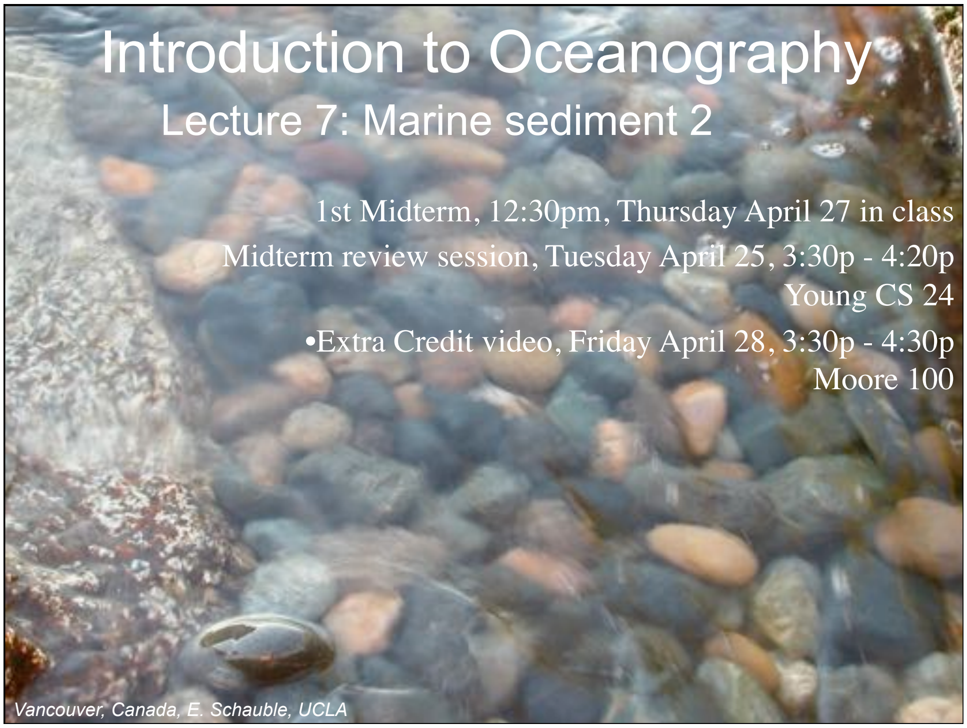


Genetic Classification of Sediments

- *Terri*genous: from continents
- *Bio*genous: from biological sources
- *Hydro*genous: seawater precipitates
  - Sometimes referred to as "authigenic" -- means formed in place
- *Cosmo*genous: extraterrestrial sources

Fluvial Terrigenous Sediments

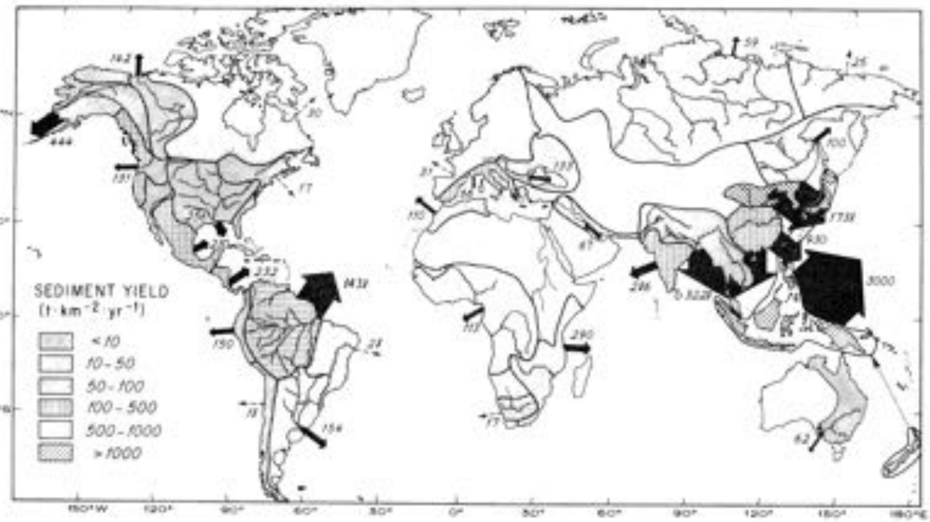
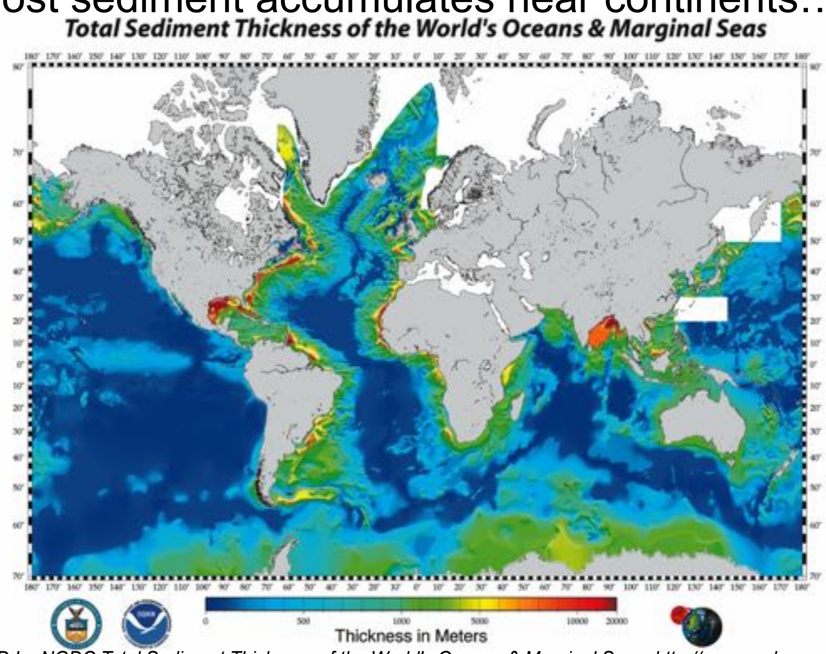


FIG. 4.—Annual discharge of suspended sediment from various drainage basins of the world; width of arrows corresponds to relative discharge. Numbers refer to average annual input in millions of tons. Direction of arrows does not indicate direction of sediment movement. The sediment yields and major rivers of the various basins also are shown; open patterns indicate essentially no discharge to the ocean.

Figure from Milliman JD and Meade RH (1983) World-wide delivery of river sediment to the oceans. J. Geology 91:1-21.

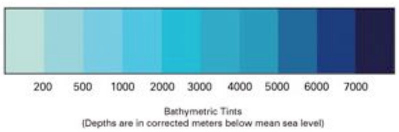
Most sediment accumulates near continents…



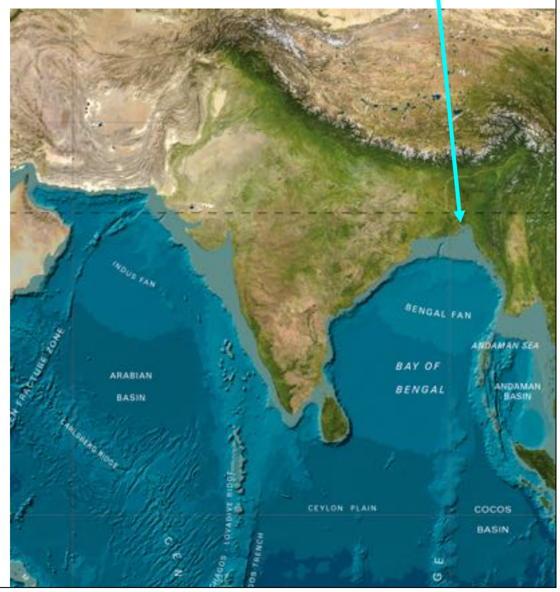
Divins, D.L., NGDC Total Sediment Thickness of the World's Oceans & Marginal Seas, http://www.ngdc.noaa.gov/mgg/sedthick/sedthick.html, Public Domain

Terrigenous sediment accumulates near sources

Bengal Fan –
World's largest pile of mud?



Bathymetry from GEBCO world map, http://www.gebco.net, education use explicitly allowed.



An interlude: Grain Size Sediment Classification

- Typical Particle Sizes:

Particle Name	**Particle Diameter**
Gravel, Granules & Pebbles	2 -64 mm
Sand	0.062 - 2 mm
Silt	0.004 - 0.062 mm
Clay	< 0.004 mm

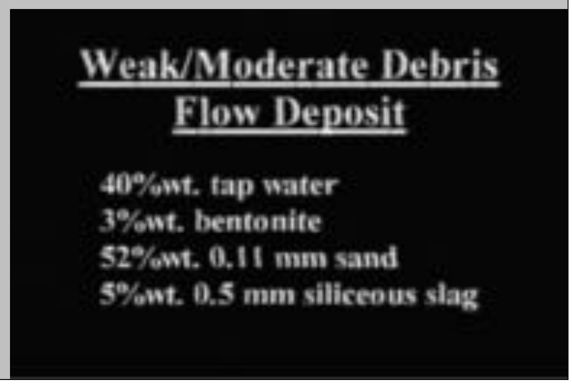
Peas: Renee Comet, Natl. Cancer Inst., Public Domain, http://visualsonline.cancer.gov/details.cfm?imageid=2612; Sugar, Fritzs, Wikimedia Commons, CC A S-A 3.0, http://visualsonline.cancer.gov/details.cfm?imageid=2612; Powdered sugar, Wikimedia Commons, JonathanLamb, Public Domain, http://en.wikipedia.org/wiki/File:Confectioners-sugar.jpg; Printer, Wikimedia Commons, Pierre Bauduin, CC A S-A 3.0, http://commons.wikimedia.org/wiki/File:HP_LaserJet_4000n.jpg

Grain Size Dependent Transport

High energy

- **Pebbles**: Hard to transport (storms, big surf, fast rivers & steep streams)
- **Sand**: in the middle (small surf, most rivers & streams)
- **Clays**: Easy to transport (tides, slow streams & rivers, long range transport by wind)

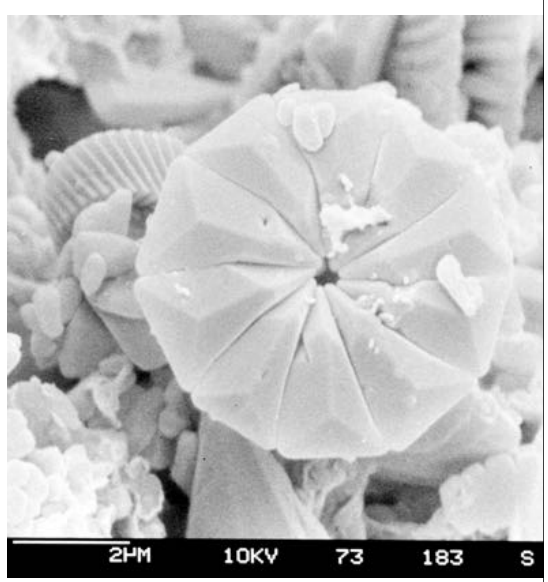
Low energy



From Sediment Transport Movie archive, Paul Heller, U. Wyoming, http://geofaculty.uwyo.edu/heller/sed_video_downloads.htm

*Bio*genous Sediments

- Mostly skeletal material produced by dominant species of plankton
  - floating ocean organisms die, shells settle to the sea floor & lithify
- Calcareous: skeletal materials of $CaCO_3$
- Siliceous: skeletal materials of opal ($SiO_2 \cdot nH_2O$)



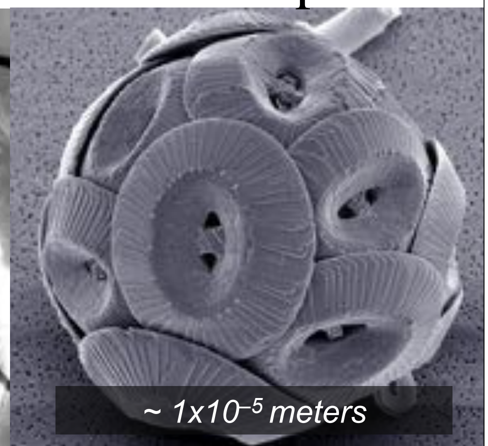
Hannes Grobe, Alfred Wegener Institute, Wikimedia Commons, Creative Commons A S-A 3.0, http://commons.wikimedia.org/wiki/File:41-366A-18-2_2101_73183.jpg

Calcareous ($CaCO_3$) Plankton

Foraminifera

Globigerina bulloides, NOAA image, Public Domain

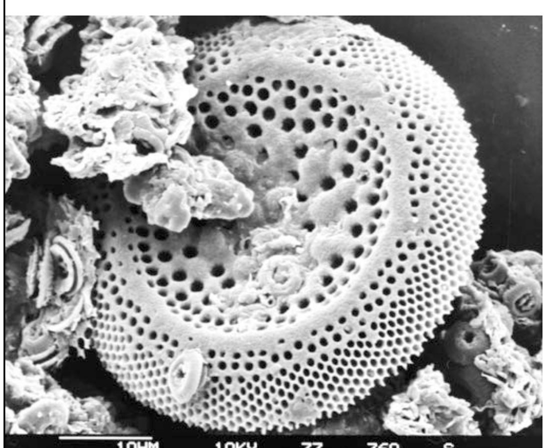
Coccolithophores



Coccolithus pelagicus, Richard Lampitt, Jeremy Young, The Natural History Museum, London, Creative Commons A S-A 2.5, http://commons.wikimedia.org/wiki/File:Coccolithus_pelagicus.jpg

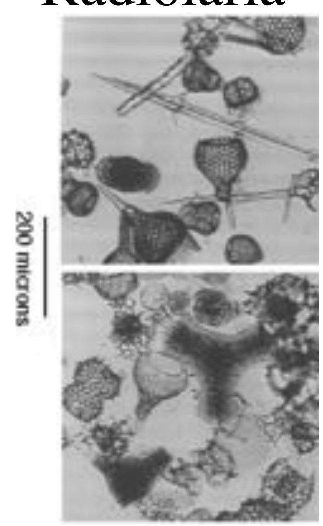
Siliceous (SiO_2) Plankton

<u>Diatoms</u>



Hannes Grobe, Alfred Wegener Institute, Wikimedia Commons, Creative Commons A S-A 2.5, http://commons.wikimedia.org/wiki/File:Diatom_hg.jpg

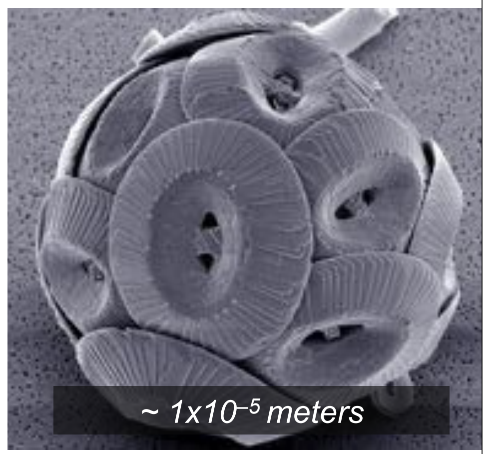
Radiolaria



P. Worstell, UCSD, http://gc.ucsd.edu/Proc/fossilsPROC2htm.html

Biogenous Sediments

- Most plankton live near the ocean surface
- Calcareous shells and skeletons produced fastest in surface waters
- Calcareous shells & skeletons tend to dissolve
  quickly in the deep ocean.
- Siliceous shells dissolve fast near surface, slowly in deep ocean.
- Found in areas with lots of nutrients (few nutrients: ~little biology --> little sediment).
- **Shallow - Calcareous**
- **Deep - Siliceous**



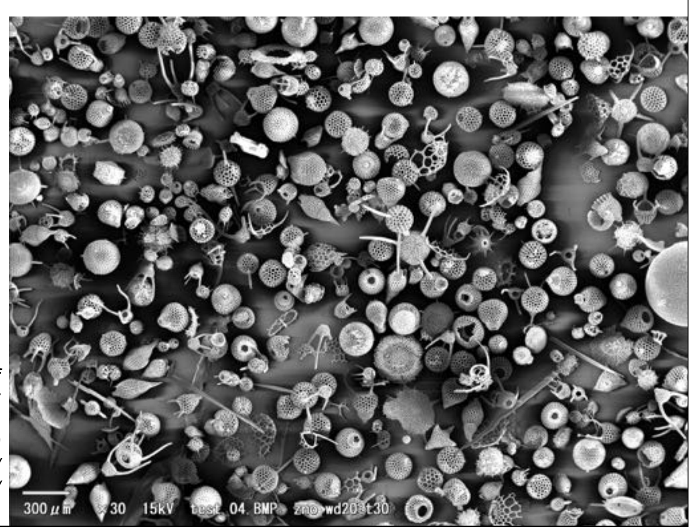
Coccolith (phytoplankton)

Coccolithus pelagicus, Richard Lampitt, Jeremy Young, The Natural History Museum, London, Creative Commons A S-A 2.5, http://commons.wikimedia.org/wiki/File:Coccolithus_pelagicus.jpg

Biogenic Oozes

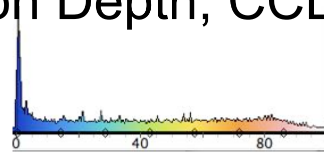
- Oozes contain > 30% biogenic material
  - Production: Shells &Skeletons
  - Destruction: Dissolves before burial
  - Dilution: Mixing with terrigenous sediments
- Oozes uncommon near continents: diluted by copious terrigenous sediments
- Oozes also uncommon where there are few nutrients

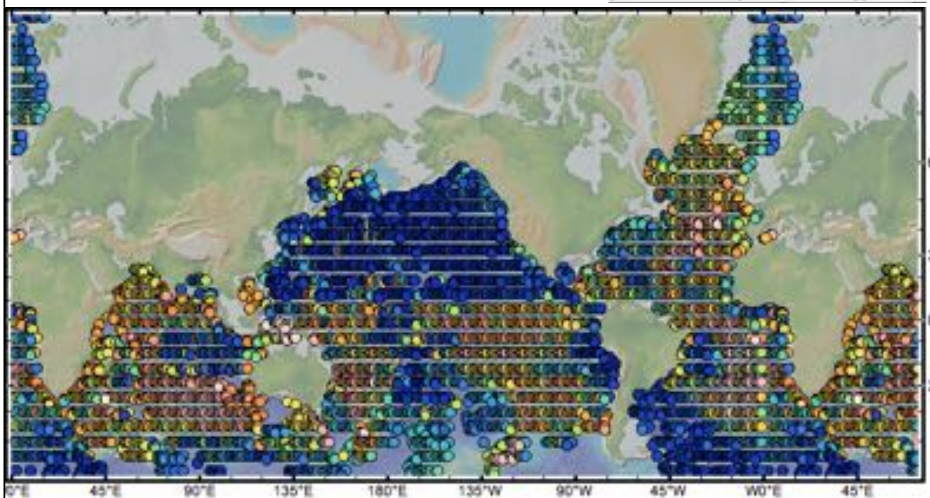
Electron micrograph of radiolarian ooze, image by Yasuhiro Hata, Creative Commons BY-NC-SA 2.0 http://www.flickr.com/photos/hatash/6195181070/in/pool-765680@N20/lightbox/,



Carbonate Compensation Depth, CCD

- **CCD**: Depth below which calcium carbonate sediments don't accumulate

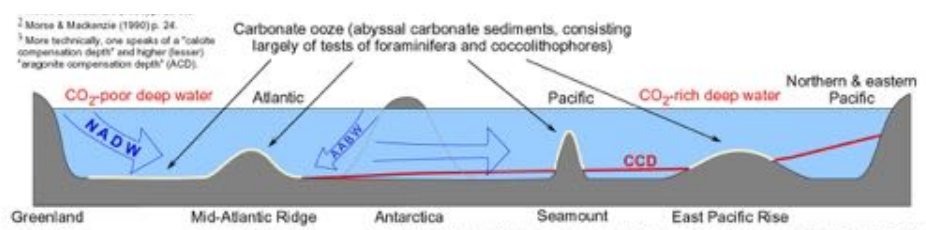




% Carbonate in seafloor sediments, created with GeoMapApp using Archer (2003) interpolated data.

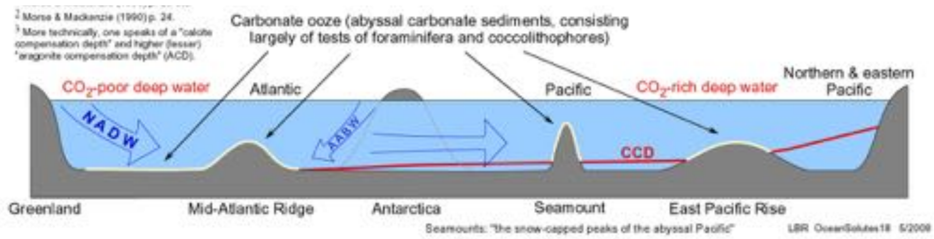
"Calcite" Compensation Depth, CCD

- **CCD**: Depth below which calcium carbonate sediments can't accumulate
  - CCD depth: high acidity, cold bottom waters dissolve $CaCO_3$ below CCD
  - Average Depth of CCD: 4,500 m
- Deeper in the Atlantic; Shallower in the Pacific



Cropped from http://www.gly.uga.edu/railsback/Fundamentals/OceanSolutes18IIIa.jpg, L. Bruce Railsback, U. Georgia,

Calcite Compensation Depth, CCD



Cropped from http://www.gly.uga.edu/railsback/Fundamentals/OceanSolutes18IIIa.jpg, L. Bruce Railsback, U. Georgia,

CO_2 mixed with water makes carbonic acid (H_2CO_3):

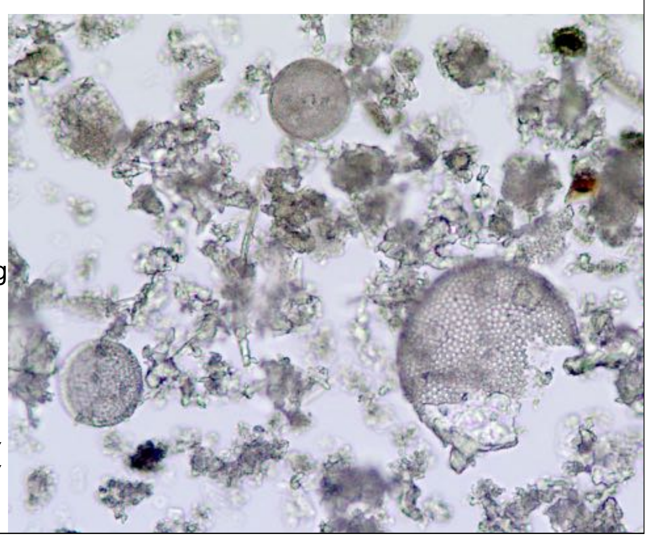
$$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^- \leftrightarrow 2H^+ + CO_3^{2-}$$

More CO_2 can dissolve in cold water.
Calcium carbonate dissolves in acid.
In today's ocean deep waters are very cold, CO_2-rich.
Therefore, calcium carbonate tends to dissolve fastest in deeper water because it tends to be more acidic.

Siliceous Oozes

Siliceous oozes found underneath regions of high productivity and

- Below CCD
- Far from continents
- Mainly in nutrient rich zones
  - Areas of upwelling flows around Antarctica & equator

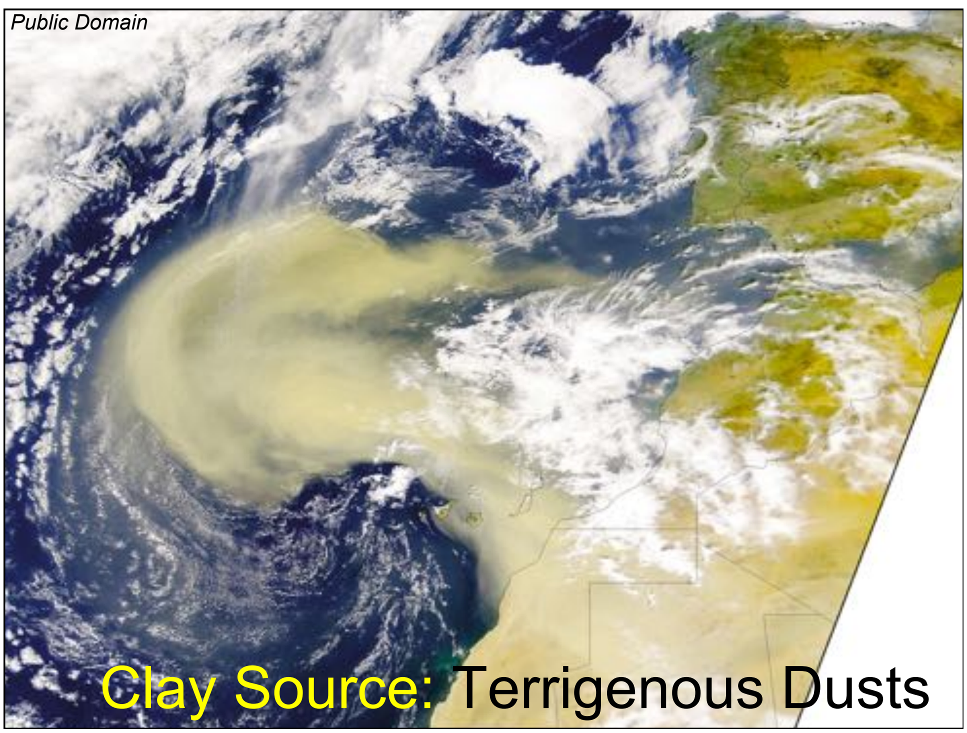


Diatomaceous earth from pool filter, Wikimedia Commons, Curtis Clark, Creative Commons A S-A 2.5, http://commons.wikimedia.org/wiki/File:Diatomaceous_earth_2001-10-18.jpg

Abyssal Clays

Dust storm, Al Asad, Iraq, Photo by Cpl. Alicia M. Garcia – USMC, Public Domain, http://www.defenselink.mil/photos/newsphoto.aspx?newsphotoid=6469

Public Domain

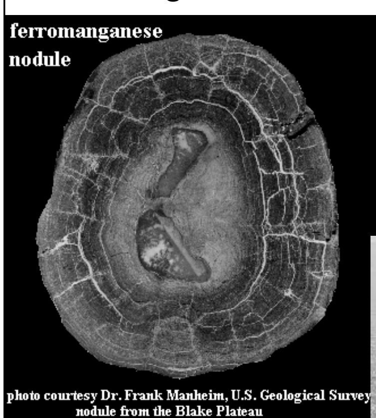


Hydrogenous Sediments

Hughes Glomar Explorer. This ship wasn't built for oceanography research.
US Government photo, Public Domain
http://www.gwu.edu/~nsarchiv/nukevault/ebb305/index.htm

Hydrogenous Sedimentary Deposits

- Chemical deposits formed by precipitation
  - Grow at water-sediment interface
  - Manganese nodules



USGS/NOAA, Public Domain, http://www.ngdc.noaa.gov/mgg/image/nodule.gif

Japan Agency for Marine-Earth Science and Technology, http://www.jamstec.go.jp/jamstec-e/30th/part6/image/p86_1.jpg

Attribution uncertain, appears to be widely disseminated, (e.g., http://www.aerospaceweb.org/question/weapons/q0268.shtml) and thus may be Public Domain

Cosmogenic Sediments

Sediments from space

Cosmic dust or meteorite impact

Painting by Don Davis, NASA, Public Domain

K-T Boundary layer, Gulf of Mexico sediment core, MARUM Research Center Ocean Margins, Bremen University , Bremen – Germany, http://www.imaggeo.net/view/45

K-T boundary in sediment

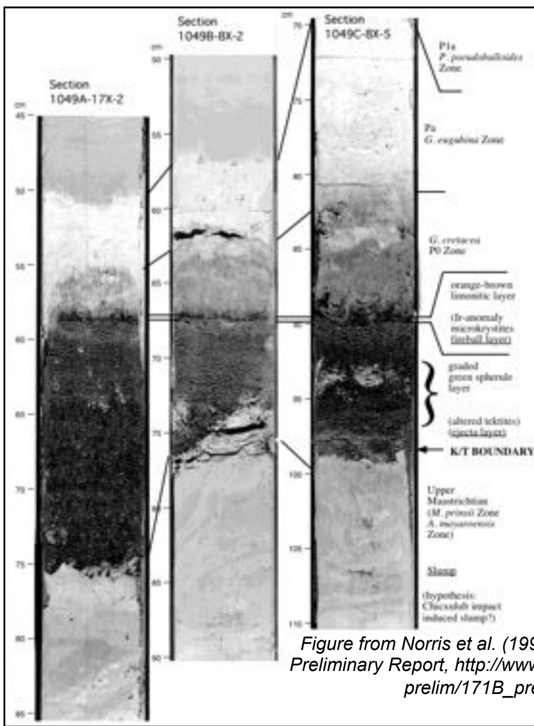


Figure from Norris et al. (1997) Ocean Drilling Program Preliminary Report, http://www-odp.tamu.edu/publications/ prelim/171B_prel/171Bprel.pdf

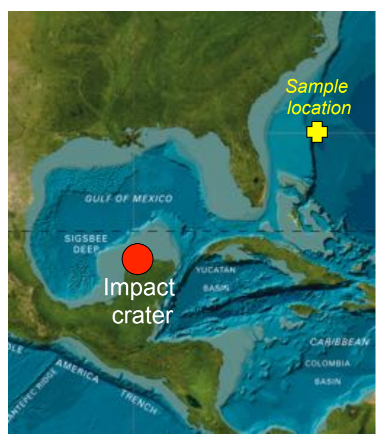


Figure based on GEBCO bathymetric map, educational use explicitly allowed

Rate of sediment addition:

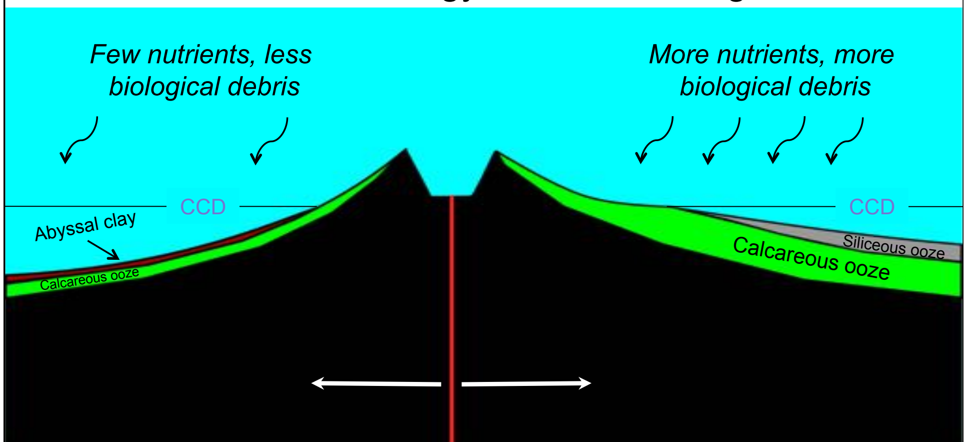
Sediment Type	**Rate (m/Myr)**
Continental Margins	~ > 50 = 0.05 mm/yr
Deep Sea	
Calcareous	10 - 30
Siliceous	2 - 10
Clay	0.5 - 2
Manganese Nodules	0.001

fast → *slow*

BIG PICTURE ON SEDIMENTS

- Terrigenous near continents
- High Bioproductivity:
  - Calcareous oozes above CCD
  - Siliceous oozes below CCD
- Abyssal clays where nothing else is getting deposited
- Give recent (~200 Myr) historical record

Sediment, biology and seafloor age



Once buried, biogenous sediments tend not to dissolve (or do so slowly and incompletely).

Thus sediment profiles record variation in sediment sources over time and space.

Figure by E. Schauble, UCLA, created with Inkscape

Global Distribution of Sediments

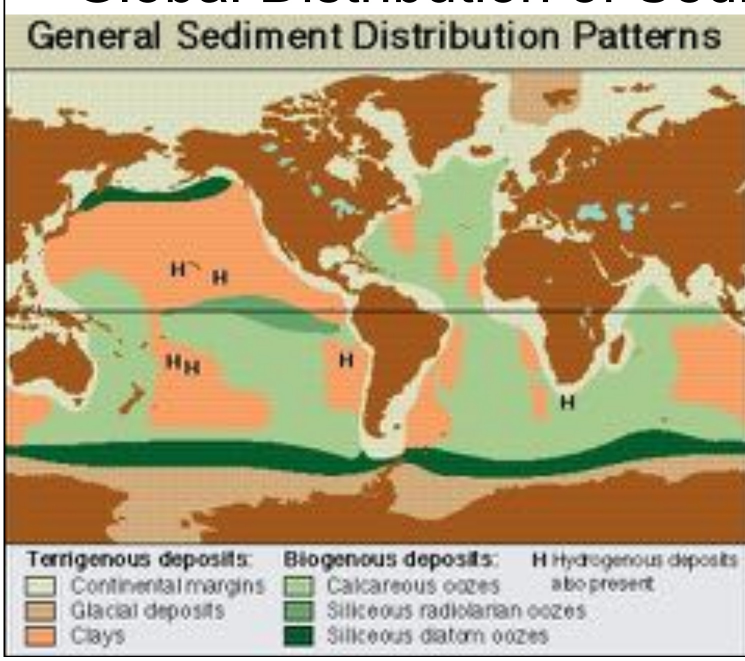
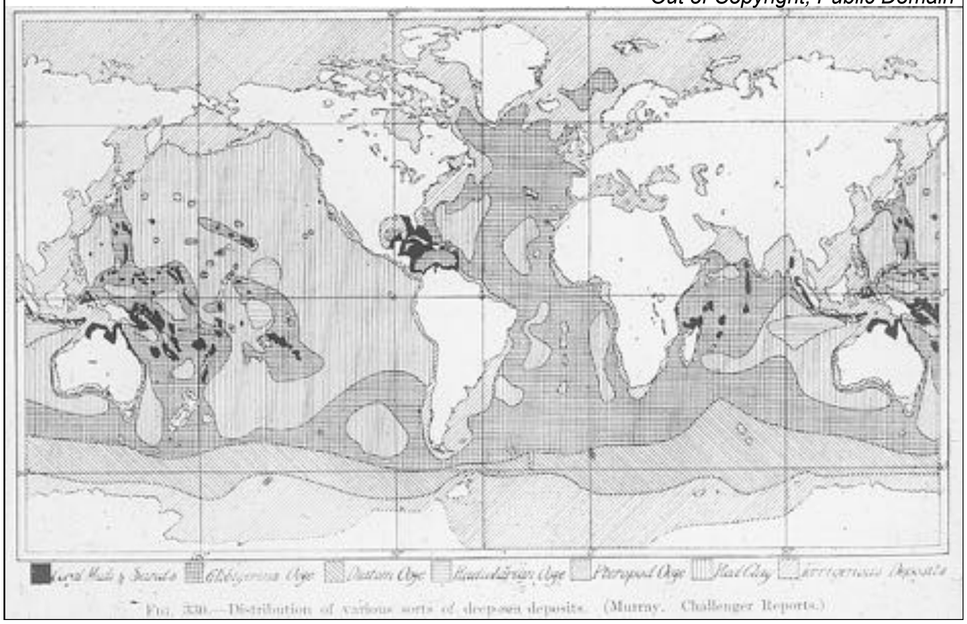


Image attribution unknown

Map of seafloor sediment distribution from the
Challenger expedition (1872-1876), by John Murray (1896).



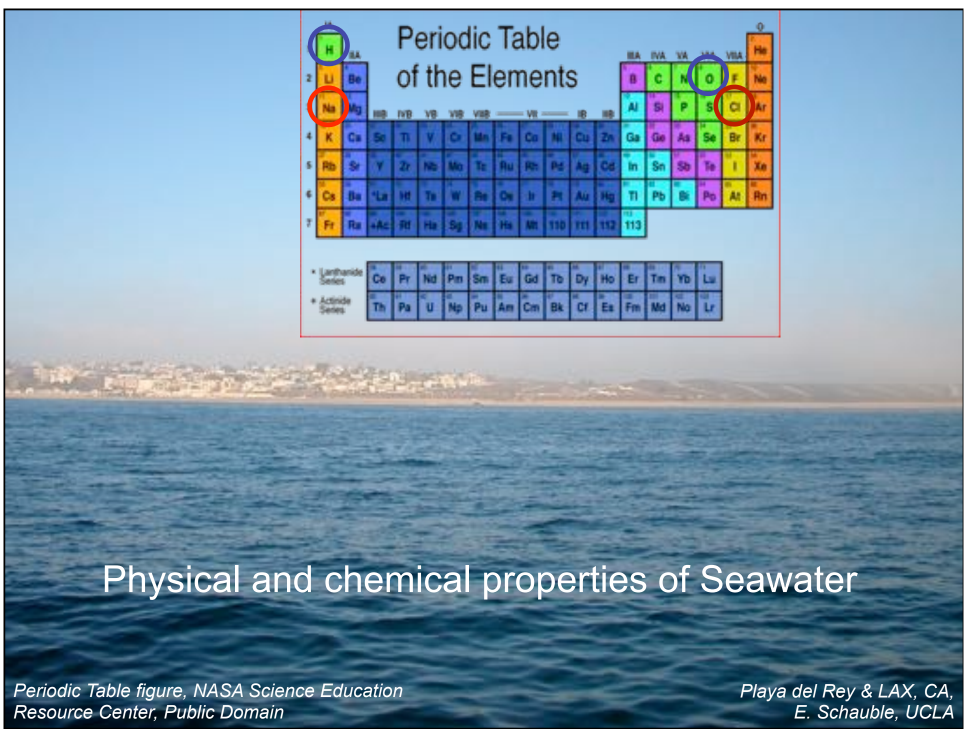
How Do We Know All This?

Drilling ships operated by international science coops, e.g., JOIDES

JAMSTEC Ship *Chikyu*

Questions

Calcareous ooze particles, Paula Worstell, SIO, BOSCORF - http://www.boscorf.org/curatorial/ccd.html



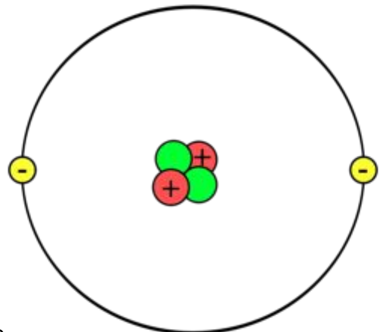
Physical and chemical properties of Seawater

Periodic Table figure, NASA Science Education Resource Center, Public Domain

Playa del Rey & LAX, CA, E. Schauble, UCLA

Atoms

- Atom: cannot be broken down into simpler parts by chemical means
- Nucleus:
  - Protons (+) & Neutrons (uncharged)
  - Massive
  - Small (~10^{-15} m)
- Electrons (–)
  - Little mass
  - Most of the volume (~10^{-10} m = 1 Å)

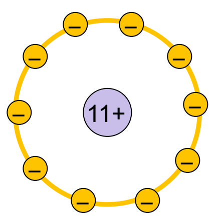


Svdmolen/Jeanot, Wikimedia Commons, Creative Commons A S-A 3.0, http://commons.wikimedia.org/wiki/File:Atom.svg

Helium

Ions

- Ions are atoms with net electrical charge
  - Anion: negative charge (Cl^-) -- extra electrons
  - Cation: positive charge (Na^+) -- electrons removed



E. Schauble, UCLA

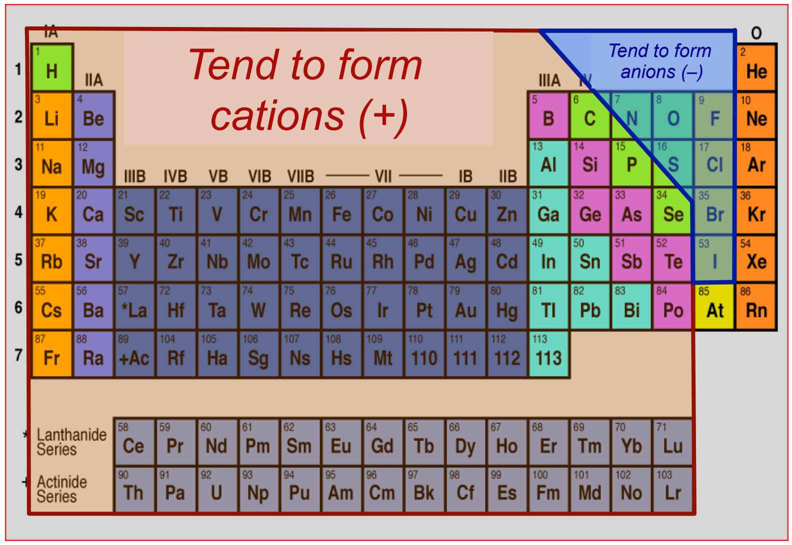
Na+: $11p^+$, $10e^-$

Elements on the left side of the periodic table of elements tend to become positive (H, Na, Mg). Elements near the right side of the periodic table tend to become negative (O, F, Cl)

Molecules

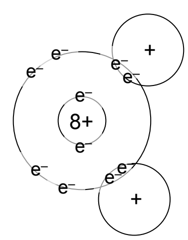
- Substances made up of chemically bonded atoms

What kind of ions will an element form?

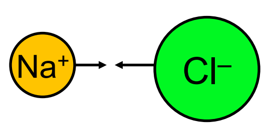


NASA image, Science Education Resource Center, http://serc.carleton.edu/images/usingdata/nasaimages/periodic-table.gif, Public Domain

Chemical Bonds



- Covalent: e⁻ **shared** between atoms (i.e., H_2O)
- Ionic: Charges **borrowed** by anions
  - Like Na^+Cl^-



- Hydrogen Bonding: in water, H has slightly + charge, which attracts negatively charged O.
  H in water molecules also attracts anions like Cl–
  O in water molecules also attracts cations like Na+

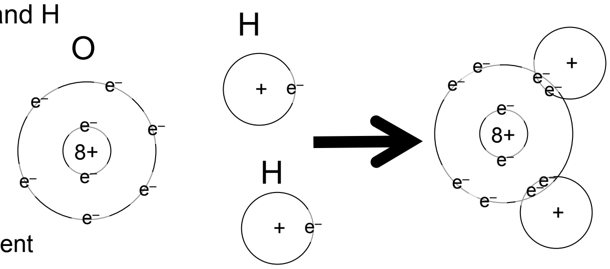
Bond Strength: Covalent > Ionic > H-bond

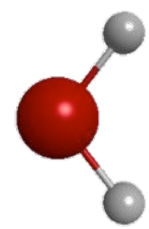
All images E. Schauble, UCLA

Water Molecule: H_2O

Covalent bond between O and H

- Polar Molecule
  - Positive “ears”-105º
  - Mickey Mouse
  - Polar structure
- Hydrogen Bonding
  - Effect of polarization
  - ~5% as strong as covalent bonds
  - tends to make molecules clump together – i.e., condense





E. Schauble, UCLA
ball & stick model rendered using MacMolPlt

Liquid Water

- Hydrogen Bonding
  - Each H_2O: 4 possible H-bonds
  - Makes liquid water “clump” together
  - Accounts for many peculiarities
    - Great solvent power
      - Saline ocean water
    - Thermal and density properties

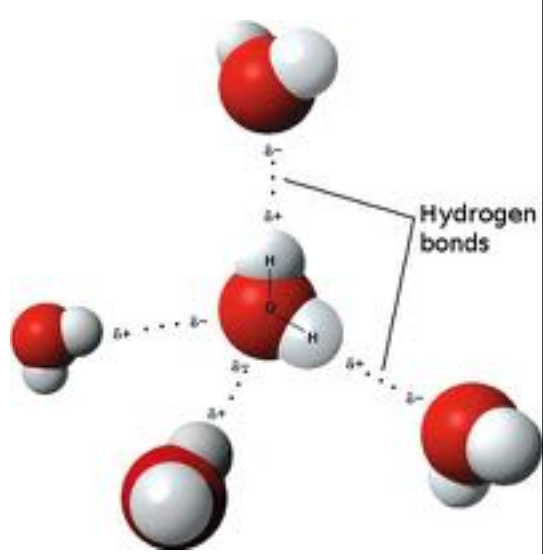


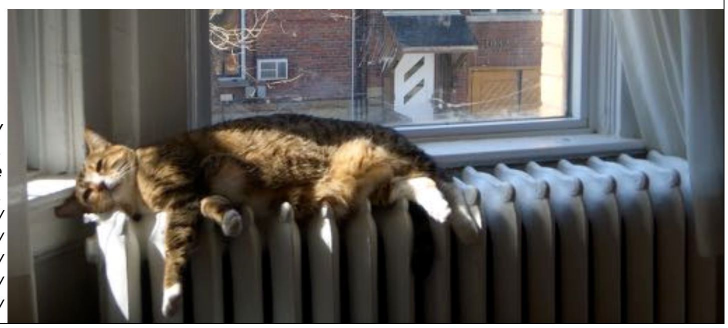
Figure by Qwerter/Michal Maňas, Wikimedia Commons, Creative Commons A S-A 3.0, http://en.wikipedia.org/wiki/File:3D_model_hydrogen_bonds_in_water.jpg

Heat Capacity

Substance	Heat Capacity (cal/gram/^{o}C)
Granite	0.20
Gasoline	0.50
Water	**1.00**
Ammonia	1.13

The **only** common liquid with higher heat capacity than water is ammonia!

Photo by ..its.magic.., Flickr, Creative Commons 2.0, http://www.flickr.com/photos/rizielde/3373257326/sizes/l/



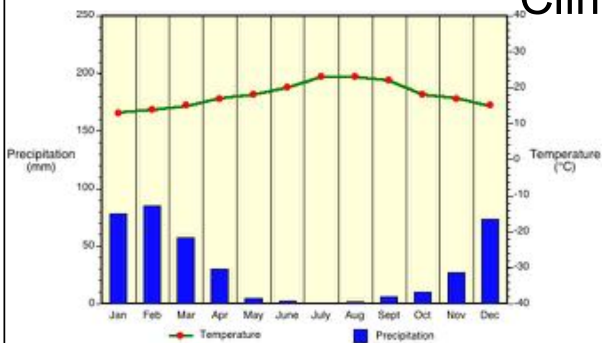
Heat Capacity

Examples:

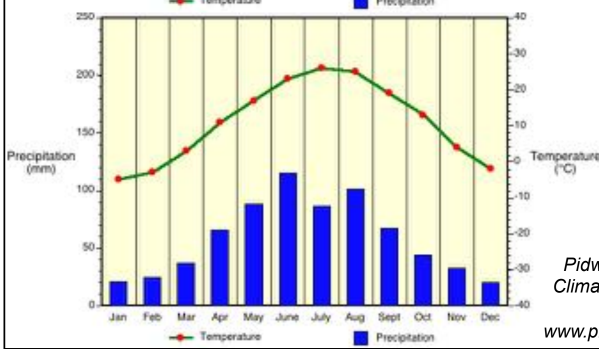
- TV dinner: Aluminum Foil vs. Gravy. Both are at the same temperature, but gravy has much higher heat capacity – it hurts!
- At the beach: Sand vs.water

Photo by A. Lau, "are you gonna eat that", http://www.flickr.com/photos/andreelau/186536202, Creative Commons Attribution-NonCommercial-NoDerivs 2.0 Generic

Climate Comparison



LAX -- on coast.
Strong ocean influence.
Little daily/seasonal variation in Temp.



Omaha, NE –
middle of continent.
Weaker ocean influence.
Variable Temp.

Pidwirny, M. (2006). "Climate Classification and Climatic Regions of the World". Fundamentals of Physical Geography, 2nd Edition. http://www.physicalgeography.net/fundamentals/7v.html

Physical States of Matter

Solid: molecules bonded in a fixed lattice

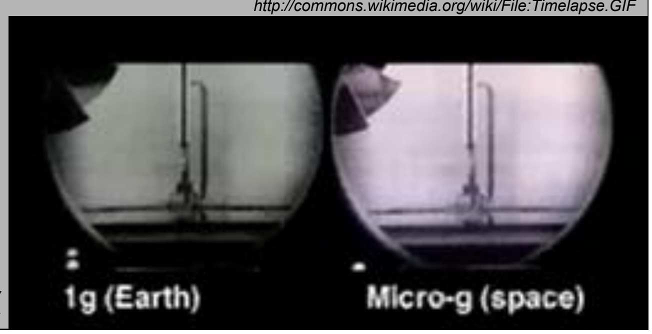
- Add energy (i.e., latent heat of fusion)…

Zeitraffer, Wikimedia Commons, CC A S-A 3.0, http://commons.wikimedia.org/wiki/File:Timelapse.GIF

Liquid: bonded molecules but in no fixed lattice

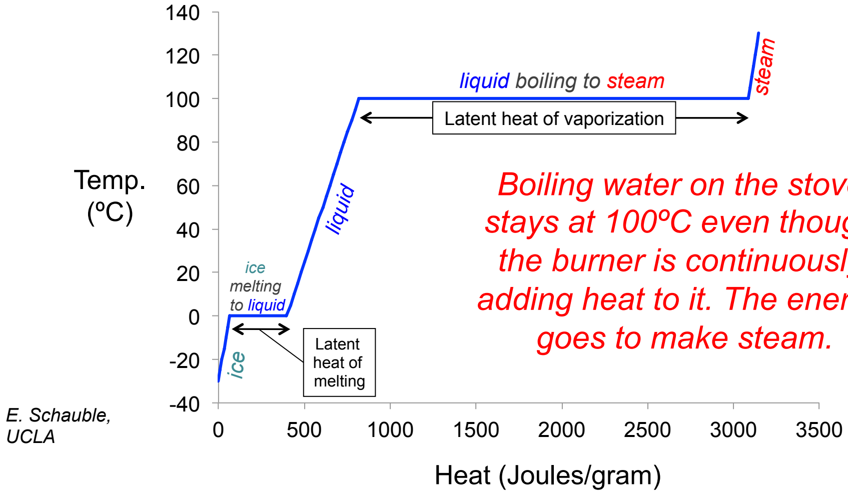
- Add energy (i.e., latent heat of vaporization)…

Gas:
Free molecules



NASA, Public Domain, http://ksnn.larc.nasa.gov/videos/poolboil.mov

Relationship between Heat and Temperature for H_2O



Sensible Heat: measurable change in temperature when heat is added or subtracted (sloping lines).

Latent Heat: no temperature change with added/subtracted heat (flat lines).