GS106 Physical and Chemical Oceanography

I. Chemistry of Sea Water

A. pH and the Calcium Carbonate System as Related to Sea Water

Calcium Carbonate System

a. pH Defined

(1) pH Defined: the "activity" of hydrogen ions in a solution; defines the concepts of acidity and alkalinity.

(a) "activity" = essentially equivalent to the effective concentration of a given ion in solution.

(b) By definition, a pure substance such as water, or a solid mineral, has an activity = 1.0.

(c) The lower the overall concentration of ions in solution, the closer activity= concentration.

i) As concentration of dissolved ions increases, e.g. seawater, activity of a given ion is generally < than its conentration.

ii) activity accounts for resistive interference of given ions to reaction, by other electrostatically charged ions in solution.

(d) Hence pH = negative log base 10 of hydrogen ion activity of a solution:

$pH = -\log_{10}[H+]$

H activity = 0.0001 = 10^{-4} pH = $-\text{Log}_{10}(10^{-4}) = 4$ (acidic)
H activity = 10^{-14} pH = $-\text{Log}_{10}(10^{-14}) = 14$ (basic)

1. Calcium Carbonate Stability as Function of pH

a. Definitions:

(1) Ion Solubility: the relative ability of ionic/elemental species to dissolve into solution. High Solubility = very dissolvable

(2) Mineral Precipitation: the crystallization of solid compounds from ionic species in a solution.

2. Important reactions involving CO_2, H_2O, $CaCO_3$, and pH.

a. Dissolution of Carbon Dioxide (gas) in water results in production of Carbonic Acid, which subsequently dissociates into free H^+ ions and the bicarbonate anion

(HCO_3^-), <u>hence increasing hydrogen ion activity, and by definition decreasing pH (becoming more acidic)</u>.

$CO_2 + H_2O$ ------ H_2CO_3

H_2CO_3 ------- H+ + HCO_3-

$CO_2 + H_2O$ ---- H+ + HCO_3-

b. As Calcium Carbonate (solid) reacts with water in presence of free hydrogen ions, the solid Calcium Carbonate dissolves forming free Ca^{+2} ions and free bicarbonate ions, <u>hence consuming free hydrogen ions, decreasing hydrogen ion activity, and by definition increasing pH (becoming more basic)</u>. i.e. Calcium Carbonate acts to neutralize or buffer the solution by consuming hydrogen ions.

$CaCO_3 + H_2O + CO_2$ ------ Ca_{+2} + $2HCO_3$-

c. Dissolution of Calcium Carbonate as a Function of pH

d. General relationship: as Carbon Dioxide content of water increases, hydrogen ion actvity increases, pH decreases (more acidic)------<u>solid Calcium Carbonate undergoes dissolution</u>

(1) Dissolved Carbon Dioxide content is temperature dependent, as T >, Carbon Dioxide content <, hence hydrogen ion activity decreases, pH increases (<u>conducive to calcium carbonate precipitation</u>)

As T <, Carbon Dioxide content >, hence hydrogen ion activity increases, pH decreases (<u>conducive to calcium carbonate dissolution</u>)

Hence >T, <P, <CO2, >pH, Calcium Carbonate Precipitation
<T, >P, >CO2, <pH, Calcium Carbonated Dissolution

e. In Sum: carbon dioxide in water creates carbonic acid and limestone dissolves

(1) If carbon dioxide is decreased pH > and calcite precipitates

B. Composition of Seawater

1. Ionic components

Ion	% by wt.	g/1000 g (ppt)
Na	30.66	10.77
Mg	3.65	1.29
Ca	1.17	0.41
K	1.13	0.40
Sr	0.023	0.008
Cl	55.2	19.35
SO_4	7.71	2.71
HCO_3	0.3	0.12
Br	0.19	0.067

2. Total Constituents in 1 kg of average sea water

	mass (g)
H_20	965.31
Cl^-	19.10
Na^+	10.62
SO_4^{-2}	2.66
Mg^{+2}	1.28
Ca^{+2}	0.40
K^+	0.38
all others	0.25

C. Other Chemical Properties

1. Salinity -measured of dissolved ions in sea water
   a. units = parts per thousand = ppt = g of solute / kg of water
   b. Empirical relationship: Salinity (ppt) = 1.81 x (conc. Cl^- in ppt)
   c. Source of dissolved solids in ocean
      (1) chemical weathering of continental and oceanic crust
      (2) volcanic eruptions (seafloor vents)
      (3) river transport of dissolved load
   d. salt cycle
      (1) evaporite formation vs. weathering/dissolution

2. Controlling Factors of Density
   a. temperature (> temp, < density)
   b. salinity (>salinity, > density)
   c. Density-temperature stratification of water bodies

3. Vertical Structure of Oceans (Latitude Controlled: solar influx)
   a. Pycnocline = density gradient with depth
   b. Thermocline = temp. gradient with depth
   c. Halocline = salinity gradient with depth

4. Carbon Dioxide Solubility
   a. carbon dioxide highly soluble in sea water (see above)

5. Alkalinity / Buffering Capacity
   a. alkalinity - measure of ability to consume free H+ ions
      (1) source of alkalinity in oceans
         (a) $HC03^{-}$ (bicarbonate anions)
         (b) $CO3^{-2}$ (carbonate anions)
         (c) dissolution of CaCO3 from seafloor, consumes H+ ions
   b. buffering capacity = alkalinity is a measure of solution's ability to consume H+ ions, and maintain constant pH

II. Physics of the Ocean

A. Light Absorption and Ocean Water

Depth (m)	% Absorption	% Transmittance
1 m	55%	45%
10 m	84%	16%
100 m	99%	1%

   a. Absorption according to selective wavelengths
      (1) red end absorbed first at shallow depths
      (2) blue-green end absorbed at greater depths
   b. Factors affecting visibility
      (1) water chemistry
      (2) turbidity - concentration of suspended sediment

B. Sound Transmission in Seawater

1. average velocity = 1450 m/sec (air = 334 m/sec)
2. sound vel > with > temperature, > salinity, >pressure

C. Water, Waves and Coastal Dynamics

1. Beach and coastal areas represent sites of dynamic sedimentation, erosion and re-working of river-borne sediments as they reach coastal regions

   a. Dynamic interaction between wind, waves, sedimentation and erosion
   b. Coastal areas noted for extremely variable meteorologic conditions
   c. Hurricanes and storms profoundly influence coastal morphology

      (1) Wave energy and wind energy during coastal storms exhibit great capability to do work in the form of erosion and transportation of sediment

(2) Eg. storm wash-over processes
(3) storm surges
(4) changes in coastal morphology via erosion and sedimentation

d. Gross coastal configuration primarily a function of
(1) plate tectonic history,
(2) global sea levels (eustacy)

2. The Ocean and Wave Activity

a. Beach/coastal sand/sediment profoundly influenced by wave action
(1) waves provide motion/energy for transportation and erosion of sediment

b. Waves generated by wind shear blowing across ocean surface for long distances
(1) shear creates orbital rotation of water to form water waves

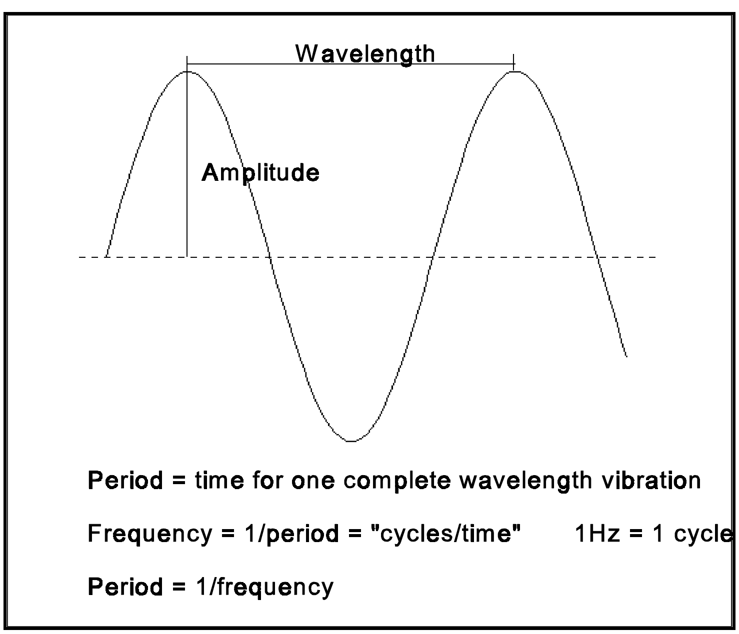
(a) orbital motion = circular to and fro motion, diminishing in intensity at depth from surface

(b) Although the wave is passed through the water as a medium; actual water molecules are NOT displaced as the wave is propagated

(2) Wave form controlled by:
(a) wind velocity
(b) duration of wind / storms
(c) fetch- distance over which wind blows (length across water) (> fetch, > wave amplitude)

increase velocity, wind duration, fetch = increase in wave height

c. Wave Morphology



(1) Wave crest: high upper peak of wave train
(2) Wave trough: low separating two crests
(3) Wave Height: vertical distance between crest and trough

  (a) Avg. Wave Ht = 1 to 15 Feet
  (b) Storm Waves up to 50 Ft wave height

(4) Measuring wave height
  (a) microseismometers
    i) measures inland vibration caused by waves
    ii) e.g. coastal waves can be measured from Corvallis!!!

  (b) pressure transducers
    i) measure height of wave related to water pressure

(5) "Tsunami" = seismically induced water wave, produced by tectonic displacement of sea floor, accompanied by earthquakes
  (a) Very long wavelengths: ~ 100 km, and low amplitudes (1 m or less)
  (b) As wave approaches land, breaking to heights of 100 m or more
    i) highest "tidal wave" recorded = 278 Ft off coast of Japan.

(6) Storm Surges: piled mass of water pushed shoreward by very high winds
  (a) Common by-product of hurricanes

    i) upward bulging of ocean surface due to low atmospheric pressure above ocean surface

    ii) Wind pile-up
      a) Surge in sea level of 2-5 m common

(7) Typical Wave Characteristics
  (a) Wave Length: horizontal straight line distance between two crests or two troughs
    i) Avg. wave length = 130-1300 Ft

  (b) Wave Velocity: average 15-55 mi/hr

  (c) Wave base: depth at which the energy of the wave is totally dissipated in water
    i) Wave Base = 0.5 (Wavelength)

d. "Surf" Zone: zone along coastal area where waves overturn and "break" upon themselves

(1) High energy water environment

(2) Wave breaking occurs in response to shallowing of water depth as wave approaches beach

(a) As depth < wave base, wave "feels" bottom and wedges water upward

i) Wavelength decreases as waves approach shoreline, "piling" up of water according to resistance of near-shore beach area.

ii) "Breaker" a wave that is oversteepened to the point of the crest toppling forward (moving faster than main body of wave)

iii) "Surf Zone": coastal zone characterized by numerous breakers

a) high turbulence zone
b) characterized by to and fro swash action
c) Swash = incoming motion, Backwash = seaward drag of water
d) effective sediment sorting mechanism

D. Nearshore Circulation Processes

1. Wave Refraction: Tendency of wave to become "refracted" or bent as it reaches shore

a. net result is wave train becoming more parallel to shore

2. Wave Crests usually approach shore at some angle other than parallel.

a. Results in sweeping of wave along coastal interface

3. Longshore Currents:

a. Current established as wave crest approaches beach at some angle to shore

b. Sweeping action of wave along shoreline

c. Longshore Current: current forms parallel to shore as more and more waves refract in that direction

(1) Seaward Edge of Current: outher surf zone

(2) Landward Edge of Current: Shoreline

(3) Longshore currents can effectively transport large volumes of sediment along a shoreline (parallel to shore)

4. Rip-Currents

   a. Narrow Currents that flow perpendicular to shoreline in a seaward direction (seaward return flow of water)

   b. Highest velocity at surface, dying out at depth

   c. Effective seaward sediment transportation mechanism, moving sediment beyond beach zone onto shelf

   d. Characterized by low wave height and variable wave orientations

5. Tides: diurnal, vertical fluctuation of sealevel under the influence of planetary gravity. Results in bulging of sealevel sytematically throughout the day, around the world.

   a. tides set in motion by gravitational attraction of the moon and sun (heavenly bodies close and large enough respectively to influence force of gravity on earth).

      (1) gravitational pull of sun and moon result in pulling at the ocean surface, causing it to bulge. Since the earth's crust in rigid and relatively unaffected by this gravitational pull, tidal fluctuations of sea level occur relative to land. (tidal pull is relatively negligible in surface bodies of water, i.e. lakes)

      (2) Moon has most significan daily impact on tidal levels. Gravitational effectiveness of sun relative to the moon in 44%.

   b. Normal tidal bulges: influenced by moon primarily, moon in line with equator, pulling bulge equatorially, low tides at top and bottom, hide tides at equator

      (1) tidal bulge follows the moon as it orbits around earth, water facing the moon is drawn/bulged towards the moon, side opposite moon is also bulged outward because the solid portion of the earth (facing the moon) is pulled away from the ocean on the side opposite the moon.

         (a) at same time as tidal bulge, there are compensating low tides at 90 degrees to the bulge

      (2) Entire effect is complicated by the earth's revolution from east to west, also coupled with moons revolution around earth: result in 2 complete tidal cycles every 24 hours and 50 minutes. (i.e. 2 high and 2 low tides in a little over each day)

   c. Spring Tides: sun and moon in alignement equatorially, result in highest tides possible, largest bulge at equator.

- d. Neap Tides: sun aligned with equator, moon with poles, perpendicular to one another, results in lowest tides possible at equator.

- e. Tidal Cycles: rising tide or flood tide occurs for 6 hr and 13 min, reaches high tide, then falling tide or ebb tide for 6 hr and 13 min, until low tide, happens twice each day about.

  - (1) tidal range: vertical difference between high and low tide. Height of tidal range varies with configuration of coastline, from several feet to perhaps 50 feet, as the highest tidal fluctuation noted.

- f. Tidal Currents: ebb and flood tide sets up currents through tidal channels, inlets and coastal rivers

E. Deep Ocean Circulation
- 1. Defined
  - a. Ocean Circulation - flowing streams of ocean water within the sea
  - b. Sources of Circulation
    - (1) wind-driven
      - (a) air flow and shear across the ocean surface
      - (b) air-sea coupling
      - (c) horizontal currents, relatively shallow depths
    - (2) density-driven
      - (a) temperature and salinity driven ("thermohaline")
      - (b) vertical currents
      - (c) different water masses
  - c. Importance of Circulation
    - (1) dissolved oxygen transport in ocean
    - (2) transport of nutrients as part of food chain

- 2. Coriolis Effect (deflection of ocean and air currents due to Earth rotation)
  - a. Coriolis = apparent shift due to rotation and velocity variation by latitude
    - (1) Earth rotating in counterclockwise direction as viewed from north pole, rotating from west to east
    - (2) Net result:
      - (a) Northern Hemisphere: currents deflected to right in the direction of travel
      - (b) Southern Hemisphere: currents deflected to left in direction of travel
  - b. View from north pole
    - (1) counter clockwise rotation
    - (2) current deflection to right, due to coriolis
  - c. View from south pole
    - (1) clockwise rotation
    - (2) current deflection to left, due to coriolis

3. Horizontal Circulation (wind shear driven)
   a. equatorial currents - diverge in the tropics away from the equator
      (1) coriolis effect influences directional component
         (a) northern equatorial current deflected to right
         (b) southern equatorial current deflected to left

   b. Western Boundary Currents
         (a) currents that flow towards the western boundaries of the ocean basins
            i) e.g. Gulf Stream in Atlantic
            ii) western boundary flow driven by coriolis and deflection along continental margins

   c. Eastern Boundary Currents
      (1) currents travelling along the eastern boundary of ocean basins

   d. Subtropical Gyres - circular ocean circulation
      (1) net effect of western and eastern boundary currents
         (a) northern hemisphere - clockwise
         (b) southern hemishpere - counterclockwise
      (2) center of gyres result in piling of water with increase of sea surface height up to 2 m above edges of gyre
         (a) the sea surface is not flat! it has topography!

   e. Ekman Spiral
      (1) wind-driven surface circulation in combination with Coriolis
         (a) surface water moves at 45 degree angle to prevailing wind direction
            i) deflection to right in northern hemisphere
            ii) deflection to left in souther hemisphere
         (b) surface water circulation is at greatest velocity, current velocity decrease with depth (away from air-sea interface)
         (c) Net result with depth
            i) decrease in current velocity
            ii) deflection of current and increasing angles relative to wind direction
            iii) results in downward spiraling cork-screw current

4. Vertical Circulation (density driven)

   a. thermohaline circulation - vertical ocean circulation driven by temperature and salinity differences in sea water
      (1) temperature-density relations (inversely proportional)
         (a) > temp, < density ==== "rising water"
         (b) <temp, > density ===== "sinking water"
         (c) sinking of cold water masses at poles
         (d) rising and expansion of warm equatorial waters
      (2) salinity-density relations (directly proportional)
         (a) > salinity, > density ===== "sinking water"

        (b) <salinity ,< density ====== "rising water"
            i) salinity range of ocean water: 33 - 37 parts per thousand dissolved salts

b. Wind-Influence Thermohaline Circulation Patterns
    (1) wind pushes water - creates mass deficit that is replaced by bottom waters
    (2) upwelling - rising waters from ocean bottom
        (a) driven by wind-displacement of surface water masses
    (3) Coastal Upwelling
        (a) common along continental margins
        (b) offshore winds push surface water out to sea, away from continent
            i) modified by Ekman flow
        (c) mass deficit results in upwelling of cold bottom waters along the coast

5. Famous Currents
a. Atlantic Ocean
    (1) north and south atlantic gyres
    (2) Gulf Stream
        (a) northward tropical water along east coast of U.S.

b. Pacific Ocean
    (1) Kuroshio Current - north Pacific, clockwise gyre
        (a) north Pacific Current
        (b) California Current