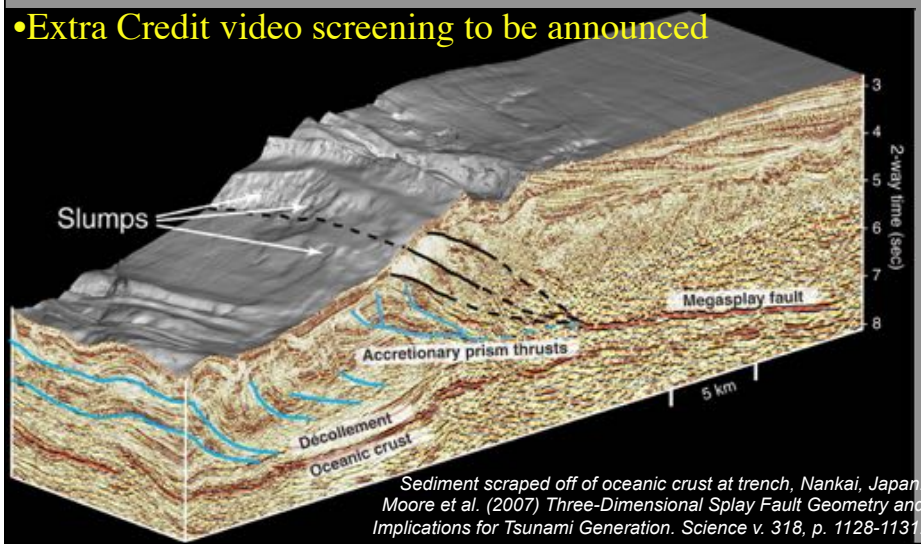
Introduction to Oceanography

- Lecture 6: California tectonics, marine sediment

Scarp from the El Mayor-Cucapah earthquake, April 4, 2010. Photo by Austin Elliott(?)
http://blogs.agu.org/tremblingearth/2011/04/09/el-mayor-cucapah-earthquake-anniversary/

Introduction to Oceanography

- 1st Midterm, 12:30pm, Thursday April 27 in class
- Midterm review session, to be announced
- Extra Credit video screening to be announced



Sediment scraped off of oceanic crust at trench, Nankai, Japan.
Moore et al. (2007) Three-Dimensional Splay Fault Geometry and Implications for Tsunami Generation. Science v. 318, p. 1128-1131.

Tectonic Evolution of Ocean Basins

Oceanic life cycles (Wilson Cycle): ~200-500 million years to open and close

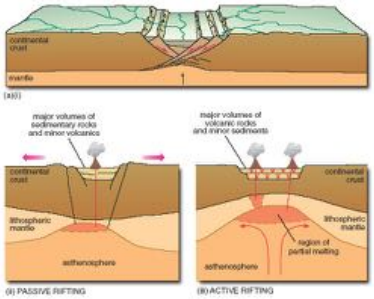
African Rift Valley: An embryonic ocean?

Ol Doinyo Lengai, photo by Clem23, Wikimedia Commons Creative Commons A S-A 3.0, http://commons.wikimedia.org/wiki/File:NgareSero.jpg

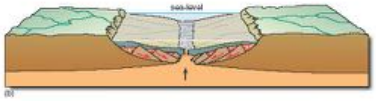
Tectonic Evolution of Ocean Basins

Oldest oceanic crust is less than 200 million years old – oceans are created and destroyed repeatedly.

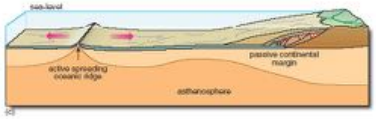
Embryonic – linear rift valleys



Juvenile – narrow seaway



Mature – broad ocean, well-developed passive margins



Declining/terminal – active margins, narrowing or irregular basin

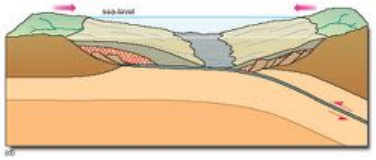
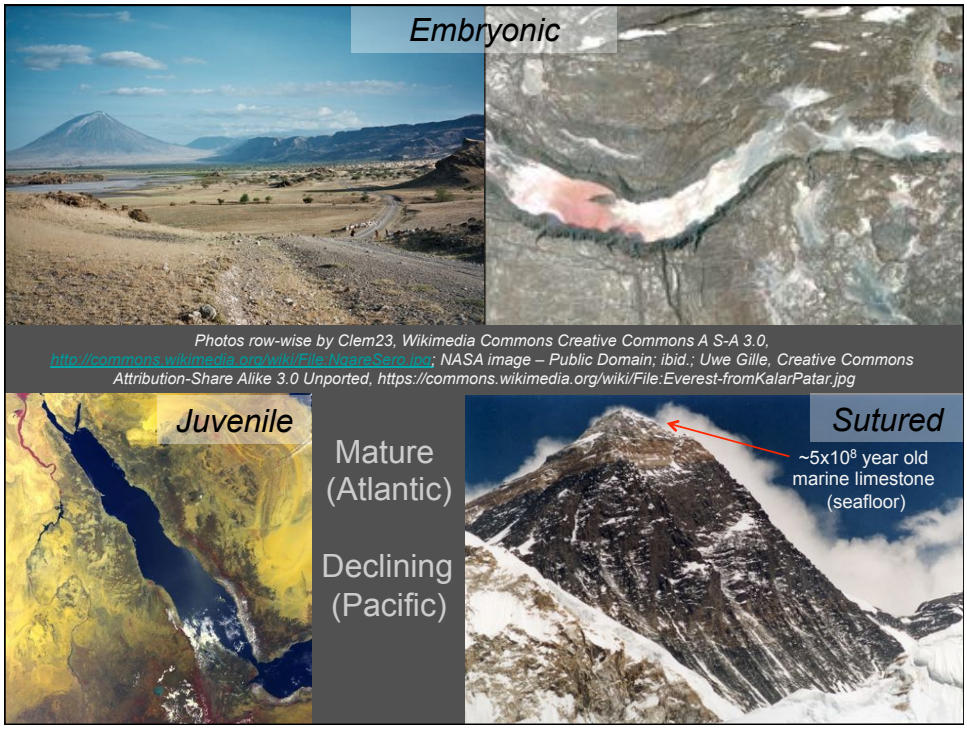
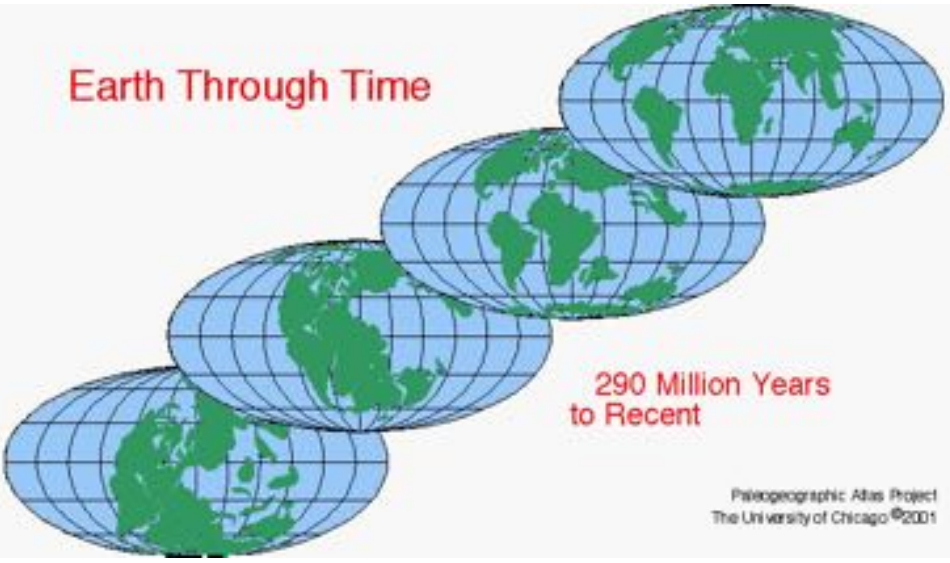


Figure from Open University Learning Space, "Geological processes in the British Isles", Creative Commons A S-A 2.0, http://dspace.jorum.ac.uk/xmlui/download/bitstream/handle/123456789/993/Items/SXR260_1_006i.jpg?sequence=33



Photos row-wise by Clem23, Wikimedia Commons Creative Commons A S-A 3.0, http://commons.wikimedia.org/wiki/File:NgaraSero.jpg; NASA image – Public Domain; ibid.; Uwe Gille, Creative Commons Attribution-Share Alike 3.0 Unported, https://commons.wikimedia.org/wiki/File:Everest-fromKalarPatar.jpg

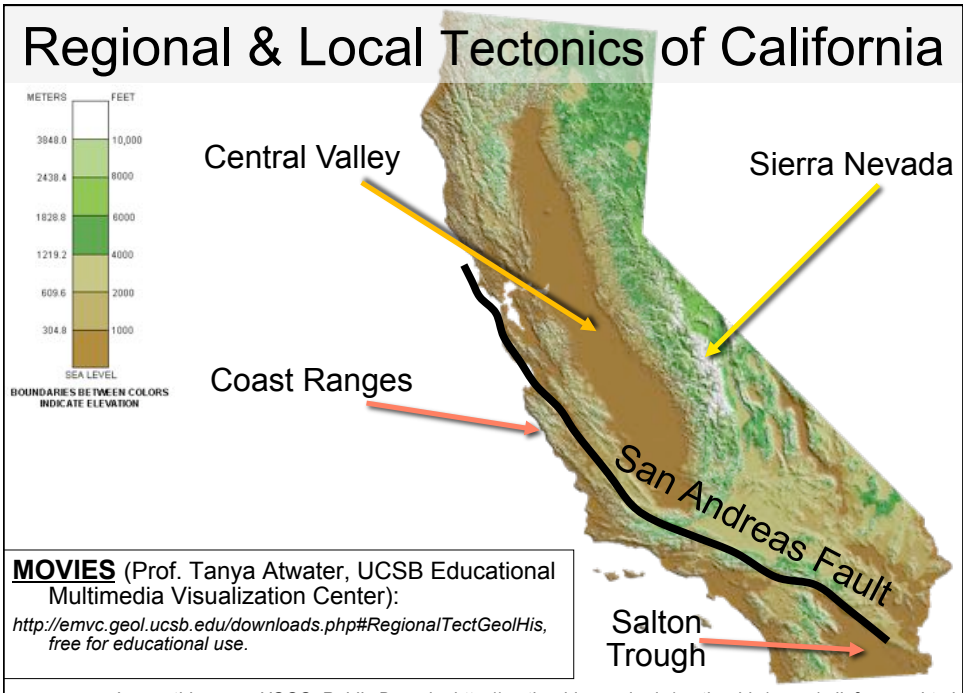
Paleogeographic reconstruction



Paleogeographic Atlas Project, Ziegler et al., U. Chicago, http://www.geo.arizona.edu/~rees/global290-0pgeogrev.mov

Lots of alternative visualizations have been made by Christopher Scotese (e.g., https://www.youtube.com/watch?v=g_iEWvtKcuQ)

Regional & Local Tectonics of California

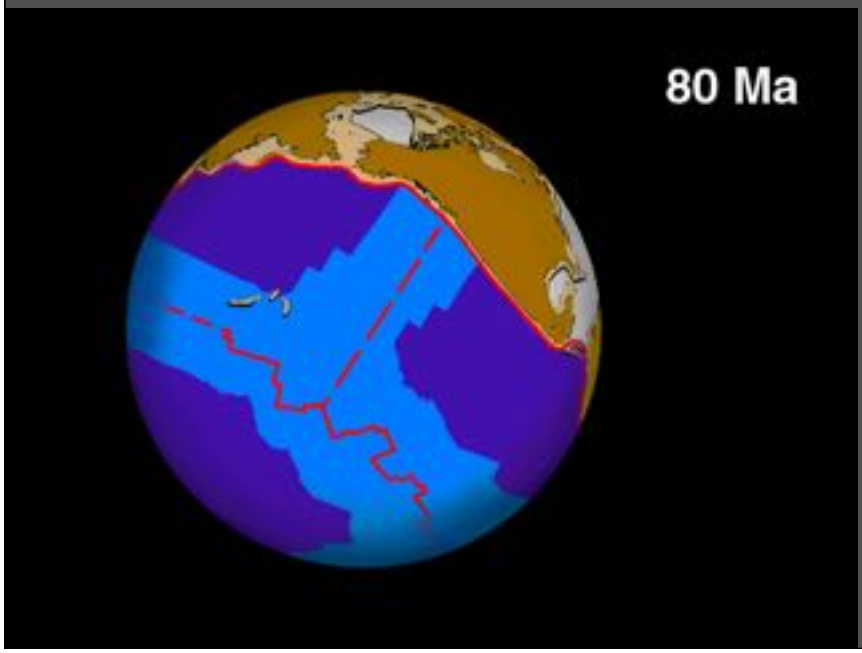


MOVIES (Prof. Tanya Atwater, UCSB Educational Multimedia Visualization Center):

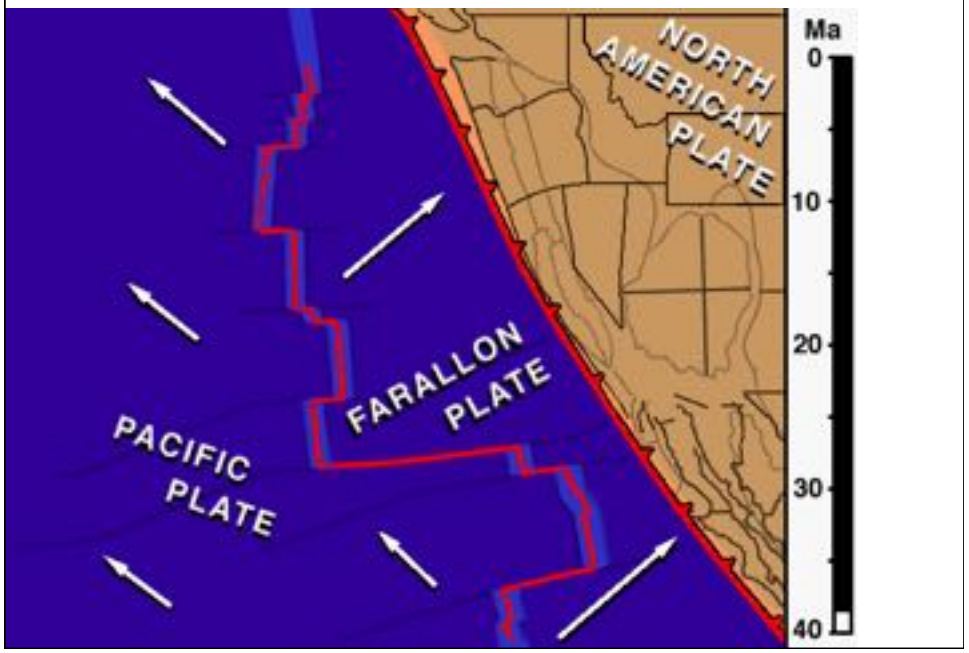
http://emvc.geol.ucsb.edu/downloads.php#RegionalTectGeolHis, free for educational use.

Image this page: USGS, Public Domain, http://earthguide.ucsd.edu/earthguide/maps/reliefmapca.html

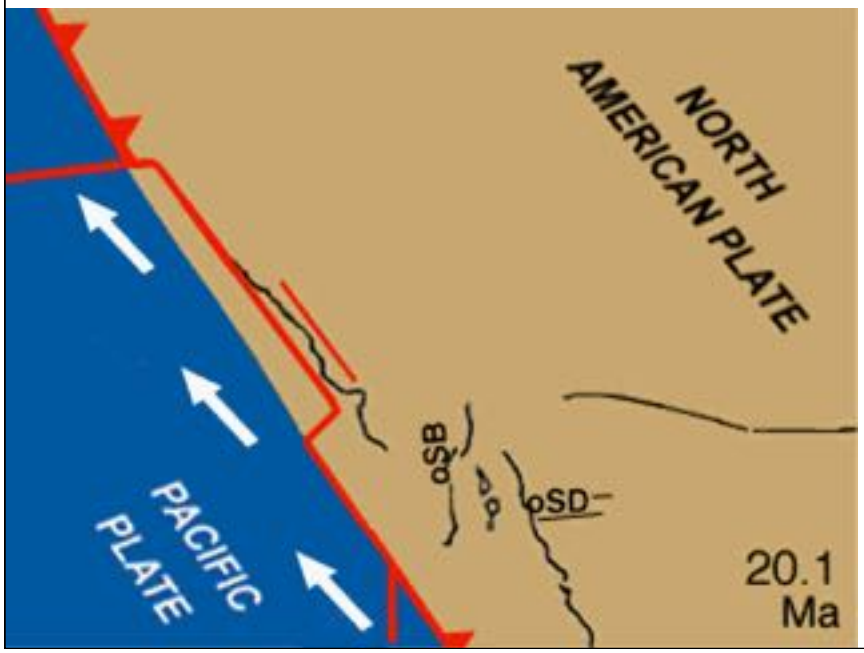
Pacific Plate Evolution



Easternmost Pacific Plate Evolution

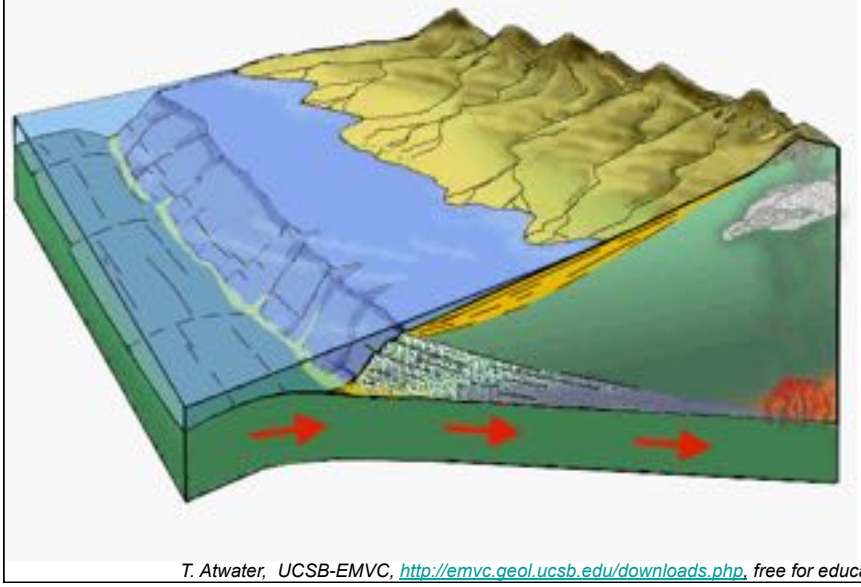


Southern CA Evolution



Coast Ranges & Central Valley

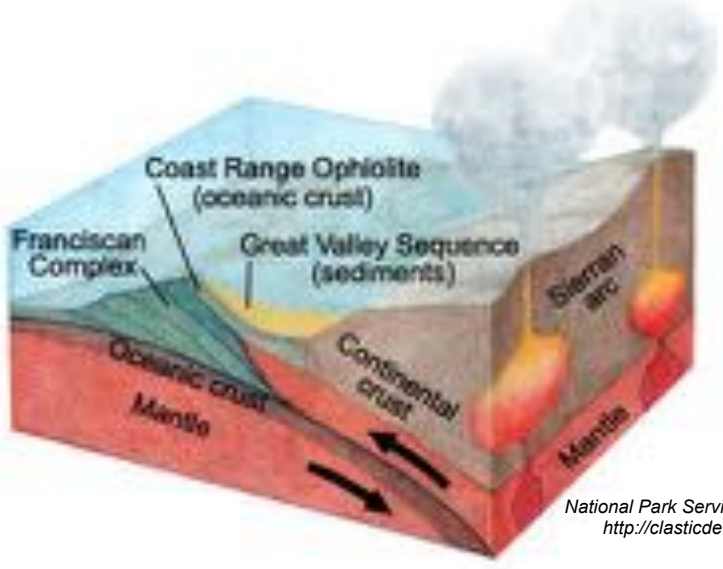
- Between subduction zone and the Sierras



T. Atwater, UCSB-EMVC, http://emvc.geol.ucsb.edu/downloads.php, free for educational use.

Coast Ranges & Central Valley

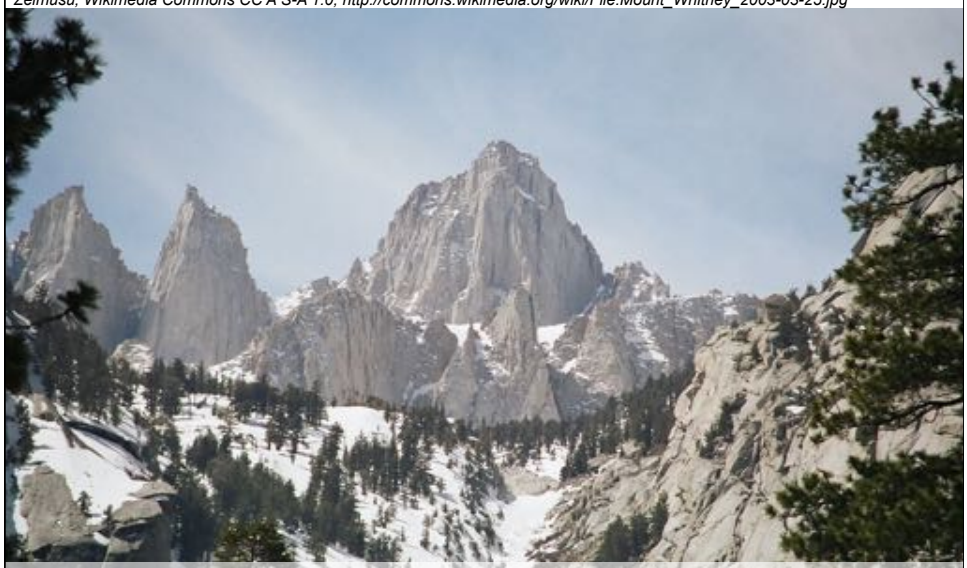
- Between subduction zone and the Sierras



National Park Service Figure, Public Domain, http://clasticdetritus.files.wordpress.com/2008/02/subduct-nps.jpg

The Sierra Nevada

Zeimusu, Wikimedia Commons CC A S-A 1.0, http://commons.wikimedia.org/wiki/File:Mount_Whitney_2003-03-25.jpg

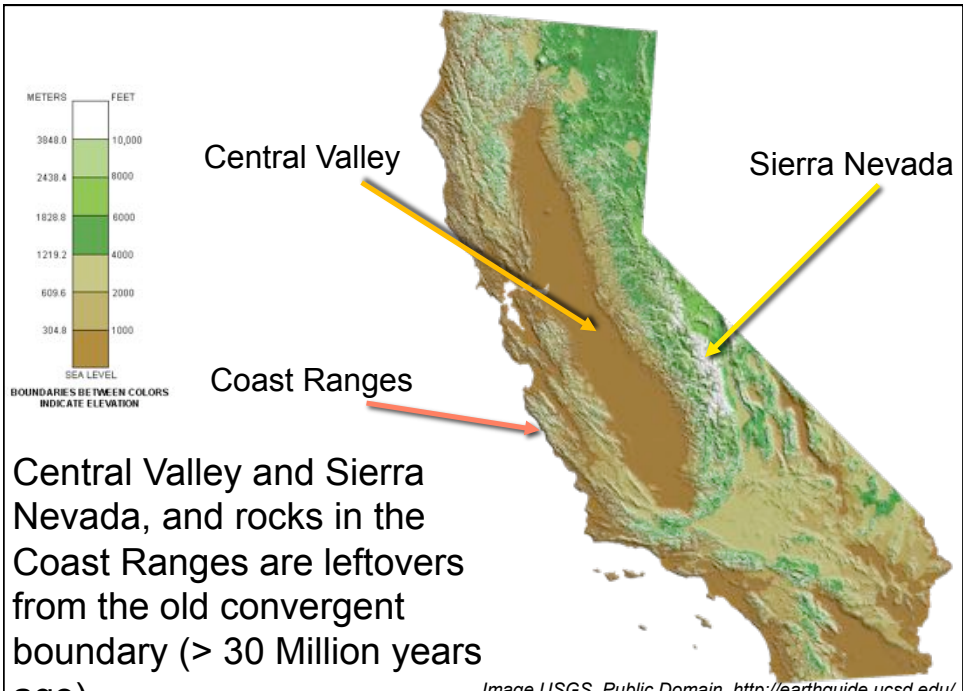


The Sierra Nevada are the roots of ancient volcanoes

Ocean-Continent ConvergentBoundary

Coast Ranges (scraped off the Farallon Plate)

Glen Canyon Park, San Francisco. Eric A Schiff, Wikimedia Commons CC A S-A 2.5, http://en.wikipedia.org/wiki/File:Glen_Canyon_Park_Chert_Outcrop.jpg



Central Valley and Sierra Nevada, and rocks in the Coast Ranges are leftovers from the old convergent boundary (> 30 Million years ago)

Image USGS, Public Domain, http://earthguide.ucsd.edu/earthguide/maps/reliefmapca.html

Young features (< 30 Million years) San Andreas, Salton Sea, Gulf of California, Santa Monica Mtns.

San Andreas: A transform boundary

San Andreas forms a complex web of faults, including many in LA region

Produces regions of tension and compression between active fault segments

Leads to

- **Transpressional** ranges (Santa Monica Mtns.)
- **Pull-apart** basins (LA Basin, Death Valley, Salton Sea)

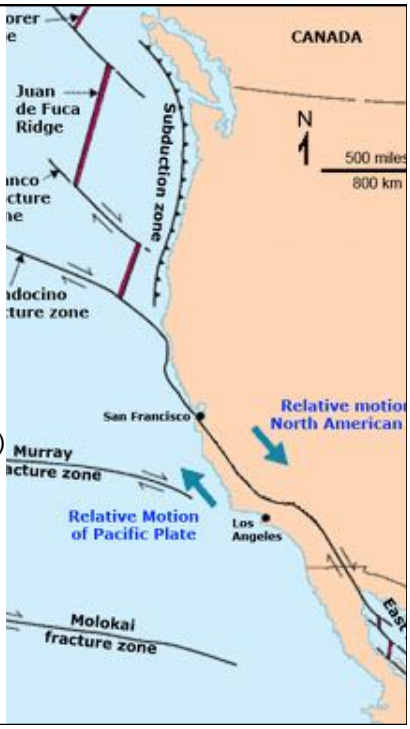


Figure by USGS, This Dynamic Earth, Public Domain, http://pubs.usgs.gov/gip/dynamic/understanding.html

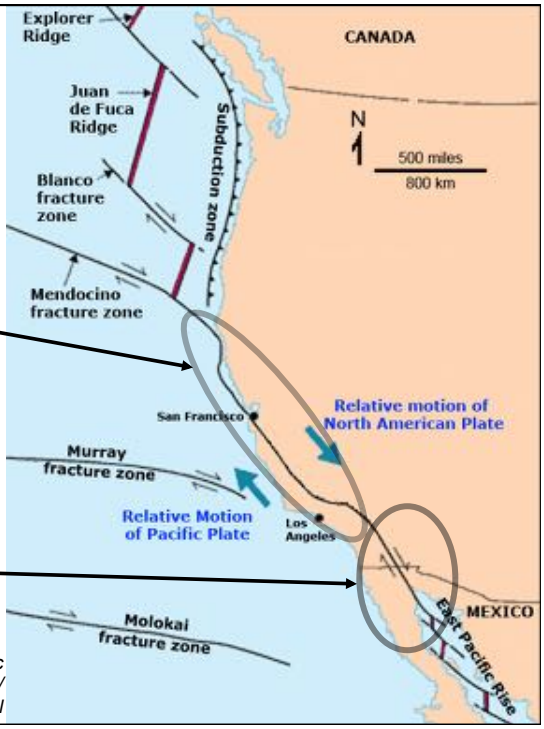
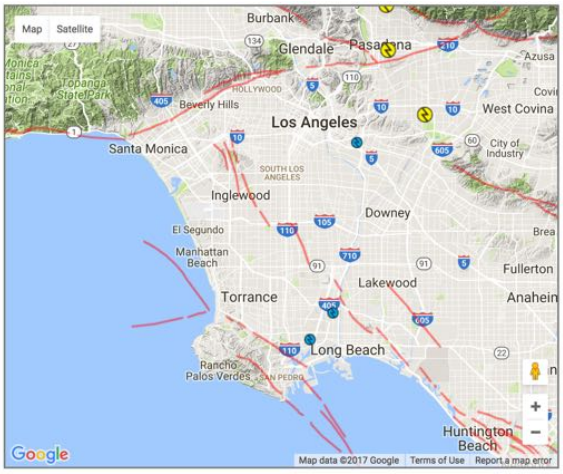
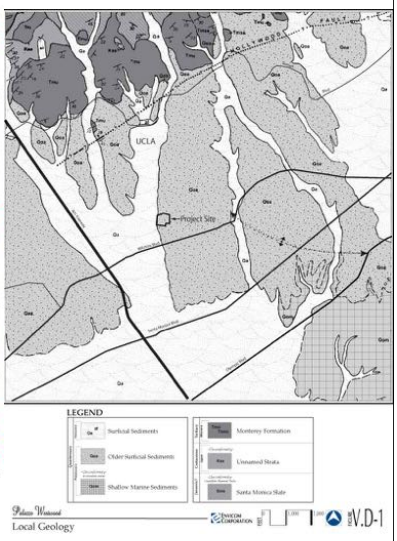


Figure by USGS, This Dynamic Earth, Public Domain, http://pubs.usgs.gov/gip/dynamic/understanding.html

The San Andreas isn't the only fault in Southern California



Southern California Fault Map, Southern California Earthquake Center. Authors Ihrig, Bhaskaran, and Marqui; based on data from Jennings, 1994, http://scedc.caltech.edu/significant/index.html



Palazzo Westwood planning documents, LA City Planning, http://cityplanning.lacity.org/eir/Palazzo/figures/VD-02.jpg

QUESTIONS?

Image USGS, Public Domain, http://earthguide.ucsd.edu/earthguide/maps/reliefmapca.html

USGS Image, Robert Wallace

Sediment drill cores from the first mission of the RV Chikyu. Image from the Integrated Ocean Drilling Program, http://www.iodp.org/chikyu-first-coring-operations/

Sedimentation: Big Picture

- Sediments get deposited in layers on the ocean floor
- Younger seds overlay older seds, all atop the basaltic crust
- Sediments contain 200 million years of **planetary history**
  - Past climates, plate tectonics, volcanic activity, biological evolution, etc.
- Eventually most deep-sea sediments are subducted or scraped off onto continents at active margins (e.g., Coast Ranges).

Coast Ranges (scraped off the Farallon Plate)

Glen Canyon Park, San Francisco. Eric A Schiff, Wikimedia Commons Creative Commons A S-A 2.5, http://en.wikipedia.org/wiki/File:Glen_Canyon_Park_Chert_Outcrop.jpg

Global Distribution & Thickness of Marine Sedimentary Layers

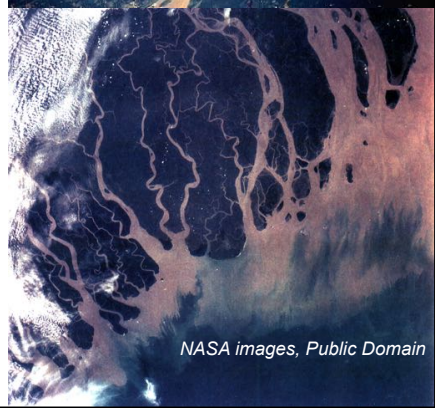
Region	Percent of Ocean	Volume % of Seds	Average Thickness
Continental Margins	22%	87%	7.5 km (4.7 mi)
Deep-Sea Floor	78%	13%	0.6 km (0.4 mi)

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

*Terri*genous Sediment Sources

- Weathering & erosion of continental crust
- Dominant source of marine sediment (rich in SiO_2, silicates)
- Mostly deposited in continental margins
  - **Continental shelf sediments**: distributed by wind, waves and ocean currents
  - **Slope, rise & abyssal plains**: distributed by gravity flows
    - Submarine canyon slumps, slides, turbidity currents



Fluvial Terrigenous Sediments

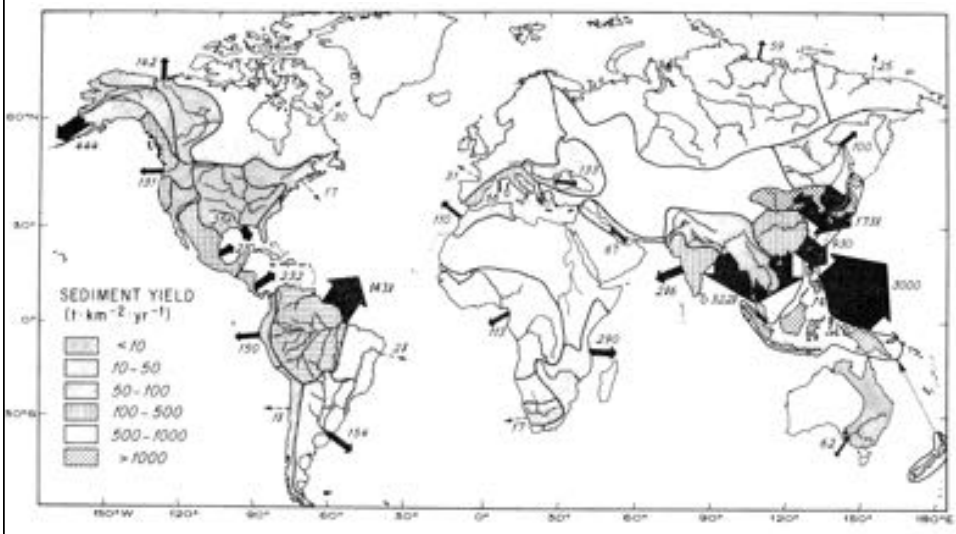
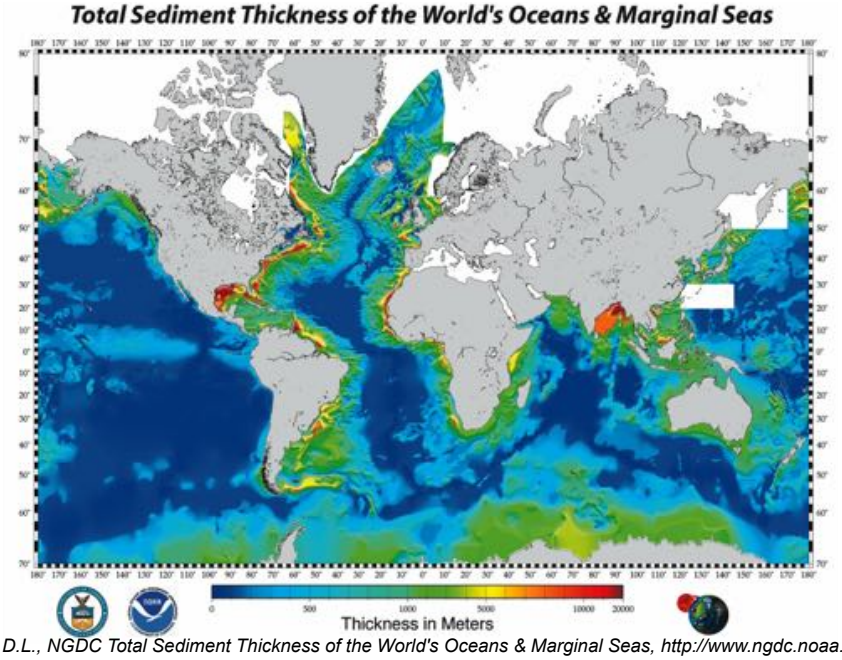


FIG. 4.—Annual discharge of suspended sediment from various drainage basins of the world; width of arrows corresponds to relative discharge. Numbers refer to average annual input in millions of tons. Direction of arrows does not indicate direction of sediment movement. The sediment yields and major rivers 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.

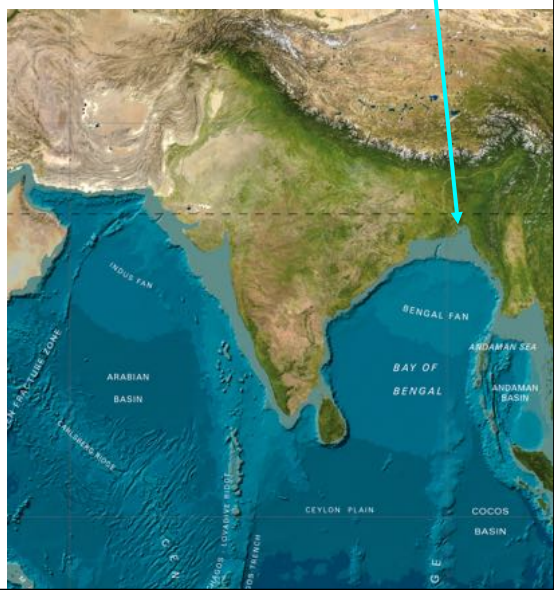
Most sediment accumulates near continents…

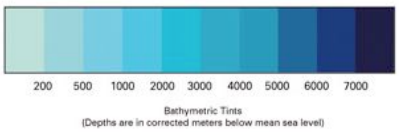


Divins, D.L., NGDC Total Sediment Thickness of the World's Oceans & Marginal Seas, http://www.ngdc.noaa.gov/mgg/sedthick/sedthick.html, Public Domain

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

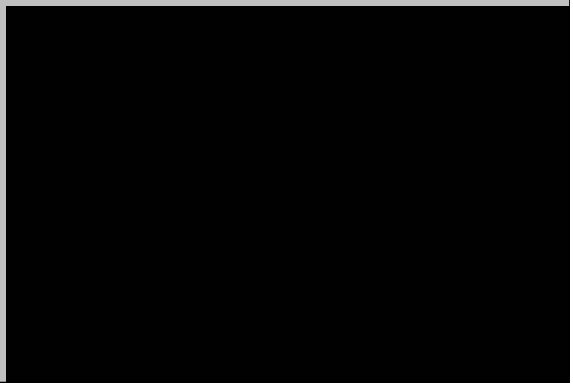
Peas: Renee Comet, Natl. Cancer Inst., Public Domain, http://visualsonline.cancer.gov/details.cfm?imageid=2612; Sugar, Fritzs, Wikimedia Commons, CC A S-A 3.0, http://visualsonline.cancer.gov/details.cfm?imageid=2612; Powdered sugar, Wikimedia Commons, JonathanLamb, Public Domain, http://en.wikipedia.org/wiki/File:Confectioners-sugar.jpg;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

Low energy

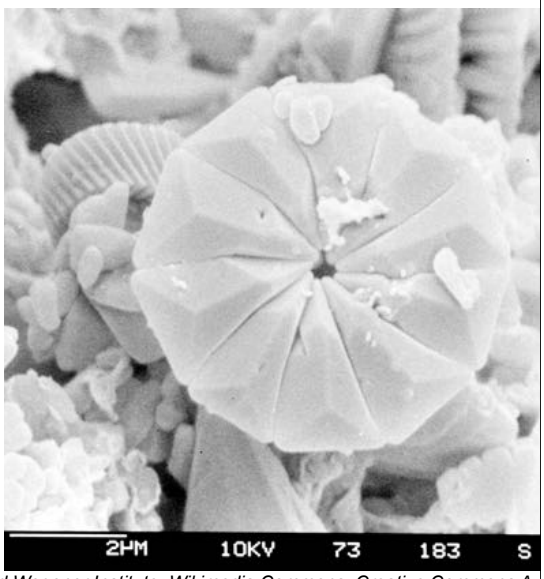
- **Pebbles**: Hard to transport (storms, big surf, fast rivers & steep streams)
- **Sand**: in the middle (small surf, most rivers & streams)
- **Clays**: Easy to transport (tides, slow streams & rivers, long range transport by wind)



Movie by John Gaffney, U. Minnesota, https://www.youtube.com/watch?v=RJxOI0uUIAw

*Bio*genous Sediments

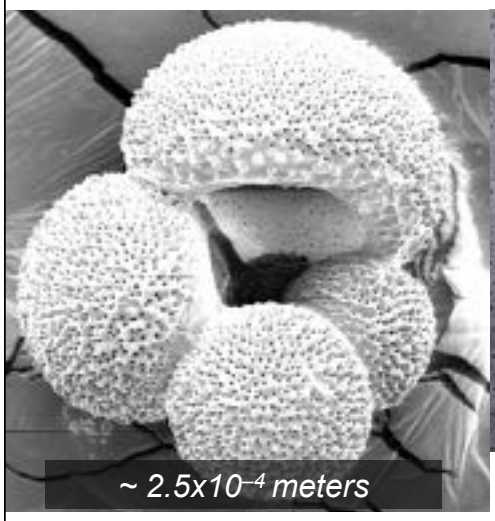
- Mostly skeletal material produced by dominant species of plankton
  - floating ocean organisms die, shells settle to the sea floor & lithify
- Calcareous: skeletal materials of $CaCO_3$
- Siliceous: skeletal materials of opal ($SiO_2 \cdot nH_2O$)



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

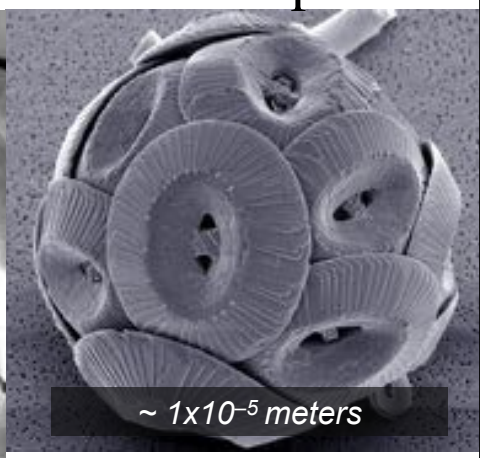
Calcareous ($CaCO_3$) Plankton

Foraminifera



Globigerina bulloides, NOAA image, Public Domain

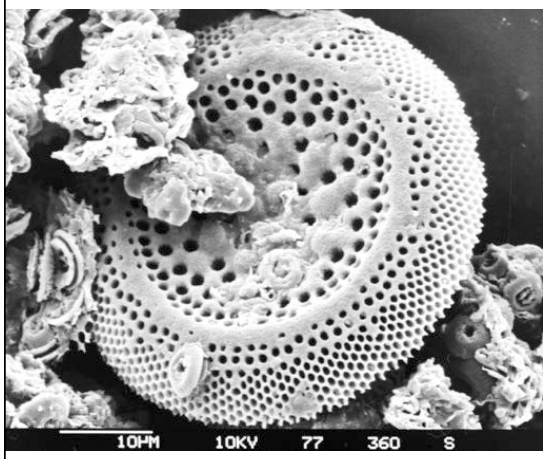
Coccolithophores



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

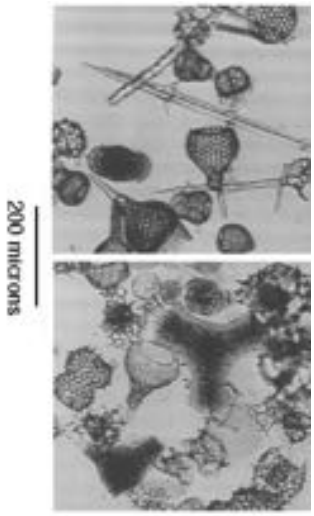
Siliceous (SiO_2) Plankton

Diatoms



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

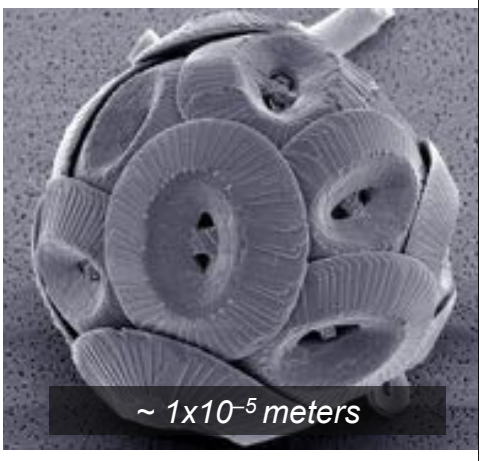
Radiolaria



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**

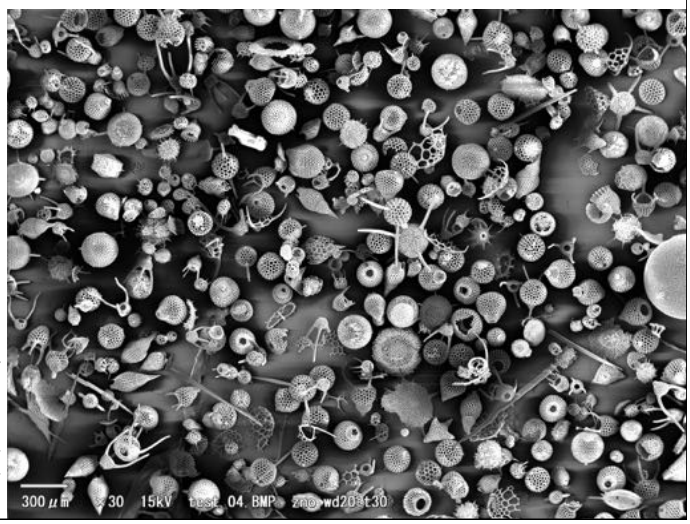


Coccolith (phytoplankton)

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

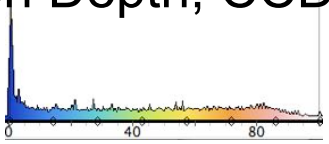
- Oozes contain > 30% biogenic material
  - Production: Shells &Skeletons
  - Destruction: Dissolves before burial
  - Dilution: Mixing with terrigenous sediments
- Oozes uncommon near continents: diluted by copious terrigenous sediments
- Oozes also uncommon where there are few nutrients

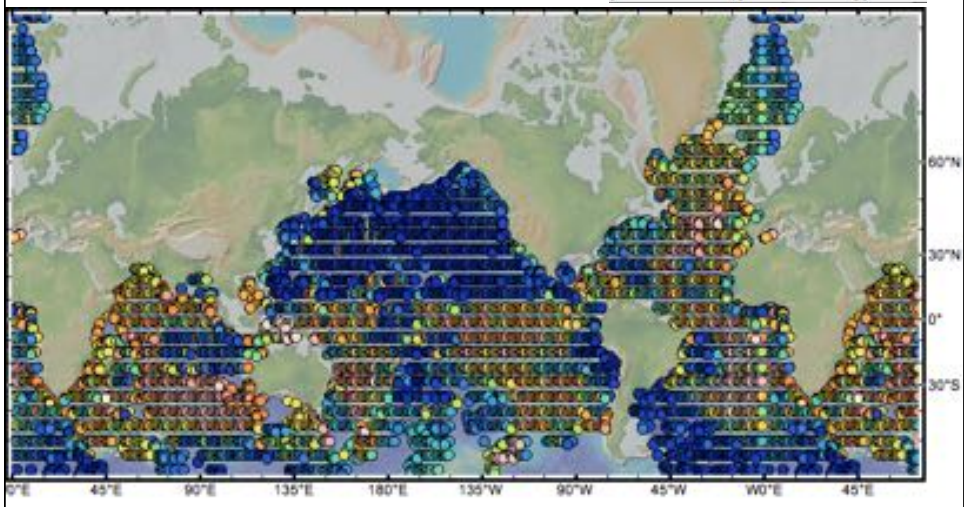


Electron micrograph of radiolarian ooze, image by Yasuhiro Hata, Creative Commons BY-NC-SA 2.0 http://www.flickr.com/photos/hatash/6195181070/in/pool-765680@N20/lightbox/,

Carbonate Compensation Depth, CCD

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

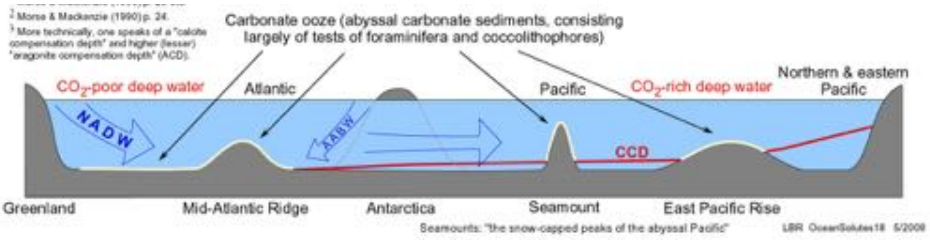




% Carbonate in seafloor sediments, created with GeoMapApp using Archer (2003) interpolated data.

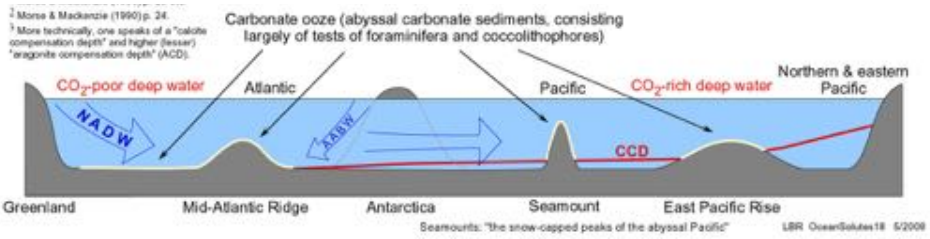
"Calcite" Compensation Depth, CCD

- **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):

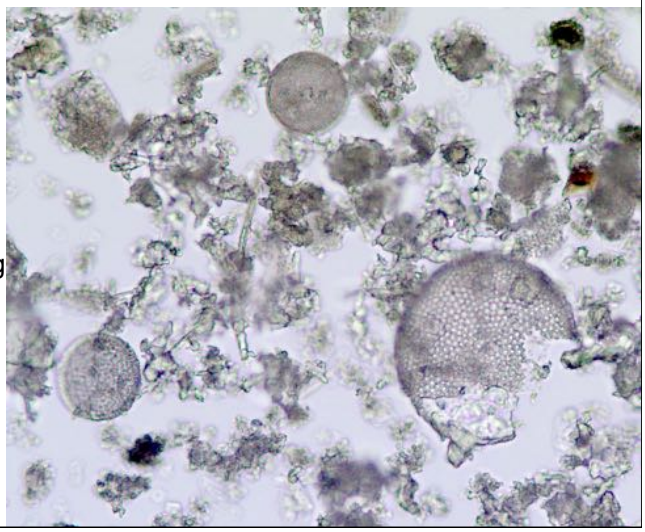
$$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^- \leftrightarrow 2H^+ + CO_3^{2-}$$

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

Found where no other sediments accumulate rapidly

Dominated by wind-blown dusts

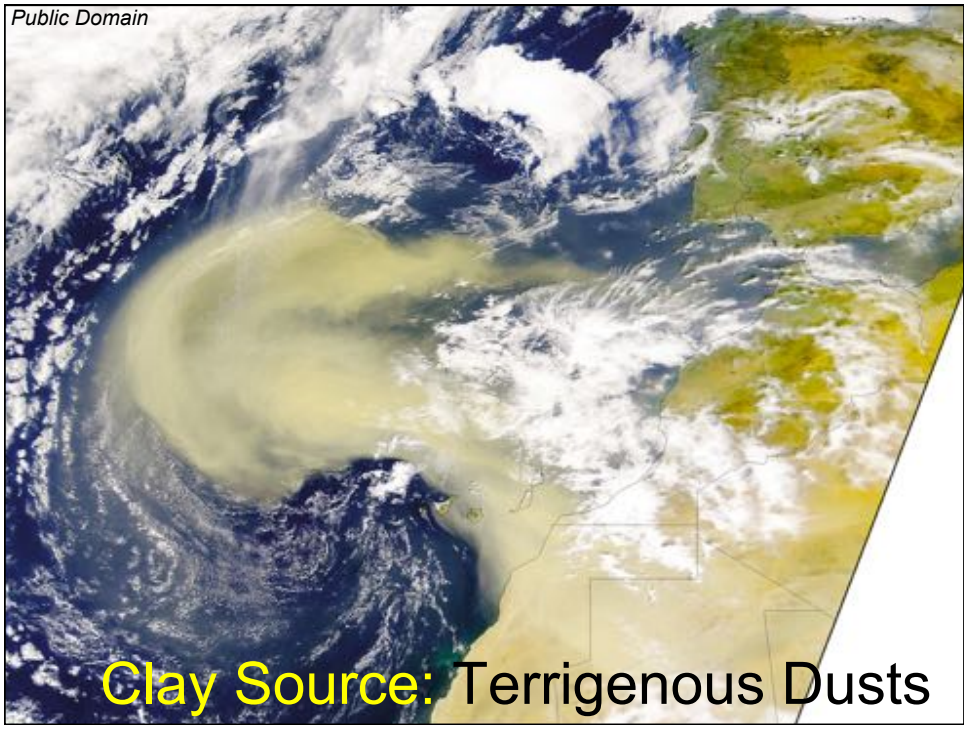
Common in deep basins

Below CCD

Regions of low bioproductivity

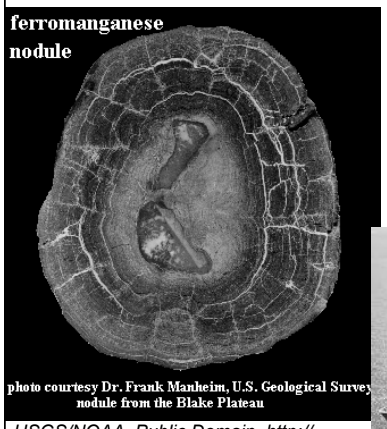
Far from continents

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



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

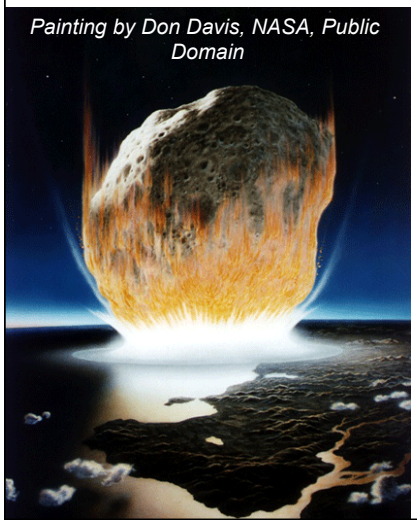
Japan Agency for Marine-Earth Science and Technology, http://www.jamstec.go.jp/jamstec-e/30th/part6/image/p86_1.jpg

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

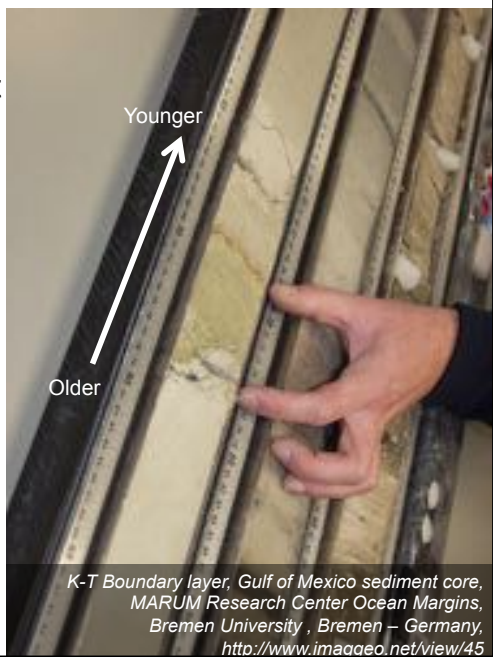
Cosmogenic Sediments

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

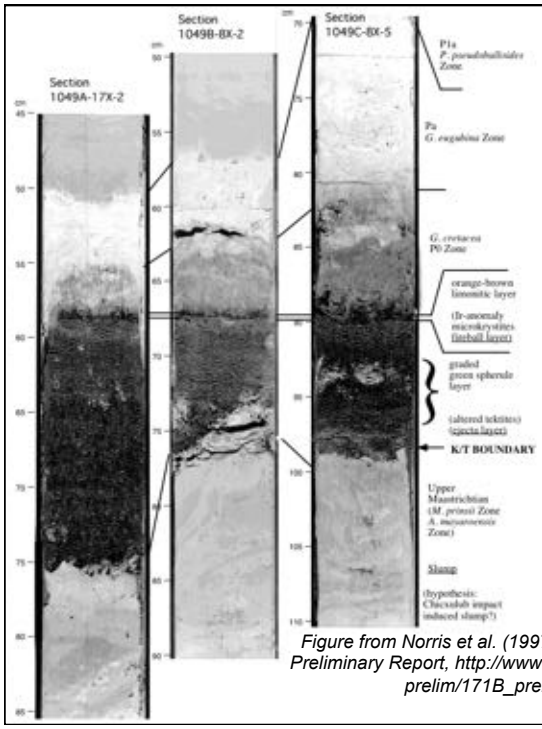


Figure from Norris et al. (1997) Ocean Drilling Program Preliminary Report, http://www-odp.tamu.edu/publications/prelim/171B_prel/171Bprel.pdf

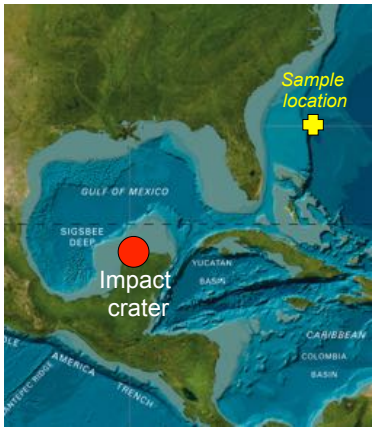


Figure based on GEBCO bathymetric map, educational use explicitly allowed

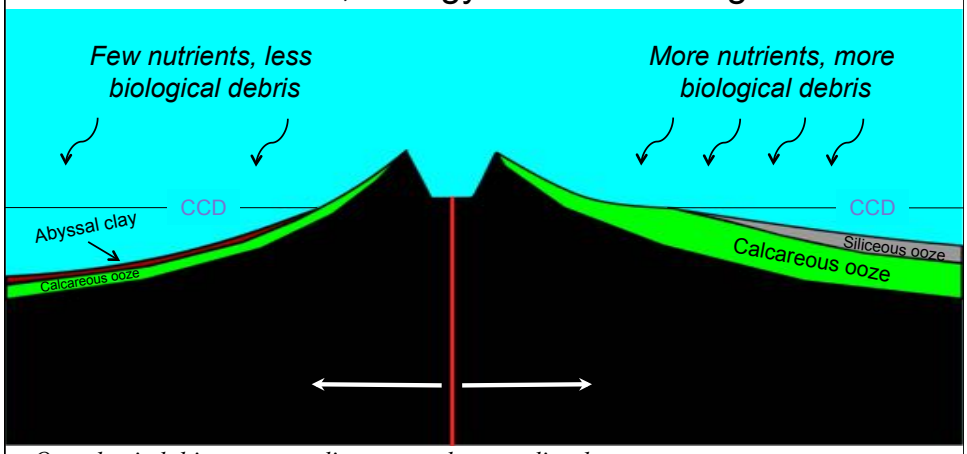
Rate of sediment addition:

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

BIG PICTURE ON SEDIMENTS

- Terrigenous near continents
- High Bioproductivity:
  - Calcareous oozes above CCD
  - Silicieous 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.

E. Schauble, UCLA, created with Inkster

Global Distribution of Sediments

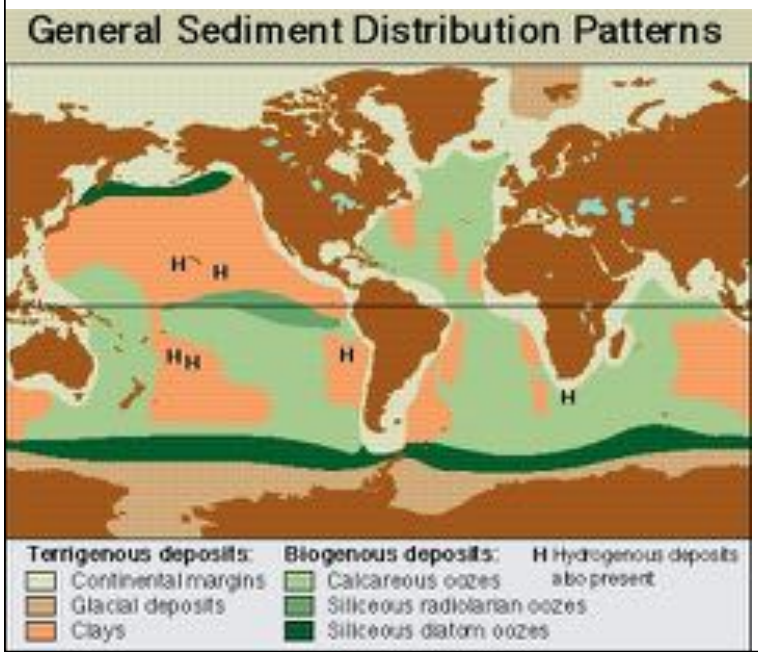


Image attribution unknown