5 minutes East of Greenwich* |
| **Convert minutes to hours** | *5 ~~minutes~~ x 1 hr = 0.083 hr*<br>*1 60 ~~minutes~~* |
| **Convert hours to° of longitude** | *0.083 ~~hr~~ x 15° of longitude = 1.25° of longitude E of PM*<br>*1 1 ~~hr~~* |

| When it is solar noon in San Francisco, your clock reads 12:15 pm. You then travel to Hilo, Hawaii and do not change your clock. The longitude of Hilo Hawaii is 155°W. The longitude in San Francisco is 122°W. What time should your clock read when it's solar noon in Hilo? | |
|---|---|
| **How many degrees of longitude and what direction away from San Francisco are you?** | *155°-122° = 33° West – Hawaii is 33° West of San Francisco* |
| **Convert longitude to hours and minutes.** | *33° x 1 hr = 2.2 hrs = 2 hours and 12 minutes*<br>*1 15° of longitude* |
| **Add or subtract the time as necessary** | *Should say 12:15 + 2 hrs and 12 minutes = 2:27 pm* |

# Weekly Reflection

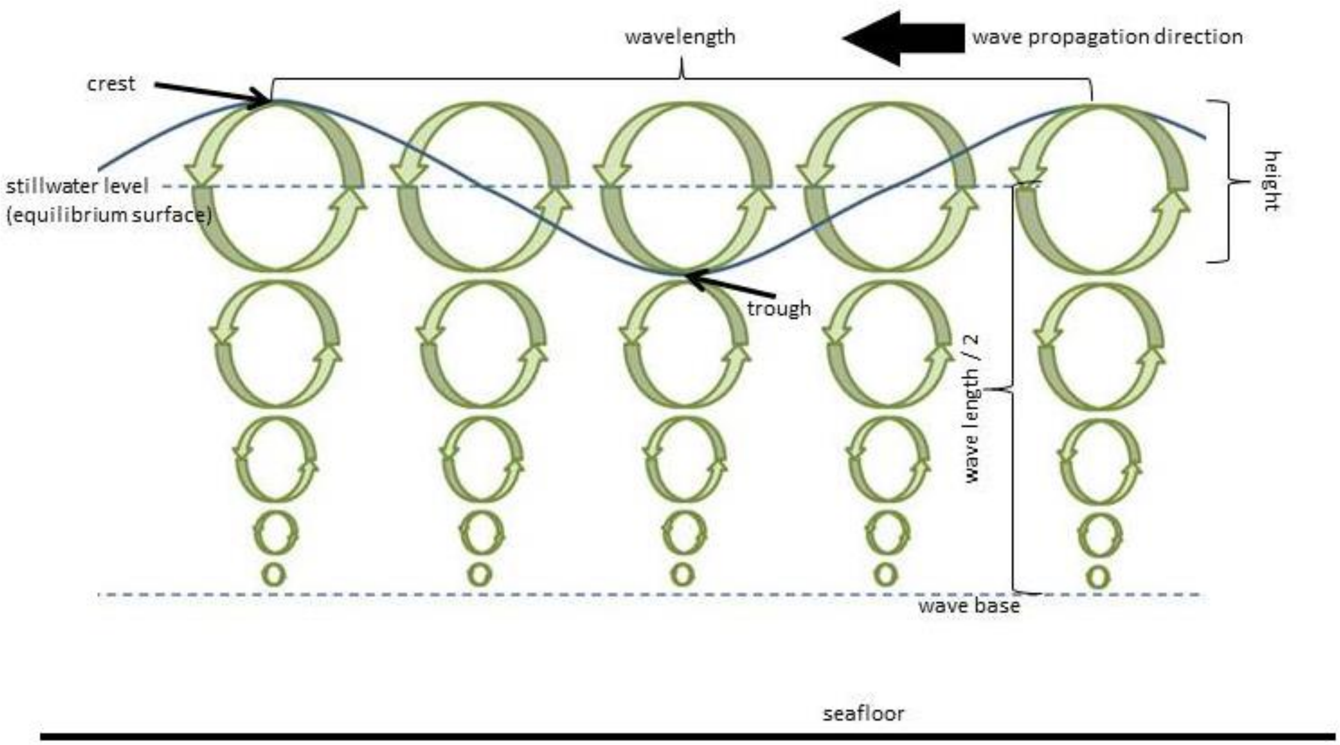
Take a moment to reflect on your comfort level and mastery of the week's objectives and describe an action plan for how you will practice or improve on anything that challenged you.

| **Weekly objective** | **Self-assessment of mastery level** | **Action plan for improvement** |
|---|---|---|
| Evaluate the causes, impacts, and global patterns of **surface and deep-water currents**. | A \| B \| C \| D \| F | |
| Compare and contrast the ways in which **waters of different densities, temperatures, and salinities** remain separated on monthly scales but mix over longer time scales (~1,000 years). | A \| B \| C \| D \| F | |
| Evaluate the impact of global ocean circulation and mixing on the **distribution of pollutants**. | A \| B \| C \| D \| F | |
| Compare and contrast **upwelling and downwelling** including the causes, locations, and impacts. | A \| B \| C \| D \| F | |
| Recognize and evaluate the timing, causes, and impacts of the **El Niño, La Niña oscillations**. | A \| B \| C \| D \| F | |

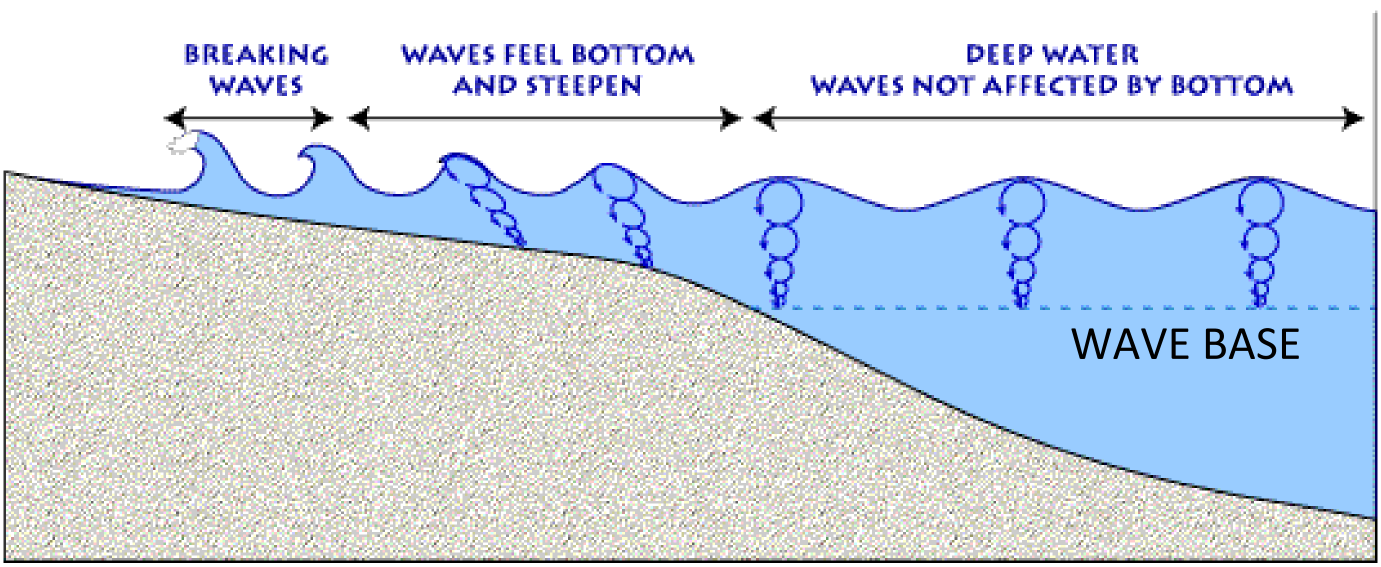
# AHA! Moments

What content from this week really resonated with you, helped you understand something you've always wondered about, or made you think about the world with new eyes?

# WAVES




*Idealized wave showing its components/characteristics including trough and crest; wavelength (from crest to crest or trough to trough or midpoint to next similar midpoint); height; stillwater level or equilibrium surface; and wave base (½ the wavelength measured down from equilibrium surface). Note: because this wave's base doesn't intersect the seafloor, it doesn't "feel" bottom and thus thinks it's in deep water. It's considered a deep-water wave. Also shown are the circular orbits that represent motion of the water and any objects in the water when this wave moves through.*




*Changes to wave height, length, and motion when waves approach the shore and wave base hits seafloor. (Wave base = ½ wavelength measured below stillwater point.) Image from USGS*

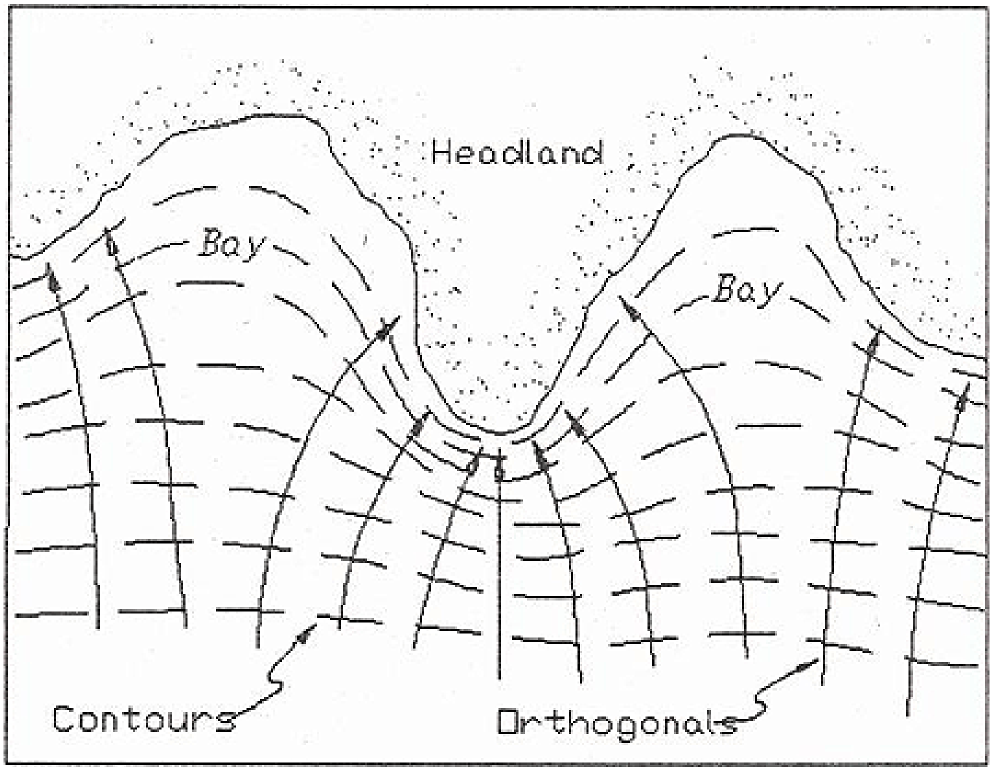
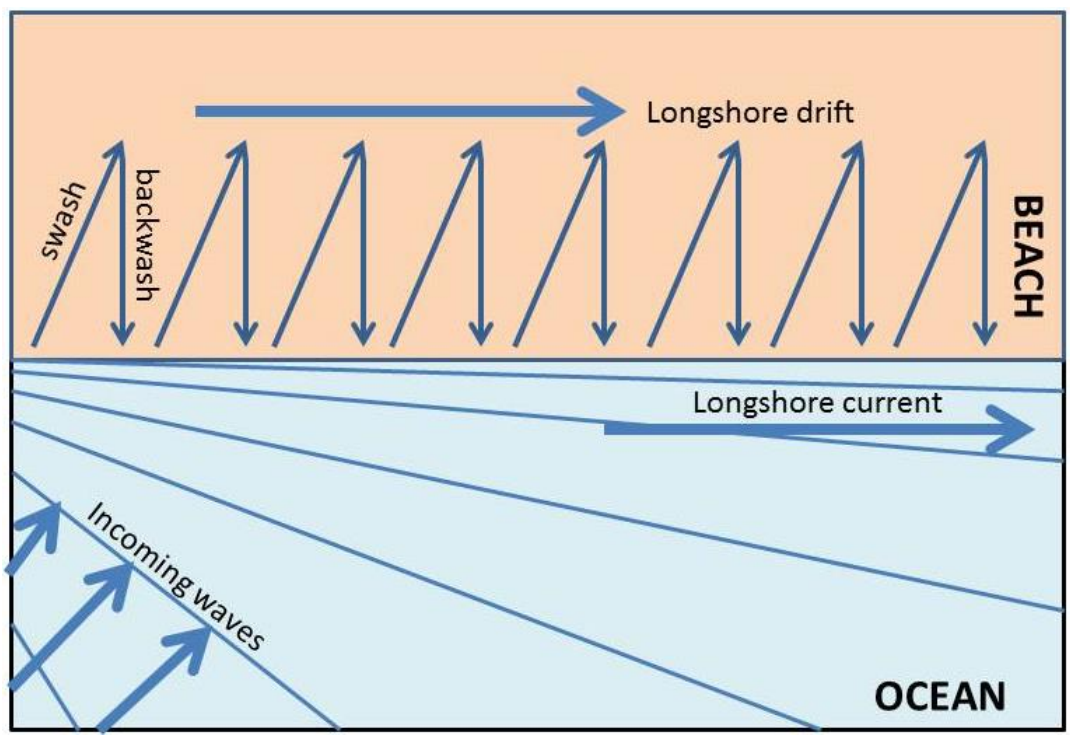
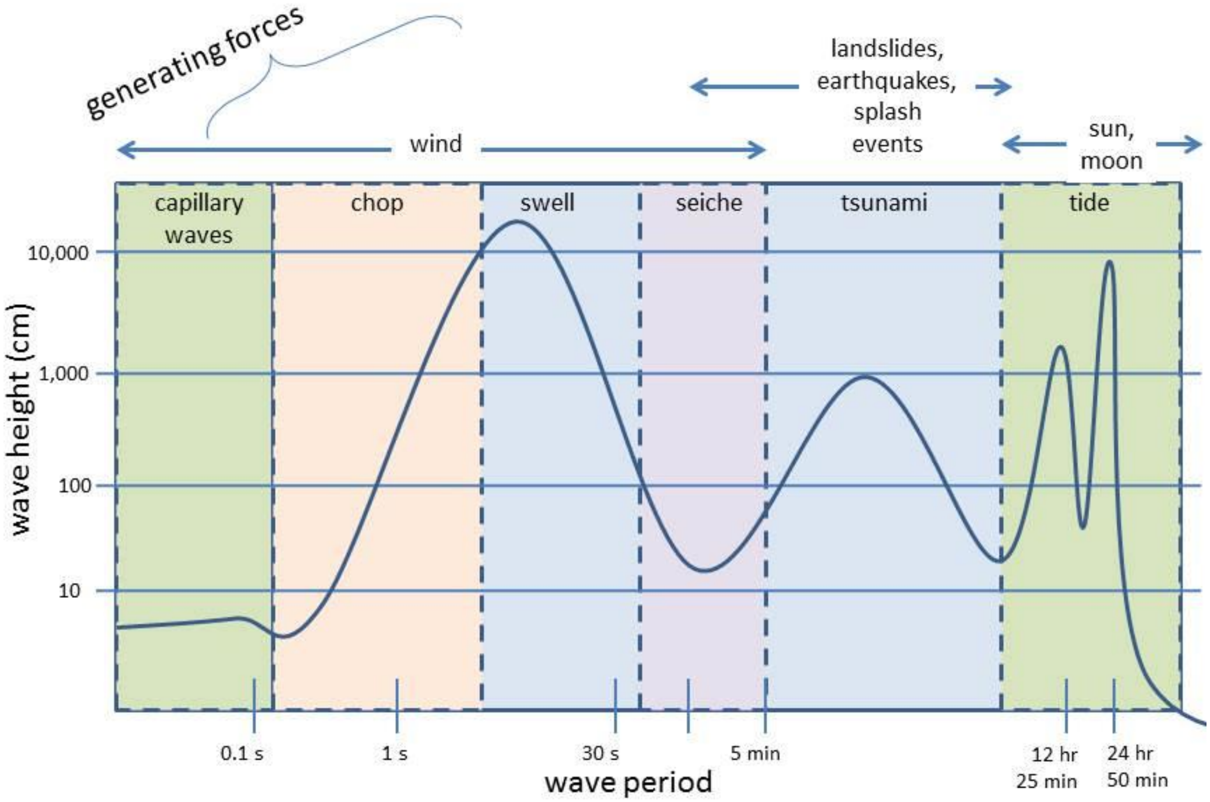



*Image from US Department of Transportation, Federal Highway Administration. Note: Orthogonals are rays (or arrows) indicating the direction that the wave is travelling. Contours are lines of equal depth in the ocean. These waves are approaching an irregular shoreline and bending or REFRACTING as one part of the crest feels bottom first, slows down, and the faster-moving crest bends toward the slower part. Anything that sticks out from the shoreline (such as headlands) will act as a focal point for waves, which bend toward it. And waves will bend toward the shore coming in nearly parallel (but never perfectly parallel.)*




*Generalized schematic of how waves approaching the shore at an angle produce a zig-zag migration of sand and water along the beach. The incoming waves push the sand up at an angle. Gravity returns it straight down.*
*The result = beach and longshore drift (sand migration) and longshore current (water migration).*

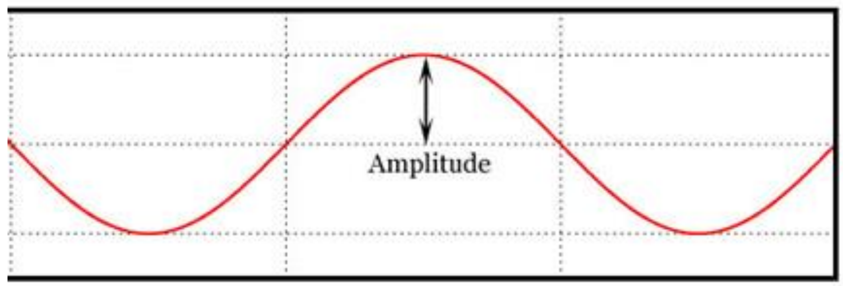



*Generalized wave heights and periods of waves produced by different generating forces.*

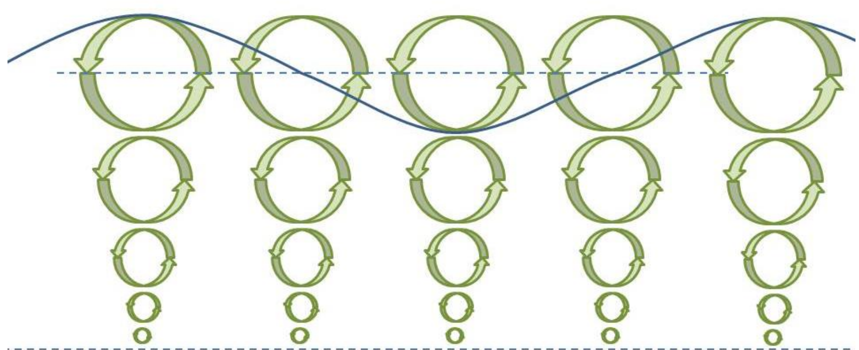
| Wave type | Generating force | Period | Wavelength | Wave height |
|---|---|---|---|---|
| **Capillary** | Local wind (restoring force = surface tension) | <1 s | < 2cm | <4 cm |
| **Chop/Sea** | Local wind | 1 to 30 s | 1-10 m | 0.01 to 50 m |
| **Swell** | Distant storm (windy there) | 30s to 5 min | <100s of m | 1 m to 100 m |
| **Standing** | Wind, earthquakes, tides, wave reflection | 1/6 to 10 hr | <100s of km | ~ 1 m |
| **Tsunami** | Earthquake or landslide under water | ~15 min | 100-300 km | 0.5 to 10 m |
| **Tide** | Gravitational attraction | 12.4 or 24.8 hr | ~18,000 km = ½ the Earth's circumference | 1 cm to 20 m |

# Waves Chapter Worksheet

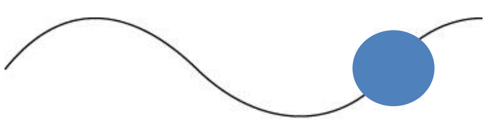
1. Which of the following is true of **swell**?
   CIRCLE: found in the area of the wind that generated it | found far away from wind that generated it
   caused by wind | caused by earthquakes | presents as multiple wave trains | single wave train
2. Circle which of these are **restoring forces** for waves. CIRCLE: gravitational forces between Earth and Moon | Earth's gravity
   earthquakes | landslides | surface tension | wind
3. Circle which of these are **generating force(s)** for waves. CIRCLE: gravitational forces between Earth and Moon | Earth's gravity
   earthquakes | landslides | surface tension | wind
4. Circle which of these forces restores a **capillary wave**. CIRCLE: gravitational forces between Earth and Moon | Earth's gravity
   earthquakes | landslides | surface tension | wind
5. Circle which of these forces generates a **capillary wave**. CIRCLE: gravitational forces between Earth and Moon | Earth's gravity
   earthquakes | landslides | surface tension | wind
6. Which of the following is true of an **internal wave**? CIRCLE: Found at surface | Found along pycnoclines
   Found along seafloor
7. On this figure, label **crest, trough, equilibrium surface, height,** and **wavelength**. Be precise. (Make it clear where height and length start and stop – mark crest and trough with an X).




8. What are the number of **wavelengths** shown in the image above?
9. Which of the following would be considered a **standing wave**? CIRCLE: Tsunami | Swell | Chop | Seiche | Tides
10. Which of the following would be considered a **progressive wave**? CIRCLE: Tsunami | Swell | Chop | Seiche | Tides
11. In this image, label **wavelength** and **wave base**. (Give equation for wave base and make it clear from where it's measured.)



12. If this wave has a wavelength of 30 m, what is the wave base depth?
13. In this drawing of a floating ball on the water, indicate with arrows the motion of the ball when a wave passes through from the right side.



←wave direction

14. If 4 wavelengths pass a point in 2 minutes, what is the **wave period**?
15. What is the equation for **wave speed** – not an approximation, but one that is true under all conditions?
16. How fast do tsunami travel?
17. What's the average period of a **tsunami**?
18. What's the average wavelength of a **tsunami**?
19. With a **period** of 10 seconds and a wavelength of 50 m, what is the wave speed?

| | |
|---|---|
| 20. As a wave approaches shore and feels bottom, what happens to:<br>**wave speed** -- CIRCLE: increases \| decreases \| no change \| **wave height** -- CIRCLE: increases \| decreases \| no change<br>**wave length** -- CIRCLE: increases \| decreases \| no change \| **wave period** -- CIRCLE: increases \| decreases \| no change | |
| 21. What happens to **wave motion (shape)** after a wave feels bottom and approaches shore? | |
| 22. At what ocean depths is a 30-m wavelength wave considered a **deep water wave**? | |
| 23. At what ocean depths is a 30-m wavelength wave considered NOT a **deep water wave**? | |
| 24. Which types of waves have the potential to have the **largest height**? | |
| 25. Which of the following would be considered a **deep-water wave in the open ocean**? | CIRCLE: Tsunami \| Swell \| Chop \| Seiche in Pool/Lagoon/Bay |
| 26. Which of the following will increase **wind wave height** in the open ocean? | CIRCLE: Strong winds \| Moderate winds \| Weak winds<br>CIRCLE: Consistent winds \| Gusting winds \| Changing winds<br>CIRCLE: Large fetch \| Moderate fetch \| Minimum fetch |
| 27. As a result, where in the world's oceans do we get the largest open ocean wind waves? Why? | |
| 28. What type of interference causes **episodic** (or rogue) waves? | CIRCLE: constructive \| destructive |
| 29. What is the equation for **wave steepness**? | |
| 30. With a wavelength of 50 m, and a wave height is 1 m, what is **wave steepness**? | |
| 31. What is the **maximum steepness** a wave can be? | |
| 32. What happens when it reaches that point? | |
| 33. What is the steepness of the wave in Question 7? | |
| 34. Could such a wave actually exist? | CIRCLE: Yes \| No |
| 35. Which direction does a **rip current** move? | CIRCLE: along the shore \| towards the shore \| away from the shore |
| 36. What cause(s) **rip currents**? | CIRCLE: jetty \| headland \| two longshore currents colliding \| wave direction |
| 37. Can they be predicted? | CIRCLE: yes \| no |
| 38. Which direction does a **longshore current** move? | CIRCLE: along the shore \| towards the shore \| away from the shore |
| 39. What cause(s) **longshore currents**? | CIRCLE: jetty \| headland \| two longshore currents colliding \| wave direction |
| 40. Circle which of the following is true for tsunami: | CIRCLE: deep-water wave \| shallow-water wave<br>earthquake caused \| landslide caused \| wind caused<br>rogue (episodic) wave \| standing wave \| progressive wave |
| 41. What's the average height of a **tsunami in the open ocean**? | |
| 42. Are tsunami dangerous in the open sea? What happens when they reach shore? | |
| 43. Based on table of wave characteristics at start of this chapter in the workbook: which types of waves have the smallest wavelength, height, and period? | |
| 44. Based on table of wave characteristics at start of this chapter in the workbook: which types of waves have the largest wavelength? | |
| 45. Based on table of wave characteristics at start of this chapter in the workbook: which types of waves have the longest period? | |

# Making a Wave Bottle

(FYI – do on own if want…)

**MATERIALS**

- Paint thinner
- Rubbing Alcohol
- Plastic bottle with cap
- Electrical tape
- Sharpie (black)
- Funnel
- Food coloring

1. Open an empty plastic bottle and insert funnel.
2. Pour 8 oz of rubbing alcohol into plastic bottle (**<u>cap alcohol bottle immediately</u>**).
3. Drop 1-2 drops of food coloring into bottle (don't mix yet – watch fluids separate).
4. Pour 8 oz of paint thinner into plastic bottle (**<u>cap paint thinner bottle and your wave bottle immediately</u>**).
5. Tighten the cap on your wave bottle.
6. Use electrical tape to seal your wave bottle: first run tape clockwise around cap, then over lip. Stretch vinyl tape around lip to ensure proper seal.
7. With black sharpie, label the neck of the bottle:

    **WARNING! FLAMMABLE**
    **Do not drink.  Paint thinner + alcohol.**

# Waves Practice Activity

1. SLINKIES:
   Two people stand apart holding tight to slinky.
   Sketch to right a standing wave with **wavelength = distance between the two**. Label wavelength and height.

2. SLINKIES:
   Two people stand apart holding tight to slinky.
   Sketch to right a standing wave with **wavelength = ½ distance between the two**. Label wavelength and height.

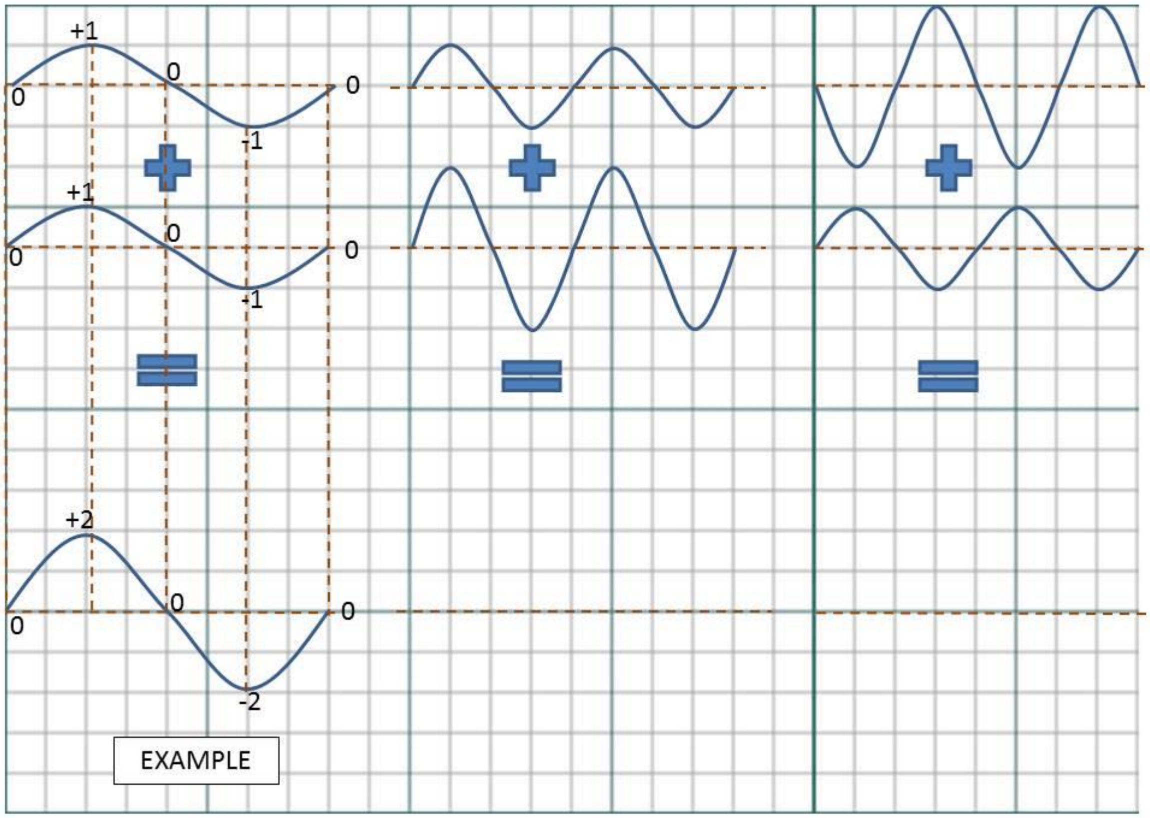
3. SLINKIES:
   Two people stand apart holding tight to slinky.
   Sketch to right a standing wave with **wavelength =twice the distance between the two**. Label wavelength and height.

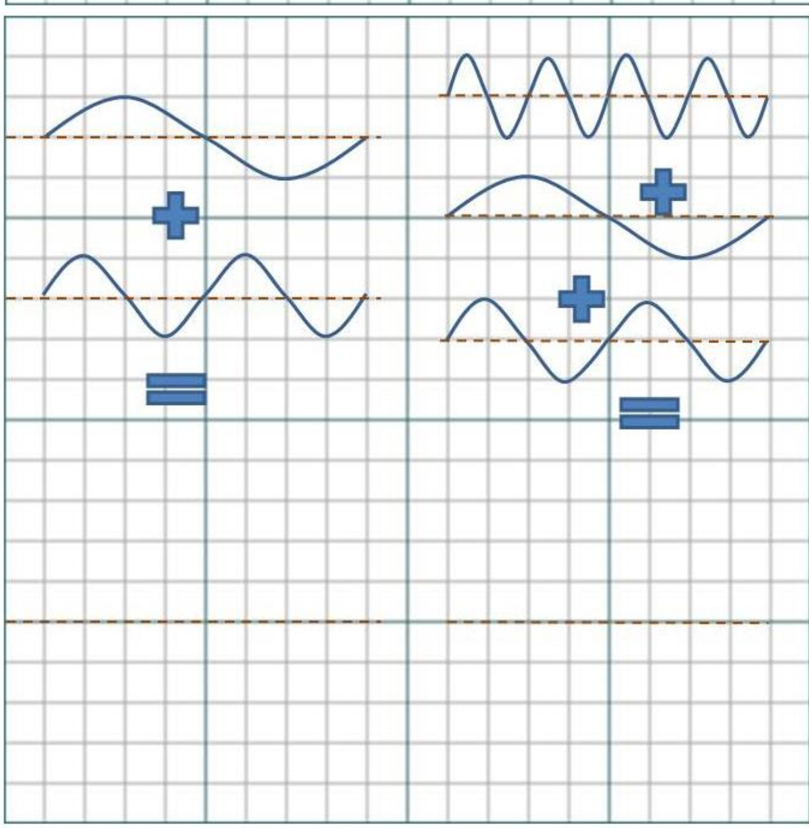
4. Draw to scale an ocean wave with a steepness of 1/10.

5. Draw to scale an ocean wave that is maximum steepness and label all components (crest, trough, wavelength, height, stillwater level, wave base).

**INTEREFERENCE:**

6. Complete these interference diagrams. Add the two top waves together and then build the resulting wave. (See example at top left). When done, label where constructive and destructive interference are happening and annotate with notes/explanations as appropriate. **Place X where a boat would be most challenged.**



# Weekly Reflection

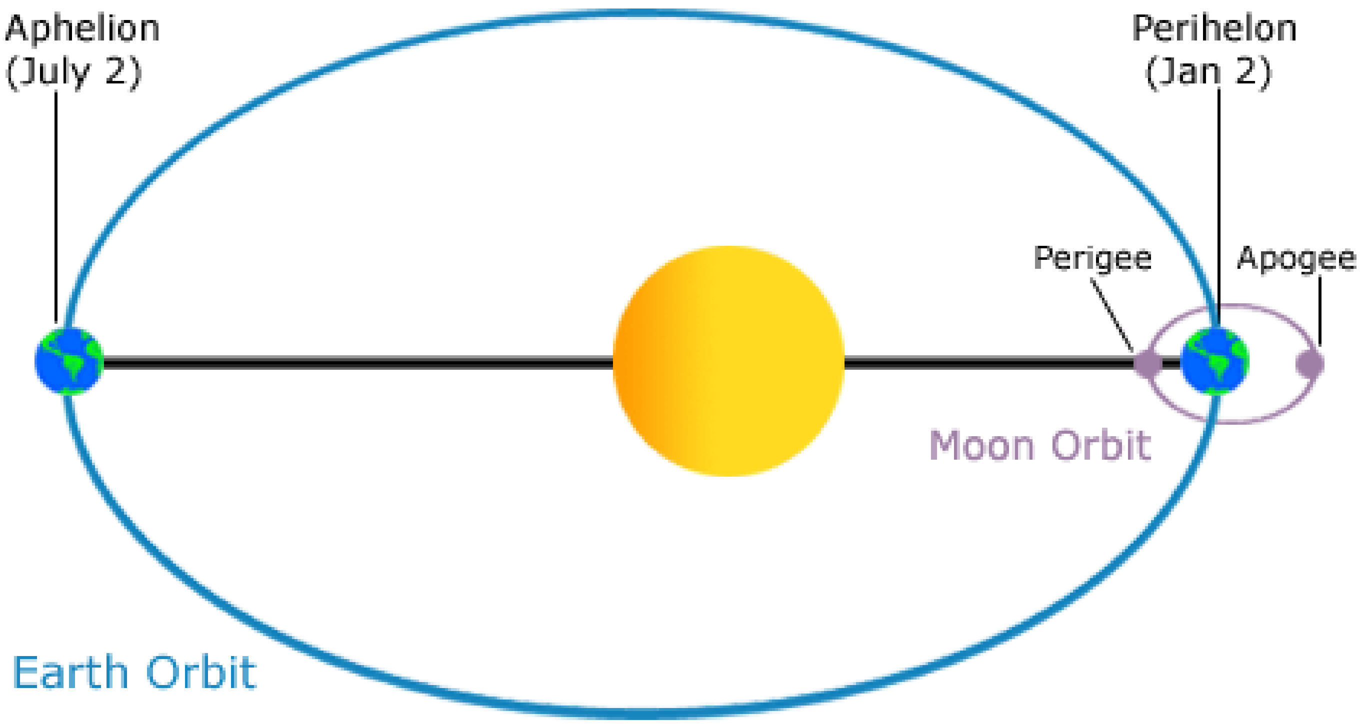
Take a moment to reflect on your comfort level and mastery of the week's objectives and describe an action plan for how you will practice or improve on anything that challenged you.

| **Weekly objective** | **Self-assessment of mastery level** | **Action plan for improvement** |
|---|---|---|
| Recognize and calculate the important characteristics of **ocean waves including height, wavelength, period, speed, steepness, and wave base**. | A \| B \| C \| D \| F | |
| Diagram the **motion of water as waves move through it**. | A \| B \| C \| D \| F | |
| **Classify ocean waves** by cause, size, and depth. | A \| B \| C \| D \| F | |
| Analyze the changing behaviors and impacts of ocean waves when they **interfere** with each other. | A \| B \| C \| D \| F | |
| Analyze the **impacts to and from ocean waves when they interact with the seafloor and shoreline**, including longshore and rip currents. | A \| B \| C \| D \| F | |
| Evaluate the causes and variable impacts of **tsunami** and how we detect them in the open ocean. | A \| B \| C \| D \| F | |

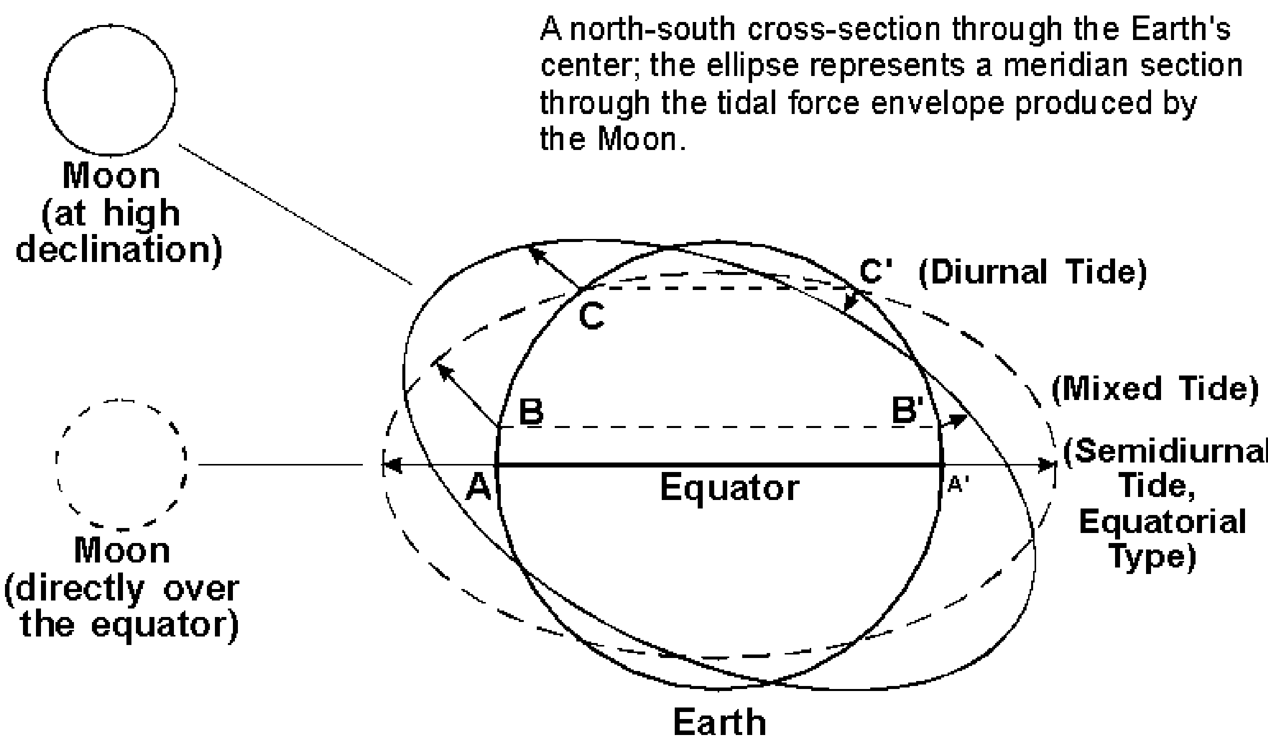
## AHA! Moments

What content from this week really resonated with you, helped you understand something you've always wondered about, or made you think about the world with new eyes?

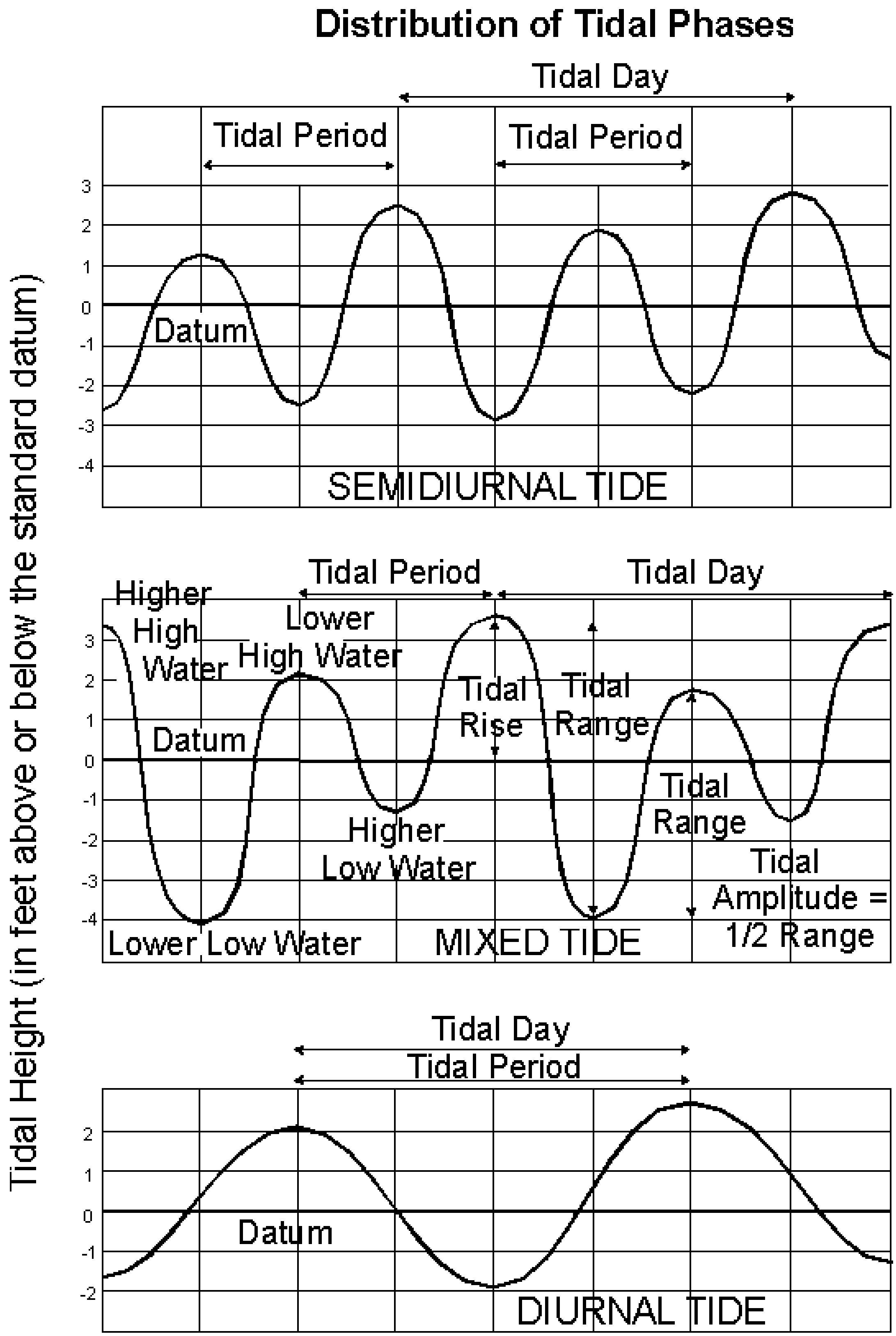
# TIDES




*Earth's orbit around the Sun (and moon's orbit around Earth). Note the Earth is closest to the sun on Jan 2. Image: NOAA*

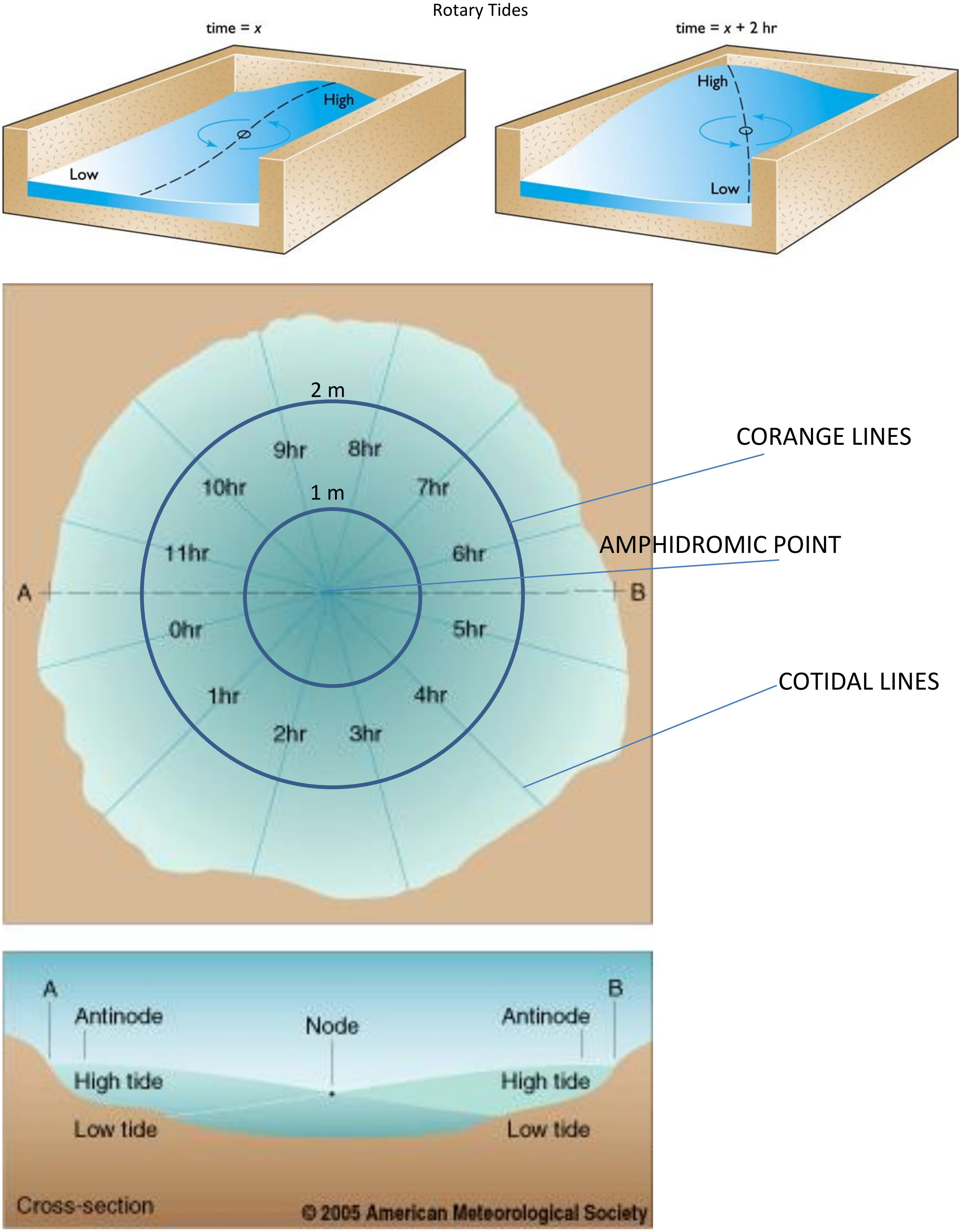



*Tidal patterns with latitude as moon's declination changes. Image: NOAA*

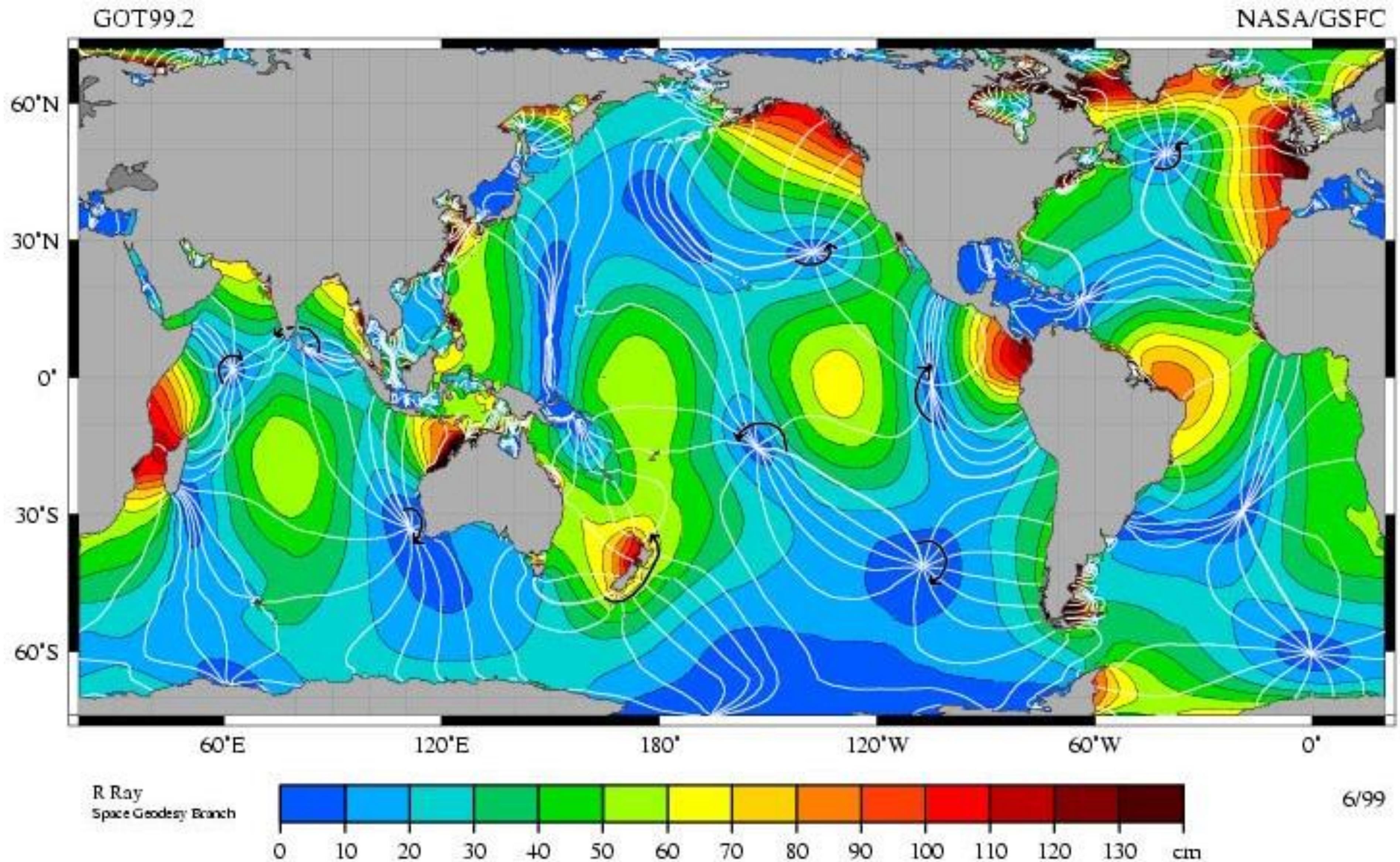



*Three main tidal patterns, showing over ~50 hours (2 lunar days). Image: NOAA*

Rotary Tides



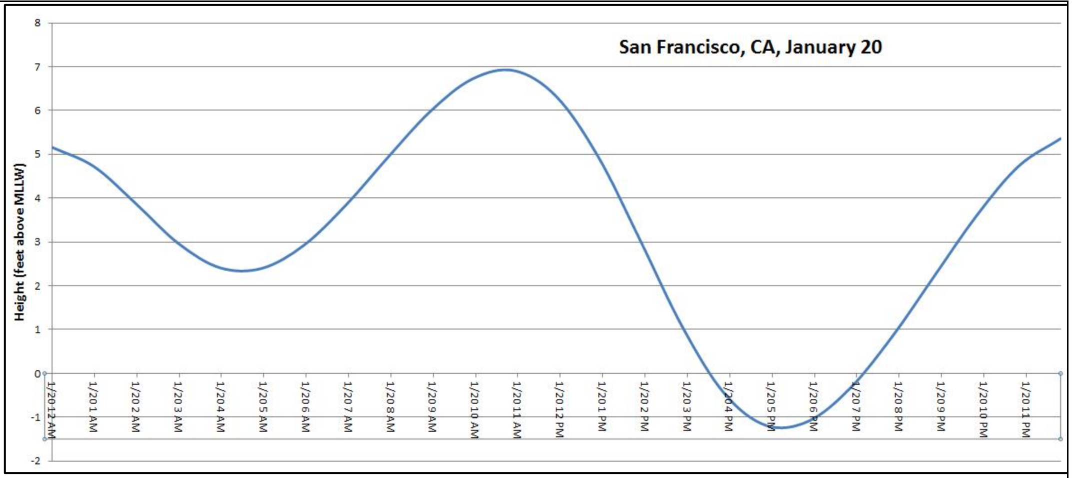

*Rotary amphidromic tidal waves.*
*Top image shows the sloshing effect of the water around the ocean basins.*
*The middle picture shows the effect from a birds eye view (northern hemisphere).*
*The lower picture shows what it looks like in cross-section.*




*Generalized world amphidromic (rotary tidal wave) systems. Amplitude is indicated by color, and the white lines are cotidal differing by 1 hr. The curved arcs around the amphidromic points show the direction of the tides, each indicating a synchronized 6 hour period. Image credit: R. Ray, and NASA - Goddard Space Flight Center, NASA - Jet Propulsion Laboratory, Scientific Visualization Studio, Television Production NASA-TV/GSFC*

# Tides Chapter Worksheet

1. In this image, label:
- **Higher high water (HHW)**
- **Higher low water (HLW)**
- **Lower high water (LHW)**
- **Lower low water (LLW)**
- **Slackwater (SW)**
- **Ebb current (EC)**
- **Flood current (FC)**
- **Tidal range (TR)**
- **Tidal period (TP)**




**Y-axis:** Height (feet above MLLW): -2 feet at bottom; + 8 feet at top. **X-axis:** 1-hour increments from midnight to midnight over 1 day.

2. **Tidal datum** means?

3. **MLW** means?

4. **MLLW** means?

5. The period of a **semidiurnal** tide is?

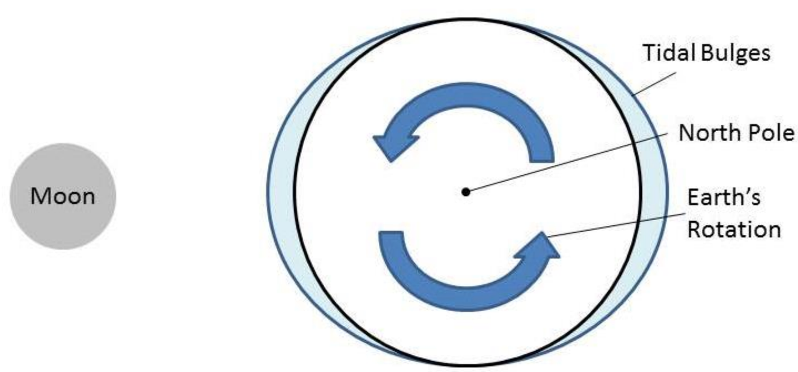
6. The period of a **diurnal** tide is?

7. The definition of a **semidiurnal mixed** tide is?

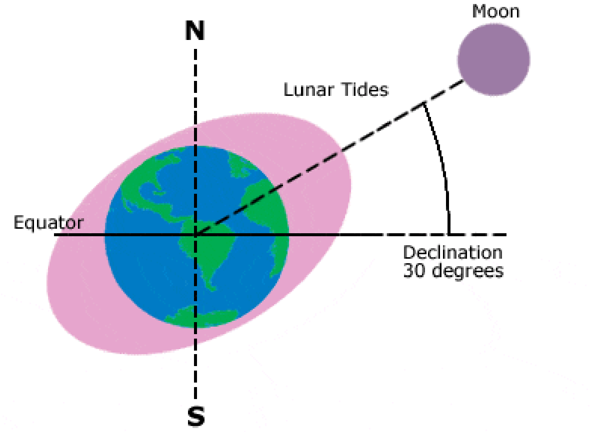
8. How long does it take the moon to orbit the Earth? What do we call that?

9. Ocean tides are caused by the differences felt on opposite sides of the Earth in the gravitational pull between the moon and the Earth. Gravitational force is stronger on the side of the Earth nearer to the moon and is weaker on the side farthest from the moon because Gravitational Force weakens as distance increases. All Earth's oceans are pulled toward the center of the Earth-Moon orbital system, but the far side is pulled less, thus it lags behind, while the near side jumps ahead, thus producing two bulges – near and far side. The solid Earth then rotates once every 24 hours and 50 minutes under these bulges. Why the extra 50 minutes?

10. Using this diagram, explain **high tide** and **low tide**.

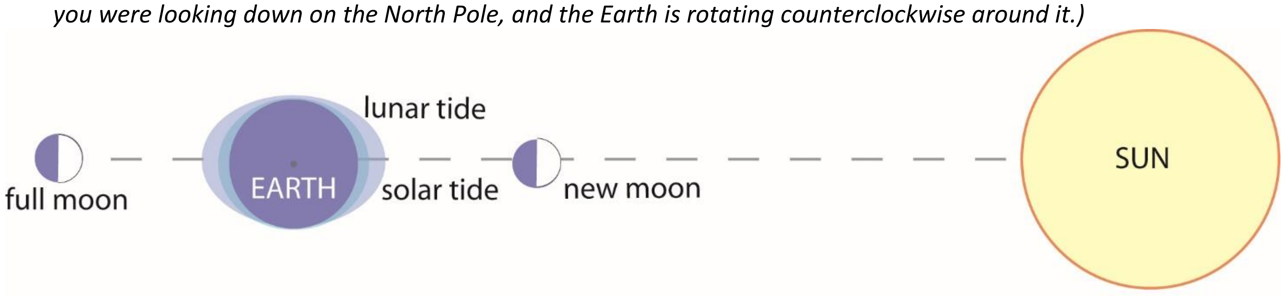


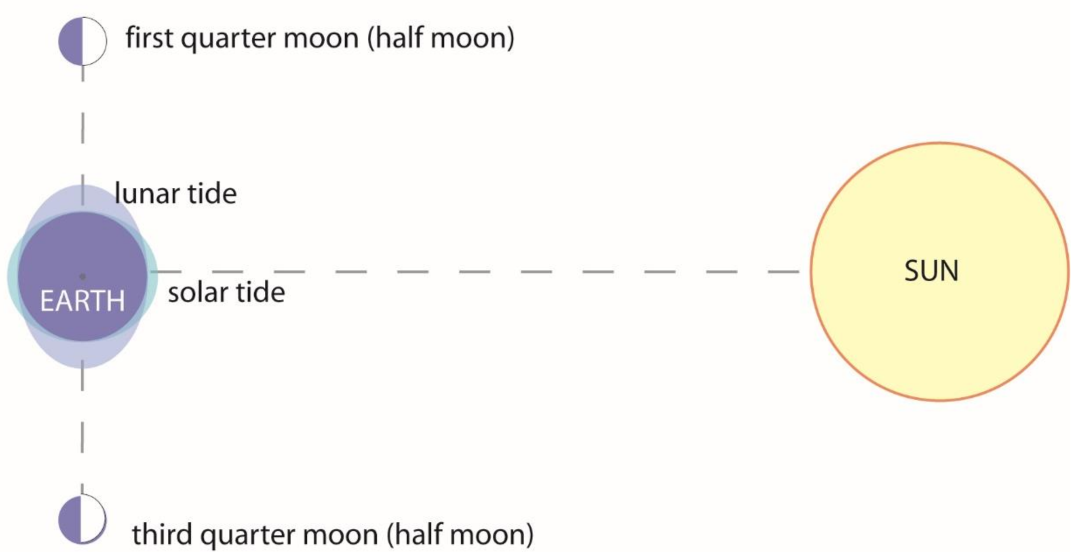
11. Earth's declination to its orbital plane has what effect on tides?




*(Image: NOAA)*

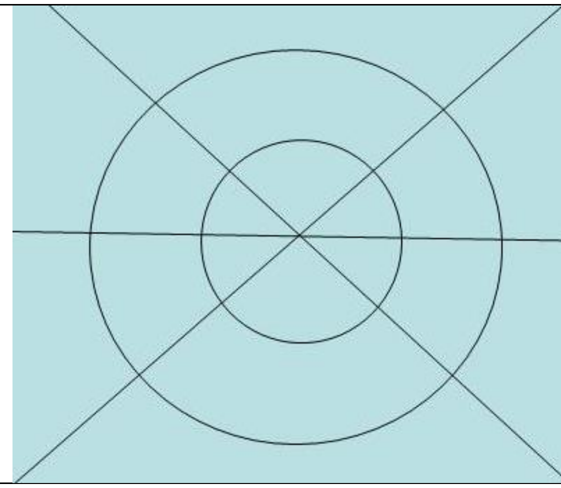
12. Label these images with **spring tide** or **neap tide** and interference types as appropriate. *(Images are produced as though you were looking down on the North Pole, and the Earth is rotating counterclockwise around it.)*



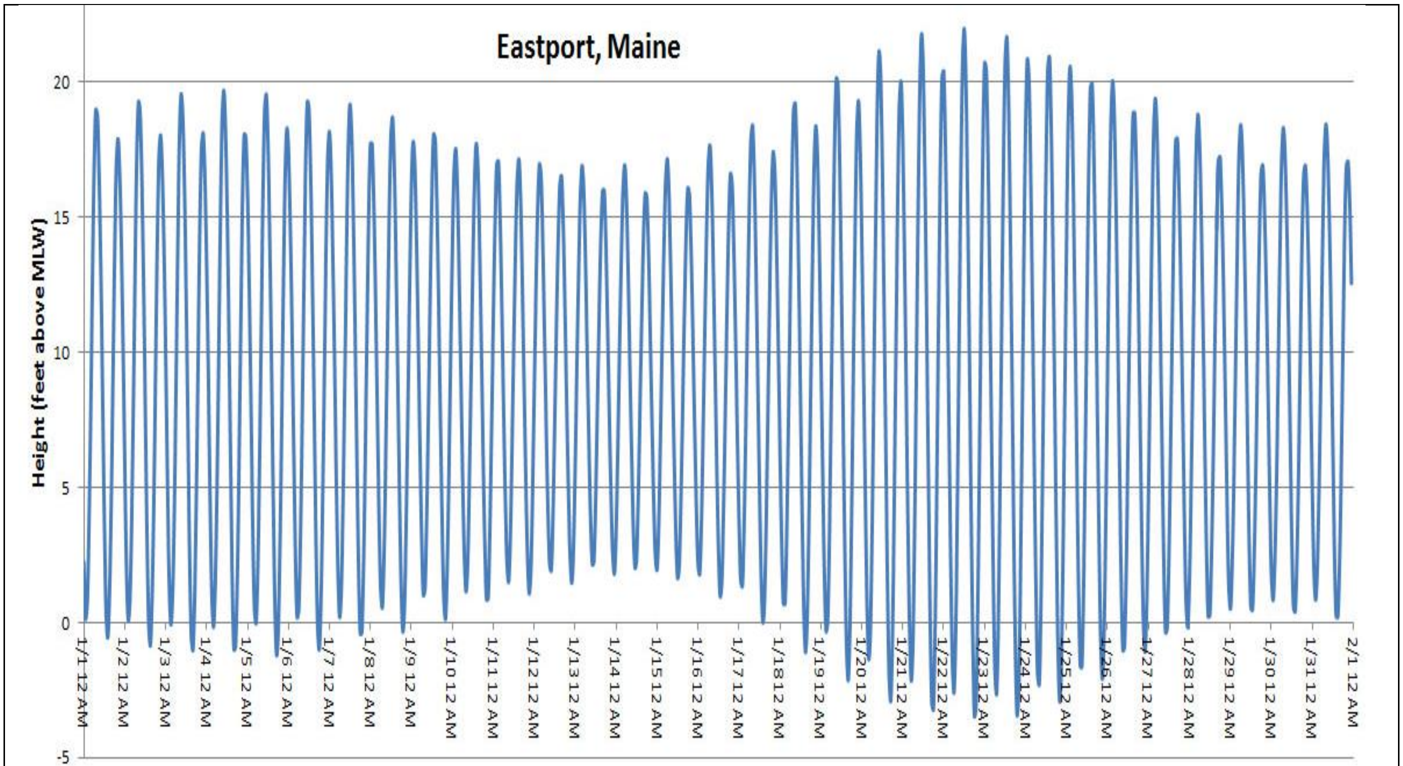




13. Which of the following is true of **NEAP** tides?

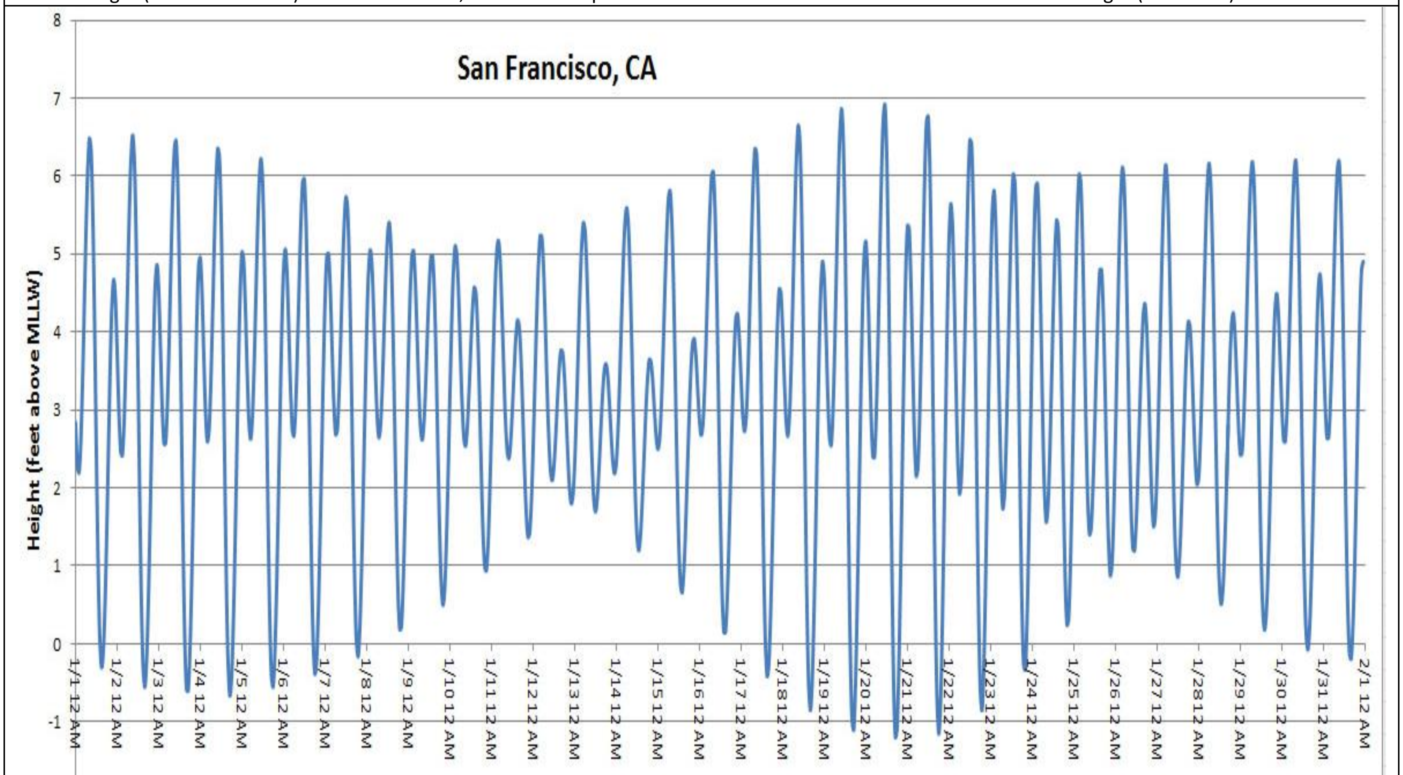
CIRCLE: Highest highs | Lowest lows | Largest tidal range | Smallest tidal range
Caused by constructive interference | caused by destructive interference
Associated with: half moons | new moons | full moons
Repeat every 2 weeks | repeat monthly | repeat yearly

| | |
|---|---|
| 14. Which of the following is true of **SPRING** tides? | CIRCLE: Highest highs \| Lowest lows \| Largest tidal range \| Smallest tidal range<br>Caused by constructive interference \| caused by destructive interference<br>Associated with: half moons \| new moons \| full moons<br>Repeat every 2 weeks \| repeat monthly \| repeat yearly |
| 15. Earth's elliptical orbit around the Sun has what effect on tides? | |
| 16. In this map-view image of a **rotary standing tidal wave**, label:<br>• **Amphidromic point**<br>• **Cotidal lines**<br>• **Corange lines**<br><br>Use arrows to show the direction of the tidal current for the Northern Hemisphere.<br><br>Place an X, where one would experience the highest tidal range.<br><br>***Note**: there is ALSO a small current formed by the orbital motion of the water as the tidal waves pass through. This current is in the opposite direction of the tidal wave motion. We will not focus on these in this class.* |  |
| 17. What direction do tides move along the California Coast? | |
| 18. What are the PRIMARY requirements for a region to produce a **tidal bore**? | |
| 19. The Bay of Fundy in Nova Scotia, Canada has the highest tidal range in the world. What is it (in meters)? | |
| 20. Why so high there? | |
| 21. List all the ways in which marine organisms are affected by the tides. | |

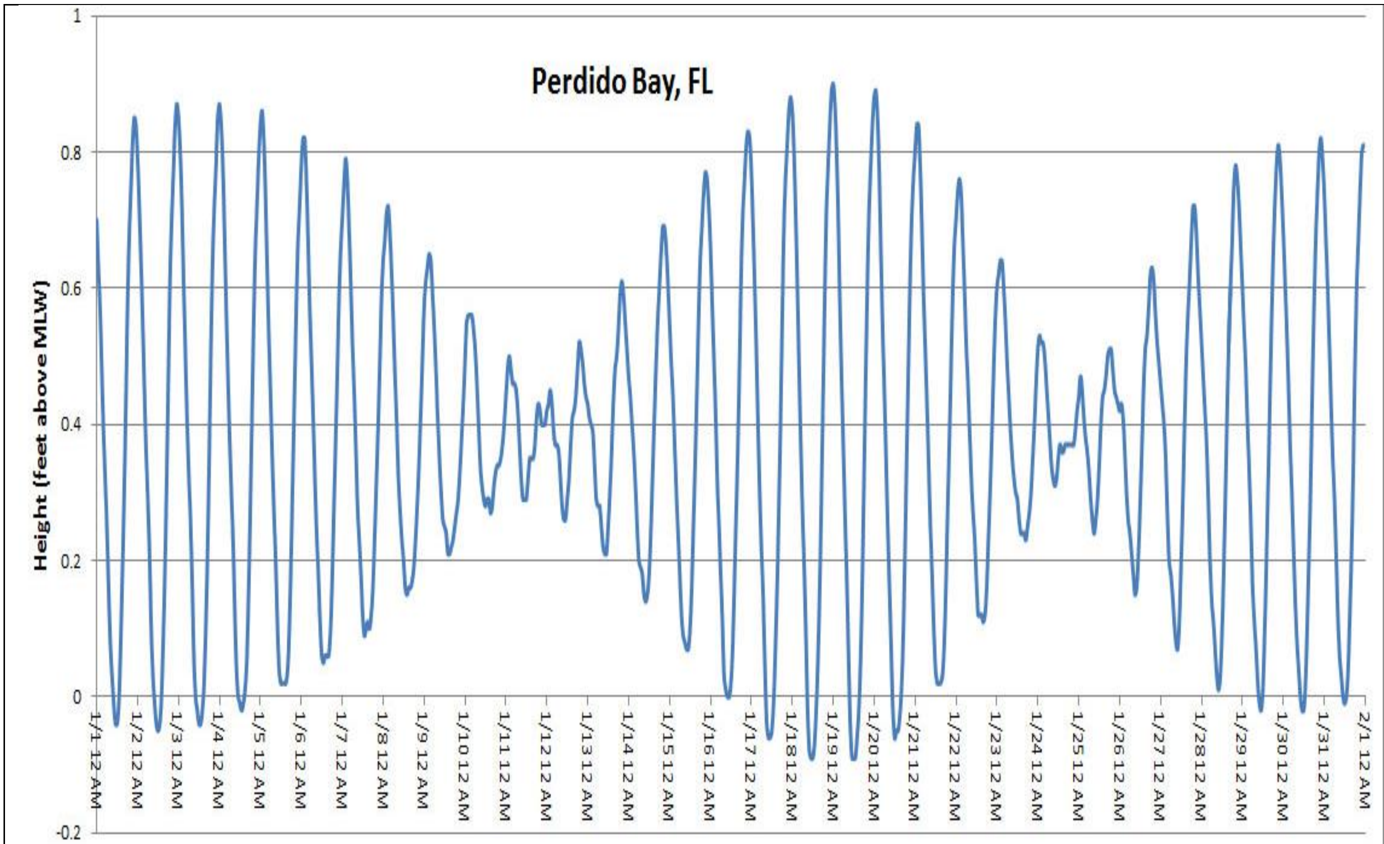
# Charting Tides Activity



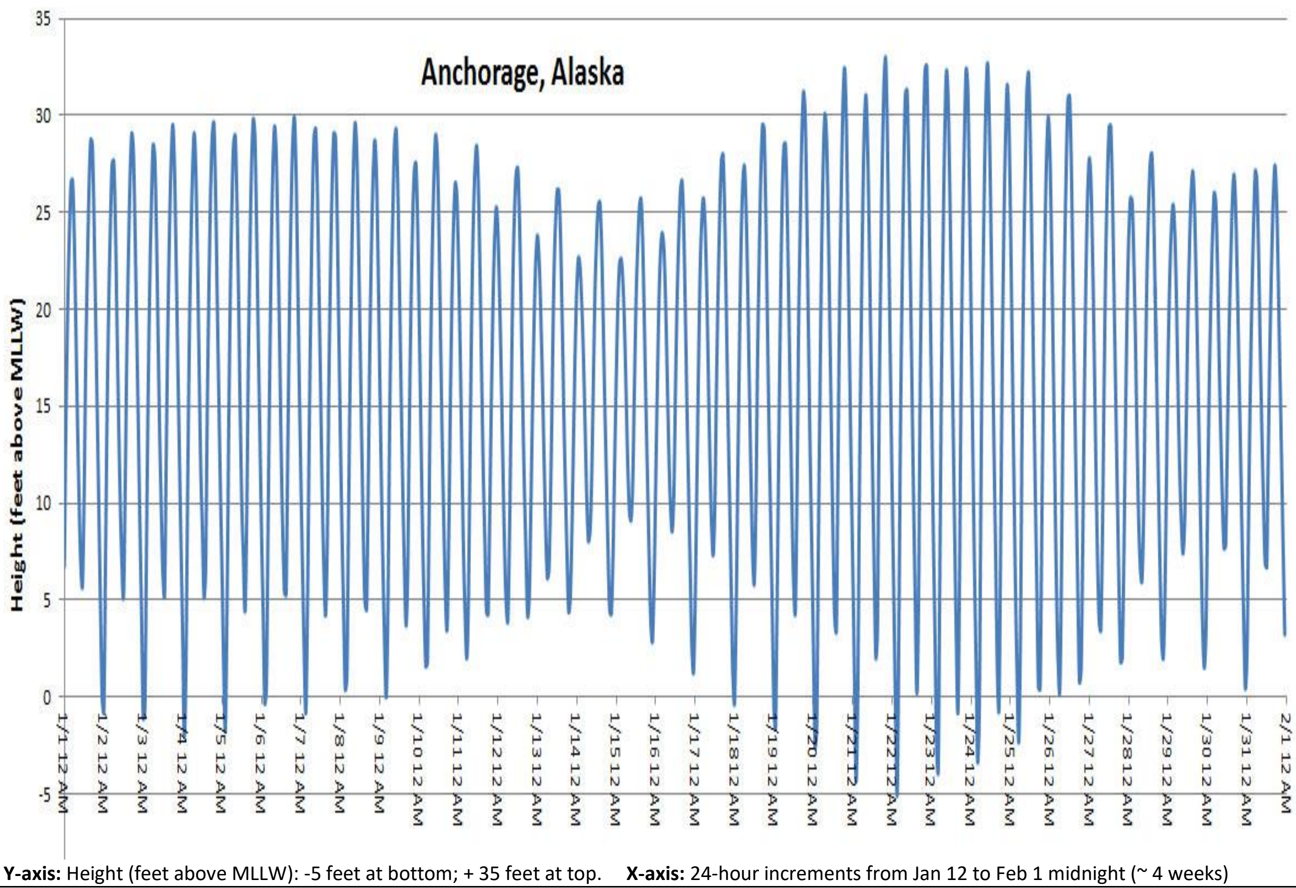

**Y-axis:** Height (feet above MLW): -5 feet at bottom; + 25 feet at top. **X-axis:** 24-hour increments from Jan 12 to Feb 1 midnight (~ 4 weeks)




**Y-axis:** Height (feet above MLLW): -1 feet at bottom; + 8 feet at top. **X-axis:** 24-hour increments from Jan 12 to Feb 1 midnight (~ 4 weeks)




**Y-axis:** Height (feet above MLW): -0.2 feet at bottom; + 1 feet at top. **X-axis:** 24-hour increments from Jan 12 to Feb 1 midnight (~ 4 weeks)




**Y-axis:** Height (feet above MLLW): -5 feet at bottom; + 35 feet at top. **X-axis:** 24-hour increments from Jan 12 to Feb 1 midnight (~ 4 weeks)

**Eastport, Maine**

1. The **tidal pattern** is? CIRCLE: diurnal | semidiurnal | semidiurnal mixed
2. **Largest tidal range** for this chart is? (Label on chart)
3. Days of the month in which neap tides are occurring? (circle on chart)
4. **Tidal datum** (choice of zero reference point) for this chart? CIRCLE (there should be only one!): MLW (mean low water) | MLLW (mean lower low water) | MSL (mean sea level) | MTL (mean tide level) MHW (mean high water) | MHHW (mean higher high water).

**San Francisco, CA**

5. The **tidal pattern** is? CIRCLE: diurnal | semidiurnal | semidiurnal mixed
6. **Largest tidal range** for this chart is? (Label on chart)
7. Days of the month in which neap tides are occurring? (circle on chart)
8. **Tidal datum** (choice of zero reference point) for this chart? CIRCLE (there should be only one!): MLW (mean low water) | MLLW (mean lower low water) | MSL (mean sea level) | MTL (mean tide level) MHW (mean high water) | MHHW (mean higher high water).

**Perdido Bay, FL**

9. The **tidal pattern** is? CIRCLE: diurnal | semidiurnal | semidiurnal mixed
10. **Largest tidal range** for this chart is? (Label on chart)
11. Days of the month in which neap tides are occurring? (circle on chart)
12. **Tidal datum** (choice of zero reference point) for this chart? CIRCLE (there should be only one!): MLW (mean low water) | MLLW (mean lower low water) | MSL (mean sea level) | MTL (mean tide level) MHW (mean high water) | MHHW (mean higher high water).

**Anchorage, AK**

13. The **tidal pattern** is? CIRCLE: diurnal | semidiurnal | semidiurnal mixed
14. **Largest tidal range** for this chart is? (Label on chart)
15. Days of the month in which neap tides are occurring? (circle on chart)
16. **Tidal datum** (choice of zero reference point) for this chart? CIRCLE (there should be only one!): MLW (mean low water) | MLLW (mean lower low water) | MSL (mean sea level) | MTL (mean tide level) MHW (mean high water) | MHHW (mean higher high water).

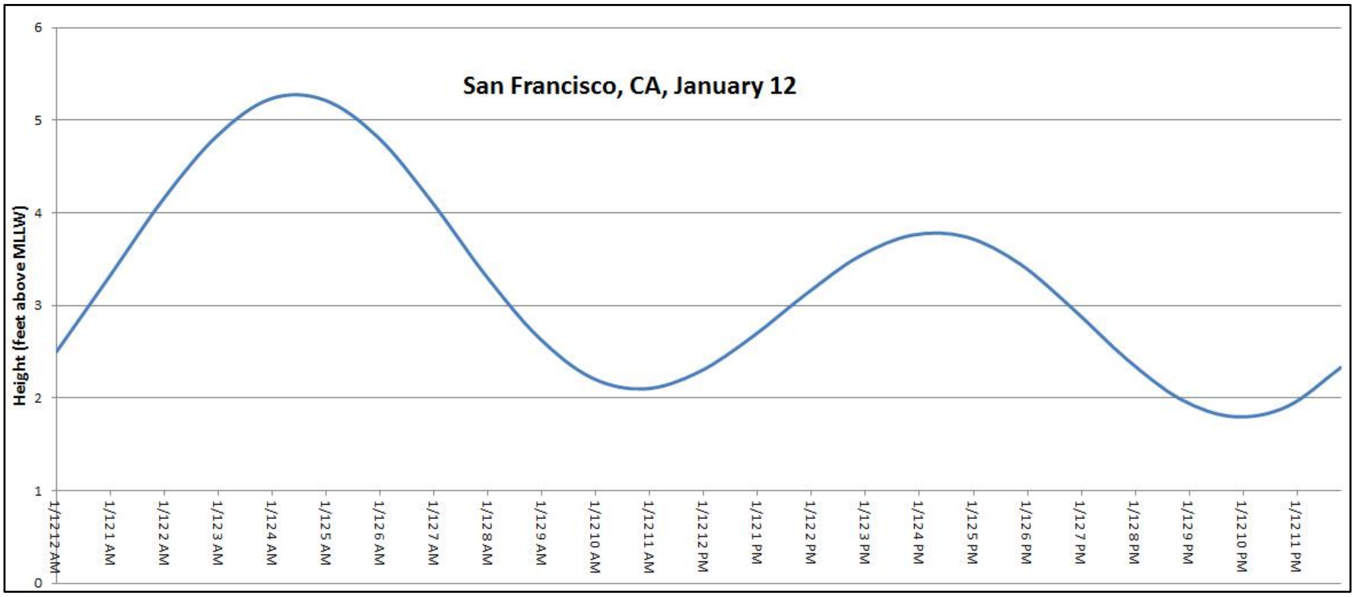
**Comparisons**

17. Which of these regions is a good candidate for tidal bores? Which day?

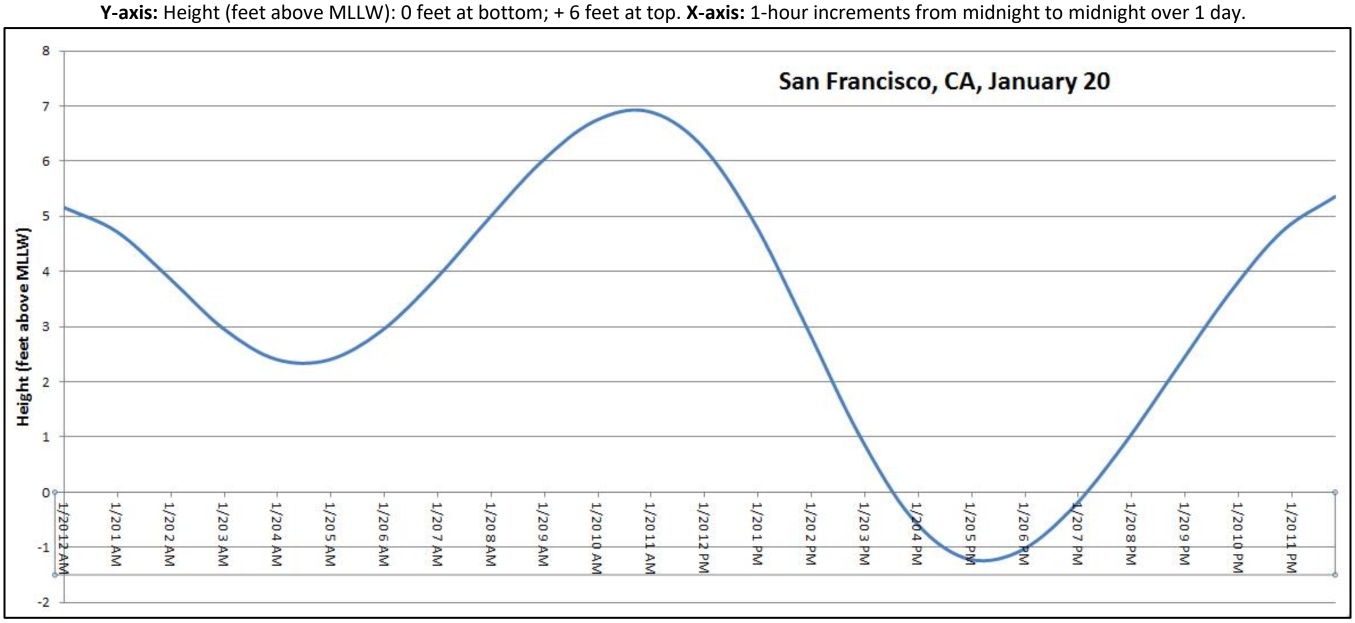
18. Which of these regions is a good candidate for building a house along the beach? Why?

## San Francisco Bay

| | |
|---|---|
| 19. Reviewing the two day tidal charts on the following page, what would be a good day AND time to move your boat to a tidal grid (a device that cradles your boat when the tide retreats) to hold your boat above sea level for the maximum time and allow you to clean the bottom? How long would your boat be above water? | |
| 20. Reviewing the two day tidal charts on the following page, what would be a good day AND time to bring a large crane under the Golden Gate Bridge | |
| 21. Reviewing the two day tidal charts on the following page, what would be a good day AND time for a 4-hr beach race (in which you don’t want to worry much about changing tides)? | |
| 22. Reviewing the two day tidal charts on the following page, what would be a good day AND time to move a boat out of a harbor that has a shallow entrance? | |
| 23. Reviewing the tidal charts above, what would be a good day AND time to plan a tidepooling trip? | |




**Y-axis:** Height (feet above MLLW): 0 feet at bottom; + 6 feet at top. **X-axis:** 1-hour increments from midnight to midnight over 1 day.




**Y-axis:** Height (feet above MLLW): -2 feet at bottom; + 8 feet at top. **X-axis:** 1-hour increments from midnight to midnight over 1 day.

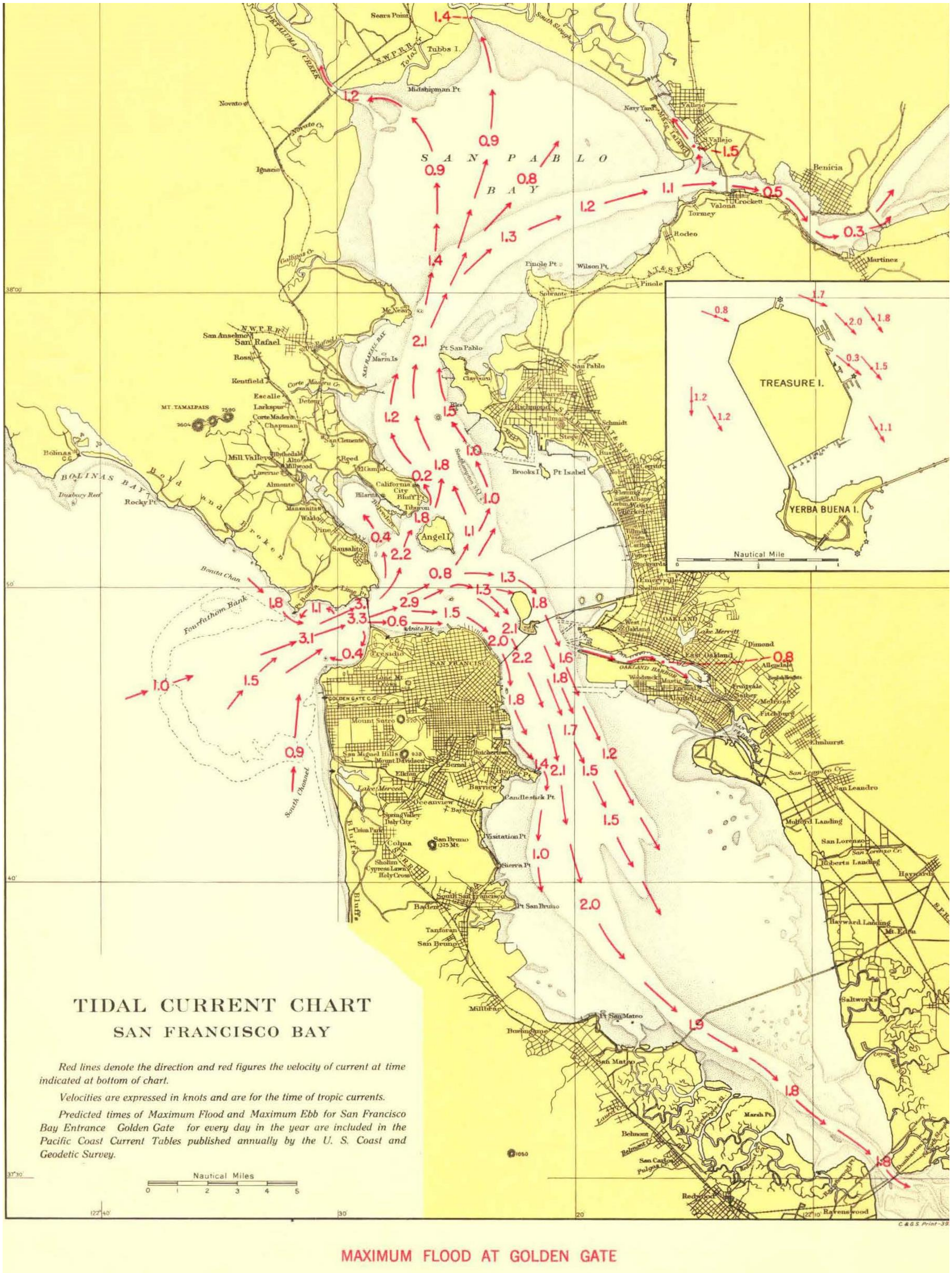
24. Reviewing the tidal charts above, what would be a good day AND time to plan a kayaking trip for beginners (limit current) from Sausalito (inside the Bay) to under the Golden Gate Bridge and back?

25. Reviewing the tidal charts above, what would be a good day AND time to plan a kayaking trip for experts (maximize current) from Rodeo Lagoon (outside the Bay) to under the Golden Gate Bridge and back? *(Remember: Currents reach maximum speed halfway between High and Low Tide.)*

26. Reviewing the tidal charts above, what would be a good day AND time to see marine organisms laying eggs on the beach? Why?

27. On the charts above, indicate which is the most likely candidate for a new moon, full moon, or half moon.

28. Review figure on the next page of the incoming maximum flood current into San Francisco Bay. Where is current fastest? How fast? Where is current slowest? How slow?




**Tidal Chart of San Francisco Bay during Maximum Flood Current at the Golden Gate Bridge from U.S. Department of Commerce – 5th Edition (1955)**

#s given are speeds in knots (1 nautical mile/hour)

# Weekly Reflection

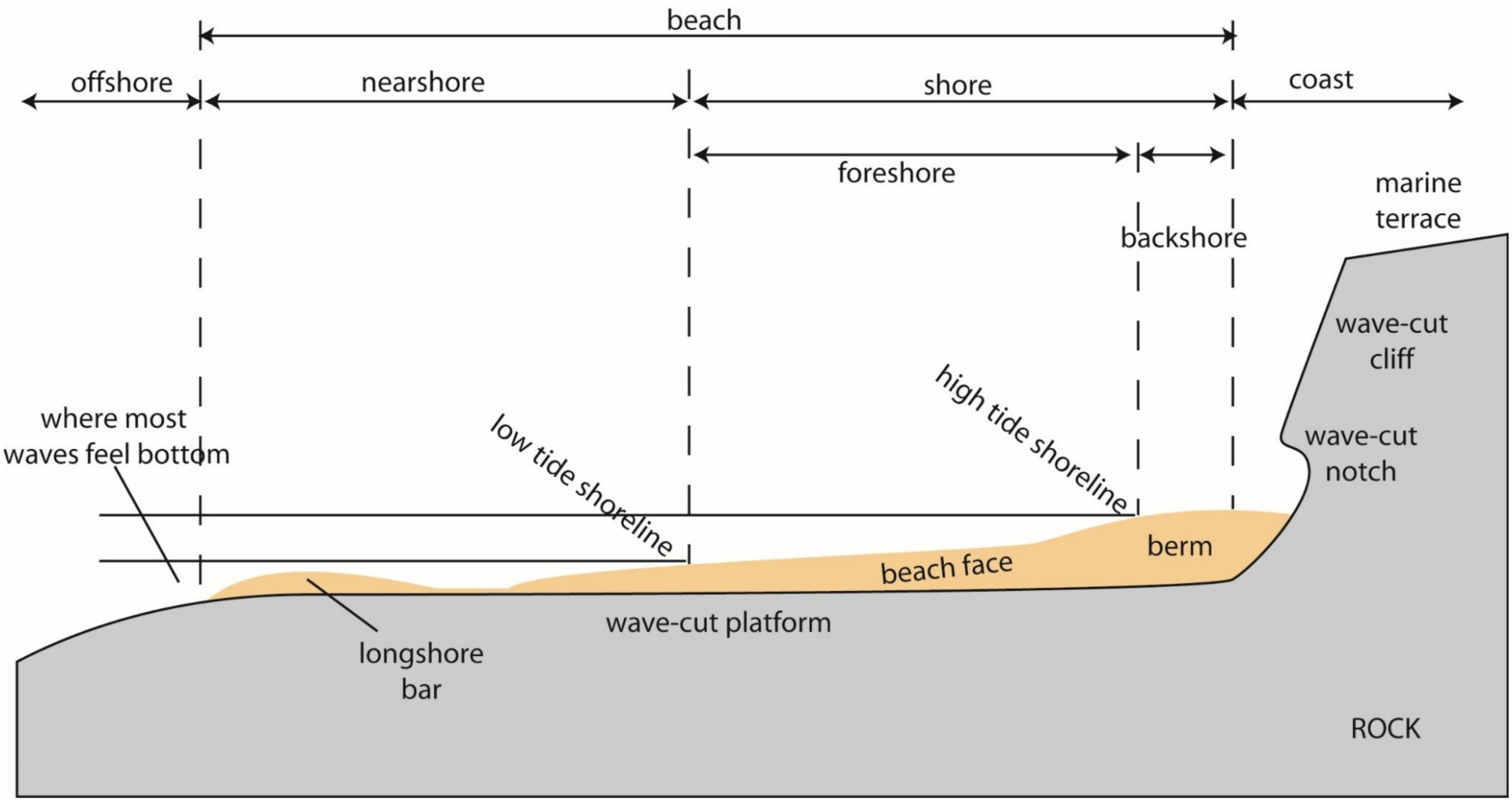
Take a moment to reflect on your comfort level and mastery of the week's objectives and describe an action plan for how you will practice or improve on anything that challenged you.

| Weekly objective | Self-assessment of mastery level | Action plan for improvement |
|---|---|---|
| Analyze the **causes of tidal waves**. | A \| B \| C \| D \| F | |
| Evaluate and diagram **how tidal waves behave in enclosed ocean basins**. | A \| B \| C \| D \| F | |
| Compare and contrastthe causes, behaviors, distribution, and impacts of **different tidal patterns**. | A \| B \| C \| D \| F | |
| Evaluate how and why **tidal range varies throughout the month and year and the impact on marine organisms**. | A \| B \| C \| D \| F | |
| Apply an understanding of tides to evaluate and describe how tides **behave in and impact the San Francisco Bay area**. | A \| B \| C \| D \| F | |

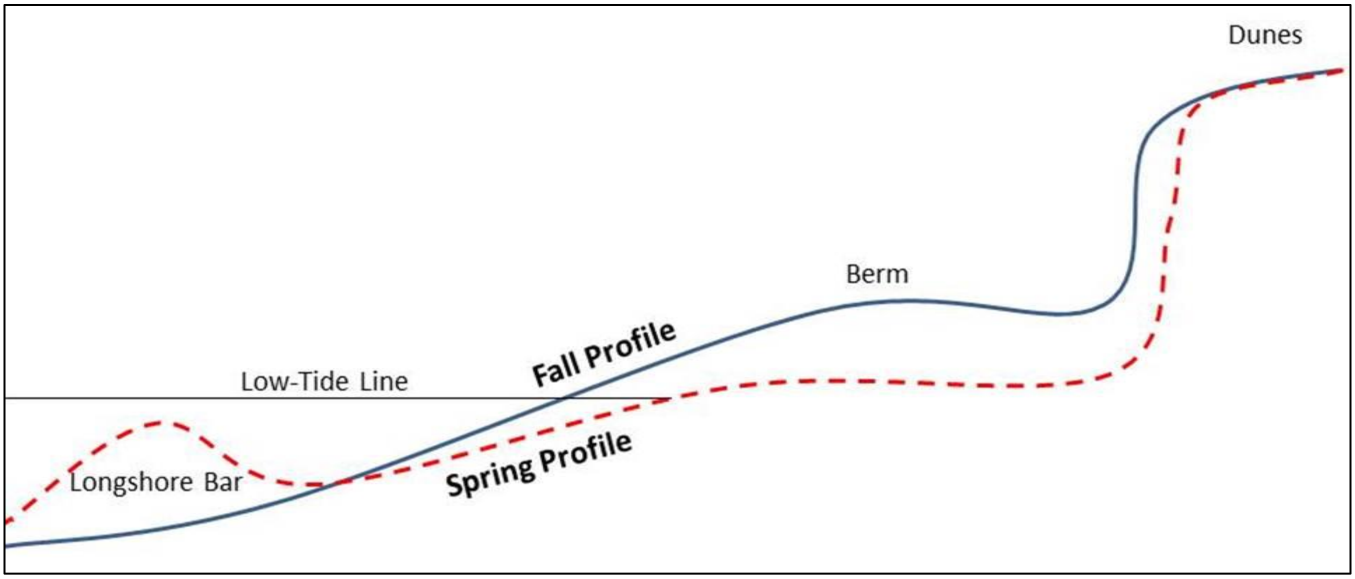
## AHA! Moments

What content from this week really resonated with you, helped you understand something you've always wondered about, or made you think about the world with new eyes?

# COASTS, BEACHES, AND ESTUARIES

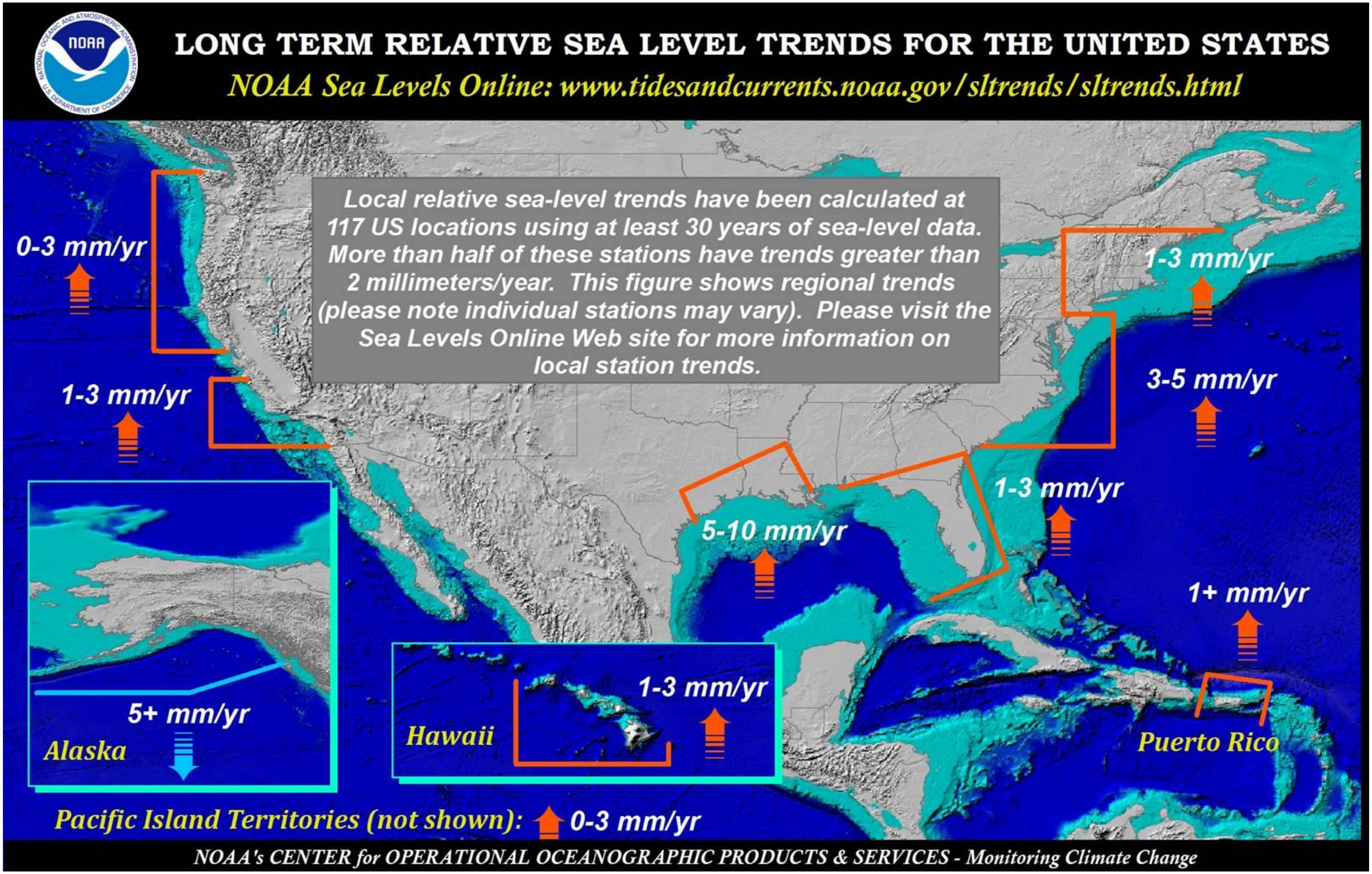



*Generalized beach profile along coast with a resistant, eroding cliff at the back of the beach. Yellow represents sand.*

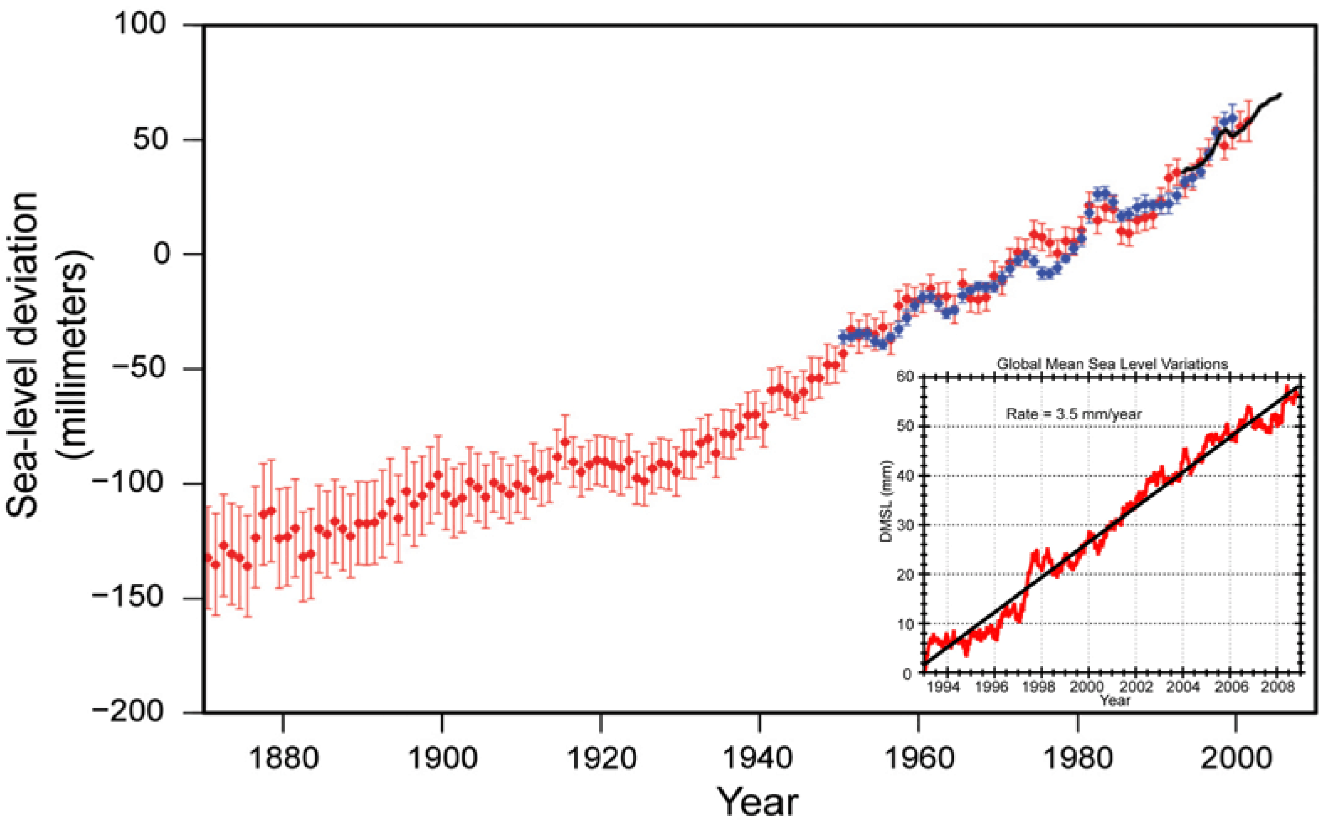



*Beach profiles – from dunes/cliff to offshore bar – based on seasons.*

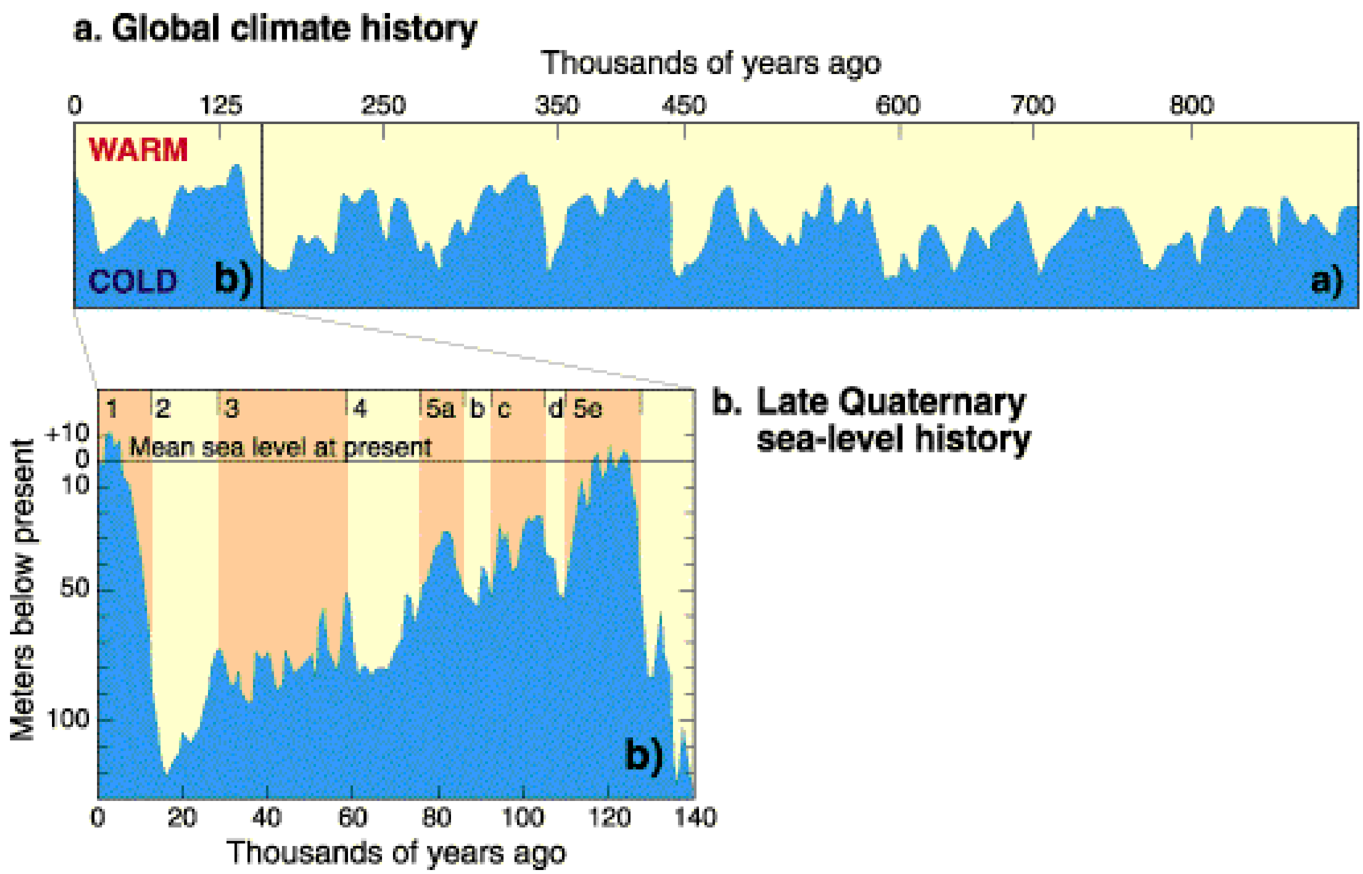
*View from the Cliff House towards the sand dunes that will become the site of the Golden Gate Park and the Sunset district c. 1865 photographer: HC Hecht*



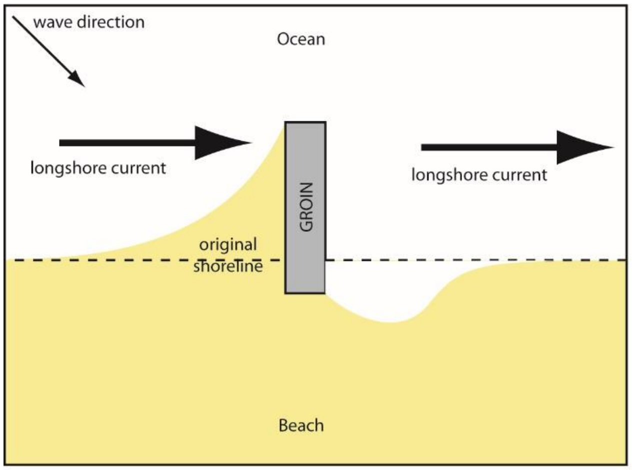
LONG TERM RELATIVE SEA LEVEL TRENDS FOR THE UNITED STATES
NOAA Sea Levels Online: www.tidesandcurrents.noaa.gov/sltrends/sltrends.html
Local relative sea-level trends have been calculated at 117 US locations using at least 30 years of sea-level data. More than half of these stations have trends greater than 2 millimeters/year. This figure shows regional trends (please note individual stations may vary). Please visit the Sea Levels Online Web site for more information on local station trends.
0-3 mm/yr
1-3 mm/yr
1-3 mm/yr
3-5 mm/yr
1-3 mm/yr
5-10 mm/yr
1+ mm/yr
5+ mm/yr
Alaska
Hawaii
1-3 mm/yr
Puerto Rico
Pacific Island Territories (not shown): 0-3 mm/yr
NOAA's CENTER for OPERATIONAL OCEANOGRAPHIC PRODUCTS & SERVICES - Monitoring Climate Change

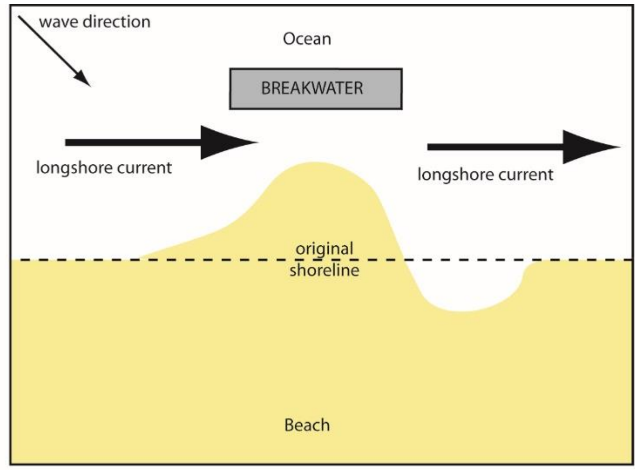


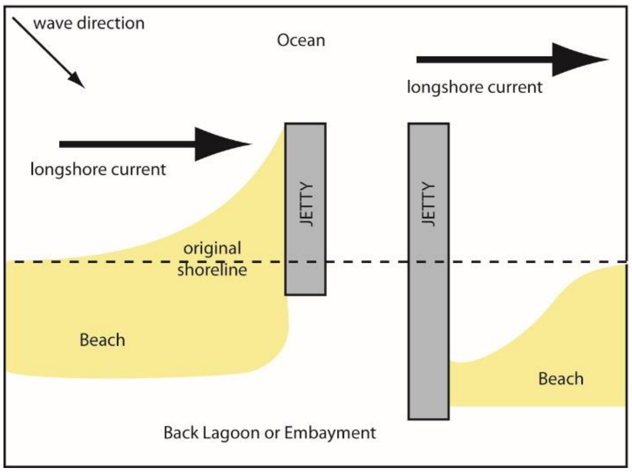

*Average global sea level changes over the past 100 years. Image from NOAA*

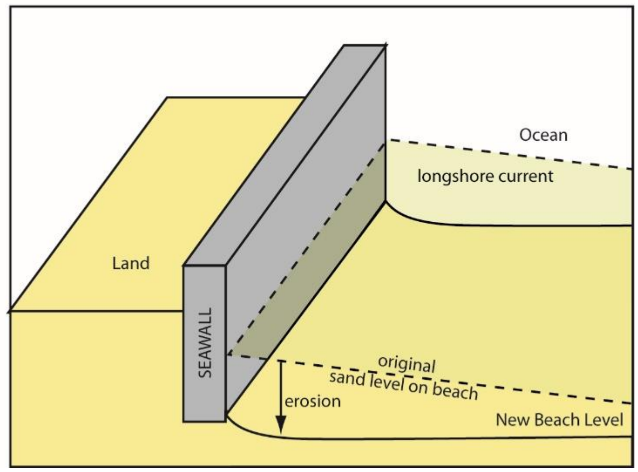



*Sea level changes over the past 1 million years. Image from NOAA*



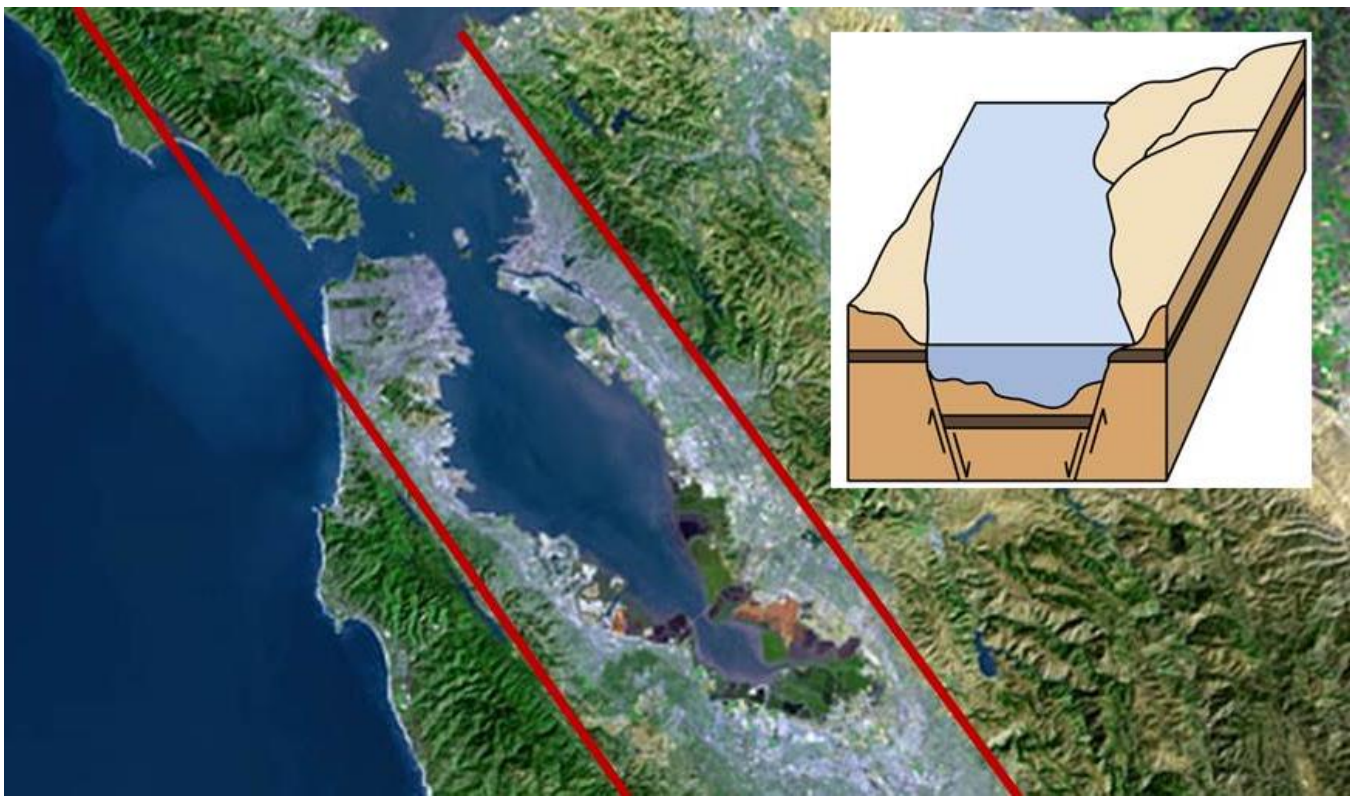



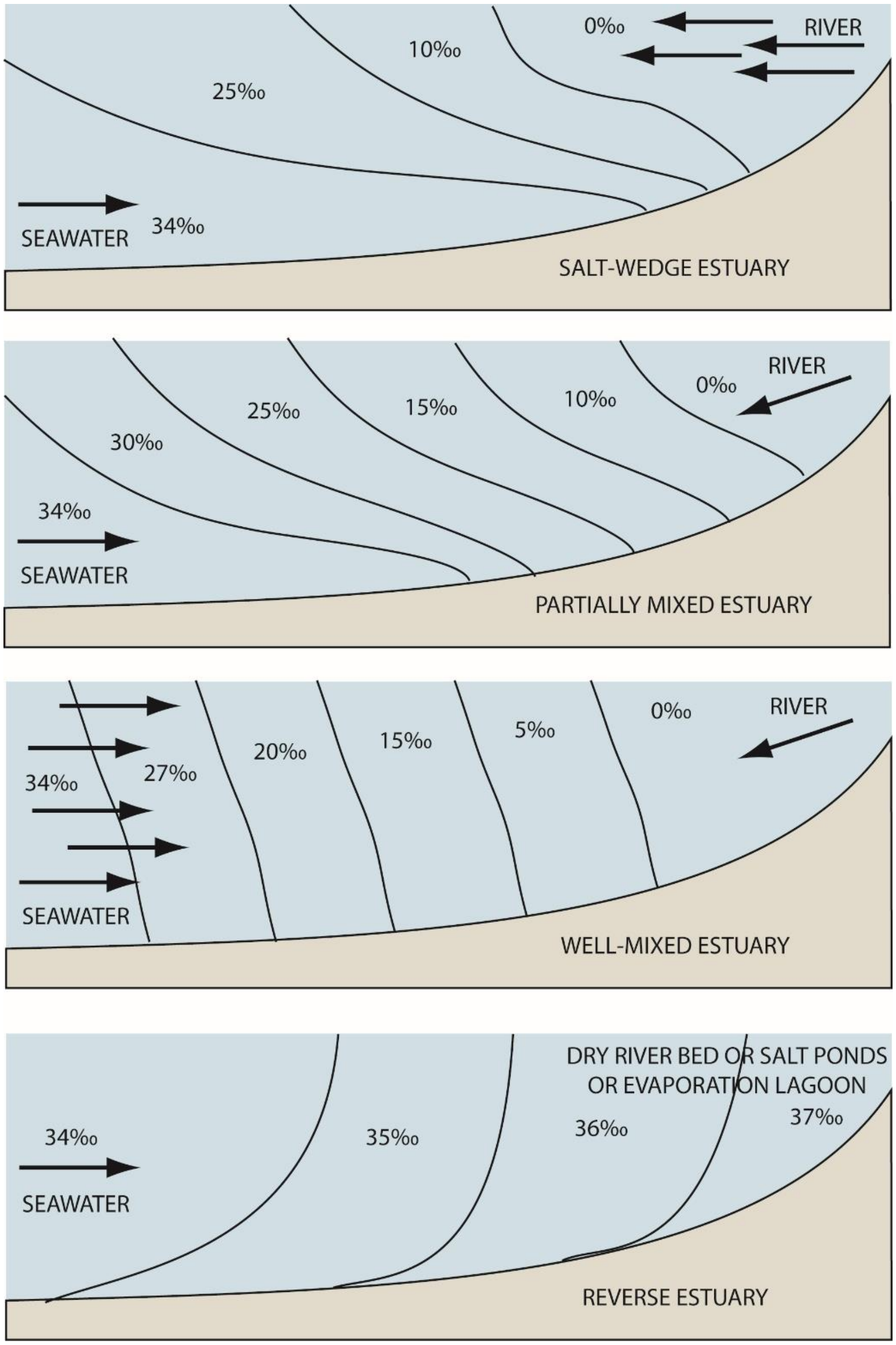




| **Structure** | **Groin** | **Jetty** | **Seawall** | **Breakwater** |
|---|---|---|---|---|
| **Picture or description** | Wall running perpendicular to beach, extending off beach | Two parallel walls running alongside harbor mouth, perpendicular to beach | Wall running parallel to beach, on the beach | Wall running parallel to beach, but offshore |
| **Why used?** | Create a beach | Prevent mouth closing | Prevent homes, roads, etc. from erosion | Create a gentle water region for boats to anchor |
| **Results?** | Another beach is eroded to compensate; wall must be maintained. | Sand builds up in harbor mouth eventually and must be dredged. Beach forms in one location at expense of another. Jetty must be maintained. | Sand on local beach diminishes; erosion increases elsewhere; rip rap must be added. | Sand on local beach grows, eventually requiring dredging; erosion increases downcurrent; wall must be maintained. |

*Satellite image of North San Francisco Bay, which is a drowned river valley (as sea level rose, the Sacramento River delta was pushed inland to where it is today in Sacramento). (USGS)*



*Satellite image of South San Francisco Bay, which is a down-dropped tectonic basin that sits between the Hayward and San Andreas Faults. (USGS image + Unknown source for inset graben)*




*Cross-sections through the range of different types of estuarine mixing, with river water entering from the right and tidal input from the left.*

| **Mixing type** | **Definition/Cause** | **Examples** |
|---|---|---|
| Salt Wedge | Strong, high-volume river (stronger than the tidal action); strong halocline | Mouths of Columbia and Mississippi Rivers. Mouth of the Sacramento River (local effect) |
| Well–mixed | Weak, low-volume river (much weaker than the tidal action); No halocline | Shallow estuaries like the Chesapeake and Delaware Bays. Also South San Francisco Bay. |
| Partially mixed | Medium-volume river (river and tides are more well matched); Weak halocline | Deeper estuaries like the Puget Sound, North San Francisco Bay, Strait of Georgia |
| Fjord | Moderately high river input – little tidal mixing – in fjord with sill that blocks entrance. Deeper water may stagnate behind sill. Strong halocline. | British Columbia, Alaska, Norway, Iceland, Greenland, New Zealand, Chile |
| Evaporative or reverse | High evaporite content along dry river bed. River gone. Tides are only water source. | Red Sea and Mediterranean Sea. Salt ponds of San Francisco's South Bay. |

# Coasts, Beaches, and Estuaries Chapter Worksheet

| | | |
|---|---|---|
| 1. | Which of the following features are caused by **deposition**? (Sand piling up) | CIRCLE: barrier island \| berm \| delta \| sand spit \| beaches headlands \| wave-cut notches \| marine terrace |
| 2. | Which of the following features are caused by **erosion**? (Rock being removed) | CIRCLE: sea arches \| cliffs \| wave-cut platform \| sea stacks blowholes \| tombolos \| barrier islands \| marine terrace |
| 3. | Reviewing the beach profile image in the preceding pictures, what is the term used for the solid rock surface eroded by waves and covered by sand that migrates with the waves**?** | |
| 4. | Shorelines that have marine terraces are likely experiencing what process(es)? | CIRCLE: deposition \| erosion<br>CIRCLE: subsidence \| uplift \| sea level rise \| sea level drop |
| 5. | Which process dominates the **East Coast** of the United States? | CIRCLE: deposition \| erosion |
| 6. | Why? | |
| 7. | Which process dominates the **West Coast** of the United States? | CIRCLE: deposition \| erosion |
| 8. | Why? | |
| 9. | **San Francisco's North Bay** is a drowned river valley (**Sacramento River**) that formed as sea level rose after the last ice age**. San Francisco's South Bay** is a fault-bounded, tectonic estuary. It sits between the **Hayward and San Andreas Faults** and represents a down-dropped basin that filled with water. On the map of San Francisco Bay, displayed a few pages earlier, identify and label all the features highlighted in bold in this question *(North Bay, South Bay, Hayward Fault, San Andreas Fault, and Sacramento River)*.<br>(Make sure you understand how each formed.) | |
| 10. | List three causes of global or **eustatic sea level change** (*review from Seafloor Sediments Chapter Worksheet*). | |
| 11. | What is the highest sea level has been during the last 900,000 years of periodic ice ages? *(Refer to preceding image showing Global climate history for this time period.)* | |
| 12. | What is the lowest sea level has been during the last 140,000 years of periodic ice ages? *(Refer to preceding image showing last 1 m.y.)* | |
| 13. | What is the rate of increase today? | |
| 14. | What is the projected height for 2100? | |
| 15. | Reviewing the beach profile image in the preceding pictures, what is another term used for the **intertidal zones** (between high and low tide)? | |
| 16. | Reviewing the beach profile image in the preceding pictures, what is another term used for the **surf zone** (the zone that occurs shoreward of when a wave feels bottom)? | |
| 17. | The main effect of waves hitting shore at an angle is the movement of sand and water along a beach. What is the name given to the sand movement? | |
| 18. | Waves that hit our beaches are caused primarily by? | CIRCLE: local winds \| far-distant winds |
| 19. | **Swell** generally approach the North American coastline from the north. Why? What's there? | |
| 20. | General direction of longshore current in North America is? | |

| | | |
|---|---|---|
| 21. | Which of the following is true of **summer** swell in California? | CIRCLE: created by local winds \| created by long-distant winds<br>CIRCLE: high energy \| moderate energy \| low energy<br>CIRCLE: generally come from North \| come from West \| come from South<br>CIRCLE: erosion > deposition \| deposition > erosion<br>CIRCLE: backwash > swash \| swash > backwash |
| 22. | Which of the following is true of **winter** swell in California? | CIRCLE: created by local winds \| created by long-distant winds<br>CIRCLE: high energy \| moderate energy \| low energy<br>CIRCLE: generally come from North \| come from West \| come from South<br>CIRCLE: erosion > deposition \| deposition > erosion<br>CIRCLE: backwash > swash \| swash > backwash |
| 23. | During what month of the year would you expect the **berm** on the beach to be smallest? | |
| 24. | During what month of the year would you expect the **berm** on the beach to be largest? | |
| 25. | What is the primary source of all beach sand? (~90% globally) | |
| 26. | What is the secondary source of global beach sands? | |
| 27. | What is a third source of beach sands globally (dominant in tropical shorelines)? | |
| 28. | What are the two primary sinks for all beach sand globally? | |
| 29. | What are the primary mechanisms for moving sand from one area of the coast to another (including to its ultimate sinks)? | |
| 30. | What is the ultimate source of beach sand at Ocean Beach? | |
| 31. | Which of these coastal structures is installed specifically to prevent coastal erosion? | CIRCLE: seawall \| jetty \| groin \| breakwater \| none |
| 32. | Which of these coastal structures is installed to create protected low-energy water for boats? | CIRCLE: seawall \| jetty \| groin \| breakwater \| none |
| 33. | Which of these coastal structures results in bigger beaches in a particular location? | CIRCLE: seawall \| jetty \| groin \| breakwater \| none |
| 34. | Which of these coastal structures results in increased erosion in a particular location? | CIRCLE: seawall \| jetty \| groin \| breakwater \| none |
| 35. | Which of these coastal structures results in increased wave height in a particular location? | CIRCLE: seawall \| jetty \| groin \| breakwater \| none |
| 36. | Which of these coastal structures requires continued maintenance? | CIRCLE: seawall \| jetty \| groin \| breakwater \| none |
| 37. | Which of the following is true of an **estuary**? | CIRCLE: embayment \| freshwater and saltwater mix<br>freshwater only \| saltwater only |
| 38. | Which type of estuarine mixing occurs when large volume rivers enter the ocean? | CIRCLE: partially mixed \| reverse \| salt wedge \| well mixed |
| 39. | Which type of estuarine mixing occurs when moderate volume rivers enter the ocean (usually evenly matched by tides)? | CIRCLE: partially mixed \| reverse \|<br>salt wedge \| well mixed |
| 40. | Which type of estuarine mixing occurs when low volume rivers enter the ocean? | CIRCLE: partially mixed \| reverse \| salt wedge \| well mixed |
| 41. | Which type of estuarine mixing creates no halocline? | CIRCLE: partially mixed \| reverse \| salt wedge \| well mixed |
| 42. | Which type of estuarine mixing creates the strongest halocline? | CIRCLE: partially mixed \| reverse \| salt wedge \| well mixed |

# Understanding Tsunami Activity

**THIS ASSIGNMENT SPANS MULTIPLE PAGES DUE TO THE LARGE IMAGES USED. BE SURE YOU COMPLETE ALL THE PAGES (21 QUESTIONS). Some answers come from past assignments. Be sure those are correct!**

****For questions below, review your corrected, completed Waves and Water Planet chapter question sheets. REVIEW:**

- **Deep-water waves**: wave base of wave doesn't touch bottom *(remember: wave base = ½ wavelength, so these waves are in water deeper than ½ wavelength)*
- **Shallow-water waves**: wave base of wave does touch bottom (*waves are in water shallower than ½ wavelength)*
- *(Technically intermediate-water waves touch bottom, but their wavelength is between 0.5 and 0.05 of depth – for purposes of this assignment, ignore this limitation and designate waves as either deep-water or shallow-water)*

| | | |
|---|---|---|
| 1. Oceans: average depth | 2. Oceans: Shelf break depth | 3. Oceans: deepest depth |
| 4. Tsunami: average wavelength | 5. Tsunami: average wave base | 6. Use standard speed equation (given below) to calculate tsunami average speed: **speed**= $\frac{wavelength}{period}$ |
| 7. Tsunami are shallow-water waves everywhere in the ocean. Use the definitions from above and the data above to explain why. | | |

## Shallow-water wave speed equation (short):

**Speed =** $\sqrt{9.81\frac{\text{m}}{s^2}\,\text{x depth of water }(in\ meters)}$

**CONVERSION: Speed in** $\frac{m}{s} \times 3.6$ **= Speed in** $\frac{km}{hr}$

**Completed examples:**

In the surf zone, swell is a shallow-water wave. For swell in a depth of 8 meters, speed would be $\sqrt{9.81\frac{\text{m}}{s^2}\text{x } 8\text{ m}}$ = $\sqrt{78.48\frac{m^2}{s^2}}$ = 9 m/s.

**CONVERSION: 9** $\frac{m}{s} \times 3.6$ **= 32** $\frac{km}{hr}$

| | |
|---|---|
| 8. Tsunami: calculate tsunami speed in **deepest ocean location.** Give answer in km/hr. *(Use short-cut equation above.)* | |
| 9. Tsunami: calculate tsunami speed in **average ocean depth.** Give answer in km/hr. *(Use short-cut equation above.)* | |
| 10. Tsunami: calculate tsunami speed at **edge of continental shelf** Give answer in km/hr. *(Use short-cut equation above.)* | |
| 11. Tsunami: calculate tsunami speed in **water 5 meters deep.** Give answer in km/hr. *(Use short-cut equation above.)* | |
| 12. What happens to tsunami speed as it approaches the shore? | |

**CALCULATING TSUNAMI TRAVEL TIMES**

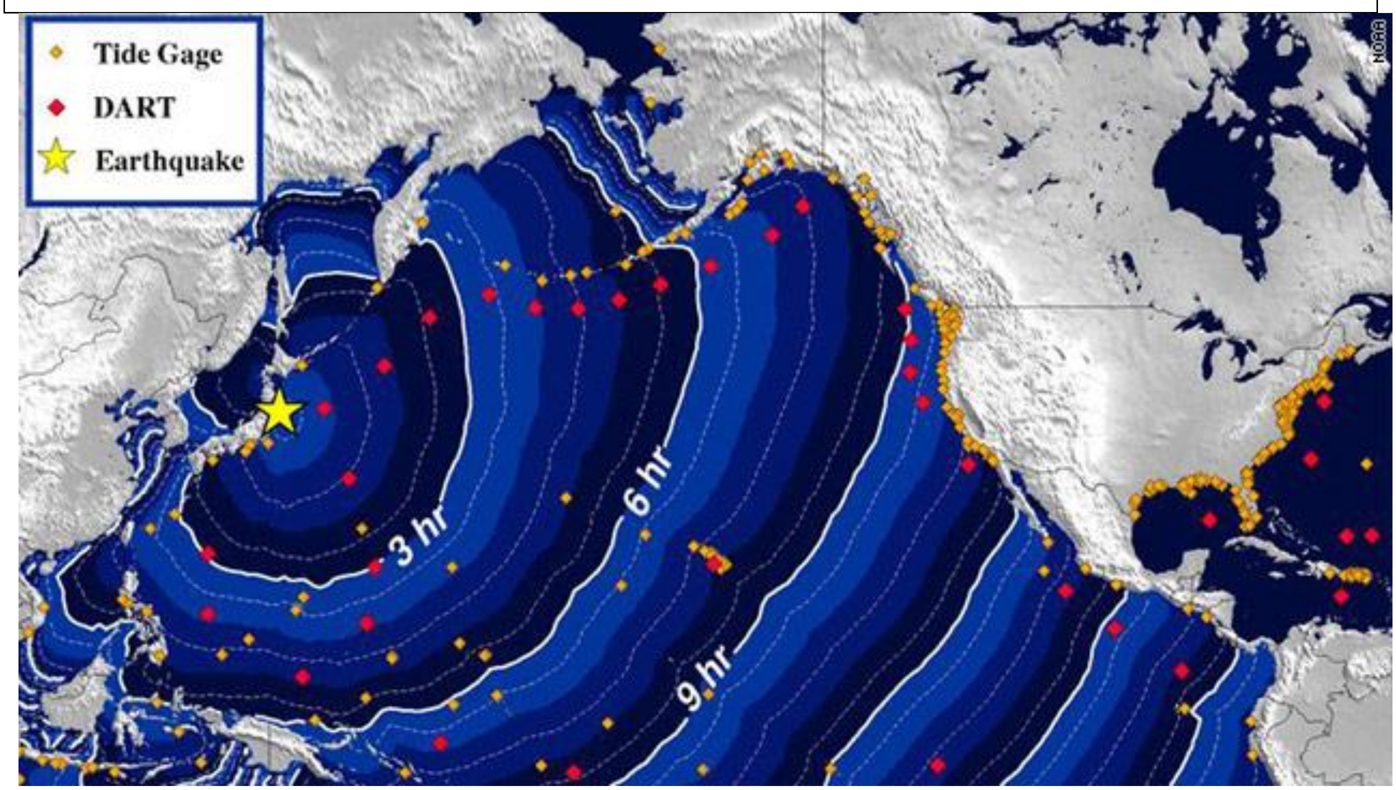
To calculate tsunami travel times, you have to solve the basic speed equation for time. **Time = distance/speed**

**Example:** Assuming average depth of the oceans, what would be the travel time for 15-s-period **swell** between Japan and San Francisco, which are 7700 km apart?

In average depth oceans, swell is a deep-water wave, so its speed, as calculated previously, is 84 km/hr.

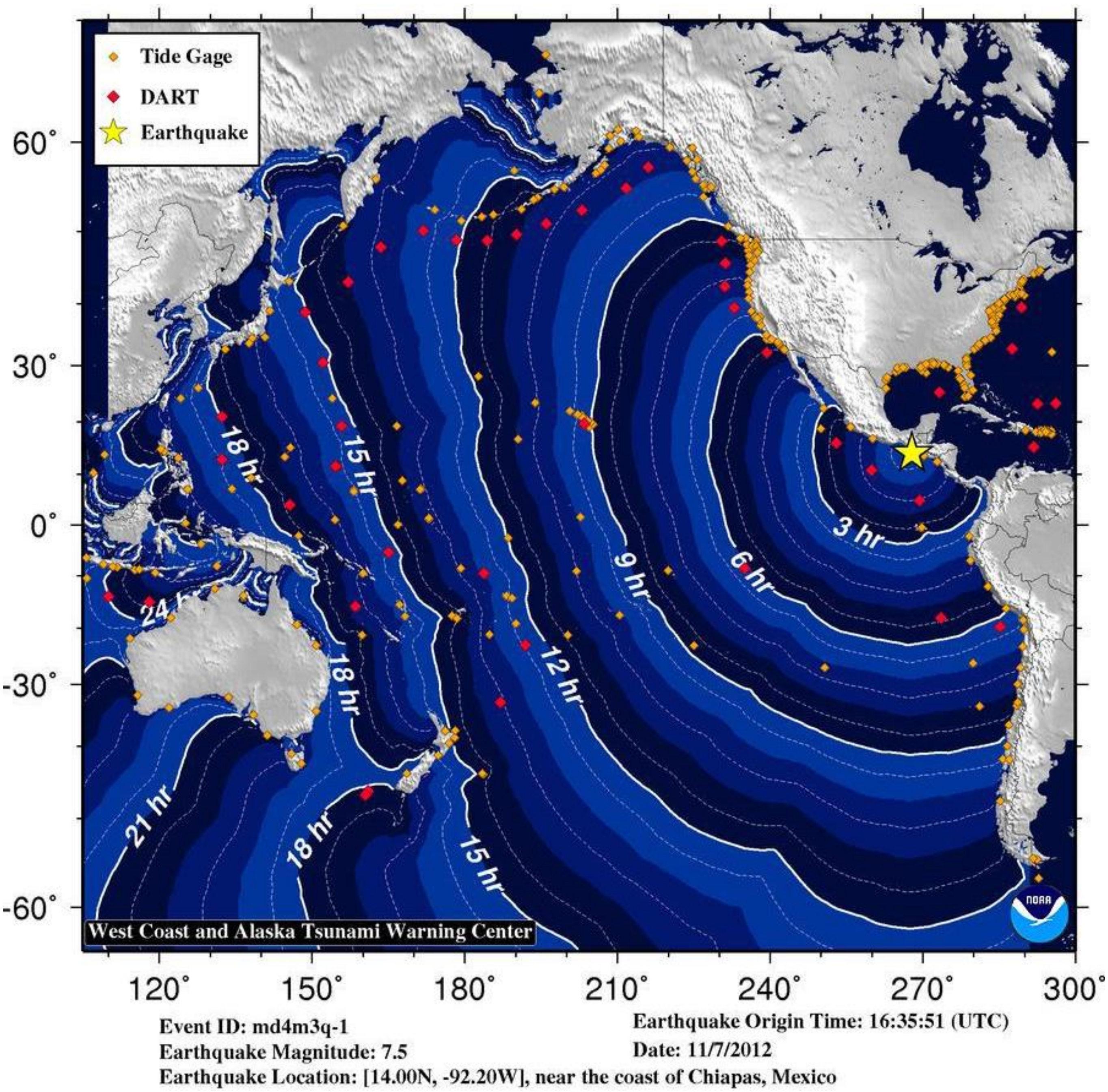
TIME = distance/speed = 7700 km/ 84 km/hr = **92 hrs**

| | |
|---|---|
| 13. Assuming average depth of the oceans and average speed of a tsunami at that depth (get answers from previous page calculations), what would be the tsunami travel time between Japan and San Francisco, which are 7700 km apart? | |
| 14. The image below provides Japan tsunami time arrivals based on data received at coastal tide stations. What did they indicate was the travel time between Japan and San Francisco? | |
| 15. How do above two answers compare? If there's a difference, why? | |

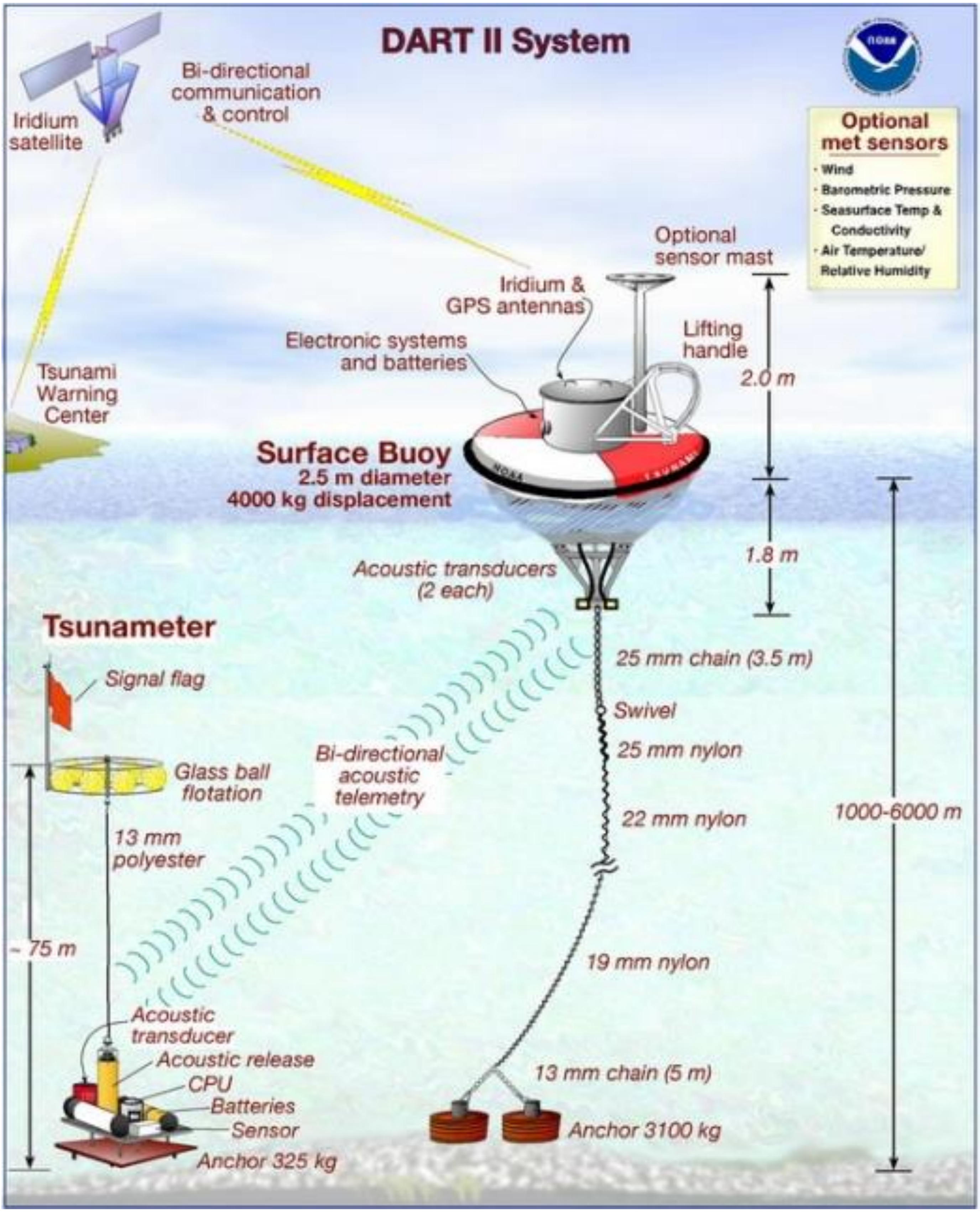



*Tsunami Travel Times (travel time contours every 30 mins, beginning from the Japan 2014 earthquake origin time). NOAA*

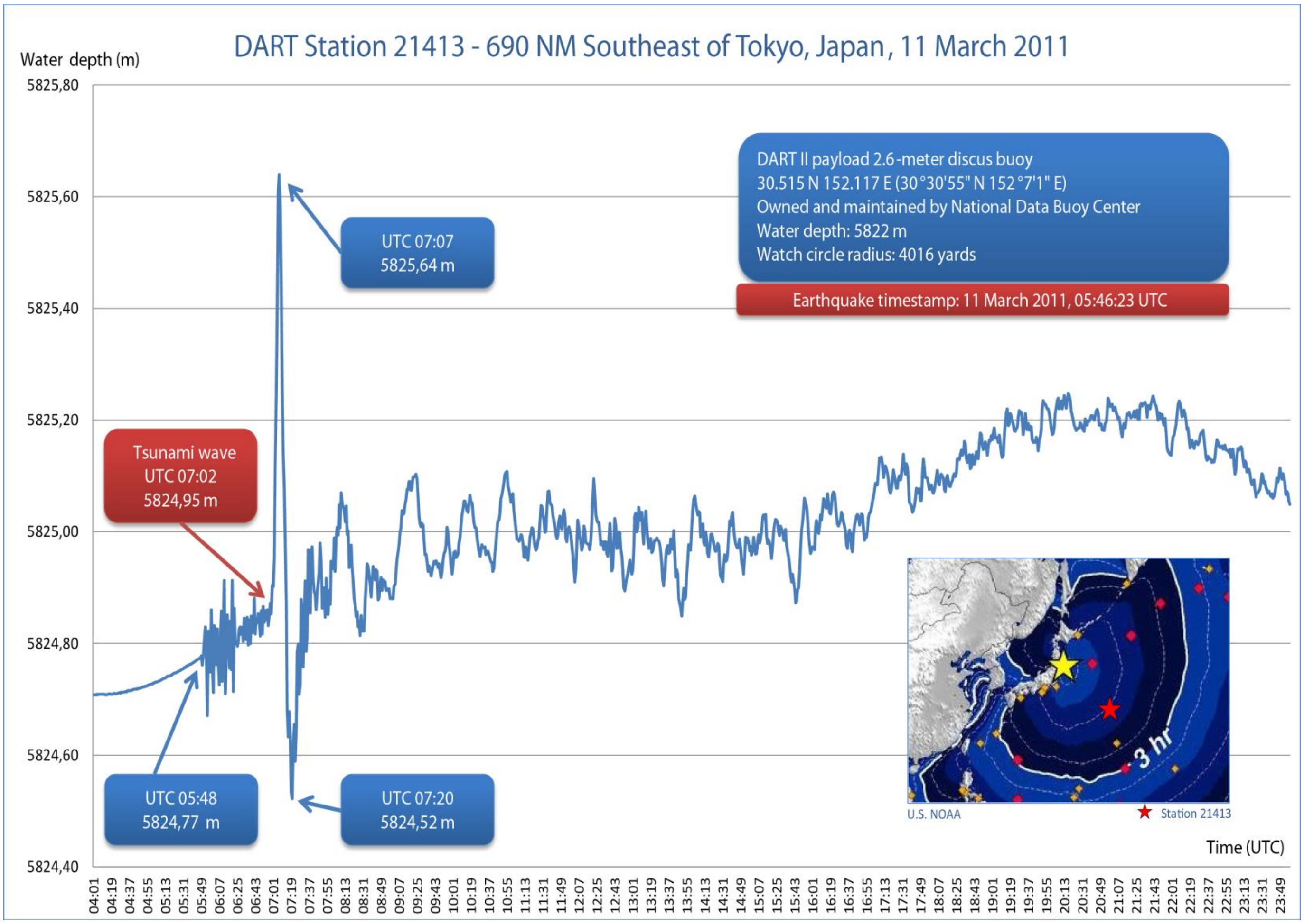
| | |
|---|---|
| 16. Assuming average depth of the oceans and average speed of a tsunami at that depth (get answers from previous page calculations), what would be the tsunami travel time between Chiapas Mexico and the Southern Tip of Baja, California (Mexico), which are 2300 km apart? | |
| 17. The image below provides Chiapas tsunami time arrivals based on data received at coastal tide stations. What did they indicate was the travel time between Chiapas and the southern tip of Baja? | |
| 18. How do above two answers compare? If there's a difference, why? | |




*Tsunami Travel Times (travel time contours every 30 mins, beginning from Chiapas 2012 earthquake origin time). NOAA*




*System used to measure tsunamis in the open ocean (DART). Note two separate components: the tsunameter is anchored to seafloor and measures the pressure of water column above it. The surface buoy is separate. It is tethered to an anchor on seafloor to keep it in place and receives sound waves from the tsunameter, which it then transmits via satellite to NOAA.*



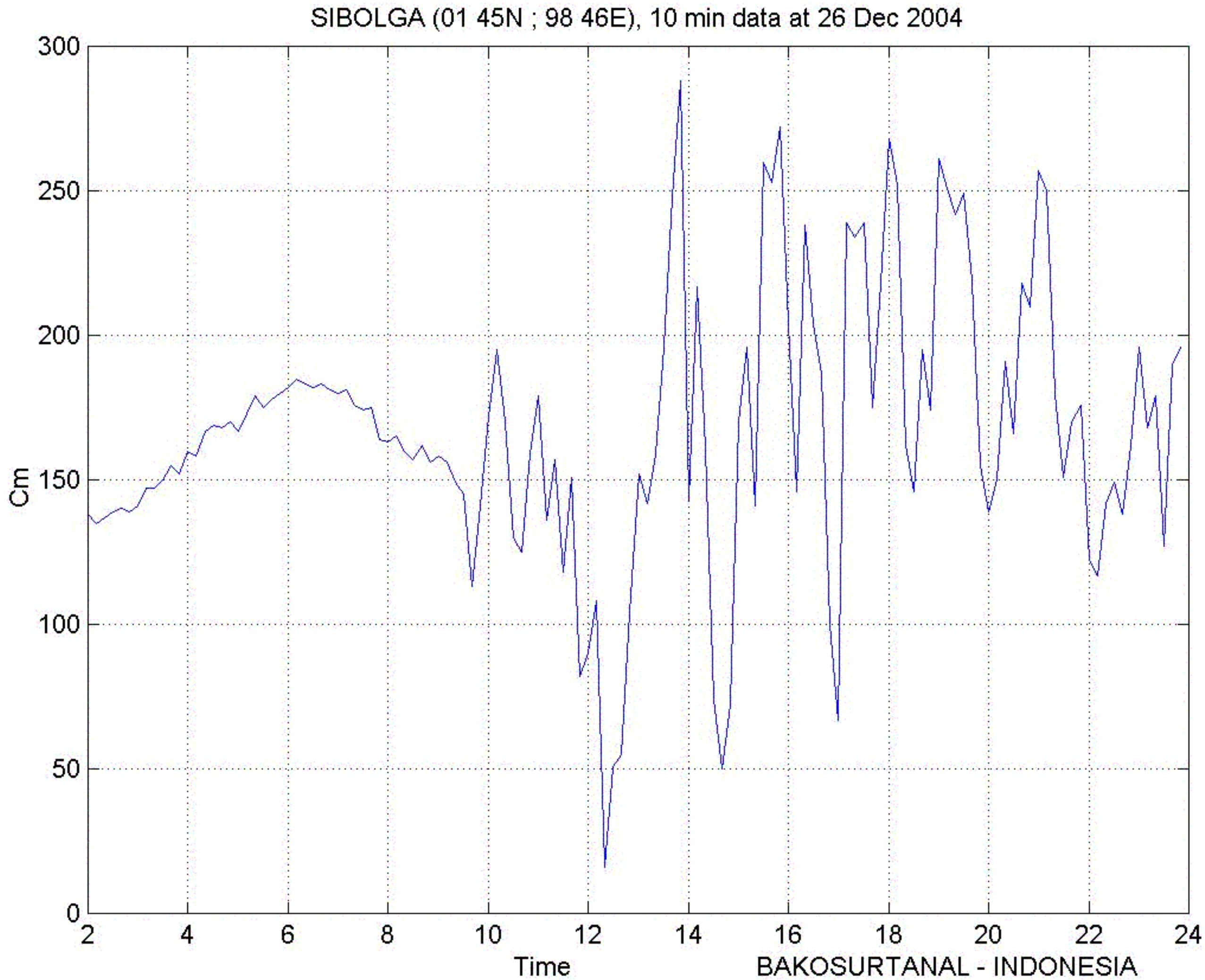

*Time versus water depth pressure sensor from DART. As tsunami passes, the water depth above the sensor changes. Note: comma is used here instead of decimal point. 5824,52 means 5824.52 m. NOAA.*

| | |
|---|---|
| 19. Review the DART station map recording of the Japan, 2011 Tsunami (above). At what depth was the DART station deployed?<br>What height wave was recorded? How does this compare with what you've learned to date about average tsunami height in the open ocean? | |
| 20. How were the data for the above chart gathered and transmitted? | |

The following pages contain graphs showing water-level data from coastlines around the world during tsunami. These are real data points from real tsunami. Questions to consider as you review these data:

- Can you identify when the first tsunami wave appears?
- What kind of water-level changes are happening before the tsunami arrives? What causes those?
- What part of the tsunami waves arrives first? Trough? Crest? Something in between?
- How many waves arrive?
- Are all wave heights the same at a single location? The same for different beaches for the same tsunami?
- If not, which is the highest?
- What's the period?

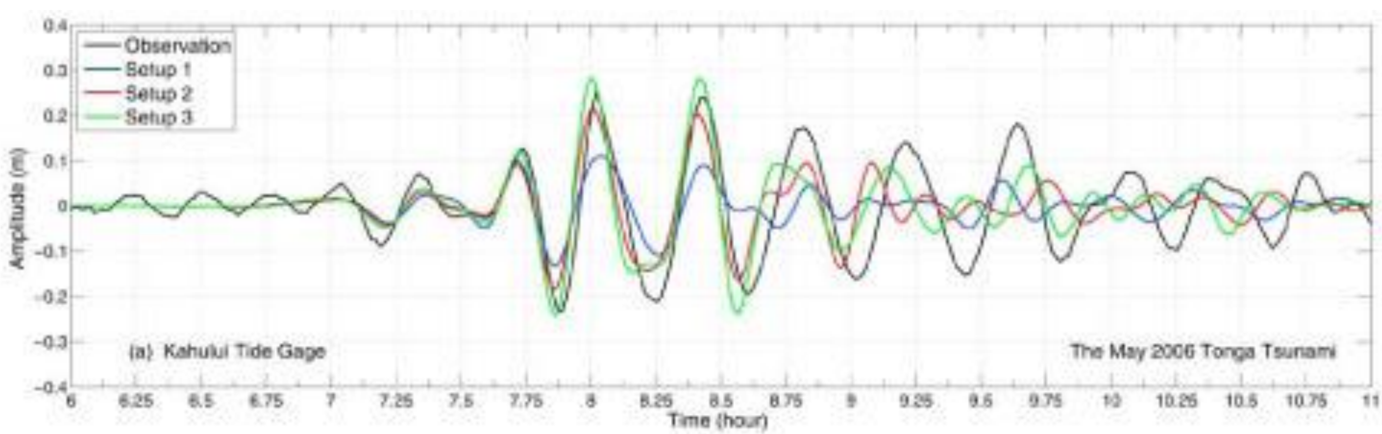
21. After reviewing these tsunami data come back and answer this question. What new insights do you have about how tsunami manifest themselves on shorelines? What would you do if you thought you were experiencing a tsunami locally?



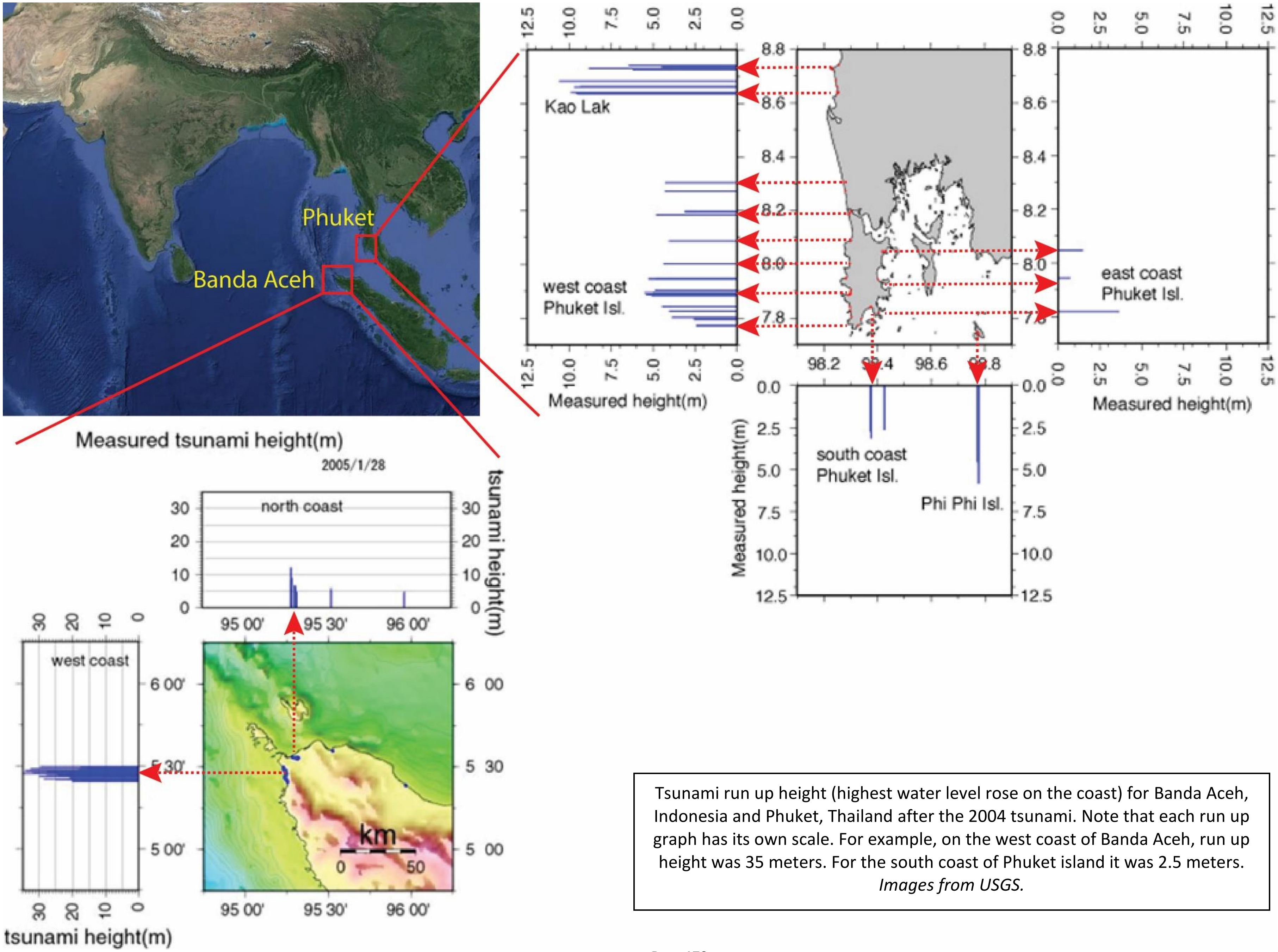

*Water level recorded at a coastal tidal gauge station the day of the Indian Ocean 2004 tsunami.*

SOURCE: [http://www.drs.dpri.kyoto-u.ac.jp/sumatra/obs/t_Sibolga.GIF](http://www.drs.dpri.kyoto-u.ac.jp/sumatra/obs/t_Sibolga.GIF)

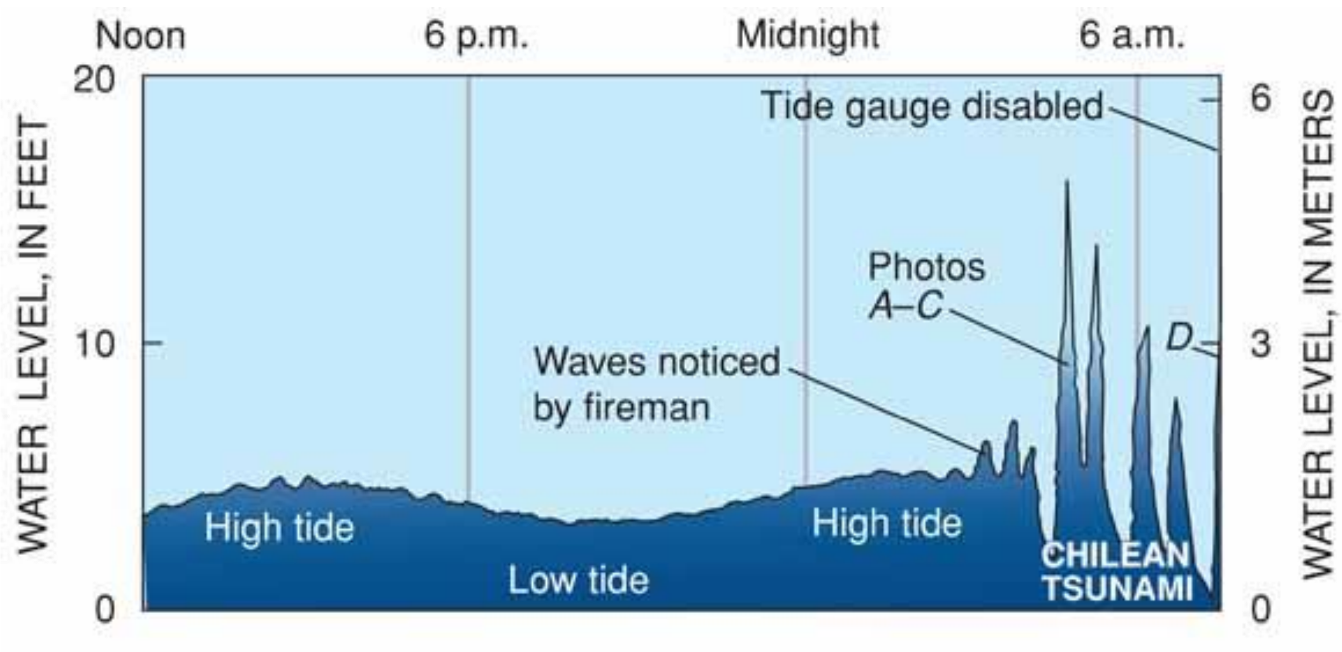
Review the above tidal gauge data from SIBOLGA, for the Indian Ocean Tsunami in 2004. First notice that two waves are interfering: a tsunami and a tidal wave (daily tides) which has a period of 12 hrs and 25 minutes (so two would appear in one 24 hour, 50 minute time period).



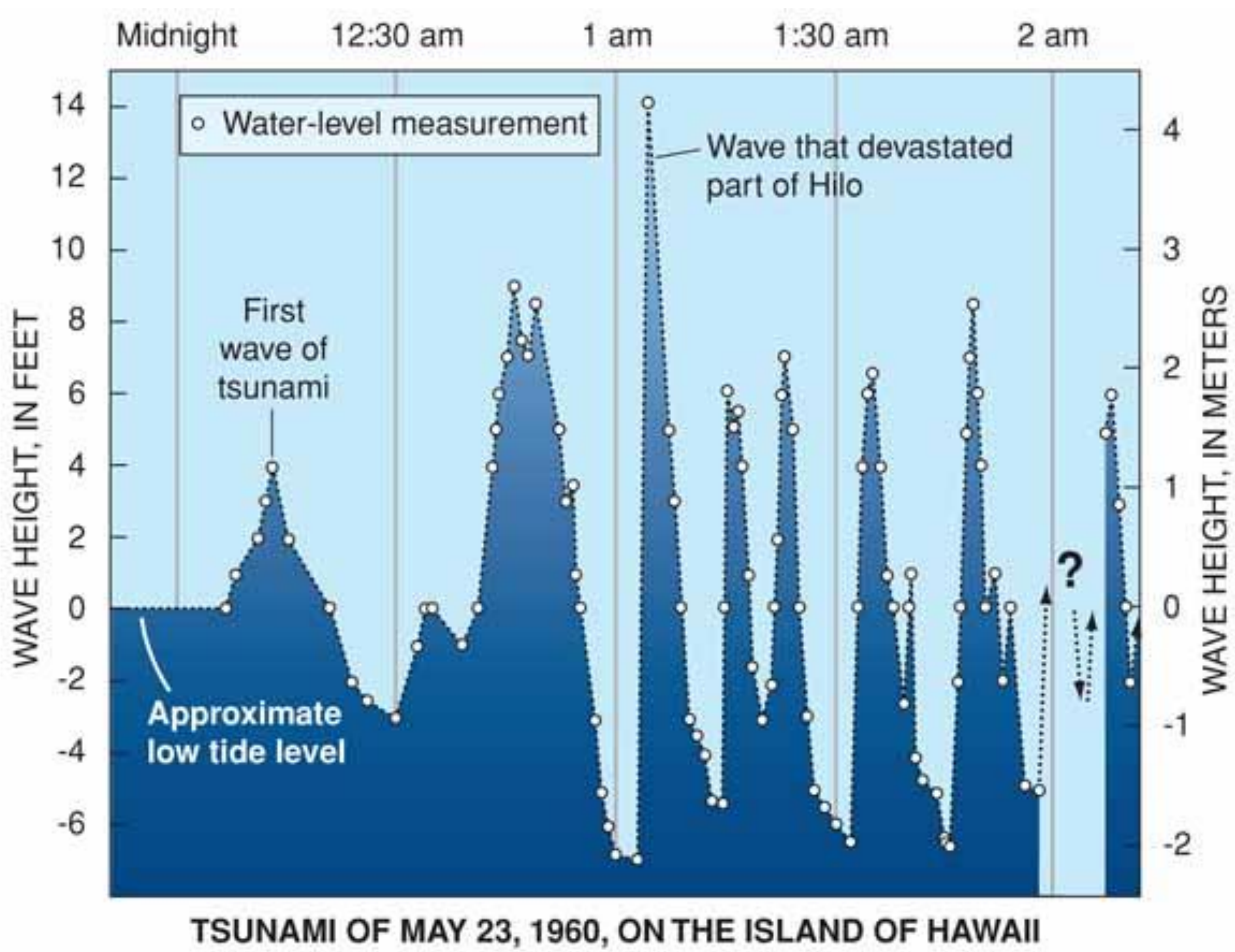

*Tsunami wave height as experienced on land in Hawaii during the 2006 Tonga tsunami. Black is the observed wave height. The colors represent modeled behaviors (simulations). NOAA.*




Tsunami run up height (highest water level rose on the coast) for Banda Aceh, Indonesia and Phuket, Thailand after the 2004 tsunami. Note that each run up graph has its own scale. For example, on the west coast of Banda Aceh, run up height was 35 meters. For the south coast of Phuket island it was 2.5 meters. *Images from USGS.*




*Onagawa Harbor water levels after Chilean tsunami arrived. NOAA*




*1960 Tsunami Wave Height on big island of Hawaii. NOAA*

# Weekly Reflection

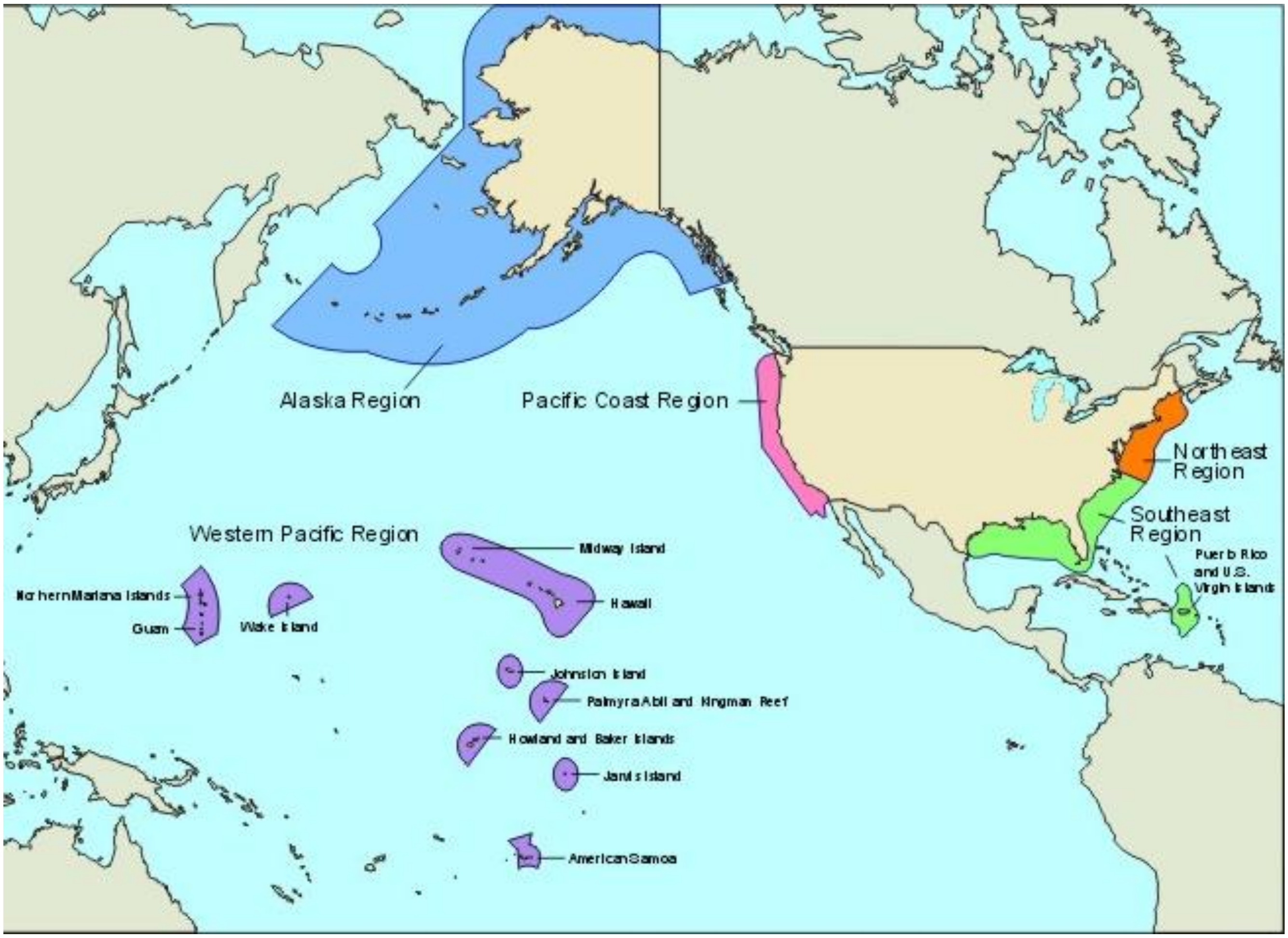
Take a moment to reflect on your comfort level and mastery of the week's objectives and describe an action plan for how you will practice or improve on anything that challenged you.

| **Weekly objective** | **Self-assessment of mastery level** | **Action plan for improvement** |
|---|---|---|
| Compare and contrast**erosional and depositional processes** at work on the shoreline, including their causes and impacts. | A \| B \| C \| D \| F | |
| Evaluate the **sources, sinks, and transport mechanisms for sand** along the shoreline, including seasonal changes to this system. | A \| B \| C \| D \| F | |
| Review the **causes for global (eustatic) sea level change** and the impacts to the shoreline, especially in San Francisco, during the last 2 million years of fluctuating ice ages. | A \| B \| C \| D \| F | |

## AHA! Moments

What content from this week really resonated with you, helped you understand something you've always wondered about, or made you think about the world with new eyes?

# MARINE POLLUTION




*US Exclusive Economic Zone. Image: NOAA*

# Biomagnification, Bioaccumulation, and Mercury

Modified from material found at:

- Woods Hole: http://www.whoi.edu/oceanus/
- USGS http://wi.water.usgs.gov/mercury/mercury-cycling.html
- EPA http://www.epa.gov/hg/

Forms of mercury:
Hg – elemental mercury
$Hg^{2+}$ -- ionized mercury (lost two electrons – thus reactive and ready to combine with sulfur, oxygen, and other reactive materials in the environment
MMHg – monomethyl mercury (or methylated mercury), which is highly toxic to living organisms.

"Alkali and metal processing, incineration of coal, and medical and other waste, and mining of gold and mercury contribute greatly to mercury concentrations in some areas, but atmospheric deposition is the dominant source of mercury over most of the landscape. Once in the atmosphere, mercury is widely disseminated and can circulate for years, accounting for its wide-spread distribution. Natural sources of atmospheric mercury include volcanoes, geologic deposits of mercury, and volatilization from the ocean. Although all rocks, sediments, water, and soils naturally contain small but varying amounts of mercury, scientists have found some local mineral occurrences and thermal springs that are naturally high in mercury."

Sunlight ionizes Hg in the atmosphere – producing $Hg^{2+}$ -- which deposits in surface sediments and waters through rainfall. About 80% of the deposited $Hg^{2+}$ in the ocean converts back to Hg and evaporates. Some of the $Hg^{2+}$ remaining in the ocean adheres to organic particles and falls to the ocean floor, where bacteria convert it to MMHg.

"Studies have shown that bacteria that process sulfate ($SO_4^{=}$) in the environment take up Hg, and through metabolic processes convert it to MMHg. The conversion of Hg to MMHg is important for two reasons: (1) MMHg is much more toxic than Hg, and (2) organisms require considerably longer to eliminate MMHg. MMHg-containing bacteria may be consumed by the next higher level in the food chain, or the bacteria may release the MMHg to the water where it can quickly adsorb to plankton, which are also consumed by the next level in the food chain." (USGS)

MMHg is thought to be produced by bacteria living in oxygen-poor sediments, such as in wetlands, and possibly even in open ocean water at the oxygen-minimum zone (about 400 to 1000 m below the surface).

"The concentration of dissolved organic carbon (DOC) and pH have a strong effect on the ultimate fate of mercury in an ecosystem. Studies have shown that for the same species of fish taken from the same region, increasing the acidity of the water (decreasing pH) and/or the DOC content generally results in higher body burdens in fish. Many scientists currently think that higher acidity and DOC levels enhance the mobility of mercury in the environment, thus making it more likely to enter the food chain." (USGS)

Bioaccumulation happens when an organism ingests a toxin at rates faster than their bodies eliminate them. As a result, continued eating/ingesting means they accumulate each day, more and more. Biomagnification is what happens when these toxins move up the food chain. For example, imagine phytoplankton that have accumulated 10,000 times more MMHg than the seawater around them. Concentrations magnify (biomagnification) ten times for every trophic level of the food chain. (Zooplankton end up with 100,000 times the surrounding mercury levels; herring 1,000,000 times. And so on…)

"MMHg affects the immune system, alters genetic and enzyme systems, and damages the nervous system, including coordination and the senses of touch, taste, and sight. MMHg is particularly damaging to developing embryos, which are five to ten times more sensitive than adults. Exposure to MMHg is usually by ingestion, and it is absorbed more readily and excreted more slowly than other forms of mercury. Hg, the form released from broken thermometers, causes tremors, gingivitis, and excitability when vapors are inhaled over a long period of time. Although it is less toxic than MMHg, Hg may be found in higher concentrations in environments such as gold mine sites, where it has been used to extract gold. If Hg is ingested, it is absorbed relatively slowly and may pass through the digestive system without causing damage." (USGS)

**Hg and Bacteria**

(Modified from information provided by Woods Hole): The toxic form of mercury (Hg) is monomethyl mercury – MMHg – which is produced by bacteria in oxygen-poor sediments. These bacteria respire anaerobically (without oxygen) through a process that reduces sulfate ($SO_4^{2-}$) to sulfide ($S^{2-}$). A byproduct of that respiration process (which is done to release energy for use by the bacteria), is the entrance of Hg into the cells of the bacterial and the methylation of it within the cell (MMHg). The process:

1. Ionized mercury ($Hg^{2+}$) in seawater and sediments does not enter bacterial cells.
2. In low-oxygen environments, bacteria respire (get energy from sugars, for use in metabolic processes) anaerobically. In the process sulfate ($SO_4^{2-}$) in the surrounding water is brought into the cell and reduced to sulfide ($S^{2-}$), which is then expelled.
3. Sulfide ($S^{2-}$) combines with ionized mercury ($Hg^{2+}$) to form mercuric sulfide (HgS).
4. Mercuric sulfide CAN enter (through diffusion) bacterial cells.
5. Inside cells, more chemical reactions replace the $S^{2-}$ in the mercuric sulfide with a methyl group ($CH_3^-$), producing MMHg.
6. MMHg can diffuse out of bacterial cells into the seawater, where it is available for uptake by phytoplankton and then accumulate and magnify up the food chain.

*Bacterial reduction (per above process) happens in sediments in shallow and deep water within the ocean.

**San Francisco Bay and Hg**

In San Francisco Bay, we have a problem with Mercury (Hg). The Hg came from the old gold mining days and is trapped in the sediment at the bottom of the bay. When it is processed by vegetation it becomes methylated and is a huge toxin problem for all organisms. Another problem: when old sediment is mixed up, the Hg enters the water column.

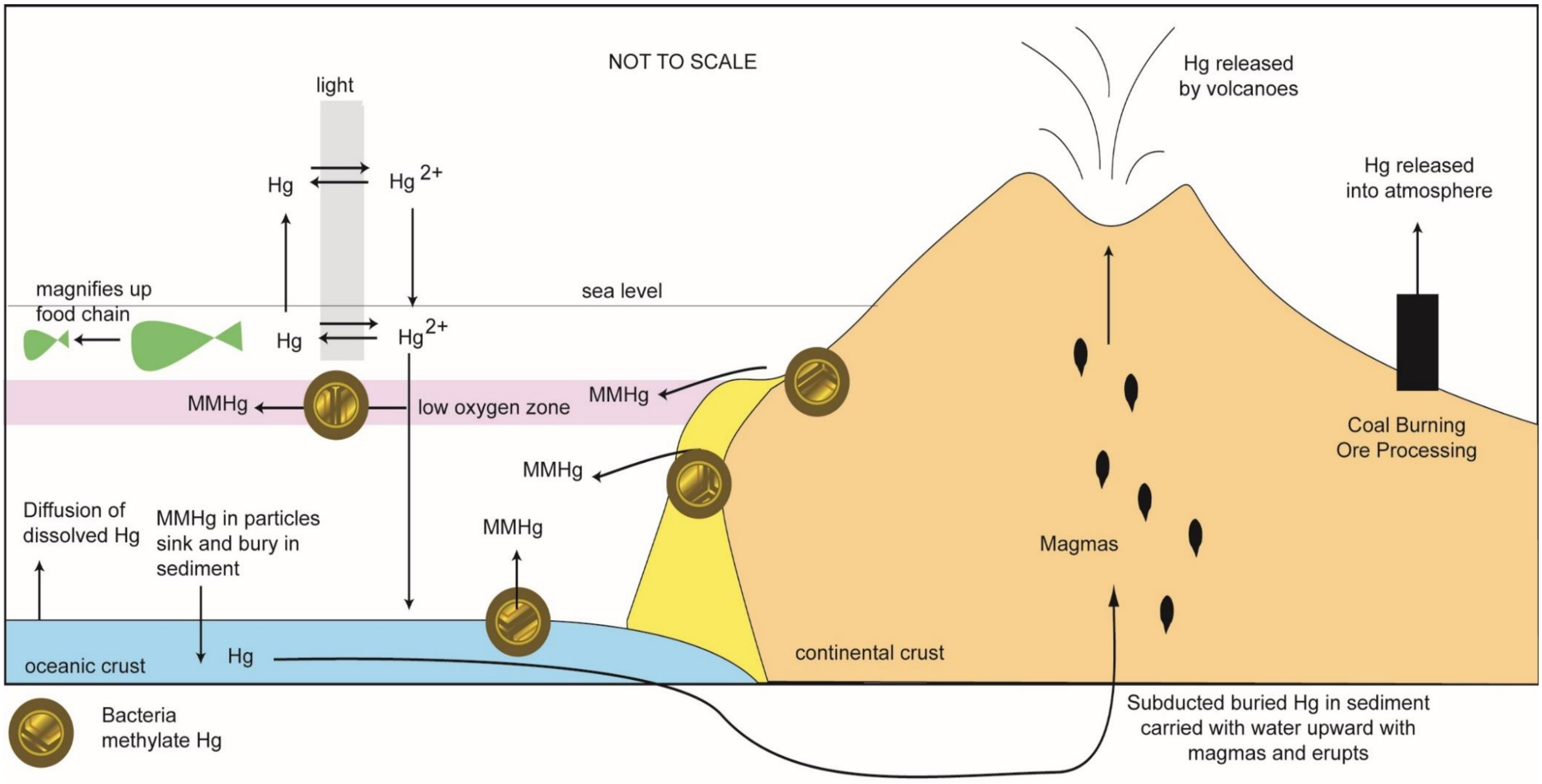



*Diagram showing the movement of mercury (Hg) through the global ecosystem. Image modified from materials from Woods Hole (http://www.whoi.edu/oceanus/)*

# Marine Pollution Chapter Worksheet

| | | |
|---|---|---|
| 1. | Which of the following are considered **pollution?** | **CIRCLE:** Natural oil seeps \| Oil spills (from ships or platforms) \| Oil from roads<br>Hot water from electrical plants \| Pesticides from agricultural runoff<br>Fertilizer from agricultural runoff \| Plastic bags caught in wind or water<br>Detergents from roads \| Drugs (prescription and otherwise) from urine |
| 2. | What are some other types of marine pollution? | |
| 3. | What types of marine pollution last the longest? How long? | |
| 4. | What types of marine pollution last the least amount of time? How long? | |
| 5. | Which of the following is true of **hypoxic zones**? | CIRCLE: high oxygen \| moderate oxygen \| low oxygen<br>commonly found at:<br>CIRCLE: river mouths where nutrients are high \| zones of upwelling |
| 6. | What are the primary results of increased carbon dioxide dissolved in the oceans? | |
| 7. | **Wetland** is an area alternately exposed by low tide and covered by high tide. How often does this cycle repeat? | |
| 8. | How do wetlands benefit the coastal environment? | |
| 9. | What % of San Francisco Bay wetlands have been lost? Why? | |
| 10. | Through what methods do **exotic species** (**biological invaders**) enter a region? What are the negative effects? | |
| 11. | What happens to **bycatch** in the fishing industry? | |
| 12. | California State Waters extend 3 nautical miles offshore. Federal Territorial Waters extend 12 n.mi (22 km). What is the standard width/extension of the shoreline for the **Exclusive Economic Zone (EEZ)?** | |
| 13. | **Nations also have rights to the seabed on their continental shelf out how far?** | |
| 14. | What are the political consequences of the EEZ? What do countries have control over in this zone? | |
| 15. | Where does mercury in the San Francisco Bay Area come from? | |
| 16. | Methylated mercury (Hg) is a difficult chemical for organisms to pass. It remains in the body for a long time. As a result, if an organism eats Hg-laden food at a faster rate than it is eliminated, it will accumulate in the body, reaching toxic levels. This process is called? | |
| 17. | Furthermore, organisms at the top of the food chain will magnify the problem by eating organisms that have already accumulated Hg in their systems. This process is called? | |
| 18. | What are some of the challenges that San Francisco Bay has endured since humans arrived? | |

# Marine Pollution Concept Sketch

Pick one of the many forms of marine pollution you studied and draw a concept sketch below (or on a separate page) that address the following questions:

- What are the sources of this pollution?
- What are the impacts to marine organisms and humans from this pollution? (Be sure to include time scales here for how long this pollution lasts.)
- What can we do to mitigate the negative impacts of this type of marine pollution?
- What about this pollution is of most interest to you, personally? Why did you pick it?

****Note: You will need to do some research before producing your concept sketch.** The expectation is that you will learn additional information beyond what's found in the course materials. Therefore you must reference other sources (reliable, preferably community reviewed sources that involve multiple scientists). Some sample good sources include: NOAA, USGS, NASA, National Geographic, Monterey Bay Aquarium, and Peer-reviewed science journals like Nature. Be sure you carefully cite your sources.

# Weekly Reflection

Take a moment to reflect on your comfort level and mastery of the week's objectives and describe an action plan for how you will practice or improve on anything that challenged you.

| Weekly objective | Self-assessment of mastery level | Action plan for improvement |
|---|---|---|
| Evaluate the variety of **changes humans have made** to the coastal and global ocean environment, including the results of human-built coastal structures, pollution, overfishing, damming of rivers, diversion of river water, and wetland destruction. | A \| B \| C \| D \| F | |
| Analyze the **Exclusive Economic Zone** and its political impacts on the oceans. | A \| B \| C \| D \| F | |

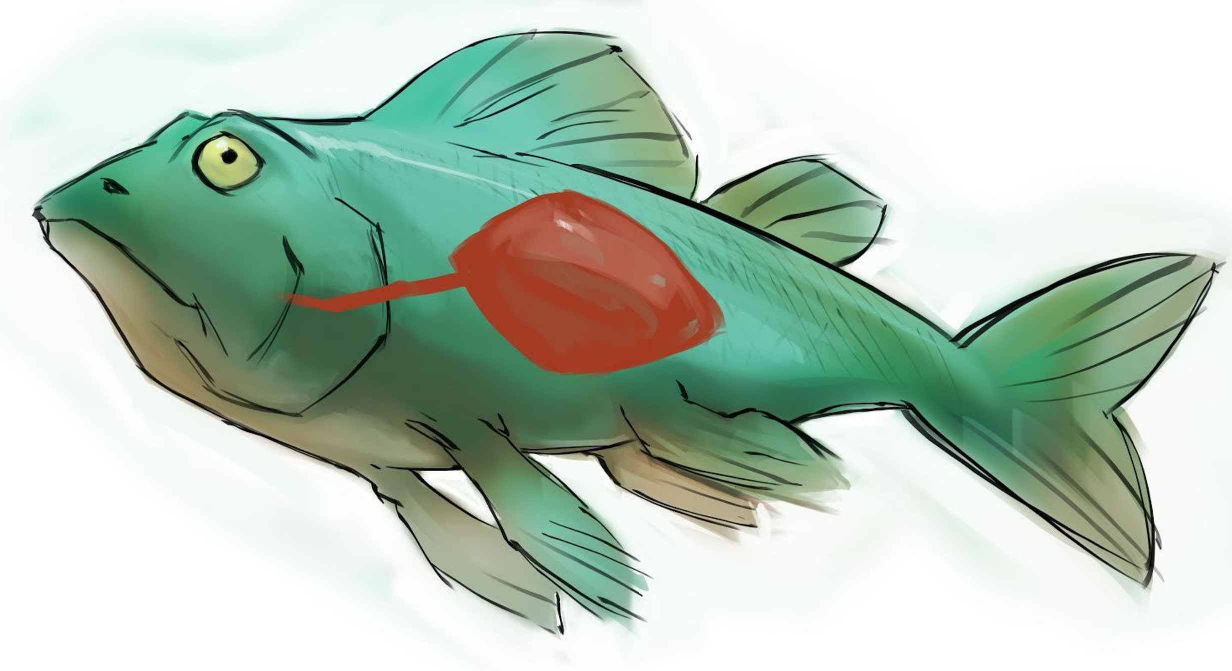
## AHA! Moments

What content from this week really resonated with you, helped you understand something you've always wondered about, or made you think about the world with new eyes?

# LIVING OCEAN &
# MARINE ORGANISMS CLASSIFICATION

## SWIM BLADDERS

Swim bladders are flexible, cigar-shaped gas-containing organs used by most bony fish to maintain neutral buoyancy at any depth. Unlike more rigid gas containers, they can't be crushed – and the fish can travel as deep as necessary. However, they are slow to adjust to changes in pressure, so fish must rise or sink slowly in water. If they rise too quickly (before they can remove enough gas to equalize pressure), the swim bladder will blow up like a bag of potato chips carried to the mountains. If they drop too quickly (before the fish can add gas to equalize pressure), the swim bladder will be crushed, like a water bottle brought from the mountains down to sea level.

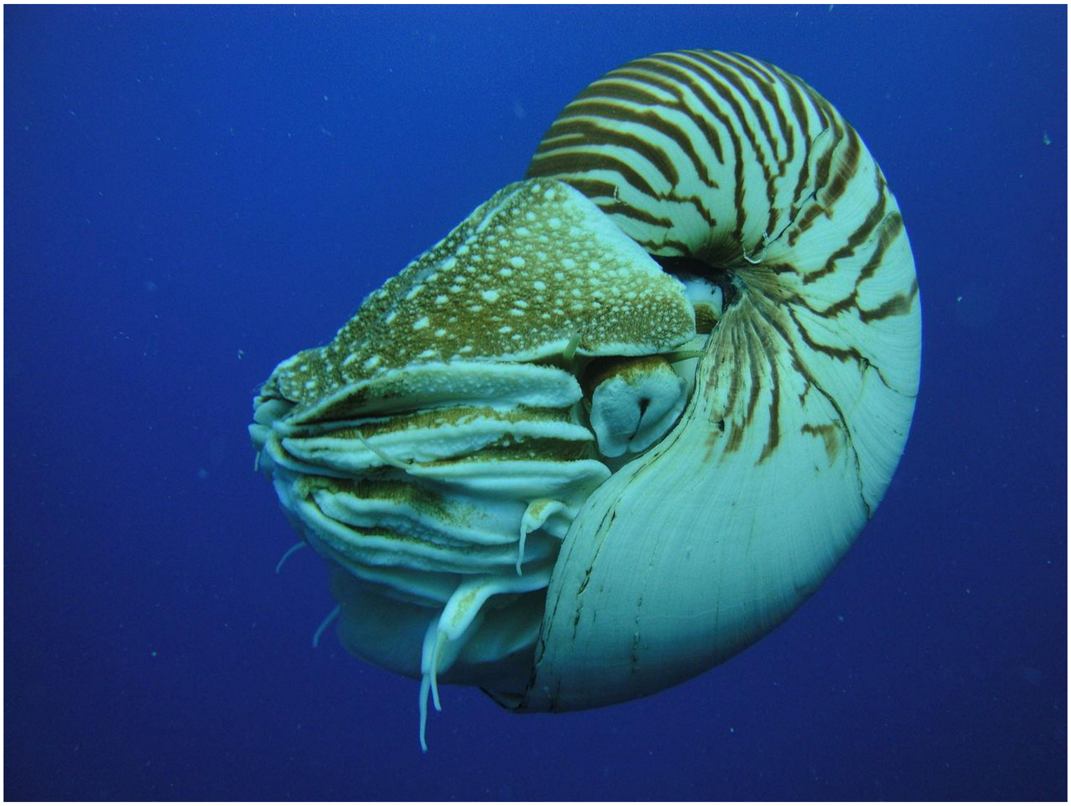


ABOVE IMAGE: Swim bladder muscles relax; more gas fills bladder (from blood flow – arteries); fish is less dense and can rise upward and equilibrate to new pressure while still maintaining neutral buoyancy. Image: Matt Lao © used with permission.

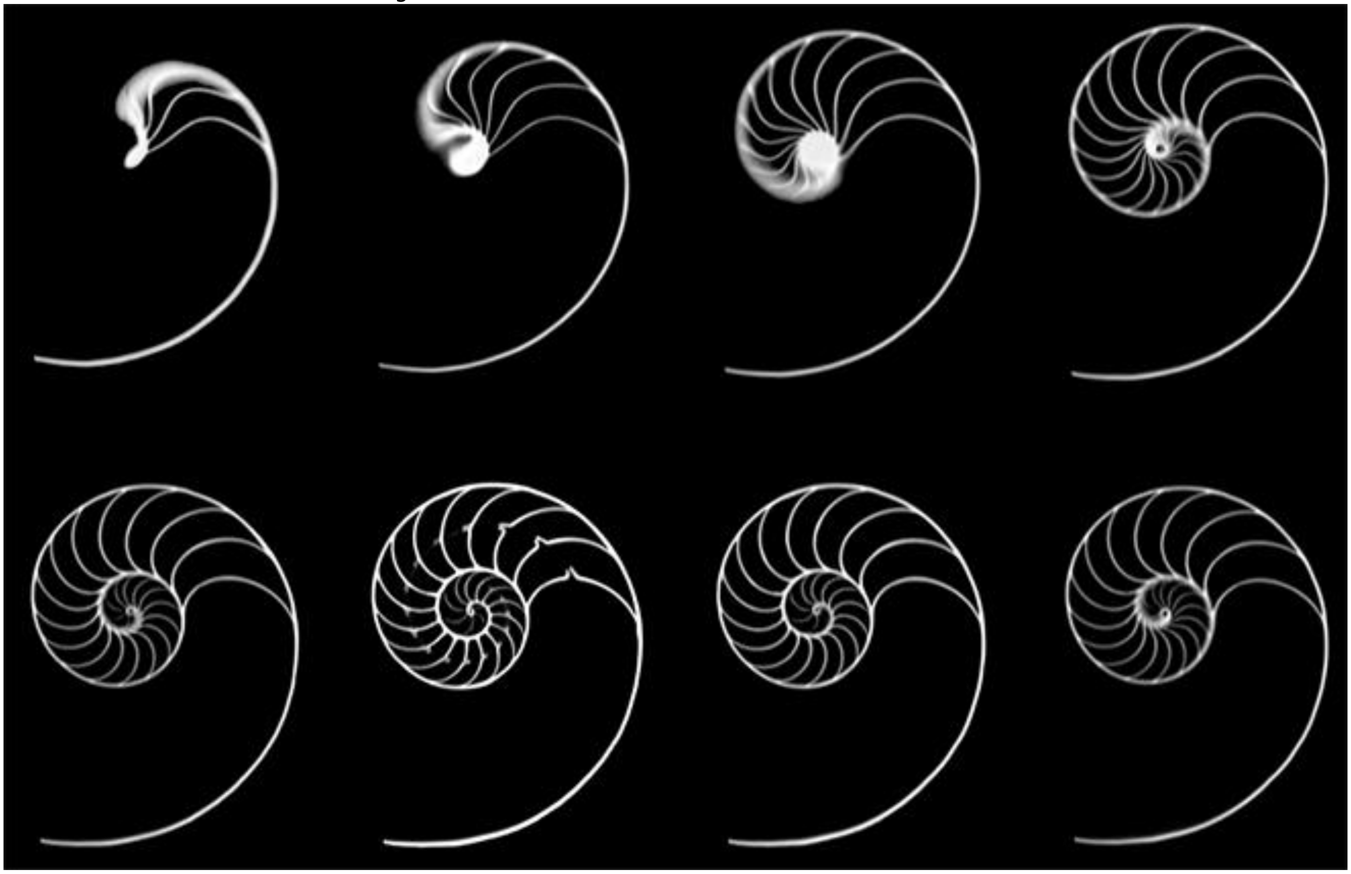
ABOVE IMAGE: Swim bladder muscles tighten, gas leaves bladder (goest into blood flow – arteries); fish is denser and can sink downward and equilibrate to new pressure while still maintaining neutral buoyancy. Image: Matt Lao © used with permission.

## GAS CONTAINERS

Gas containers are rigid containers (like chambers in a shell) that contains gas. They are used to help an organism achieve neutral buoyancy. However, they work only for relatively shallow depths. If an organism with a rigid gas container travels too deep in the oceans, the high pressures will crush the container. On the other hand, organisms with rigid gas containers can rise and fall within the water column quickly, because they do not rely on internal gas equilibration to maintain the shape of the container.



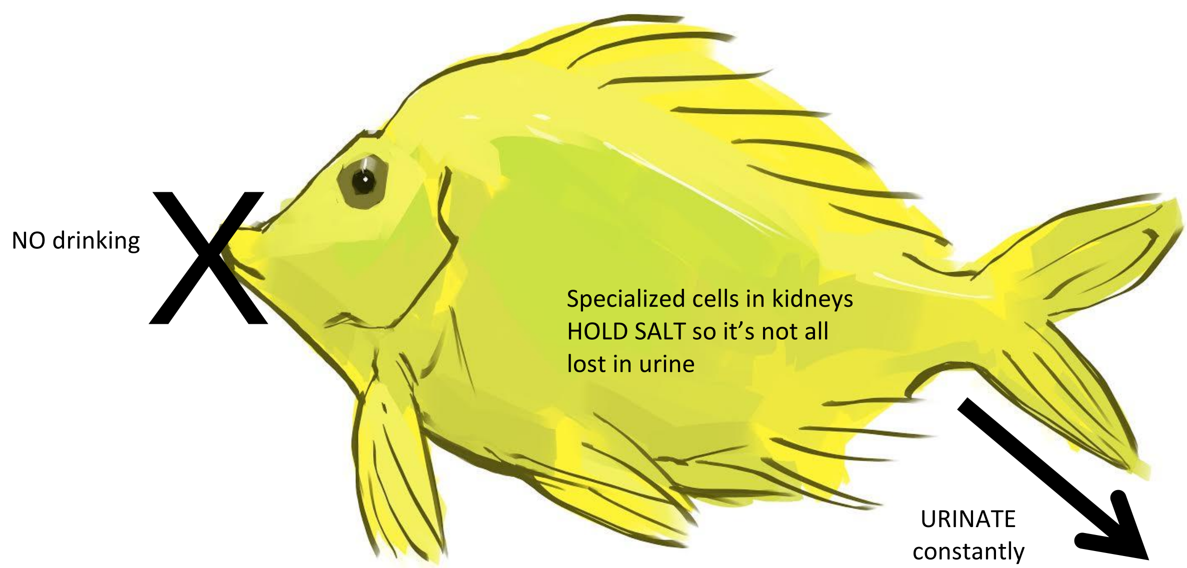
*Chambered Nautilus from Palau. These organisms have chambers within their shell (see image below of the cross-sections through a variety of chambered nautilus shells). Above image: CC BY-SA 3.0 – Attribution: Manuae.*
*Lower image: CC BY-SA 4.0 – Attribution: Forian Elias Rieser.*



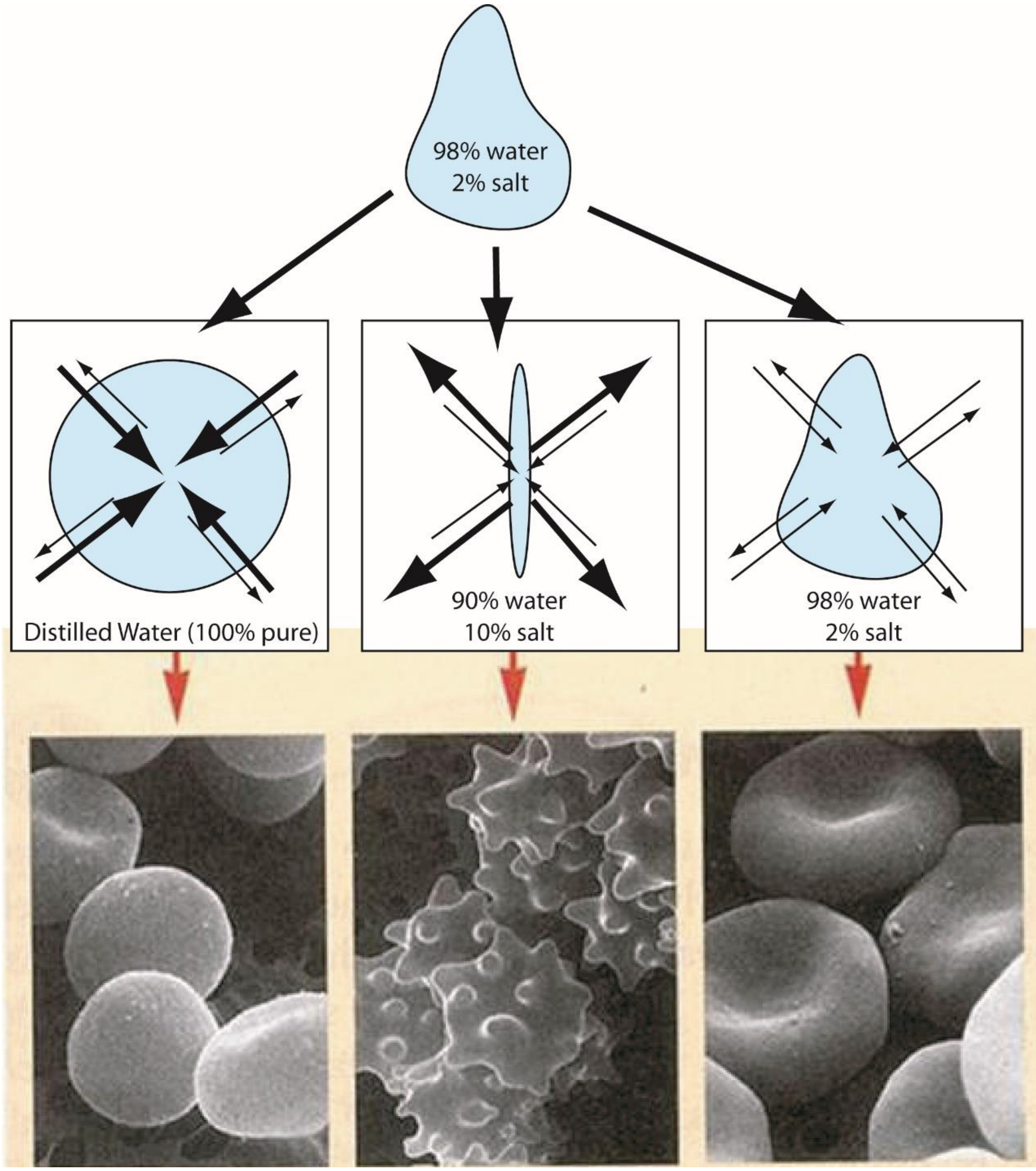
## FISH & OSMOSIS

Bottom line: during osmosis, only water moves across a cell wall/membrane. It moves in the direction that has the highest dissolved ion concentration. Think of it as "Water follows salt." Or… water moves in the direction it needs to go to dilute the saltier side, so the two sides have the same salinity.


ABOVE IMAGE: Saltwater fish. Saltier solution is OUTSIDE fish – in ocean. At all times in this fish, its own water wants to move outward to dilute the oceans. Fish image: Matt Lao © used with permission.




ABOVE IMAGE: Freshwater fish. Saltier solution is INSIDE fish – in cells. At all times in this fish, the lake or river water wants to move inward to dilute the fish. Fish image: Matt Lao © used with permission.

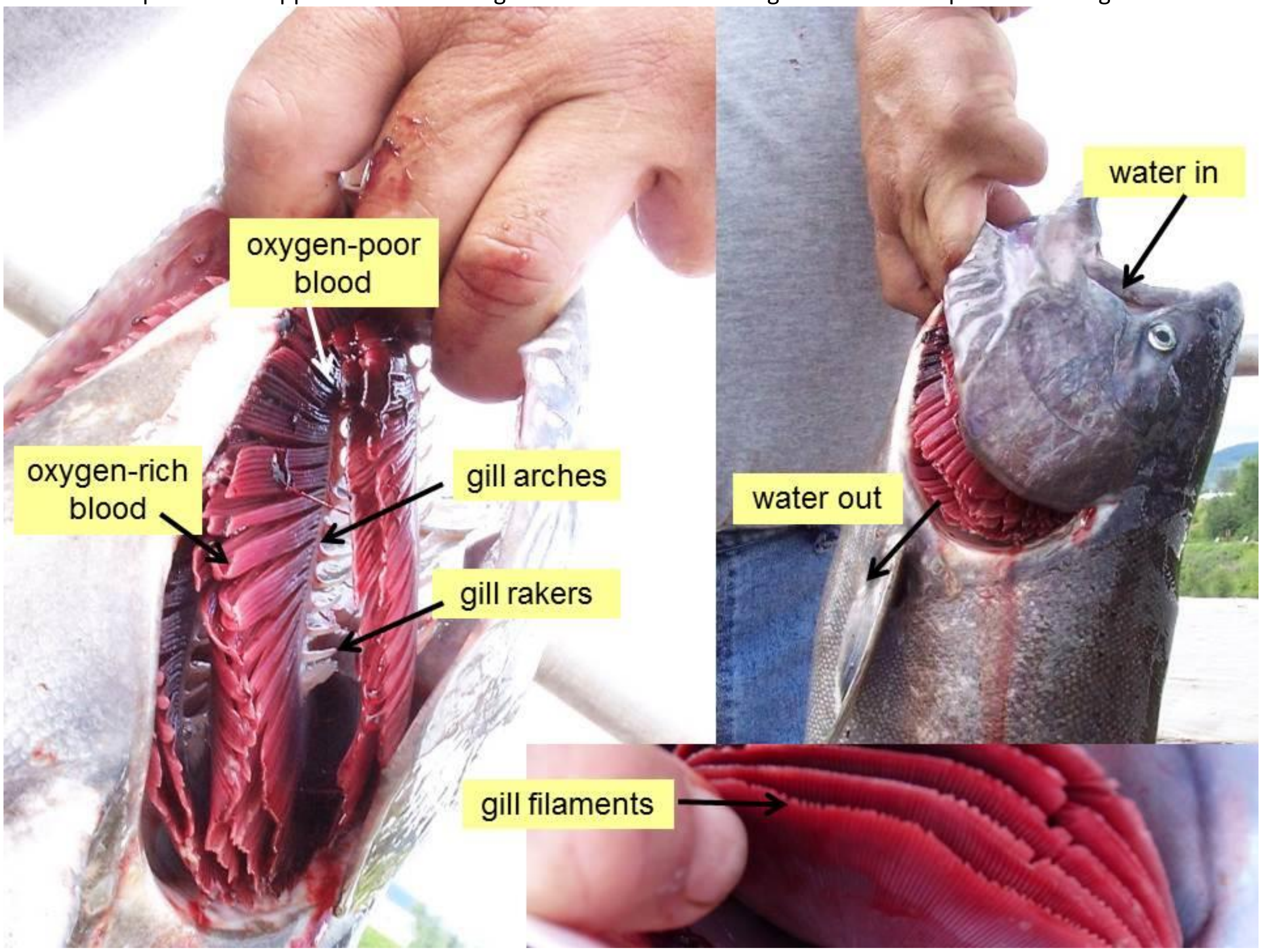



*Causes and effects of osmosis in cells. Image modified from original unknown source.*

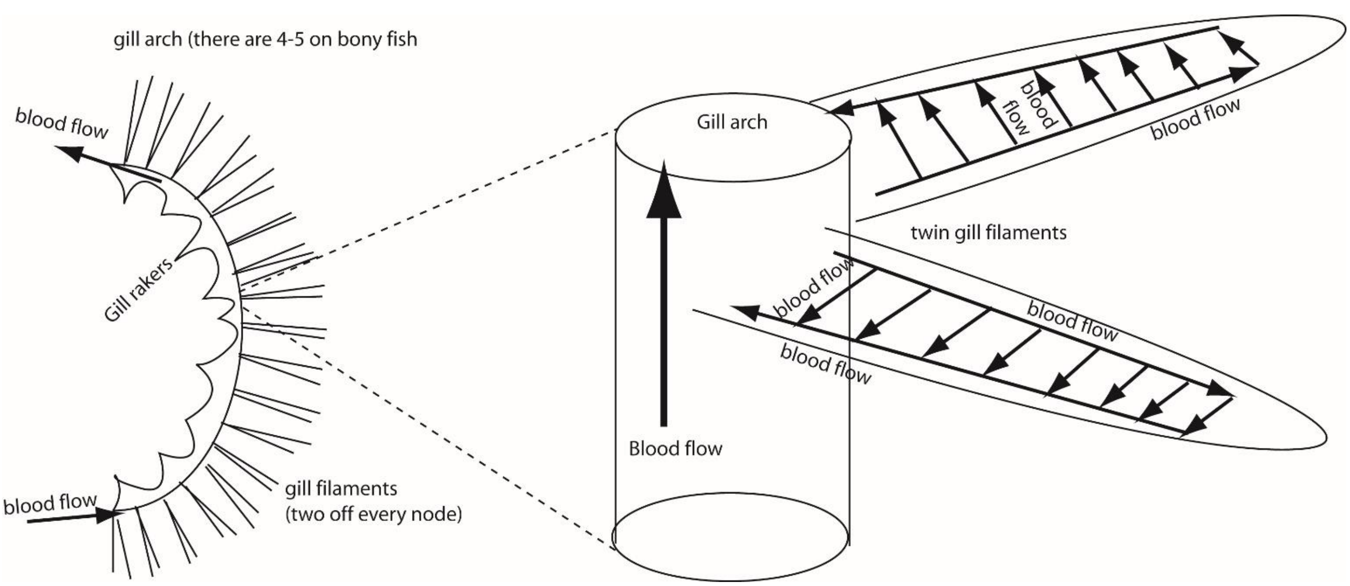
| | Salt-water fish | Fresh-water fish |
|---|---|---|
| OSMOGREG-ULATION STRATEGIES | Body fluids less salty than surroundings. Uses gills to excrete excess salt; drinks a lot of water and urinates little. | Body fluids more salty than surroundings. Body's cells absorb salt; drinks little water and urinates a lot. |
| RESULTS IF DOESN'T WORK? | Loses body's water to surroundings, so could desiccate. | Body gains water from surroundings, so could swell and burst. |

## FISH & GILLS

Fish use gills to exchange gases – bringing in oxygen used for metabolic cellular respiration and removing carbon dioxide produced as a byproduct. Cartilaginous fish have gill slits – Bony fish, an operculum, a single flap that is attached to the mouth and open on the opposite side allowing water that enters through the mouth to pass over the gills and out.



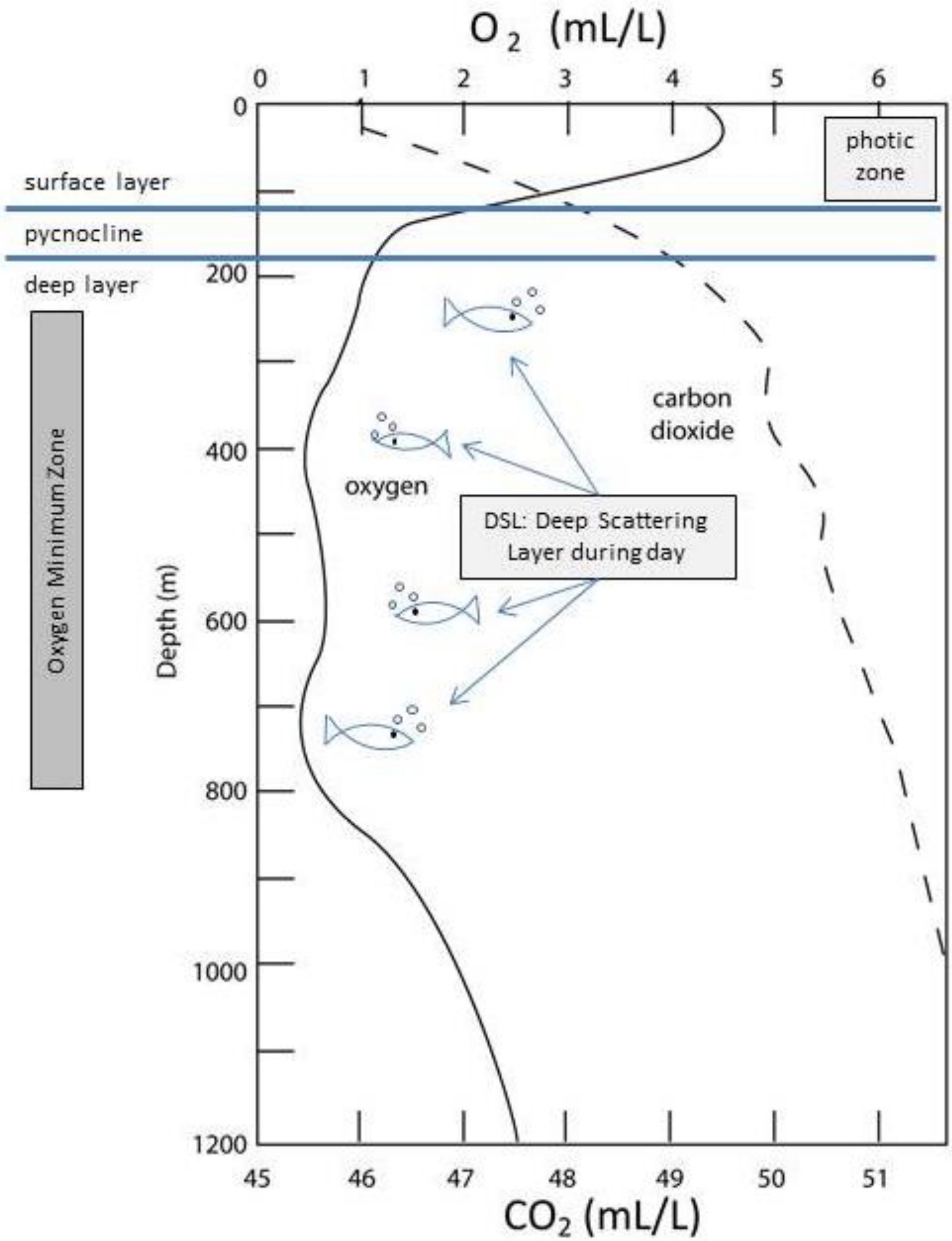

*Gills of a salmon, caught in the Bulkley River, British Columbia. NOTE: operculum is flap that covers gills:*




*Schematic of blood flow through gill arches and filaments. As water moves across the filaments, oxygen diffuses into the flood and carbon dioxide out. 85% of the oxygen available in the water surrounding the gills can be captured by the gills, thanks to their incredibly large surface area.*

## DEEP SCATTERING LAYER

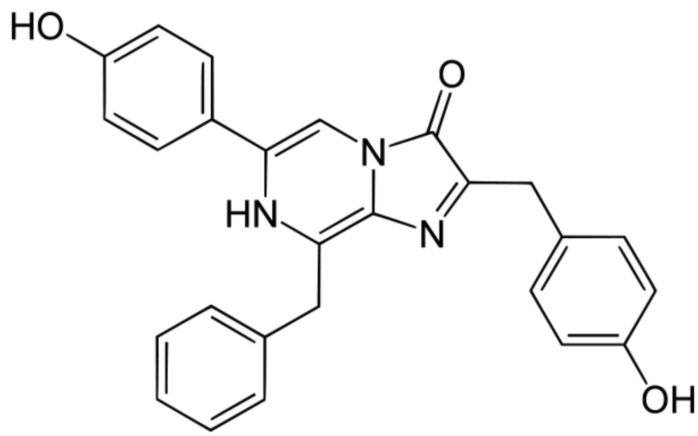
The deep scattering layer (DSL) is the large population of marine heterotrophs like krill, copepods, jellyfish, and small fish that hang out below the photic zone during the day to hide in the safety of darkness from their predators. They deplete oxygen at this depth due to their respiration (and no oxygen sources or even mixing with surface waters – as they are below the pycnocline). They return to the surface at night to feed, again, in the safety of darkness. The autotrophs on which they feed hang out exclusively in the photic zone where there's enough light during the day for photosynthesis. The base of the photic zone is defined as the depth at which only 1% of surface light remains. At that depth, net productivity = 0, which means that the amount of sugar produced through photosynthesis matches exactly the sugar needed for a given organism to survive (but no growth). Below this depth, while there's still enough light for photosynthesis, there's not enough light for autotrophs to meet their own needs. As such, the base of the photic zone is also called the **compensation depth for photosynthesis**.



## HOW BIOLUMINESCENCE WORKS

**Luciferins** are a class of substrates that are naturally present in bioluminescent organisms. We call the luciferin a substrate because it acts as a site for a chemical reaction. First, the enzyme **luciferase** attaches to the outside of the luciferin molecule, which then gives oxygen an attachment site as well. When all three are attached, a chemical reaction produces light, the luciferase is released, and oxyluciferin is the final product.

There are a number of luciferins used by a variety of marine and terrestrial organisms. Bacterial luciferin is found in bacteria, some of which live in colonies within specialized organs in squid and fish species. The light produced by these organisms is actually produced by the bacteria living within them. *Coelenterazine* is a luciferin found in organisms such as radiolarians, cnidarians, squid, copepods, fish, and shrimp. It emits blue light. Dinoflagellate luciferin is a derivative of chlorophyll and is found in dinoflagellates as well as some types of euphausiid shrimp. *(Content from Wikipedia.)*



*Coelenterazine (public domain license)*

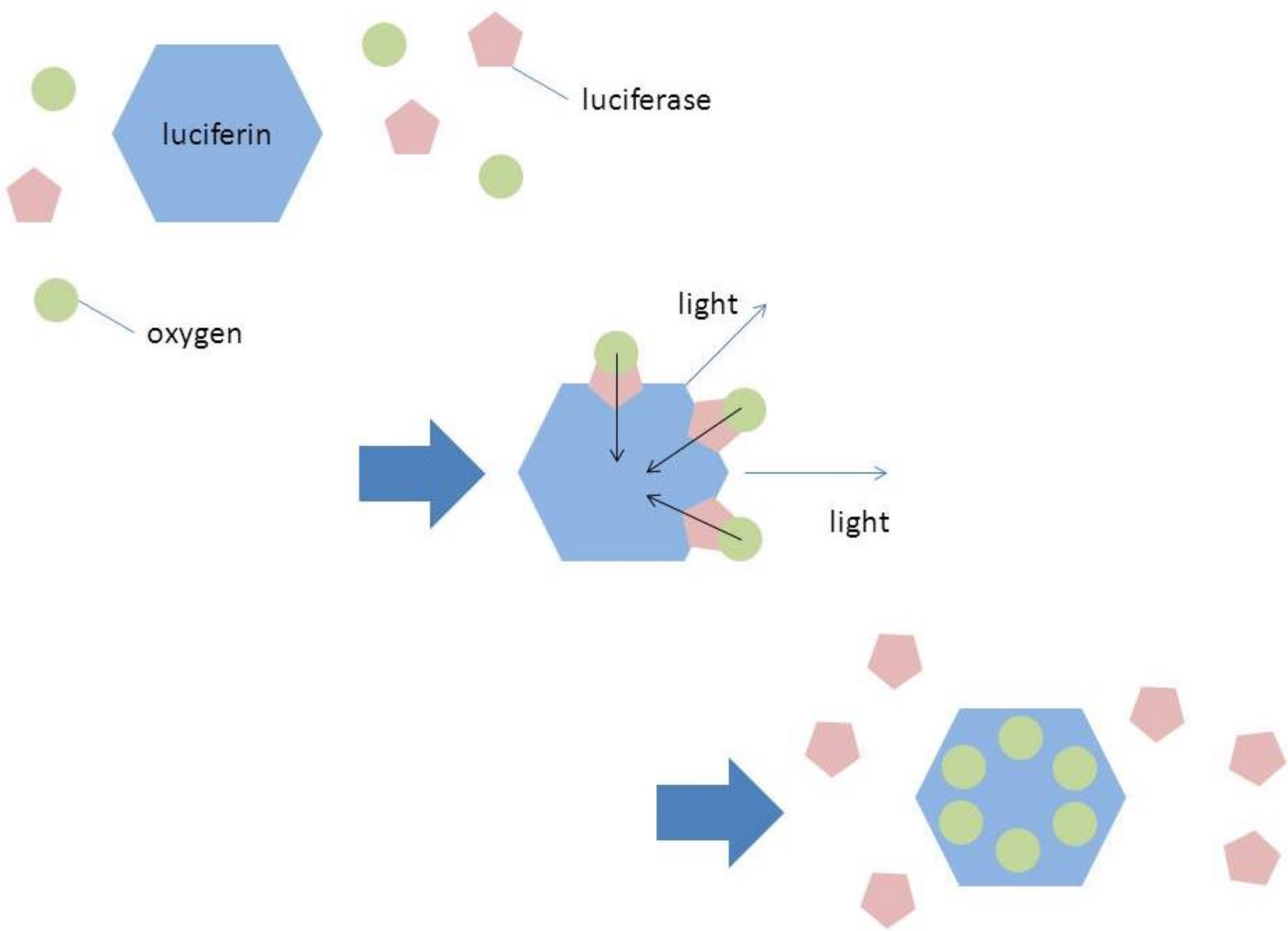
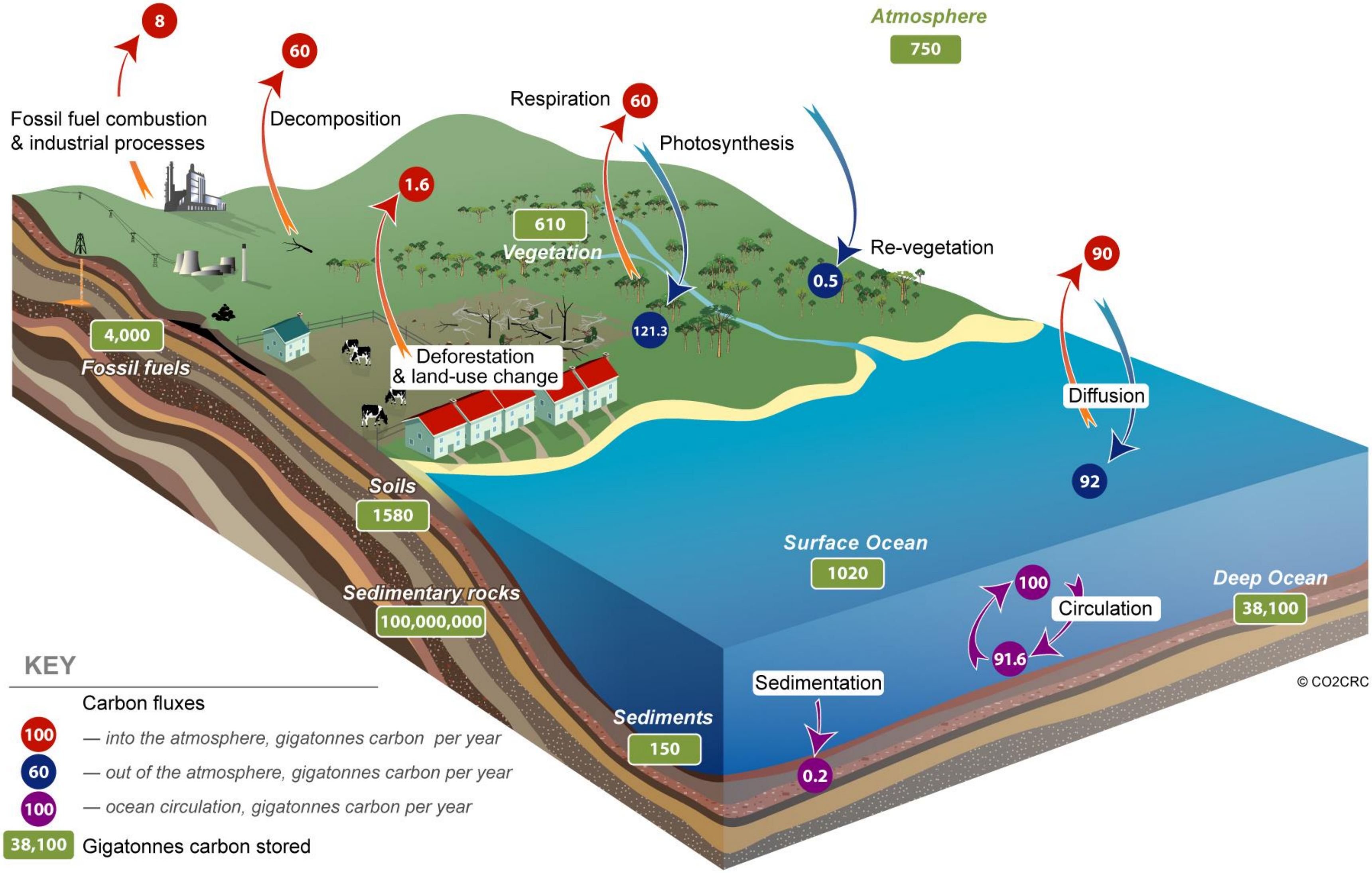



*Diagram depicting the chemical process behind bioluminescence.*




*The average $CO_2$ storage in a variety of reservoirs (shown with numbers in green squares) and exchanges of $CO_2$ between different reservoirs. Image source: CO2CRC (used with permission)*

# Living Organisms Chapter Worksheet

| | |
|---|---|
| 1. What is the size of the **smallest** organism in the ocean? | 2. What is that organism? |
| 3. What is the size of the **largest** organisms in the ocean? | 4. What is that organism? |

5. Pelagic organisms that cannot swim faster than currents are (CIRCLE: benthos | nekton | plankton)
6. Organisms that live in or on the sea bottom are (CIRCLE: benthos | nekton | plankton)
7. Organisms that swim freely from one location to another are (CIRCLE: benthos | nekton | plankton)
8. Salmon: (CIRCLE: benthos | nekton | plankton)
9. Clams, oysters, mussels: (CIRCLE: benthos | nekton | plankton)
10. Seaweed stuck to a rock: (CIRCLE: benthos | nekton | plankton)
11. Sargassum weed that floats in currents the Sargasso Sea: (CIRCLE: benthos | nekton | plankton)
12. Whales: (CIRCLE: benthos | nekton | plankton)
13. Jellyfish: (CIRCLE: benthos | nekton | plankton)
14. Diatoms, coccolithophores, radiolarian, foraminifera: (CIRCLE: benthos | nekton | plankton)

15. **REVIEW:** What is the definition of **viscosity**?

16. What type of water is most viscous? (CIRCLE: hot | cold | fresh | salty)

17. What type of water do microscopic **plankton** prefer? (CIRCLE: high viscosity | low viscosity) Why?

18. What are some adaptations plankton have developed to help them stay afloat?

19. Some nekton and plankton use swim bladders or gas containers to help stay afloat. Which of these allows for swift migration up and down the water column without fear of bodily harm? CIRCLE: swim bladder | gas container

20. Which of these is soft and takes time to regulate? CIRCLE: swim bladder | gas container

21. Which types of marine organisms are least likely to be able to handle increasing **pressure**s and thus are absent from the deep ocean? Why?

| | |
|---|---|
| 22. **REVIEW:** How much light remains at the base of the photic zone | 23. **REVIEW:** What color of light is absorbed first in seawater? |
| 24. **REVIEW:** What color of light is absorbed last in open-ocean seawater? | 25. **REVIEW:** What color of light is absorbed last in coastal seawater? |

26. What is the name of the base of the photic zone?

27. What types of organisms reside in the **Deep Scattering Layer (DSL)?**

28. Where and when does the **Deep Scattering Layer (DSL)** migrate and why?

29. What is a major consequence of the **Deep Scattering Layer (DSL)**? Where? Why?

| | |
|---|---|
| 30. What are the various reasons that marine organisms use **bioluminescence**? | |
| 31. In **bioluminescence**, how is the light created? *(review description in preceding image pages)* | |

| **32.** | **Endothermic** | **Ectothermic** |
|---|---|---|
| **Definition: internal body temperature set how?** | | |
| **Food requirements** | HIGH \| Medium \| LOW | HIGH \| Medium \| LOW |
| **Affected by local temp** | HIGH \| Medium \| LOW | HIGH \| Medium \| LOW |
| **Ability to travel widely** | HIGH \| Medium \| LOW | HIGH \| Medium \| LOW |

33. What does increased temperature do to ectothermic organisms?
34. What does decreased temperature do to ectothermic organisms?
35. What do ectothermic organisms do when the surrounding temperature changes substantially?
36. Give an example of one kind of organism that benefits from ocean **currents**, and explain why.
37. Give an example of one kind of organism that suffers from ocean **currents**, and explain why.
38. **Diffusion** is a type of molecular transport that works quickly across small distances but takes longer across large distances. Molecules move **FROM** (CIRCLE: high concentration | low concentration)
    **TO** (CIRCLE high concentration | low concentration).
    Equilibrium is reached when what is true?
39. Diffusion happens in the lungs of blue whales, the gills of fish, and the cell walls of single-celled organisms.
    What substance diffuses into the blood from the lungs (or into the blood from the water, in gills)?
40. What substance diffuses out of the blood into the lungs (or out of the blood into the water, in gills)?
41. Which organ is the most efficient (allows for the greatest gas transfer)? CIRCLE: Lungs | Gills
42. What is the name of the part of a bony fish that covers its gill filaments?
43. Which substances would diffuse in or out of a single-celled marine organism?
    CIRCLE: oxygen | carbon dioxide | Silica | Calcium | Waste | Nutrients | Toxins | Pollutants | Water
44. Which substances transfer across a cell wall/membrane during osmosis?
    CIRCLE: oxygen | carbon dioxide | Silica | Calcium | Waste | Nutrients | Toxins | Pollutants | Water
45. What direction does **salt** move across your body's cell walls during osmosis when you're swimming in seawater? CIRCLE: into the body | out of the body | neither
46. What direction does **water** move across your body's cell walls during osmosis when you're swimming in seawater? CIRCLE: into the body | out of the body | neither
47. What direction does **salt** move across your body's cell walls during osmosis when you're swimming in freshwater? CIRCLE: into the body | out of the body | neither
48. What direction does **water** move across your body's cell walls during osmosis when you're swimming in freshwater? CIRCLE: into the body | out of the body | neither

49. **REVIEW:** Which of the following are **sources** for the **carbon** cycle? CIRCLE: volcanic outgassing | respiration | shell deposition| fossil fuel burning | rice paddy methane production | buried vegetation| atmosphere | decomposition | methane hydrates trapped on sea bottom | methane hydrates released (melted) | photosynthesis | weathering of rocks/shells

***Methane hydrates are ice crystals made of water and methane. Formed when methane gas percolates out of marine sediment in deep ocean.*

50. **REVIEW:** Which of the following are **sinks** for the **carbon** cycle? CIRCLE: volcanic outgassing | respiration | shell deposition| fossil fuel burning | rice paddy methane production | buried vegetation| atmosphere | decomposition | methane hydrates trapped on sea bottom | methane hydrates released (melted) | photosynthesis | weathering of rocks/shells

51. **REVIEW:** Where is carbon dioxide gas **most abundant** in the oceans? Why?
CIRCLE: Surface | near pycnocline | at depth

52. **REVIEW:** Where is carbon dioxide gas **least abundant** in the oceans? Why?
CIRCLE: Surface | near pycnocline | at depth

53. **REVIEW:** Which of the following are **sources** for the **oxygen** cycle? CIRCLE: photosynthesis | decomposition | atmosphere |respiration | burial and sedimentation

54. **REVIEW:** Which of the following are **sinks** for the **oxygen** cycle? CIRCLE: photosynthesis | decomposition | atmosphere |respiration | burial and sedimentation

55. **REVIEW:** Where is oxygen gas **most abundant**? Why? CIRCLE: Surface | near pycnocline | at depth

56. **REVIEW:** Where is oxygen gas **least abundant**? Why? CIRCLE: Surface | near pycnocline | at depth

| **57.** | **Commensalism** | **Mutualism** | **Parasitism** |
|---|---|---|---|
| Effect on host? | Benefit \| Harm \| Neither | Benefit \| Harm \| Neither | Benefit \| Harm \| Neither |
| Effect on symbiont? | Benefit \| Harm \| Neither | Benefit \| Harm \| Neither | Benefit \| Harm \| Neither |
| Examples: | | | |

58. Which type of symbiosis describes a mixotroph (such as coral that have a garden of algae living within them; the coral feed off their garden and their waste goes directly into fertilizing/providing nutrients to the algae)?
CIRCLE: commensalism | mutualism | parasitism

# Marine Taxonomic Classification Activity

Review the following Taxonomic Classification information, and use it to answer the following questions.

## Taxonomic Classification of A SUBSET OF Marine Organisms

*(Modified from Garrison T, Oceanography: An Invitation to Marine Science, 5th edition, Appendix VI, pp. 475-476)*
*While you should know the classifications for all the organisms listed here, the BOLDED TERMS are the classification levels you are responsible for on exams. Also, please note that this list is a SUBSET of marine organisms – there are many more animal phylum, especially various worm phyla, than listed below.*

**PROKARYOTES (no nucleus, no sexual reproduction)** *(first evolved 3.8 Ga)*

**KINGDOM BACTERIA:** Single-celled prokaryotes with a single chromosome that reproduce asexually and exhibit high metabolic diversity. Some roles in oceans: base of food chain, converters of nitrogen gas into useful forms for organisms, decomposers. Some species are heterotrophs; some are autotrophs. *Cyanobacteria* (*stromatolites*).

**KINGDOM ARCHAEA:** Superficially similar to bacteria, but with genes capable of producing different kinds of enzymes. Often live in extreme environments. Some species are heterotrophs; some are autotrophs.

****NOTE: Some classifications combine the two kingdoms above into one: MONERA***

++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

**EUKARYOTES (nucleus, sexual reproduction)** *(first evolved 2.0 Ga)*

**KINGDOM PROTISTA:** Eukaryotic single-celled, colonial, and multicellular autotrophs and heterotrophs.

single celled:

PHYLUM CHRYSOPHYTA. Single-celled autotrophs with $SiO_2$ or $CaCO_3$ shells:
*Diatoms (*$SiO_2$ *shells) with two separate valves (halves); coccolithophores (*$CaCO_3$ shells); *silicoflagellates*.
PHYLUM PYRROPHYTA. *Dinoflagellates, zooxanthellae*. Mostly single-celled flagellates with two dissimilar flagella. Heterotrophic and autotrophic forms.
PHYLUM SARCODINA. Amoebas and their relatives.
Class Rhizopodea. *Foraminiferans*.
Class Actinopodea. *Radiolarians*.

multicelled:

PHYLUM **BROWN ALGAE** (PHAEOPHYTA). Brown algae, kelps. *Kelps (oakblade kelp, feather boa kelp, giant kelp, bullwhip kelp), sea palms, rockweed.*
PHYLUM **RED ALGAE** (RHODOPHYTA). Red algae, encrusting and coralline forms. *Encrusting and articulated coralline algae, brillo pad algae, Neptune's washcloth, sea sacs, iridescent algae, nori.*
PHYLUM **GREEN ALGAE** (CHLOROPHYTA). Multicellular green algae. *Sea strings, sea lettuce, ocean pin cushion.*

**KINGDOM FUNGI:** *Fungi, mushrooms, molds, lichens*; mostly land, freshwater, or highest supratidal organisms; heterotrophic – live in food and digest outside their body.

**KINGDOM PLANTAE:** Covered seeds. Photosynthetic multicellular autotrophs that evolved from Green algae. Primarily terrestrial. Roots, leaf-bearing shoots; gas exchange through leaves. Waxy coating on leaves prevents excessive water loss. Hardening of cell walls of woody tissues for support on land.
Only division found in marine environment is
DIVISION ANTHOPHYTA. Flowering plants (angiosperms). Most species are freshwater or terrestrial. Marine species include: *eelgrass, manatee grass, surf grass, turtle grass, salt marsh grasses, mangroves*.

**KINGDOM ANIMALIA:** Multicellular heterotrophs that ingest their food.

# KINGDOM ANIMALIA

## INVERTEBRATES:

PHYLUM **PORIFERA**. *Sponges.* Simplest of all marine animals. Sessile. Porous. Filter feeders. No nervous, digestive, respiratory, or circulatory system. Diffusion of wastes, nutrients, gases in and out cell walls. (Separate holes for in/out.) Water drawn into pores by beating of flagellated cells inside body. Body walls supported by spicules ($SiO_2$ or $CaCO_3$). Filters 3000x body volume/day.

PHYLUM **CNIDARIA**. Jellyfish and their kin; all are equipped with stinging cells; 9,000 species. Radial symmetry. Mouth, the only opening, is shaped like hollow pouch: tentacles line opening. Hollow = digestive cavity. Diffusion moves wastes and gases between mouth and body. No excretory or circulatory system. Reproduce by fission of polyps (sessile; mouth up) usually creating colonies or produce medusae (planktonic; mouth down) forms, which swim away, produce sperm and eggs, which combine to create polyp. (Some species do both.) Carnivores, save rare types with zooxanthellae.

- Class Hydrozoa. Polyp-like animals that often have a medusa-like stage in their life cycle, such as *Portuguese man-of-war*, *Hydroids, Siphonophores.*
- Class Scyphozoa. Jellyfish with no (or reduced) polyp stage in life cycle. *Sea Nettles, Moon Jellies.*
- Class Cubozoa. *Sea wasps*.
- Class Anthozoa. Medusa stage absent. Polyps only. *Sea anemones, coral*.

PHYLUM **ECHINODERMATA**. Spiny-skinned, benthic, radially symmetrical, as adults (bilaterally as larvae) most with a water-vascular system: a network of hydraulic canals branching into extensions called tube feet that are used to move, feed, and exchange gases.. Internal and external parts radiate from center, often as five spokes. Thin skin covers endoskeleton of hard calcareous plates. Most prickly from skeletal bumps and spines. Digestion with mouth and anus on opposite sides of body. 6000 species. Lack eyes or brain.

- Class Asteroidea. *Sea stars*.
- Class Ophiuroidea. *Brittle stars, basket stars*.
- Class Echinoidea. *Sea urchins, sand dollars, sea biscuits*.
- Class Holothuroidea. *Sea cucumbers*.

PHYLUM **BRYOZOA**. Common, small, encrusting colonial marine forms. Most widespread and numerous sessile marine animals. Live inside conjoined calcite square boxes. LOPHOPHORES (all have circular structure spirally wound and lined around entire perimeter with ciliated tentacles). U-shaped digestive tract. No head. Filter feeders.

PHYLUM **MOLLUSCA**. Mollusks. (58,000 marine species). Soft bodied, usually protected by a hard $CaCO_3$ shell. Three parts to body: muscular foot, usually used for movement; visceral mass containing most internal organs; mantle: a fold of tissue that drapes over visceral mass and secretes shell if one present. Many have toothed radula used for digging holes in rocks, removing algae from rocks, etc. Most have gills, anus, and excretory pores. Obvious heads, flow-through digestion, well-developed nervous system (with brains). Most have separate sexes with gonads (ovaries or testes). U-shaped digestive tract, with incurrent siphon and excurrent siphons.

- Class **Polyplacophora**. Shell with eight plates (articulated). Head reduced. *Chitons*.
- Class **Gastropoda**. Asymmetric body plan, usually with coiled shell. Foot cannot attach to sand or mud. Grazers, suspension feeders, predators, some planktonic. Radula rasped across rocks, kelp stipes, or surfaces. 43,000 sp. *Snails, limpets, abalones, pteropods, sea slugs* (*nudibranchs*; no shells), *sea hares, whelks*.
- Class **Bivalvia**. Enclosed in twin shells. Head reduced. Filter feeders. Paired gills. Dig with foot. Mantle forms siphons that extend to obtain water and eject waste. 13,000 sp. *Clams, oysters, scallops, mussels, shipworms.*
- Class **Cephalopoda**. Head surrounded by foot, divided into tentacles. Stiff adhesion discs on tentacles (suction cups) catch prey. Sharp beaks tear and bite. Shells reduced, absent, or internal. Locomotion by jet propulsion using siphon made from mantle. 450 species. *Squid, octopus, nautilus, cuttlefish.*

PHYLUM **ANNELIDA**. Segmented bilaterally symmetrical worms. Each segment has its own circulatory, excretory, nervous, muscular, and respiratory systems. Some are specialized, such as the head. 5400 species. Primary Class: Polychaetes (many bristles). Brightly colored or iridescent with pairs of bristly projections extending from each segment. Can be herbivores, carnivores, deposit feeders, filter feeders (tube dwellers). *Feather Duster worm.*

PHYLUM **ARTHROPODA**. Segmented. Body of two or three parts. Three or more pairs of legs. Jointed appendages (pincers, mouthparts, walking legs, and swimming appendages; and two pairs of sensory antennae). Bilateral symmetry. Exoskeleton. Striated muscles. Head with pair of eyes. Flow-through linear digestive tract. Most successful of all animal phyla.

- Subphylum Crustacea. Jaw like mandibles (30,000 species*). Copepods, barnacles, krill, isopods, amphipods, shrimp, lobsters, crabs*.
- Subphylum Chelicerata. Claw like feeding appendages. *Horseshoe crabs, sea spiders*.

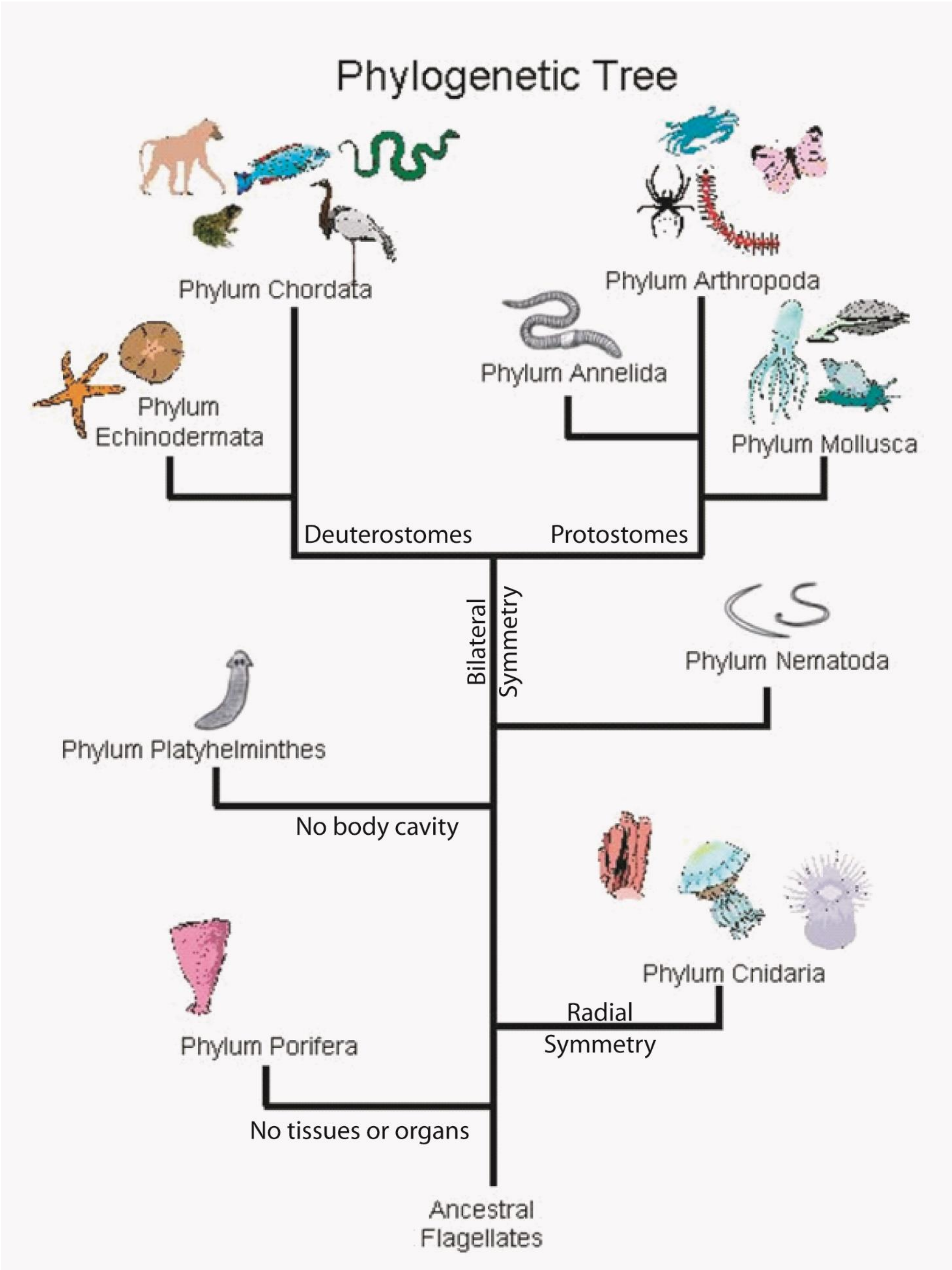
PHYLUM **CHORDATA**. (45,000 species); four structures appear at some point during lifetime: notochord, dorsal, hollow nerve chord, gill slits, muscular, post anal tail.

Subphylum **Urochordata**. Notochord disappears in adult stage. U-shaped digestion with incurrent and excurrent siphons. Mostly sessile. Filter feeders. Some colonial. Covered by tunic with 2 openings: water in and water out. *Sea squirts, tunicates, salps*.

## VERTEBRATES:

Subphylum **Vertebrata**. Notochord or backbone present throughout lifecycle. Flow-through linear digestive tract.

- Class **Jawless fishes** (Agnatha). 50 species. Cartilaginous skeleton. Gill slits. Rasping tongue. Notochord. No paired appendages to swim. External fertilization. *Lampreys, hagfishes.*
- Class **Cartilaginous fishes** (Chondrichthyes). Cartilaginous skeleton and jaws with teeth. Respiration through gills. Internal fertilization (eggs or live birth); acute senses including lateral line. Paired fins. No swim bladder. Gill slits instead of operculum. *Sharks, skates, rays, sawfish, chimeras.*
- Class **Bony fishes** (Osteichthyes). Hard, strong, light-weight bony skeletons and jaws. Operculum covers gills. Most have external fertilization and lay large numbers of eggs. Respiration through gills. Many have swim bladder. *Salmon, pike, parrot fish, barracuda, tuna, eels, sea horses, sea dragons*
- Class **Reptilia**. Tetrapods with scaly skin; respiration via lungs; lay amniotic shelled eggs or give live birth. Ectotherms. Special salt glands concentrate and excrete excess salts from body fluids. Except for one turtle, require warm waters. *Sea snakes* (50 species). *Marine crocodile* (1 species): lives in mangrove swamps and reef islands. *Sea turtles*: small streamlines hells without space to retract head or limbs. No predators as adults, save humans.
- Class **Birds** (Aves). Tetrapods with feathers. Forelimbs modified as wings. Respiration through lungs. Internal fertilization. Breed on land. Lay eggs on land. Shelled amniotic eggs. Acute vision. Endotherms. *Penguins (*No ability to fly. Use wings to swim. Great maneuverability.) *Gulls*. 115 species. *Pelicans*. // *Albatross, petrels*. *Tubenoses*. (Beak: sense airspeed, smells, and ducting for removing saline water from glands.)
- Class **Mammalia**. Warm-blooded tetrapods with young nourished from mammary glands of females. Hair. Diaphragm that ventilates lungs. Amniotic sac. Most: live birth. 4300 marine species (evolved from land mammals returning to sea 30-40 Ma).
  - Order **Cetacea**. 79 species. Fish-shaped bodies; paddle-like forelimbs and no hind limbs. Thick layer of insulating blubber.
    - Suborder Odontoceti: **Toothed whales**; *Pilot whales, belugas, killer whales, bottlenose dolphins. Porpoise*. *Sperm whale. Narwhales*.
    - Suborder Mysticeti: **Baleen whales** *Gray whales*. Short baleen. Can sieve bottom seds. // *Humpback, fin, sei, blue, Bryde's, minke*. Dorsal fins and grooved distensible throats expand like balloons. Swallowers. //*Black right whale, bowheads*. Lack grooved throats and dorsal fins. Largest baleen. Skimmers.//
  - Order **Sirenia**. Herbivores. Possess finlike forelimbs and no hind limbs. *Manatees, Dugongs (sea cows).*
  - Order **Carnivora**. Two marine families. Carnivorous. Possess sharp, pointed canine teeth and molars for shearing. Clawed toes.
    - Suborder Pinnipedia. Flipper-footed. Can safely come out on land to rest, breed, and give birth. Thick, insulating blubber.
      - Family Phocidae: True seals; No external ear (hole only). Crawl on land because front flippers are small, and hind flippers cannot rotate forward. Swimming power from large, almost fan-like rear flippers. *Harbor seals, elephant seals*.
      - Family Otariidae: External ear. Rotatable rear flippers: can walk on land. Swimming power from large front flippers. *Fur seal, sea lion*.
      - Family Odobenidae: Two long tusks. No external ear. Rotatable rear flippers: can walk on land. Two large air pouches extend from each side of the pharynx; inflate to hold head above water when sleeping, or used as resonance chambers for underwater sounds. *Walrus.*
    - Suborder Fissipedia. Toe-footed carnivores (usually land animals). No blubber – warmth comes from fur.
      - Family Mustelidae: Smallest marine mammals. Usually do not inhabit the open ocean. Live among coastal kelp beds, where they dive and hunt for a variety of shellfish and marine invertebrates. Exceptionally thick dark fur; a longer tail; no true flippers. *Sea otters*.
      - Family Ursidae: Bear family. Only marine species: *Polar bear.* Carnivorous. Depends on the ocean for a majority of food. Large head, heavily built body. Stocky legs terminate in paws, with hairy soles, and five claws. Spend most of the winter asleep in a den living off stored fat reserves.
  - Order Primates. One family that regularly enters the ocean.




*Evolutionary progression of major marine life forms. Image: modified from original unknown source*

# PART I: MARINE ORGANISMS CHARACTERISTICS

1. **REVIEW:** The first organisms to exist on planet Earth:
   (CIRCLE: eukaryotes | prokaryotes) When did they first exist?
2. **REVIEW:** Organisms with a nucleus: (CIRCLE: eukaryotes | prokaryotes)
   Organisms with sexual reproduction: (CIRCLE: eukaryotes | prokaryotes)
   Organisms with the highest oxygen needs: (CIRCLE: eukaryotes | prokaryotes)

**Kingdoms/Domains**

3. Organisms with roots and covered seeds CIRCLE: Animals | Archaea&Bacteria | Fungi | Plants | Protista
4. Prokaryotes CIRCLE: Animals | Archaea&Bacteria | Fungi | Plants | Protista
5. Eukaryotes CIRCLE: Animals | Archaea&Bacteria | Fungi | Plants | Protista
6. Single-celled autotrophs CIRCLE: Animals | Archaea&Bacteria | Fungi | Plants | Protista
7. Single-celled heterotrophs CIRCLE: Animals | Archaea&Bacteria | Fungi | Plants | Protista
8. Multi-celled autotrophs CIRCLE: Animals | Archaea&Bacteria | Fungi | Plants | Protista
9. Multi-celled heterotrophs CIRCLE: Animals | Archaea&Bacteria | Fungi | Plants | Protista

**Animal phyla**

10. Simplest animals – just a body supported by glass spicules and covered in pores (no mouth or digestive tract)
    CIRCLE: Annelid | Arthropod | Bryozoan | Cnidarian | Echinoderm | Mollusk | Porifera | Chordata
11. 5-radiating body structure, water vascular system, tube feet, and spiny extrusions covering endoskeleton
    CIRCLE: Annelid | Arthropod | Bryozoan | Cnidarian | Echinoderm | Mollusk | Porifera | Chordata
12. No brain CIRCLE: Annelid | Arthropod | Bryozoan | Cnidarian | Echinoderm | Mollusk | Porifera | Chordata
13. Makes its own stinging cells, radial symmetry, mouth is only opening
    CIRCLE: Annelid | Arthropod | Bryozoan | Cnidarian | Echinoderm | Mollusk | Porifera | Chordata
14. Usually has a shell of some kind, a foot, a mantle, and internal organs including u-shaped digestive tract
    CIRCLE: Annelid | Arthropod | Bryozoan | Cnidarian | Echinoderm | Mollusk | Porifera | Chordata
15. U-shaped digestive tract, lives in calcium carbonate houses conjoined into encrusting or branching forms.
    CIRCLE: Annelid | Arthropod | Bryozoan | Cnidarian | Echinoderm | Mollusk | Porifera | Chordata
16. Worms with identical segments (but with specialized head) and flow-through digestion.
    CIRCLE: Annelid | Arthropod | Bryozoan | Cnidarian | Echinoderm | Mollusk | Porifera | Chordata
17. Segmented body, flow-through digestion, paired appendages and antennae, striated muscles, exoskeleton
    CIRCLE: Annelid | Arthropod | Bryozoan | Cnidarian | Echinoderm | Mollusk | Porifera | Chordata
18. Most complex of all animals – most recently evolved – advanced nervous system with nerve chord
    CIRCLE: Annelid | Arthropod | Bryozoan | Cnidarian | Echinoderm | Mollusk | Porifera | Chordata
19. Eyes CIRCLE: Annelid | Arthropod | Bryozoan | Cnidarian | Echinoderm | Mollusk | Porifera | Chordata

**Mollusk classes**

20. Chitons – shells made of 8 articulated plates CIRCLE: Polyplacophora | Gastropod | Bivalve | Cephalopod
21. Snails, limpets, abalone – just one shell CIRCLE: Polyplacophora | Gastropod | Bivalve | Cephalopod
22. Mussels, clams, oysters, scallops – two hinged shells
    CIRCLE: Polyplacophora | Gastropod | Bivalve | Cephalopod
23. Octopus, squid, cuttle fish, nautilus – most intelligent of all invertebrates
    CIRCLE: Polyplacophora | Gastropod | Bivalve | Cephalopod
24. **Chordata subphyla** Loses back bone after larval stage CIRCLE: Urochordata | Vertebrata

**Vertebrata classes**

25. Endotherms CIRCLE: Birds | Bony fish | Cartilaginous fish | Jawless fish | Mammals | Reptiles
26. Have jaws CIRCLE: Birds | Bony fish | Cartilaginous fish | Jawless fish | Mammals | Reptiles
27. Lay eggs CIRCLE: Birds | Bony fish | Cartilaginous fish | Jawless fish | Mammals | Reptiles
28. External fertilization CIRCLE: Birds | Bony fish | Cartilaginous fish | Jawless fish | Mammals | Reptiles
29. Cartilaginous skeletons CIRCLE: Birds | Bony fish | Cartilaginous fish | Jawless fish | Mammals | Reptiles
30. Lungs – breathe air CIRCLE: Birds | Bony fish | Cartilaginous fish | Jawless fish | Mammals | Reptiles

**Mammal orders**

31. Four limbs – spend some time on land CIRCLE: Carnivora | Cetacea | Sirenia
32. Live in mangrove swamps and eat sea grasses CIRCLE: Carnivora | Cetacea | Sirenia
33. Have hair or fur CIRCLE: Carnivora | Cetacea | Sirenia
34. At least some have NO blubber CIRCLE: Carnivora | Cetacea | Sirenia

# PART II: MARINE ORGANISMS MATCHING

Move the following marine organisms to their correct taxonomic classification row below. Abalone, Barnacle, Blue Whale, Branching Bryozoan, California Gray Whale, Chiton, Clam, Copepod, Coral, Crab, Crocodile, Dolphin, Feather Duster Worm, Giant Green Sea Anemone, Great White Shark, Hagfish, Harbor Seal, Killer Whale, Krill, Lamprey, Limpet, Lobster, Manatee, Moon Jelly, Moray Eel, Mussel, Nautilus, Octopus, Pelican, Penguin, Salmon, Sand Dollar, Scallop, Sea Cow, Sea Cucumber, Sea Gull, Sea Horse, Sea Lion, Sea Otter, Sea Snail, Sea Star, Sea Turtle, Sea Urchin, Shrimp, Snail, Sperm Whale, Sponges, Squid, Sting Ray, Tuna, Tunicate , Walrus. ***Example shown for sponges.***

| | | | | |
|---|---|---|---|---|
| PORIFERA *sponges* | | | | |
| CNIDARIA | | | | |
| ARTHROPOD | | | | |
| BRYOZOANS | | | | |
| MOLLUSCA | Polyplacophora | | | |
| | Gastropod | | | |
| | Bivalve | | | |
| | Cephalopod | | | |
| ANNELID | | | | |
| ECHINODERM | | | | |
| CHORDATA | Urochordata | | | |
| | Vertebrata | Jawless fish | | |
| | | Cartilaginous fish | | |
| | | Bony fish | | |
| | | Reptile | | |
| | | Aves | | |
| | | Mammal | Cetacea | Toothed whale |
| | | | | Baleen whale |
| | | | Sirenia | |
| | | | Carnivora | |

# Weekly Reflection

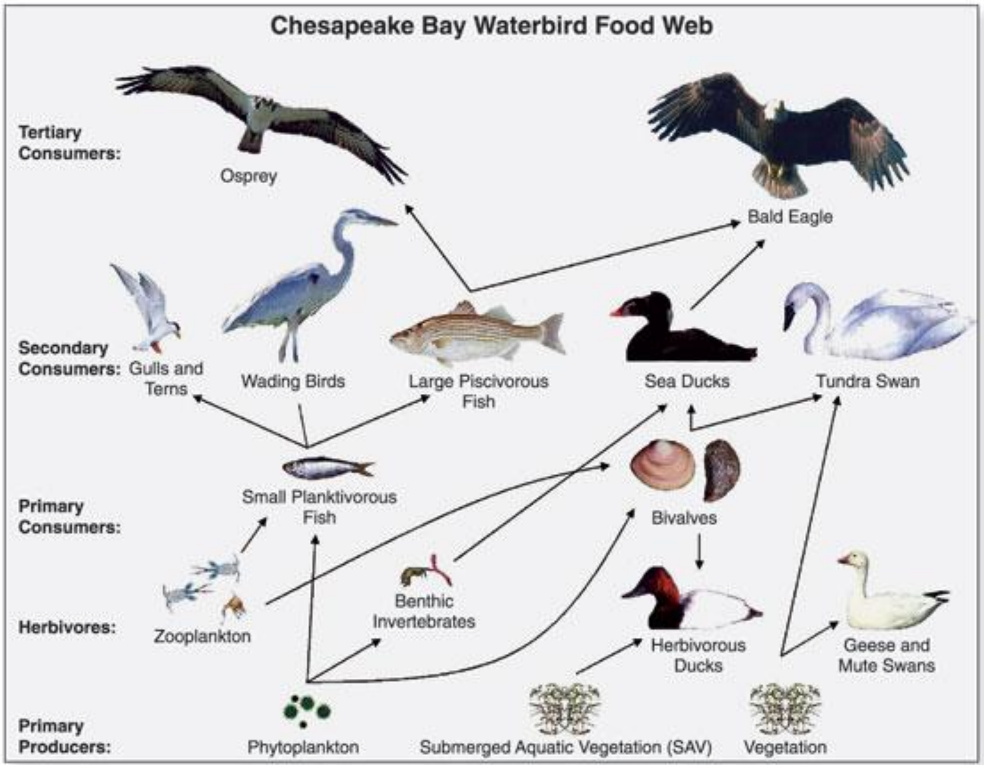
Take a moment to reflect on your comfort level and mastery of the week's objectives and describe an action plan for how you will practice or improve on anything that challenged you.

| **Weekly objective** | **Self-assessment of mastery level** | **Action plan for improvement** |
|---|---|---|
| Evaluate the similarities, differences, and evolutionary progression of marine organisms by **classifying them by taxonomy, location, energy needs, and behaviors**. | A \| B \| C \| D \| F | |
| Compare and contrast the variable **impacts of ocean viscosity, light availability, currents, and pressures** on the marine organism behavior and distribution, including adaptations developed to maximize success in a variety of environments. | A \| B \| C \| D \| F | |
| Compare and contrast the **processes of osmosis and diffusion** and their uses by and impacts on marine life. | A \| B \| C \| D \| F | |
| Evaluate the sources, sinks, transport mechanisms, and distribution of **carbon and oxygen gases and nutrients in the oceans**. | A \| B \| C \| D \| F | |
| Compare and contrast **symbiotic relationships** among marine organisms. | A \| B \| C \| D \| F | |

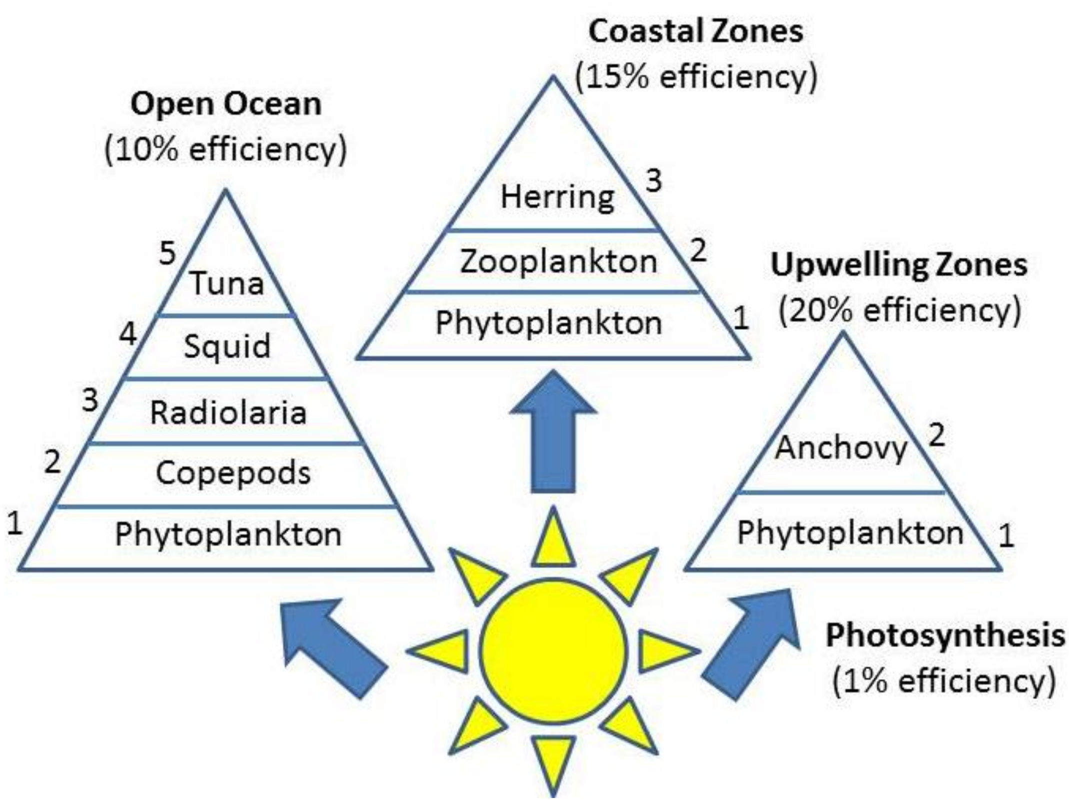
## AHA! Moments

What content from this week really resonated with you, helped you understand something you've always wondered about, or made you think about the world with new eyes?

# PRODUCTIVITY & PLANKTON




*Chesapeake Water bird Food Web – USGS – Energy transfer efficiency is 1% from sunlight to photosynthesizers, and approximately 10% from trophic level 1 (producers) to trophic level 2 (and subsequent levels as well). Note that a single organism might eat at multiple levels. For example: bivalves are filter feeders. They filter all plankton out of the water – zooplankton and phytoplankton – when eat the former, they are at trophic level 3; the latter, trophic level 2.*




*Energy flow through sample food pyramids. (Trophic Levels noted with numbers.)*

# Marine Autotrophs

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single celled:

PHYLUM CHRYSOPHYTA. Single-celled autotrophs with $SiO_2$ or $CaCO_3$ shells:
*Diatoms (*$SiO_2$ *shells) with two separate valves (halves); coccolithophores (*$CaCO_3$ shells); *silicoflagellates*.

PHYLUM PYRROPHYTA. *Dinoflagellates, zooxanthellae*. Mostly single-celled flagellates with two dissimilar flagella. Heterotrophic and autotrophic forms.

multicelled:

PHYLUM **BROWN ALGAE** (PHAEOPHYTA). Brown algae, kelps. *Kelps (oakblade kelp, feather boa kelp, giant kelp, bullwhip kelp), sea palms, rockweed.*

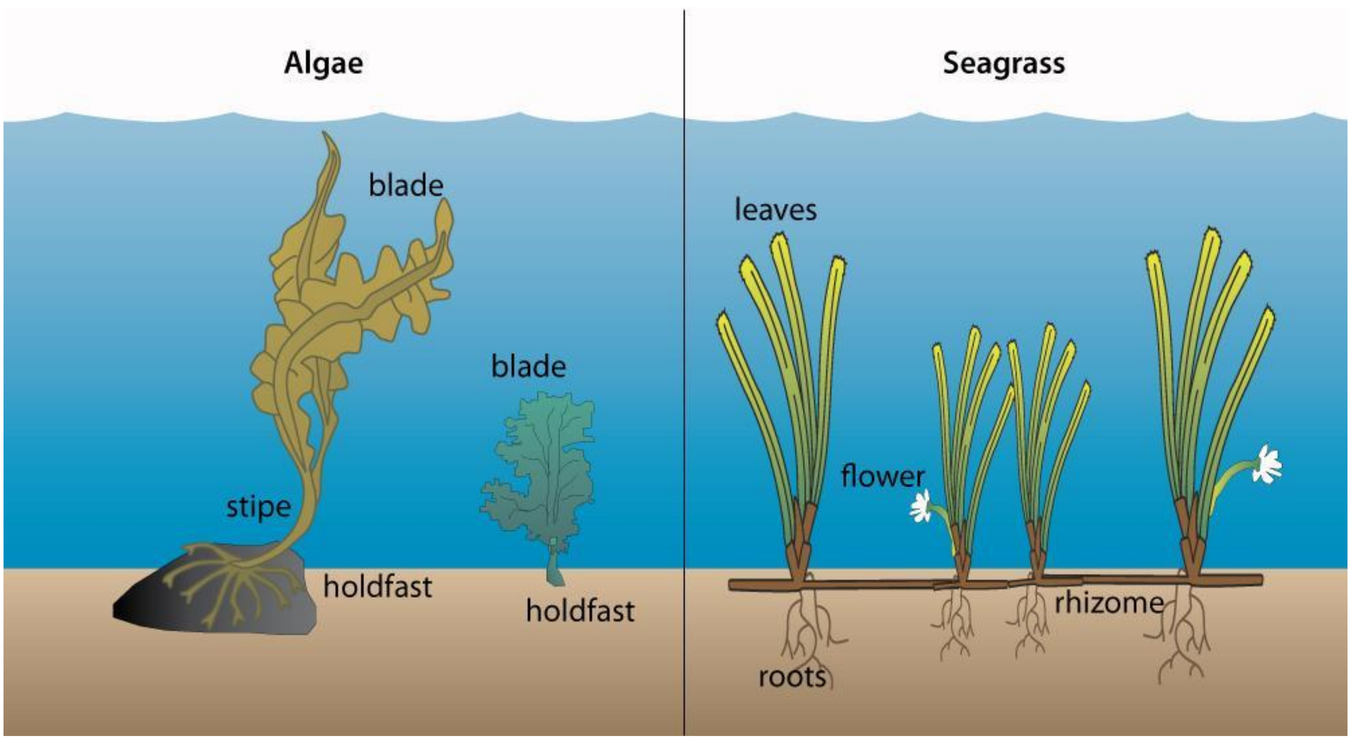
PHYLUM **RED ALGAE** (RHODOPHYTA). Red algae, encrusting and coralline forms. *Encrusting and articulated coralline algae, brillo pad algae, Neptune's washcloth, sea sacs, iridescent algae, and nori.*

PHYLUM **GREEN ALGAE** (CHLOROPHYTA). Multicellular green algae. *Sea strings, sea lettuce, ocean pin cushion.*

**KINGDOM PLANTAE:** Covered seeds. Photosynthetic multicellular autotrophs that evolved from Green algae. Primarily terrestrial. Roots, leaf-bearing shoots; gas exchange through leaves. Waxy coating on leaves prevents excessive water loss. Hardening of cell walls of woody tissues for support on land.

Only division found in marine environment is

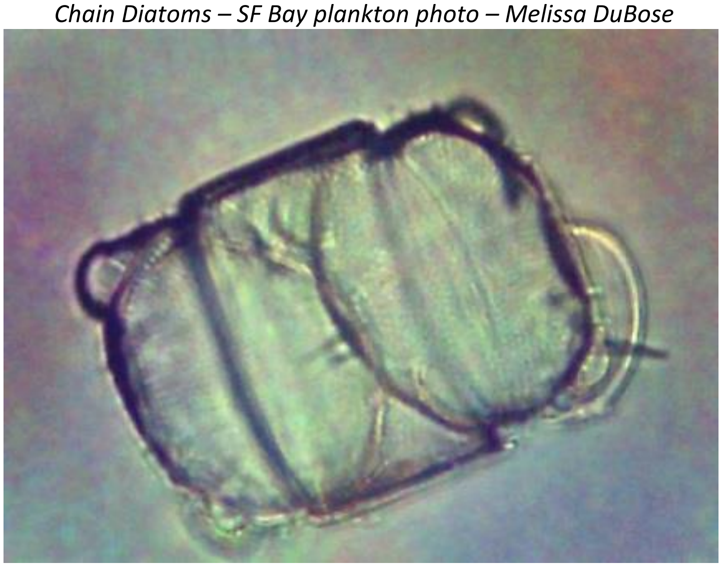
DIVISION ANTHOPHYTA. Flowering plants (angiosperms). Most species are freshwater or terrestrial. Marine species include: *eelgrass, manatee grass, surf grass, turtle grass, salt marsh grasses, mangroves*.



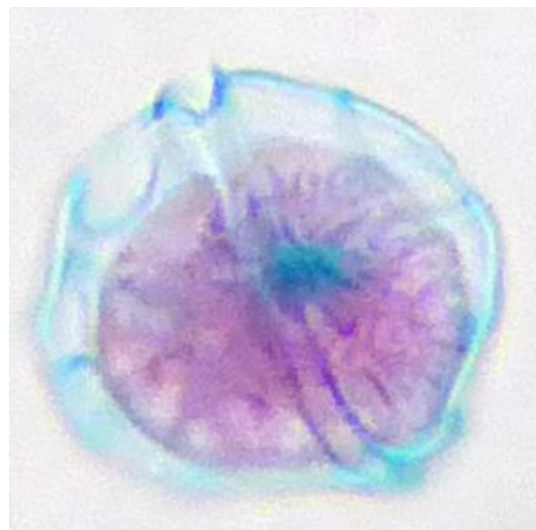

*Kelp (Protista, Brown Algae) vs Seagrass (Plants). Note that with plants, nutrients and water needed by plant are gathered through roots. In algae, any part of the body can absorb both water and nutrients in the water. Image courtesy of the Integration and Application Network (ian.umces.edu), University of Maryland Center for Environmental Science*

*Chain Diatoms – SF Bay plankton photo – Melissa DuBose*

***Dinoflagellate, Noctiluca (bioluminescent)***



Diatom, Rhizosolenia, Pillow-shaped species (Sediment)



***Dinoflagellate – false color***

***Arthropod, Copepod, Calanoid, 2 mm, Melissa DuBose***

***Copepod larvae ~1 mm (nauplius) M. DuBose***

**Global Productivity Patterns**

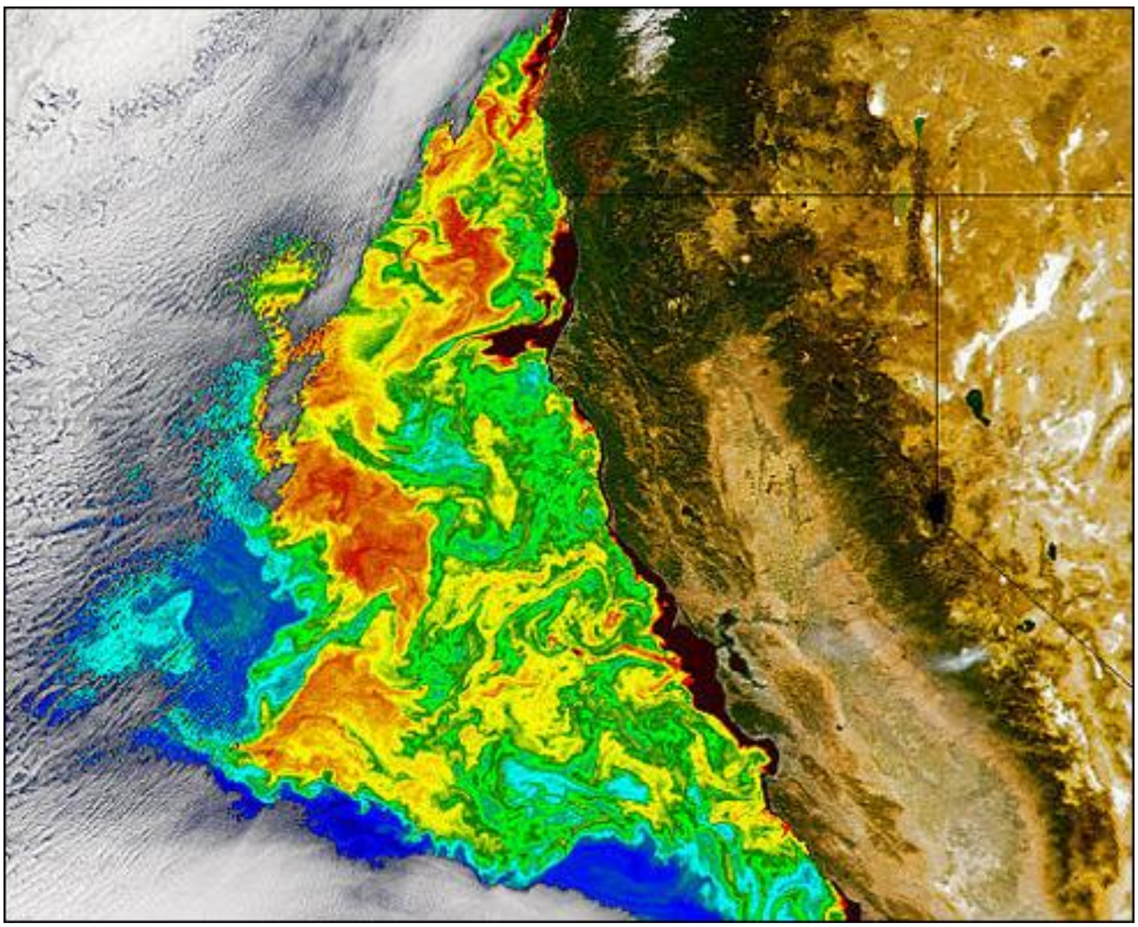
| Seas | Highest productivity? | Lowest productivity? | Why? |
|---|---|---|---|
| Polar seas | Summer | Winter | Nutrients always high, because no thermocline, but sunlight insufficient until summer. |
| Temperate seas | Spring and Fall | Summer and Winter | Winter no sunlight; Summer no nutrients because of thermocline. |
| Equatorial & tropical seas | Never | Always | Always a thermocline. |

**Sample Zooplankton**

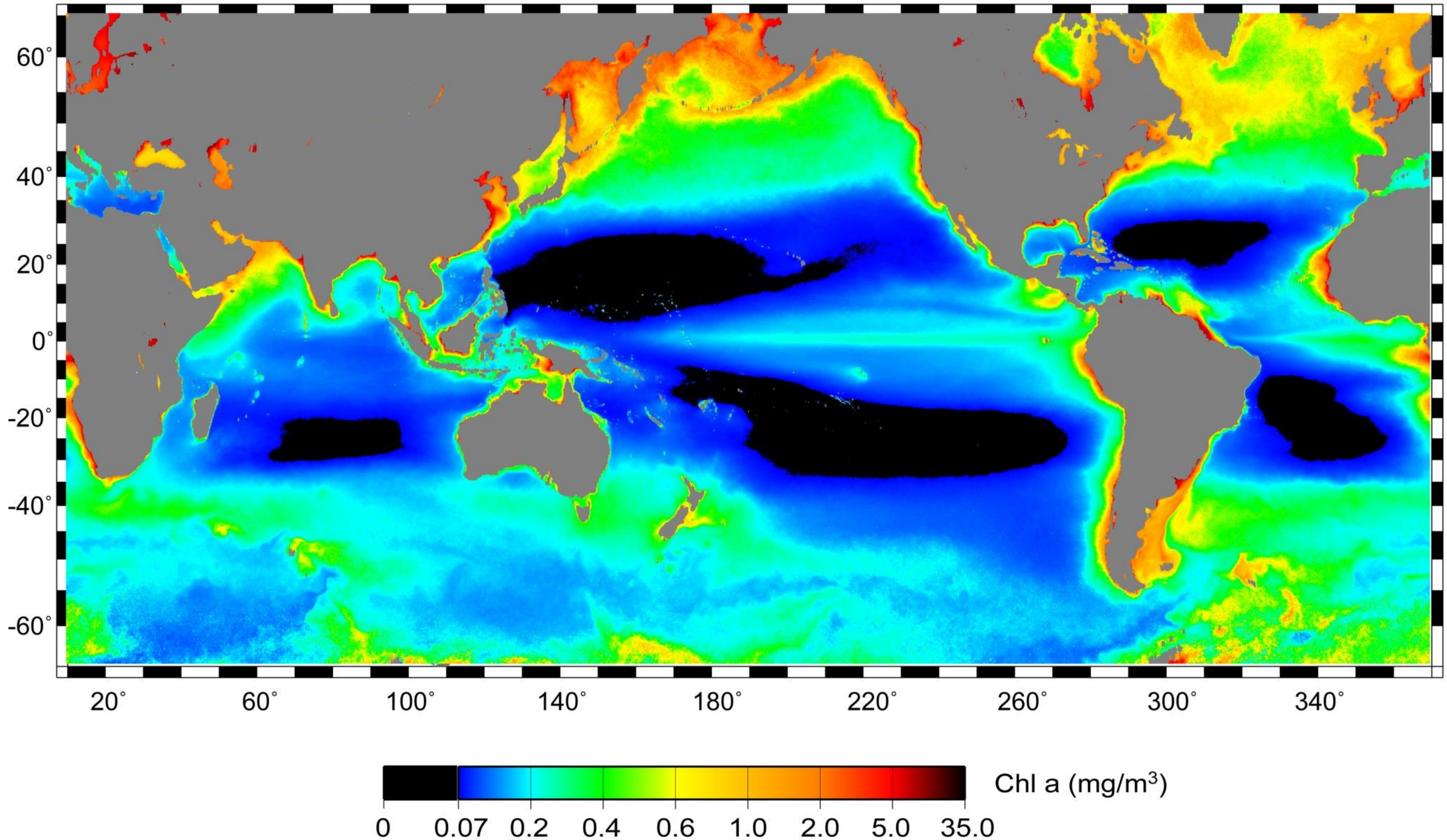
| Radiolaria | Foraminifera | Copepod | Jellyfish |
|---|---|---|---|
| Single-celled heterotrophic protista that moves and feeds by cellular extensions. Shells made of $SiO_2$. PROTISTA – Sarcodina – Actinopodea. | Single-celled heterotrophic Protista that moves and feeds by cellular extensions. Shells made of $CaCO_3$. PROTISTA – Sarcodina – Rhizopodea. | Multicelled heterotroph with exoskeleton that molts. Filter feeder. ARTHROPOD | Multicelled heterotroph with stinging cells on tentacles surrounding mouth. Suspension feeder. CNIDARIAN |

**Sample Phytoplankton**

| Diatom | Dinoflagellate | Coccolithophores |
|---|---|---|
| Single-celled autotroph with $SiO_2$ shell. PROTISTA – Chrysophyta | Single-celled autotroph (usually, some species are heterotrophic) with no shell, but two flagella. PROTISTA – Pyrrophyta | Single-celled autotroph with $CaCO_3$ shells (like pineapple rings). VERY small. 2 flagella and a haptoneme. PROTISTA – Chrysophyta |



“The ocean areas of the above image (collected on 6 October 2002) are color coded to show chlorophyll concentrations. A bright rainbow of colors are mapped to the amount of chlorophyll concentrations in the ocean off the coast of California. Bright reds indicate high concentrations and blues indicate low concentrations. Since phytoplankton moves with the ocean currents, the pattern of chlorophyll concentrations reveal intricate patterns of ocean currents.” NASA




*Global chlorophyll – a measurement of productivity – averaged over 1 years' time on the planet. NOAA*
*NASA can measure chlorophyll-bearing phytoplankton remotely with satellites, because chlorophyll reflects predominantly green light into space.*

# Productivity & Plankton Chapter Worksheet

1. What types of organisms account for 90% to 96% of the ocean's primary productivity?

2. **Chlorophyll**: CIRCLE: is essential to photosynthesis | is a pigment | is a sunlight collector
CIRCLE: is present in some photosynthesizing autotrophs | is present in all photosynthesizing autotrophs
CIRCLE: reflects all light but green | reflects green light only | reflects no light | reflects all light

3. A *red accessory pigment* (all by itself) will absorb which colors?
CIRCLE: Red | Orange | Yellow | Green | Blue | Violet | None

4. A *red accessory pigment* **WITH** chlorophyll will absorb which colors?
CIRCLE: Red | Orange | Yellow | Green | Blue | Violet | None

5. **REVIEW:** What color of light is the only one remaining at the base of the coastal photic zone?

6. Which pigments would NOT be useful for photosynthesis in this zone? Why not?

7. What are the three main roles of bacteria in the world's oceans?

8. What happens during nitrogen fixation?
By whom?

**Marine Autotrophs**

9. Photosynthesizing species in this classification all contain chlorophyll
CIRCLE: Archaea/Bacteria | Brown algae | Green Algae | Red algae | Protista (other phyla) | Plants

10. Most evolved
CIRCLE: Archaea/Bacteria | Brown algae | Green Algae | Red algae | Protista (other phyla) | Plants

11. Have holdfasts, stipes, and blades
CIRCLE: Archaea/Bacteria | Brown algae | Green Algae | Red algae | Protista (other phyla) | Plants

12. Kelp CIRCLE: Archaea/Bacteria | Brown algae | Green Algae | Red algae | Protista (other phyla) | Plants

13. Roots and covered seeds
CIRCLE: Archaea/Bacteria | Brown algae | Green Algae | Red algae | Protista (other phyla) | Plants

14. Contain single-celled organisms
CIRCLE: Archaea/Bacteria | Brown algae | Green Algae | Red algae | Protista (other phyla) | Plants

**Phytoplankton**

15. Has flagella CIRCLE: Coccolithophore | Diatom | Dinoflagellate

16. Has shell of $SiO_2$ CIRCLE: Coccolithophore | Diatom | Dinoflagellate

17. Has shell of $CaCO_3$ CIRCLE: Coccolithophore | Diatom | Dinoflagellate

18. Has no shell, so doesn't contribute to deep-sea muds and oozes
CIRCLE: Coccolithophore | Diatom | Dinoflagellate

19. Photosynthesizing autotroph CIRCLE: Coccolithophore | Diatom | Dinoflagellate

20. The amount of sugar or food produced by autotrophs living in an area MINUS the amount they use up daily to supply their own respiration needs: CIRCLE: gross primary productivity | net primary productivity

21. What are the two limiting factors for marine productivity?

22. **REVIEW:** What ARE nutrients? Give definition and some examples.

23. Which of the following are **sources** for the **nutrient** cycle? CIRCLE: rivers | rock weathering | decomposition | bacterial fixation of $N_2$ gas | nodule/sediment deposition | organism growth and ingestion

24. Which of the following are **sinks** for the **nutrient** cycle? CIRCLE: rivers | rock weathering | decomposition | bacterial fixation of $N_2$ gas | nodule/sediment deposition | organism growth and ingestion

25. Where are nutrients **most abundant** when there is a pycnocline? Why? CIRCLE: Surface | near pycnocline | sea bottom

26. Where are nutrients **least abundant** when there is a pycnocline? Why? CIRCLE: Surface | near pycnocline | sea bottom

27. At what latitudes are nutrients **always** abundant at the surface? Why?

28. At what latitudes are nutrients **never** abundant at the surface? Why?

29. At what latitudes are nutrients **seasonally** abundant at the surface? When? Why?

30. Nutrients are also abundant at the surface in the area of what two latitude-independent phenomena/features?

31. Which of the following is true of the **compensation depth**? Circle all that apply: base of the photic zone | net primary productivity = 0 | Photosynthesizing organisms can survive below this depth | Photosynthesis can still happen below this depth, but not enough to supply energy needs of individual

32. Where/when in the oceans is productivity high at the surface? Why?

33. Where/when in the ocean is productivity low at the surface? Why?

34. What types of organisms can cause **harmful algal blooms** (those that produce neurotoxins).

35. What are the primary results of these kinds of **harmful algal blooms**?

36. What are the primary causes of these kinds of **harmful algal blooms**?

37. The effects of a harmful algal bloom as described above (species of algae produce neurotoxins) are different from the effects of a regular plankton bloom in an enclosed waterway (as discussed in the Marine Environmental Challenges Video Tutorial). What are the effects of this latter type of bloom?

| | |
|---|---|
| 38. If bonito are at tropic level 4 and swordfish at trophic level 5, circle which is going to have the highest level of toxins due to biomagnification? | |
| 39. What is the average efficiency of transfer of energy between the sun and photosynthesizing autotrophs (trophic level 1)? | |
| 40. What is the average efficiency of transfer of energy between trophic levels 1 and 2 (and most other levels)? | |
| 41. How much energy, expressed as total mass of phytoplankton, is required to support a 100,000-kg killer whale that eats sharks that eat salmon that eat krill that eat phytoplankton? | |
| 42. In the above food web, what is the trophic level of the killer whale? | |
| 43. In the above food web, what is the trophic level of the salmon? | |

| **Zooplankton** | |
|---|---|
| 44. Copepod | CIRCLE: Shell of $SiO_2$ \| Shell of $CaCO_3$ \| Protista \| Arthropod \| Cnidarians \| Heterotroph |
| 45. Foraminifera (REVIEW) | CIRCLE: Shell of $SiO_2$ \| Shell of $CaCO_3$ \| Protista \| Arthropod \| Cnidarians \| Heterotroph |
| 46. Jellyfish | CIRCLE: Shell of $SiO_2$ \| Shell of $CaCO_3$ \| Protista \| Arthropod \| Cnidarians \| Heterotroph |
| 47. Radiolaria (REVIEW) | CIRCLE: Shell of $SiO_2$ \| Shell of $CaCO_3$ \| Protista \| Arthropod \| Cnidarians \| Heterotroph |

| **Plankton** | |
|---|---|
| 48. Organisms that live as plankton only for their larval stages | CIRCLE: Holoplankton \| Meroplankton |
| 49. Examples: | |
| 50. Organisms that live as plankton only for their adult stages | CIRCLE: Holoplankton \| Meroplankton |
| 51. Examples: | |
| 52. Organisms that live as plankton through their entire lifecycle | CIRCLE: Holoplankton \| Meroplankton |
| 53. Examples: | |

| |
|---|
| 54. **Cilia** are: glass spines \| soft hairs \| extra appendages \| present in all Porifera \| present in all Arthropods |

# Biological Productivity Activity

1. What are the sources and sinks that impact the amount of dissolved nutrients present at the surface of the oceans? (Remember: nutrients are dissolved ions like nitrates and phosphates – the building blocks of cells – which heterotrophs get from their food, but which autotrophs must pull from the water if they are to grow.)

| **Nutrient (include Nitrate) SOURCES** | **Nutrient (including Nitrate) SINKS** |
|---|---|
| | |

2. Look in your workbook at the last figure in the Currents chapter, where you see the average global sea surface nitrate levels (nutrients). What patterns do you see? Describe what the data show about where there's high vs low nitrate levels. Then based on known sources and sinks, explain the reasons for the **nutrient** patterns you see in that image.

| **OBSERVATIONS** | **EVALUATIONS** |
|---|---|
| | |

3. How would you expect variations in surface NUTRIENTS to impact marine life?

| **RESULTS OF TOO-HIGH NUTRIENTS** | **RESULTS OF TOO-LOW NUTRIENTS** |
|---|---|
| | |

4. Based on what you know about biological productivity globally, and the factors that impact it locally, how would you expect productivity to vary throughout the year?

| **Processes that would make biological productivity INCREASE** | **Processes that would make biological productivity DECREASE** |
|---|---|
| | |

5. Look in your workbook at the figures for Biological Productivity, where you see the average global sea surface chlorophyll levels. Since chlorophyll exists only in photosynthesizing organisms, we can measure chlorophyll to determine total biological productivity in an area. What patterns do you see? Describe what the data show about where there's high vs low chlorophylla levels. Based on known sources and sinks, explain below the reasons for the biological productivity patterns you see in that image.

| **OBSERVATIONS** | **EVALUATIONS** |
|---|---|
| | |

6. How do we measure chlorophyll from satellites?

7. Based on what you know about biological productivity globally, and the factors that impact it locally, sketch below the pattern for productivity variation throughout the year in the northern hemisphere off a coast **near the poles**.

↑ Biological Productivity Increasing

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

8. Sketch below the pattern for productivity variation throughout the year in the northern hemisphere off a coast **near the equator with no upwelling**.

↑ Biological Productivity Increasing

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

9. Sketch below the pattern for productivity variation throughout the year in the northern hemisphere off a coast **at mid-latitudes with no upwelling**.

↑ Biological Productivity Increasing

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

# Weekly Reflection

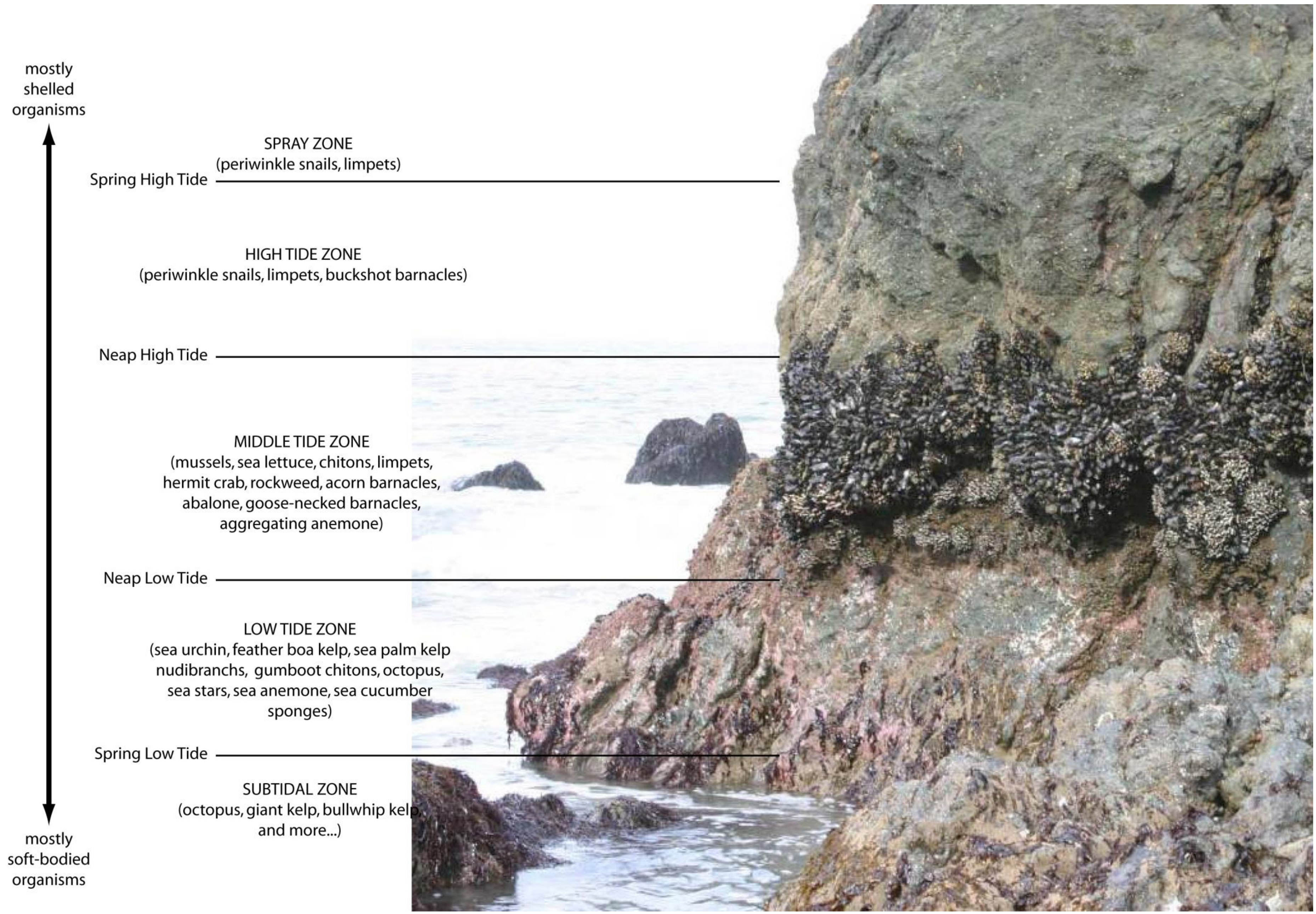
Take a moment to reflect on your comfort level and mastery of the week's objectives and describe an action plan for how you will practice or improve on anything that challenged you.

| **Weekly objective** | **Self-assessment of mastery level** | **Action plan for improvement** |
|---|---|---|
| Compare and contrast the variety of marine autotrophs that collectively contribute to **marine productivity**, including their relative abundance, behaviors, impacts, distribution, and classifications. | A \| B \| C \| D \| F | |
| Recognize, compare, contrast, and classify a variety of marine plankton by **feeding method, life cycles, and distribution**. | A \| B \| C \| D \| F | |
| Compare and contrast food webs and trophic pyramids and evaluating the **movement of energy** through these systems. | A \| B \| C \| D \| F | |
| Evaluate the causes and impacts of **harmful algal blooms**. | A \| B \| C \| D \| F | |

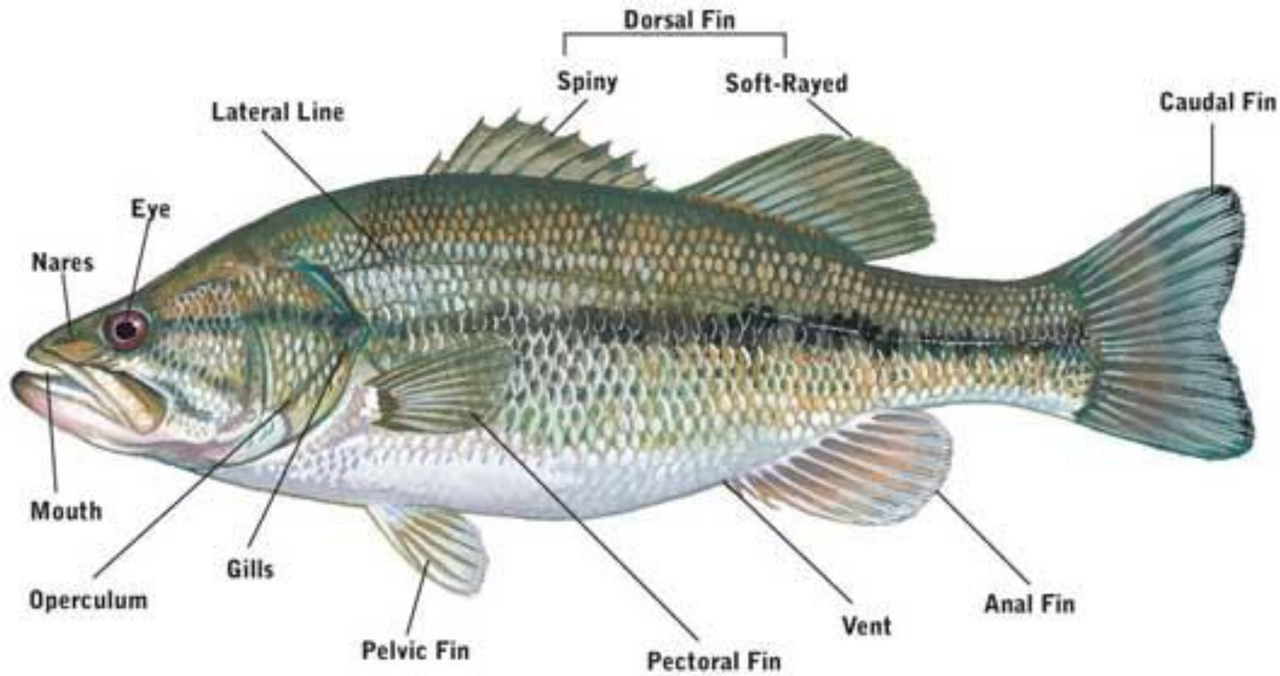
## AHA! Moments

What content from this week really resonated with you, helped you understand something you've always wondered about, or made you think about the world with new eyes?

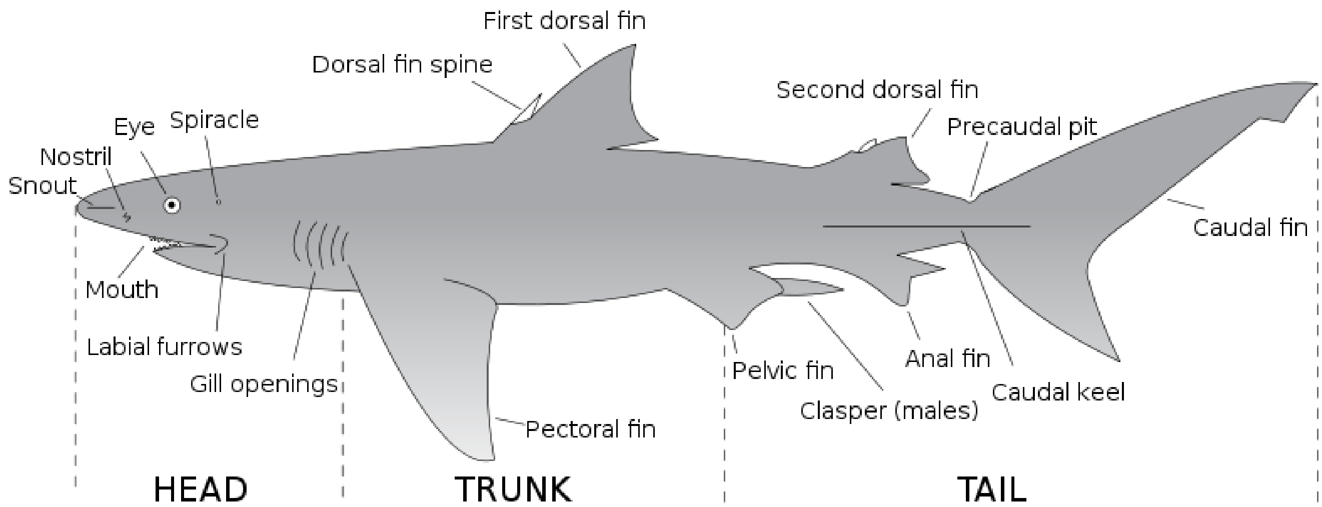
# NEKTON & BENTHOS



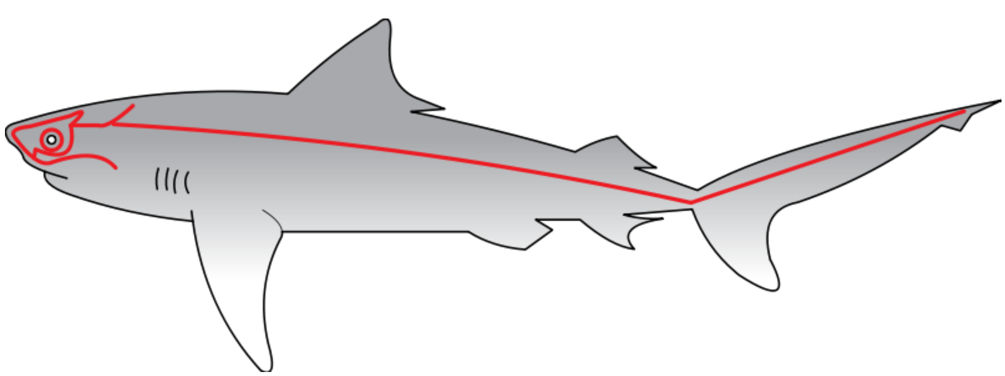
mostly shelled organisms
SPRAY ZONE
(periwinkle snails, limpets)
Spring High Tide
HIGH TIDE ZONE
(periwinkle snails, limpets, buckshot barnacles)
Neap High Tide
MIDDLE TIDE ZONE
(mussels, sea lettuce, chitons, limpets, hermit crab, rockweed, acorn barnacles, abalone, goose-necked barnacles, aggregating anemone)
Neap Low Tide
LOW TIDE ZONE
(sea urchin, feather boa kelp, sea palm kelp nudibranchs, gumboot chitons, octopus, sea stars, sea anemone, sea cucumber sponges)
Spring Low Tide
SUBTIDAL ZONE
(octopus, giant kelp, bullwhip kelp, and more...)
mostly soft-bodied organisms



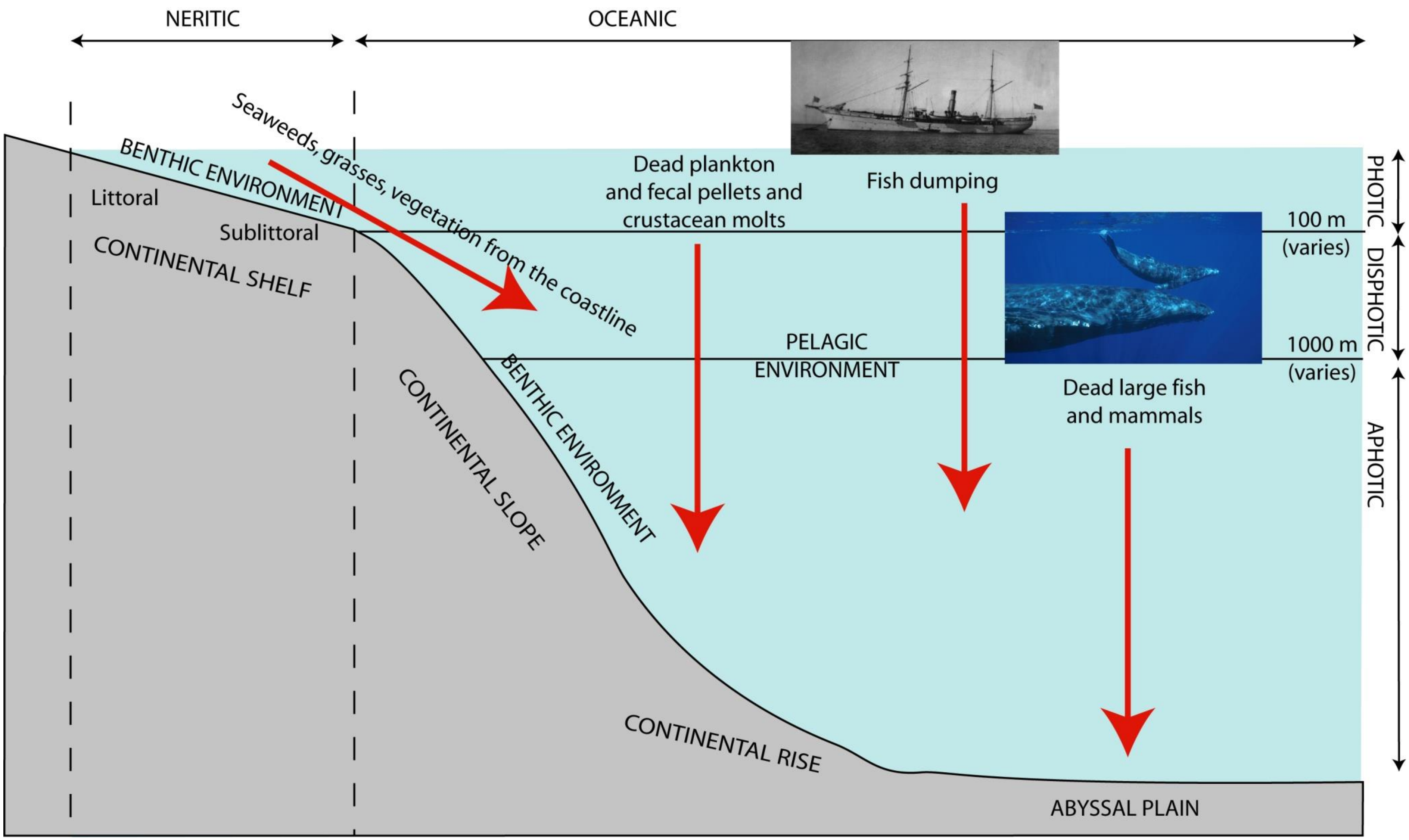

*Bony fish fins and morphology. Image: South Carolina Department of Natural Resources*



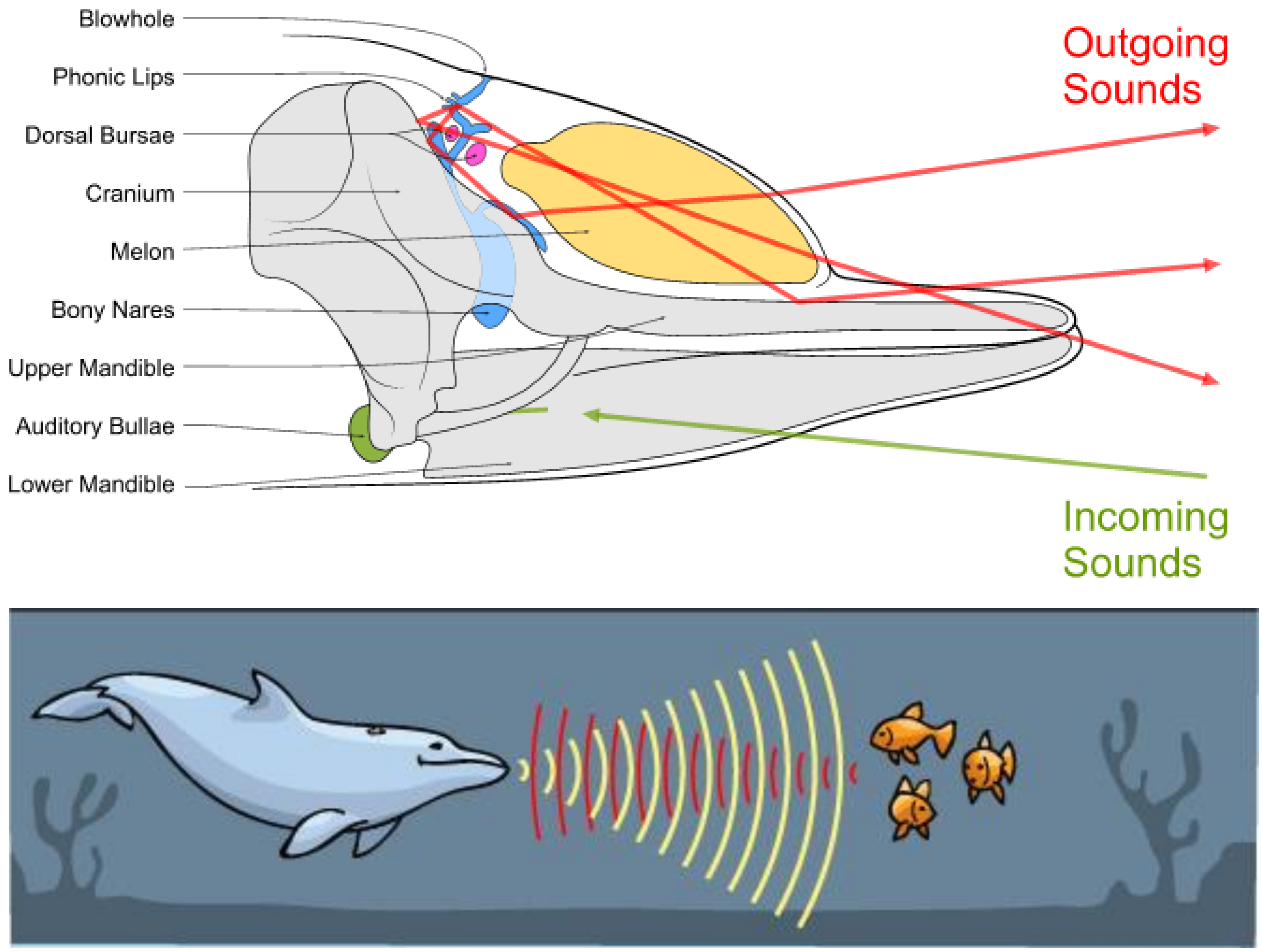

*Shark (cartilaginous fish) fins and morphology. Image: Public Domain*



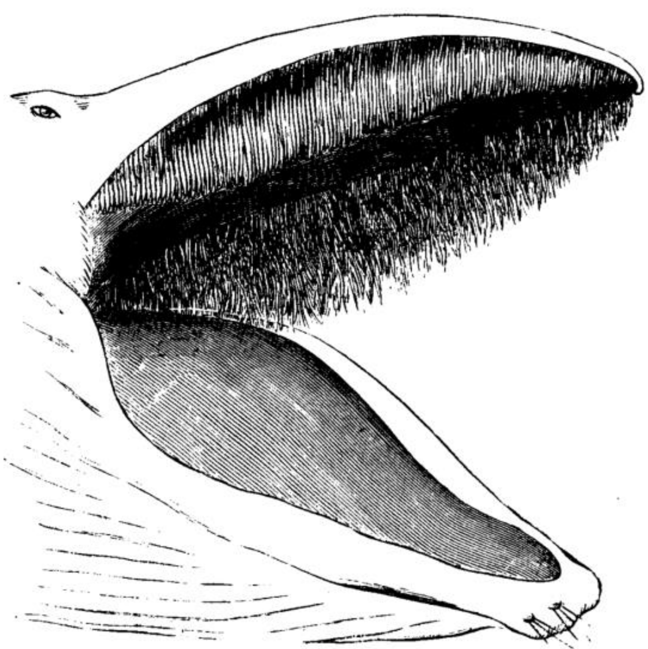
*Shark lateral line image: Public Domain*




*Detritus sources to abyssal plain. Comparison of Benthic (seafloor) and Pelagic (water column) environments and the Neritic (near shore – over the continental shelf) and Oceanic (offshore – deeper than the continental shelf) provinces. Photic zone is depths where sunlight is still available at least 1% of surface values. Dispohotic zone is where available light is between zero and 1% of surface light. The Aphotic zone has no light available.*




Echolocation in dolphin (toothed whales). Sound waves are produced through blowhole, reflected off skull, focused by melon to project outward in a particular direction. Reflected sound waves return to the dolphin and are felt as vibrations in the jaw bone, which are then interpreted by the brain. Images by *Emoscope (top) and Ask a Biologist (bottom) – CC BY-SA 3.0,*



Baleen whale – closeup of mouth with distendible grooved throat for gulping large amounts of water (like filling a balloon), and baleen plates hanging from the upper jaw. When jaw is closed, the water is squeezed out through the baleen plates, and anything larger than the baleen filter is trapped inside the mouth. A large tongue wipes across the inner baleen plates, and the food is swallowed. Image: Public Domain – Wikimedia.

**Hot Vent Community**

| **Occupants:** *Tube worms, clams, mussels, crabs, shrimp, microbial mats, chemosynthetic bacteria* | |
|---|---|
| **Dynamics**: Hot water rich in sulfide minerals percolates out of ground. Chemosynthesis of the $H_2S$ gas and sulfide minerals = base of food chain. Limited life span for organisms (vents disappear after a while or heat up more and fry the surrounding critters). Chimneys around vents are made of precipitated Cu, Zn, Ag sulfides. | **Location**: 3000-1000 m deep along rift valleys at seafloor spreading centers |

**Cold Seep Communities**

| **Occupants:** *microbial mats, sea stars, shrimp, crab, clams, mussels, limpets, snails, brittle stars, anemones, tube worms.* |
|---|

**Hypersaline Seep**

| **Dynamics**: Brines with normal water temp, but salinity as high as 46.2 ppt. Bottom of food chain is chemosynthesis of $H_2S$ and $CH_4$. | **Location**: Below 3000 m depth at base of continental slope, seeping onto abyssal plain. |
|---|---|

**Subduction Zone Seep**

| **Dynamics**: Gas from underlying sedimentary structures seeps upward through ocean sediments and to the sea bottom. Same water temp as surroundings, but with lots of $CH_4$ (methane gas), which buried sediments produced. Bottom of food chain are methane oxidizers (chemosynthesis) | **Location**: 1300-5500 m depth. Japan Trench, Cascadia Subduction Zone, Peru Chile Trench |
|---|---|

**Hydrocarbon Seep**

| **Dynamics**: Oil and gas seeps through ocean sediment (similar seep process as above, but liquids seeping upward instead of gas). Bottom of food chain chemosynthesize $CH_4$ or $H_2S$. | **Location**: Gulf of Mexico – shallow on the shelf, near oil and gas deposits. |
|---|---|

| **Challenge** | **Adaptations** |
|---|---|
| Desiccation at low tide | Seek shelter or withdraw into shells; thick skin or shell to prevent water loss. *Sea slugs, snails, crabs* |
| Strong wave activity | Strong holdfasts to prevent being washed away; strong attachment threads, muscular foot, or tube feet to allow to attach firmly to bottom. *Sea stars, mussels, kelp, snails, limpets, chiton* |
| Low tide predators | Firm attachment, Stinging cells, Camouflage, Inking response, Regenerative limbs. *Sea stars, mussels, octopus, anemones, sea slugs* |
| Difficulty finding mates for attached species | Release of large numbers of egg/sperm into water. *Abalones, urchins* |
| Rapid changes in T, salinity, pH, and O2 | Ability to withdraw into shells to minimize exposure to rapid changes. Ability to exist in varied temperatures, salinity, etc. (euryhaline, eurythermal, etc.) *Snails, barnacles* |
| Lack of abundant attachment sites | Organisms attach to others. *Bryozoans, corals, anemones* |

| **Feeding method (Definition & Examples)** |
|---|
| **Deposit feeder:** Organisms that feed directly off sediment – removing the food items from the sediment. *Sea cucumbers, worms, sand crabs, shrimp, lobster* |
| **Grazer:** Organisms that feed directly on autotrophs – going to the source. *Some snails, Limpets, Chitons, some urchin* |
| **Filter feeder:** Organisms that feed off primarily plankton filtered out of the water column. Filter feeders actively move themselves or a body part through the water to trap organisms. *Copepods, Whales, Sand dollars, Sponges, Tunicates, Barnacles, Bryozoans, Feather Duster Worm* |
| **Suspension feeder:** Organisms that have tentacles or spikes that lie in wait until another organism impales itself or is caught. Suspension feeders cannot control their motion quickly enough to catch prey. *Corals, Jellyfish, Anemones, Radiolarian, Foraminifera* |
| **Predators:** Organisms that hunt and eat live animals. *Fish, Carnivora, Reptiles, Birds, some urchin, some snails, cephalopods* |

# Nekton & Benthos Chapter Worksheet

| **Feeding methods** | |
|---|---|
| 1. | Jellyfish and anemones CIRCLE: Grazer \| Deposit Feeder \| Filter Feeder \| Suspension Feeder \| Predator |
| 2. | Scavengers CIRCLE: Grazer \| Deposit Feeder \| Filter Feeder \| Suspension Feeder \| Predator |
| 3. | Gastropods that scrape algae off rocks CIRCLE: Grazer \| Deposit Feeder \| Filter Feeder \| Suspension Feeder \| Predator |
| 4. | Sea stars that pry mussels apart and feast on the insides CIRCLE: Grazer \| Deposit Feeder \| Filter Feeder \| Suspension Feeder \| Predator |
| 5. | Killer whale CIRCLE: Grazer \| Deposit Feeder \| Filter Feeder \| Suspension Feeder \| Predator |
| 6. | Blue whale CIRCLE: Grazer \| Deposit Feeder \| Filter Feeder \| Suspension Feeder \| Predator |
| 7. | California Gray Whales CIRCLE: Grazer \| Deposit Feeder \| Filter Feeder \| Suspension Feeder \| Predator |
| 8. | Which of the following items can be found in **detritus**? CIRCLE: shells \| feces \| dead carcasses \| sunken decomposing seaweeds \| molts \| plastic \| styrofoam |
| 9. | What types of organisms feed almost exclusively on **detritus**? benthos \| nekton \| nektobenthos \| plankton |
| 10. | Which of the following is true of **baleen**? CIRCLE: made of the same material as teeth \| made of the same material as fingernails<br>used by all cetacean \| used by only some cetacean<br>can be used to filter feed \| can be used to bottom feed \| can be used to hunt individual prey |
| 11. | **Echolocation** CIRCLE: requires a melon or spermaceti organ \| uses jaw bone as a reflected wave collector<br>used by toothed whales \| used by baleen whales \| uses sound waves \| uses light waves<br>can be used to determine distances to objects \| can be used to determine density of object |
| 12. | Which of the following organisms are migrants? CIRCLE: gray whales \| great white sharks \| tuna \| lobster<br>arctic terns \| eels \| DSL \| harbor seals \| albatross \| salmon \| corals \| anemones |
| 13. | Why do organisms migrate? |
| 14. | In the pelagic zone (NOT benthic)<br>on what do deep-sea fishes feed? |
| 15. | What are some adaptations<br>deep-sea fish have developed<br>to aid them in survival? |
| 16. | Which fish have the most sensitive lateral lines? CIRCLE: Bony Fish \| Cartilaginous Fish \| Jawless Fish |
| 17. | Which of these are valid reasons why fish school? CIRCLE: protection in masses \| easier to hunt \|<br>confuse predators (look big) \| easier to find mates \| swim faster \| communication |
| 18. | What do we call the process where a favored species can outcompete<br>other species for resources, driving the unfavored species to extinction<br>and reducing the diversity of a community? |
| | **Intertidal zonation** |
| 19. | Between High Spring and High Neap Tides<br>CIRCLE: High Tide Zone \| Low Tide Zone \| Middle Tide Zone \| Spray Zone \| Subtidal Zone |
| 20. | Between Low Spring and Low Neap Tides<br>CIRCLE: High Tide Zone \| Low Tide Zone \| Middle Tide Zone \| Spray Zone \| Subtidal Zone |
| 21. | Highest zone on a beach: CIRCLE: High Tide Zone \| Low Tide Zone \| Middle Tide Zone \| Spray Zone \| Subtidal Zone |
| 22. | Highest portions of this zone are rich in mussels<br>CIRCLE: High Tide Zone \| Low Tide Zone \| Middle Tide Zone \| Spray Zone \| Subtidal Zone |
| 23. | Where kelp live: CIRCLE: High Tide Zone \| Low Tide Zone \| Middle Tide Zone \| Spray Zone \| Subtidal Zone |
| 24. | Where organisms live that can handle the least amount of water<br>CIRCLE: High Tide Zone \| Low Tide Zone \| Middle Tide Zone \| Spray Zone \| Subtidal Zone |
| 25. | Where organisms live that can handle the least amount of exposure<br>CIRCLE: High Tide Zone \| Low Tide Zone \| Middle Tide Zone \| Spray Zone \| Subtidal Zone |

| 26. **Intertidal stresses** – How are these organisms adapted to handle the following intertidal challenges? | | |
|---|---|---|
| | **Barnacles** | **Sea stars** |
| Desiccation during low tide | | |
| Strong wave activity | | |
| Low tide predators | | |
| Difficulty finding mates for attached species | | |
| Rapid changes in temp, salinity, pH, and $O_2$ | | |
| Lack of abundant attachment sites | | |

27. Which phylum of organisms is most likely to molt?

28. Why and how do they molt?

29. Which of the following is true of **hermatypic coral reefs**?
CIRCLE: found only where no rivers are nearby | requires nearby rivers
CIRCLE: requires warm waters | requires cool waters | can't survive really hot waters
CIRCLE: must have hard substrate to grow on | can grow on sands and muds
CIRCLE: requires clear salty water | can survive in all types of salinity | can survive in all types of clarity
CIRCLE: requires no wave activity | requires mild wave activity to provide $O_2$ | requires high wave activity
CIRCLE: Free floating | Sessile Polyps

30. Which of the following is true of **coral bleaching**?
CIRCLE: means coral are dead | means coral are in danger
CIRCLE: represents loss of zooxanthellae | represent infestation with zooxanthellae
CIRCLE: means coral have no food source | means coral have limited food sources

31. Through what methods do hermatypic corals feed?
CIRCLE: Grazer | Deposit Feeder | Filter Feeder | Suspension Feeder | Predator

32. What is the animal phylum that contains corals?
CIRCLE: Annelid | Arthropod | Bryozoan | Chordata | Cnidarian | Echinoderm | Mollusk | Porifera

33. **Nudibranchs** steal stinging cells from what other animal phylum?
CIRCLE: Annelid | Arthropod | Bryozoan | Chordata | Cnidarian | Echinoderm | Mollusk | Porifera

34. They do so by eating which type of organism from that phylum? CIRCLE: free floating | sessile polyps

35. **Nudibranchs** are themselves part of what animal phylum?
CIRCLE: Annelid | Arthropod | Bryozoan | Chordata | Cnidarian | Echinoderm | Mollusk | Porifera

36. Which of the following seeps/vents are cold?
CIRCLE: hydrocarbon seeps | hydrothermal vents | hypersaline seeps | subduction zone seeps

37. Which of the following seeps/vents are hot?
CIRCLE: hydrocarbon seeps | hydrothermal vents | hypersaline seeps | subduction zone seeps

38. Which of the following seeps/vents are found at seafloor spreading centers?
CIRCLE: hydrocarbon seeps | hydrothermal vents | hypersaline seeps | subduction zone seeps

# Nekton and Benthos Coral Reef Bleaching Watch
# Concept Sketch

Visit the **NOAA Coral Watch website** (links on class website). Orient yourself to the purpose of this website and the data provided. Then, follow the links on the website to look at the trends over the past 90 days in one of these locations: the Indian Ocean, the Coral Triangle, The Caribbean Sea, Florida, or Hawaii. Choose the one that most interests you..

**Draw a concept sketch of coral bleaching and include the answers to these questions:**

- What location did you choose and why?
- What is this location's coral bleaching warning stage, and what was the 90-day range you viewed?
- What has been happening to sea surface temperatures over the past 90 days and how does this compare with the trend you would expect to see for normal seasonal changes during this same time?
- What is coral bleaching?

# Weekly Reflection

Take a moment to reflect on your comfort level and mastery of the week's objectives and describe an action plan for how you will practice or improve on anything that challenged you.

| **Weekly objective** | **Self-assessment of mastery level** | **Action plan for improvement** |
|---|---|---|
| Compare and contrast the **physical environmental challenges** of a number of different ocean locations and the **consequent distribution, adaptations, and interrelationships of marine organisms** within these zones (including the intertidal zone, coral reefs, cold seeps, hot vents, and the deep sea). | A \| B \| C \| D \| F | |
| Compare, contrast, and classify nekton and benthos (especially whales, fish, crabs, corals, and more) by **feeding methods and behaviors**. | A \| B \| C \| D \| F | |
| Evaluate the **migratory habits** of a variety of marine organisms including causes and impacts, both to those who migrate and those who don't. | A \| B \| C \| D \| F | |

## AHA! Moments

What content from this week really resonated with you, helped you understand something you've always wondered about, or made you think about the world with new eyes?

# APPENDICES

# SEMESTER-LONG REVIEW SHEET

| **Distances (in kilometers or meters only!)** |
|---|
| 1. What is the elevation of **Mount Everest**? |
| 2. What is the **average elevation of land**? |
| 3. What is the **depth sea level would fall during an ice age**? |
| 4. What do we call the feature that represents that depth? |
| 5. What is the depth of the **Marianas Trench**? |
| 6. What is the **average depth of the ocean**s? |
| 7. What is the **radius of the planet**? |
| 8. What is the average **wavelength of a tsunami**? |
| 9. What is the **height of the tallest tidal wave** on the planet? |

| **Time** |
|---|
| 10. What is the **age of the Earth**? |
| 11. When did the **oceans first form**? |
| 12. When did **life first evolve**? |
| 13. When did **life move onto land**? |
| 14. What is the **age of the oldest ocean crust** currently in the oceans? |
| 15. What's the period of a **semidiurnal** tidal wave? |
| 16. What's the period of **spring tides**? |
| 17. What is the **mixing time** of the oceans? |

| **Other values (provide correct units!)** |
|---|
| 18. What is the **composition of Earth's atmosphere (components and %)**? |
| 19. What is the **average salinity of seawater**? |
| 20. What is the **average pH of the oceans**? |
| 21. What is the **maximum density of freshwater at 4°C**? |
| 22. What is the **specific heat of freshwater**? |

| **Equations** |
|---|
| 23. Write the equation for **photosynthesis.** |
| 24. Write the **buffering** equation**.** |

**Drawings and more**

25. Draw a **water molecule** with correct shape, size, and partial charges:

26. Explain why the Earth has **seasons**.

27. What makes **air rise**?

**What happens to rising air as it rises?** CIRCLE:
VOLUME: increases | decreases | stays the same
TEMPERATURE: increases | decreases | stays the same
WATER CAPACITY: increases | decreases | stays the same
RELATIVE HUMIDITY: increases | decreases | stays the same
PRESSURE ON EARTH'S SURFACE AS A RESULT: high | low | average

28. What makes **air sink**?

**What happens to rising air as it sinks?** CIRCLE:
VOLUME: increases | decreases | stays the same
TEMPERATURE: increases | decreases | stays the same
WATER CAPACITY: increases | decreases | stays the same
RELATIVE HUMIDITY: increases | decreases | stays the same
PRESSURE ON EARTH'S SURFACE AS A RESULT: high | low | average

29. Describe what happens to **temperature with depth** in the **subtropical** oceans.
**Subtropic surface** CIRCLE: high | medium | low
**Subtropic 1 km depth** CIRCLE: high | medium | low
**Subtropic 4 km depth** CIRCLE: high | medium | low

**Why?**

30. Describe what happens to **oxygen with depth** in the **subtropical** oceans. Why?
**Subtropic surface** CIRCLE: high | medium | low
**Subtropic 1 km depth** CIRCLE: high | medium | low
**Subtropic 4 km depth** CIRCLE: high | medium | low

**Why?**

31. Describe what happens to **carbon dioxide with depth** in the **subtropical** oceans. Why?
**Subtropic surface** CIRCLE: high | medium | low
**Subtropic 1 km depth** CIRCLE: high | medium | low
**Subtropic 4 km depth** CIRCLE: high | medium | low

**Why?**

32. Describe what happens to **salinity with depth** in the **subtropical** oceans. Why?
**Subtropic surface** CIRCLE: high | medium | low
**Subtropic 1 km depth** CIRCLE: high | medium | low
**Subtropic 4 km depth** CIRCLE: high | medium | low

**Why?**

33. Describe what happens to **nutrient content with depth** in the **subtropical** oceans. Why?
**Subtropic surface** CIRCLE: high | medium | low
**Subtropic 1 km depth** CIRCLE: high | medium | low
**Subtropic 4 km depth** CIRCLE: high | medium | low

**Why?**