2 The Oceanic Environment

Notes for *Marine Biology: Function, Biodiversity, Ecology*

By Jeffrey S. Levinton
The Ocean and Marginal Seas

- Oceans cover 71% of earth’s surface
- Southern hemisphere 80%, Northern hemisphere 61%
- 84% deeper than 2000m
- Greatest depth ~ 11,000 m in Marianas Trench – Challenger Deep 10,916 m (Jacques Piccard-Don Walsh 1960)
- Antarctic separated by water from other oceans, Antarctic Convergence or Polar Front
Marginal Seas-localized conditions

- Examples: Gulf of Mexico, Mediterranean Sea
- Affected strongly by
  1. regional climate,
  2. precipitation-evaporation balance,
  3. river input of fresh water and dissolved solids,
  4. limited exchange with the open ocean (e.g., sill partially cutting Mediterranean from Atlantic)
  5. Recent Geological history
MONTEREY CANYON, CA

West coast – narrow shelf

Continental shelf

15 km

canyon

MONTEREY CANYON, CA
**Topographic Features**

- Coastal plain
- Shelf
- Slope
- Abyssal plain
- Continental rise
- Seamount
- Abyssal plain
- Mid-ocean ridge
- Trench
- Marginal sea
- Volcanic island

Depth (miles)

Depth (km)
Earth’s surface is divided into **plates**: borders are ridge systems, faults
San Andreas Fault, California

Plate movements and submarine earthquakes generate tsunamis.
Tsunami at coast of Indonesia February 2014
Earth’s surface is divided into **plates**: borders are ridge systems, faults
Symmetry of magnetic anomalies on either side of mid-oceanic ridge

**FIG. 2.4** (a) Generalization of magnetic anomalies into a map of bands on either side of the ridge center. Note that the current magnetic field of the earth (recorded at spreading center) is positive. (b) Trace of magnetic anomalies across a spreading ridge center, with transect reversed to show match of anomalies on either side of spreading center.
Earth’s surface is divided into **plates**: borders are ridge systems, faults, trenches.
The Oceanic Crust: Crust is formed at ridges, moved laterally, and destroyed by subduction, which forms trenches.
Earth’s surface is divided into **plates**: borders are ridge systems, faults, trenches
The Ocean

Seawater Properties
Water Relationships in the Ocean

Pleistocene causes sea level fluctuation > 100 m
Atmosphere
0.130
rt=9.6d

0.024 0.004
P  E

254.2
rt=106000a

Ocean
3.85 4.25
P  E

0.397

1.081 0.708
P  E

24
rt=4290a

Run off
0.376

Rivers, Lakes
2.25
rt=6.0a

Ground Water?

Ground Water
(to 4000m depth)
80.6

0.0039

Greenland

13 480
rt=3170a

All figures in $10^{20}$ g water
Ocean as a Receptacle

- Water
- Particulate mineral matter
- Dissolved salts
- Particulate organic matter (POM)
- Dissolved organic matter (DOM)
- Atmospheric precipitation
- Volcanic sources
Water molecule

- Asymmetry - angle of charge distribution on water molecule - increases ability to form bonds with charged ions - makes water excellent solvent
Water properties

- High heat capacity (4.1 J per deg K)
- High heat of evaporation (2260 J/g)
- High dissolving power
- High transparency (absorbs infrared, ultraviolet)

\[ J = \text{kg m}^2/\text{s}^2 \]
Latitudinal Gradient of Surface Sea Water Temperature

Net capture of heat

Net loss of heat

Average temperature for the World Ocean

Indian

Atlantic

Pacific
Vertical Temperature Gradient: Open Tropical Ocean

- Surface layer
- Thermodline layer
- Deep water
- Bottom water
- Wind mixing
Vertical Temperature Gradient:
Long Island Sound - seasonal
Temperature

• Oceanic range (-1.9 to +40 °C) less than typical terrestrial range (-68 to +58 °C)

• Deep ocean is cold (2 – 4 °C)
# Heat Changes in the Ocean

<table>
<thead>
<tr>
<th>Additions</th>
<th>Losses</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Solar radiation</strong></td>
<td>Back radiation of surface – long wave</td>
</tr>
<tr>
<td><strong>Geothermal heating</strong></td>
<td>Convection of heat to atmosphere</td>
</tr>
<tr>
<td><strong>Internal Friction</strong></td>
<td>Evaporation</td>
</tr>
<tr>
<td><strong>Water Vapor Condensation</strong></td>
<td></td>
</tr>
</tbody>
</table>
Salinity

• Definition: g of dissolved salts per 1000g of seawater; units are o/oo or ppt or psu (practical salinity unit – no unit written!)
• Controlled by:
  Increases: evaporation, sea-ice formation
  Reductions: precipitation, river runoff

Salinity in open ocean is 32-38
Latitudinal salinity gradient

Excess of evaporation over precipitation in mid-latitudes
Excess of precipitation over evaporation at equator
Measurement of Salinity
ratio of Cl/salinity = constant!

• Chlorinity: g of chlorine per 1000 ml of seawater
• Salinity = 1.81 x chlorinity (o/oo or ppt)
• Salinity is measured by chemical titration, conductivity, index of refraction
• Conductivity -> Practical Salinity Unit (no units – dimensionless number)

E.g., salinity = 10
Seawater density (mass/volume)

• Influenced by salt, no maximum density at 4 °C (unlike freshwater)

Density

- increases with increasing salinity
- increases with decreasing temperature

Special significance: vertical density gradients
## Important elements in seawater

<table>
<thead>
<tr>
<th>Element</th>
<th>mg/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorine</td>
<td>19,000</td>
</tr>
<tr>
<td>Sodium</td>
<td>10,500</td>
</tr>
<tr>
<td>Magnesium</td>
<td>1,300</td>
</tr>
<tr>
<td>Sulfur</td>
<td>900</td>
</tr>
<tr>
<td>Calcium</td>
<td>400</td>
</tr>
<tr>
<td>Potassium</td>
<td>380</td>
</tr>
<tr>
<td>Bromine</td>
<td>65</td>
</tr>
<tr>
<td>Carbon</td>
<td>28 (variable)</td>
</tr>
</tbody>
</table>

Trace elements in seawater: <1 mg/L = 1 ppm, is equivalent to 1 oz of salt in 32 tons of potato chips! e.g., Sr, Cu, Hg
How is chlorinity related to total salinity??

1. Salinity = chlorinity + 1.8
2. Salinity = chlorinity x 1.8
3. Salinity has no known constant relation to total salinity.
How is chlorinity related to total salinity??

1. Salinity = chlorinity + 1.8
2. Salinity = chlorinity x 1.8
3. Salinity has no known constant relation to total salinity.
Principle of Constant Element Ratios: Forchhammer’s Principle

- Ratios between many major elements (e.g., Na/K) are constant all over the ocean, even though salinity varies

\[ \frac{dN}{dt} \quad T = \text{residence time} \quad N \quad \frac{dN}{dt} \]

Box Model of Ocean
**Principle of Constant Element Ratios. Throughout the Ocean**

- Why? Because residence time of elements with constant ratios is much greater than time to mix them evenly throughout ocean by water currents (ca. 1000 y)

*Residence time >>> Mixing time*

\[ \text{dN/dt} = \text{entry rate (} = \text{departure rate) of element into ocean} \]
Principle of Constant Element Ratios

• Residence time of Na, Cl, Sr is on the order of millions of years
• But, mixing time of water is on order of thousands of years
• Therefore ocean is well mixed, relative to input or removal for elements with very long residence times
Composition of pee

- water 95% 
- Urea ($\text{CH}_4\text{N}_2\text{O}$) 9.3 g/l
- chloride 1.87 g/l
- sodium 1.17 g/l
- potassium 0.750 g/l
- Creatinine ($\text{C}_4\text{H}_7\text{N}_3\text{O}$) 0.670 g/l

Source: http://chemistry.about.com/
Ocean mixing = 1000 years

### Table 7.3  Approximate Residence Times for Constituents of Seawater

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Residence Time (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chloride (Cl(^2))</td>
<td>100,000,000</td>
</tr>
<tr>
<td>Sodium (Na(^1))</td>
<td>68,000,000</td>
</tr>
<tr>
<td>Magnesium (Mg(^{2+}))</td>
<td>13,000,000</td>
</tr>
<tr>
<td>Potassium (K(^+))</td>
<td>12,000,000</td>
</tr>
<tr>
<td>Sulfate (SO(_4^{2-}))</td>
<td>11,000,000</td>
</tr>
<tr>
<td>Calcium (Ca(^{2+}))</td>
<td>1,000,000</td>
</tr>
<tr>
<td>Carbonate (CO(_3^{2-}))</td>
<td>110,000</td>
</tr>
<tr>
<td>Silicon (Si)</td>
<td>20,000</td>
</tr>
<tr>
<td>Water (H(_2)O)</td>
<td>4,100</td>
</tr>
<tr>
<td>Manganese (Mn)</td>
<td>1,300</td>
</tr>
<tr>
<td>Aluminum (Al)</td>
<td>600</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>200</td>
</tr>
</tbody>
</table>

*Sources: Data from Broecker and Peng, 1982; Bruland, 1983; Riley and Skirrow, 1975.*

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Principle of Constant Element Ratios

-If residence time is >>> mixing time then ratios will be constant throughout ocean

-Principle does not apply to elements that cycle rapidly, especially under influence of biological processes (e.g., nitrogen, phosphorous)
The Ocean

Circulation in the Ocean
## Coriolis Effect - Earth’s Rotation

<table>
<thead>
<tr>
<th>LATITUDE</th>
<th>Eastward Velocity (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>90° N. Latitude</td>
<td>??</td>
</tr>
<tr>
<td>60° N. latitude</td>
<td>830</td>
</tr>
<tr>
<td>30° N. latitude</td>
<td>1440</td>
</tr>
<tr>
<td>Equator</td>
<td>1670</td>
</tr>
</tbody>
</table>
FOR OBJECT NOT CONNECTED TO EARTH
Coriolis Effect - Movement of fluids, in relation to earth beneath, results in deflections.
Example: Coriolis Effect and Deflection Of water current

Ekman Spiral
in northern hemisphere
Coastal Winds + Coriolis Effect = Upwelling

Surface water movement

Nutrient-rich water

Southern hemisphere: water moves to the left of wind
El niño - shutdown of upwelling
Oceanic Circulation - two components

- Wind-driven surface circulation
- Density-driven thermohaline deep circulation
Wind-driven Circulation

- Driven by heating of air near equator, which rises, moves to higher latitude, falls, creating circulation cells that are affected by Earth’s rotation (Coriolis effect increases with increasing latitude). Wind moves surface water.

TWO IMPORTANT OPEN-OCEAN SYSTEMS:
- **Prevailing westerlies** (40° N & S latitude)
- **Trade winds easterlies** (tropics either side of equator, toward the west)
Wind-driven Circulation

Wind systems
- Westerlies
- NE Tradewinds
- Doldrums
- SE Tradewinds
- Westerlies

Surface currents
- Subpolar gyre
- NH Subtropical gyre
- SH Subtropical gyre
- West wind drift
Wind-driven Circulation

• Combination of wind systems and shapes of ocean basins create cyclonic flow known as gyres
• Wind plus Coriolis effect tends to concentrate boundary currents on west sides of ocean at higher latitudes (40s) - creates concentrated currents such as Gulf Stream, Kuroshio current with deflection at higher latitude
AVHRR-Advanced Very High Resolution Radiometer - polar satellite
Second important type of motion: 
Thermohaline Circulation

• Water in the ocean can be divided into water masses, identified by distinct temperature, salinity, and other physico-chemical characteristics → density

• Density
\[ \sigma_t = (\text{density} - 1) \times 1000 \]
\[ \sigma_t \text{ increases with increasing salinity} \]
\[ \sigma_t \text{ increases with decreasing temperature} \]

Special significance: vertical density gradients
THERMOHALINE CIRCULATION: FORMATION OF DENSE SEAWATER AT SURFACE → SINKING OF COLD AND SALTY WATER
Thermohaline Circulation - Atlantic Water Masses

AABW = Antarctic Bottom Water; AAIW = Antarctic Intermediate Water; NADW = North Atlantic Deep Water
Thermohaline Circulation

- **Water masses**
- **Origin:** high latitude surface waters - high salinity, low temp --> high density
- **Waters sink, move at depth towards lower latitude** – AABW circulation \( \sim 10^2 \) years
- **Water masses each have a characteristic depth, because of their density, which is largely a function of their high latitude surface origin**
The ocean plays a major role in the distribution of the planet's heat through deep sea circulation. This simplified illustration shows this "conveyor belt" circulation which is driven by differences in heat and salinity. Records of past climate suggest that there is some chance that this circulation could be altered by the changes projected in many climate models, with impacts to climate throughout lands bordering the North Atlantic.
Circulation Recap

- **Coriolis effect** - rotation of Earth, prop. to sine of latitude, Right deflection in N. hemisphere, Left deflection in S. hemisphere - **upwelling**, deflection of currents from wind

- **Surface circulation** - driven by planetary winds, which are controlled by heating, convection, Coriolis effect - **gyres**, **eastern boundary currents**

- **Thermohaline Circulation** - driven by density, sinking, surface water brought to deep sea - water masses determined by density – **global conveyor belt**
Ocean Climate Change: “Oscillations” and Trends – Chapter 3
Oscillations vs Trends in Climate Change

Interactions: trend might affect oscillations
1990 IPCC Projections with Observed GHG Changes

Global Temperature Change (°C)

El Nino 1997-1998
OSCILLATIONS

• Not necessarily regular
• Often shift of conditions from one part of ocean to another
• Explanation is usually complex or unknown
Coastal Winds + Coriolis Effect = Upwelling

Southern hemisphere: water moves to the left of wind
El niño - shutdown of upwelling
El Niño – Southern Oscillation (ENSO) - Global Periodic Phenomenon but focused in tropics

- Periodic - every few years
- Warm water moves eastward across Pacific Ocean
- Eastern tropical and subtropical Pacific becomes warm, thermocline deepens
- Causes mortality in Pacific Americas of clams, fishes, from heat shock
- Strongly affects weather in eastern Pacific, storms increase; droughts in western Pacific
Other Periodic Oceanic Changes

- PDO – Pacific Decadal Oscillation – shift of pressure and water temperature in north Pacific
- NAO – North Atlantic Oscillation – shift of pressure, resulting in changes of climate, wind direction
- MAJOR THEME – ocean scale oscillations can have profound effects on local areas that could not be explained previously
Pacific Decadal Oscillation PDO

Warm phase

Cool phase
PDO Cool Phase – nw coast of U.S.

*Metacarcinus magister*, Dungeness crab  
*Parophrys vetulus*, English sole
San Francisco Bay

A

Filter feeding bivalves
PDO - Warm Water Phase

B

predators
PDO - Cold Water Phase

Cloern et al. 2010 Geophys. Res. Letters
Strong subtropical high, Strong low near Iceland

Weak subtropical high
Weak Icelandic Low
Strong subtropical high,
Strong low near Iceland

Weak subtropical high
Weak Icelandic Low
Strong subtropical high,
Weak Icelandic Low
Gullmar Fjord, Sweden

Strong low near Iceland
Weak Icelandic Low
EXTRA CREDIT

Keynote Speaker: Richard Prum
“The Evolution of Beauty: Darwin’s REALLY Dangerous Idea”
February 8 2019, 7:30 P.M., Earth and Space Sciences 001

Google living world stony brook
Global climate change

• Greenhouse Effect
• Ocean warming
• Acidification
Greenhouse gases: water vapor, carbon dioxide, methane, nitrous oxide, and ozone
"Keeling Curve"
Land + Ocean Climate Change

- Annual Average with 95% uncertainty
- Ten-Year Average

Global Average Temperature Anomaly (°C)

Berkeley Earth land values combined with interpolated HadSST ocean values
Above ice air temperatures used when and where sea ice is present

1850  1900  1950  2000
Global Ocean Warming

(a) Global land–ocean temperature anomaly (°C)

- Annual mean blue
- 5-year mean red

Base period = 1951–1980

(b) 2001–2005 mean surface temperature anomaly (°C)

Global mean = 0.54

Hansen, et al. 2006 PNAS
“Hockey stick temperature curve” based on “proxies” of temperatures, such as tree rings, lake varve deposits, etc.
Warming Also on Local Scale

Woods Hole, MA

Baltic Sea
IPCC 2014 projection

Global average surface temperature change

- Historical
- RCP2.6
- RCP8.5

No change
Low emission

1950 2000 2050 2100
Predicted Effects on Climate and Circulation

• Sea surface temperature warming
• Sea level rise (mainly expansion of sea water volume with increasing temperature)
• Sea level rise (melting of continental glaciers)
• Seawater acidification (due to increased dissolved carbon dioxide)
• Intensification of storms (controversial)
Acidification:

\[ \text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3 \] (carbonic acid)

\[ \text{H}_2\text{CO}_3 + \text{H}_2\text{O} \rightleftharpoons \text{HCO}_3^- + \text{H}_3\text{O}^+ \]

\[ \text{HCO}_3^- + \text{H}_2\text{O} \rightleftharpoons \text{CO}_3^{2-} + \text{H}_3\text{O}^+ \]

\[ \rightleftharpoons \text{Precipitation} \]

\[ \text{CaCO}_3 \rightleftharpoons \text{Ca}^2 + \text{CO}_3^{2-} \]

Solution→
Acidification – addition of carbon dioxide to seawater:

\[
\text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3 \quad \text{(carbonic acid)}
\]

\[
\text{H}_2\text{CO}_3 + \text{H}_2\text{O} \rightleftharpoons \text{HCO}_3^- + \text{H}_3\text{O}^+
\]

\[
\text{HCO}_3^- + \text{H}_2\text{O} \rightleftharpoons \text{CO}_3^{2-} + \text{H}_3\text{O}^+
\]

← Precipitation

\[
\text{CaCO}_3 \rightleftharpoons \text{Ca}^2 + \text{CO}_3^{2-}
\]

Solution →
Calcium carbonate, $\text{CaCO}_3$

- Two natural phases of $\text{CaCO}_3$: *calcite* and *aragonite*.
- Aragonite less stable.
- Can calculate concentrations of Ca and $\text{CO}_3^-$ ions at saturation level for calcium carbonate; saturation state $\Omega$ see p. 33 in text.
- Need 3x saturation state to precipitate aragonite.
- Aragonite in all corals, most snails, pteropods (food of juvenile ocean fish).
Who makes CaCO$_3$

- Corals
- Molluscs = bivalves, gastropods, cephalopods
- Pteropods in plankton
- Sea urchins, seastars
- BUT other non-calcifying organisms also affected by acidification
Who makes CaCO$_3$

- Corals
- Molluscs = bivalves, gastropods, cephalopods
- **Pteropods in plankton**
- Sea urchins, seastars
- BUT other non-calcifying organisms also affected by acidification
Pteropods – zooplankton, planktonic gastropods, aragonite shells
Pteropod shells,
Increased acidification →
Known effects of acidification

- Formation of larval bivalve shells – impact on bivalve fisheries, hatcheries
- Reduction of coral skeletal density
- Interaction of upwelling, hypoxia, and pH reduction (west coast)
- Interaction of hypoxia, pH reduction (east coast)
Known effects of warming

- Sea level rise – erosion of shore habitats in storms
- Shifting of biogeographic ranges of marine species – reshuffling of communities
- Facilitation of invasion of warm water species, parasites, disease
- Physiological stress – e.g., coral bleaching, mortality, effects variable on different groups
The Ocean

Coastal Processes
Waves
Tathra Beach, New South Wales, Australia
Waves

- Dimensions

Wave Length $L$
Amplitude $H$
Velocity $V = \frac{L}{t}$

Whole water column is NOT moving horizontally!
Waves

- When depth $< \frac{L}{2}$: waves “feel bottom”
- When $\frac{H}{L} > \frac{1}{7}$: wave is unstable and collapses (breaks)
Longshore currents, riptides are common features, causing erosion and transport of sand.
Beaches

• Many beaches exposed to direct wave and erosive action
• Some sandy beaches are more protected, very broad with low slope and dissipate wave energy near the low tide mark
Beaches 2

- Profile more gentle in summer; fall and winter storms cause erosion and a steeper profile
TIDES

Moon

Moon's Gravitational Pull

High Tide

Earth's Centrifugal Force

Low Tide

POLE

High Tide
Tides

Spring Tide

Neap Tide

E = Earth

m = Moon: grav. effect is 6x sun
Tide summary – vertical range varies

- Spring Tides – alignment of moon, sun, earth: greatest vertical tidal range, *highest high, lowest low*

- Neap tides – earth forms approximate right angles with moon and sun - *smallest vertical tidal range*
Tides

- Tides differ in pattern and vertical range in different areas; function of basin shape, basin size, latitude
- Amplitude varies, evenness of semidiurnal tide varies – due to tidal harmonics - synchrony of gravity and response of water body (sloshiness?)
Connecticut – even, semidiurnal tides Washington State – uneven daily
Estuaries

- Body of water where freshwater source from land mixes with seawater
- Often results in strong salinity gradient from river to ocean
- Salinity may be higher at bottom and lower at top, owing to source of river water that comes to lay on top of sea water below, or mixes with the sea water to some degree
Chesapeake Bay with summer surface salinity. Dark blue areas: tributaries have salinity $< 10$
Cape Fear Estuary and Coast,
N.C.
Estuaries - types

- Fresh water layer
- Sea water

Highly stratified estuary

Moderately stratified estuary (wind, tide mixing)

Vertically homogeneous estuary