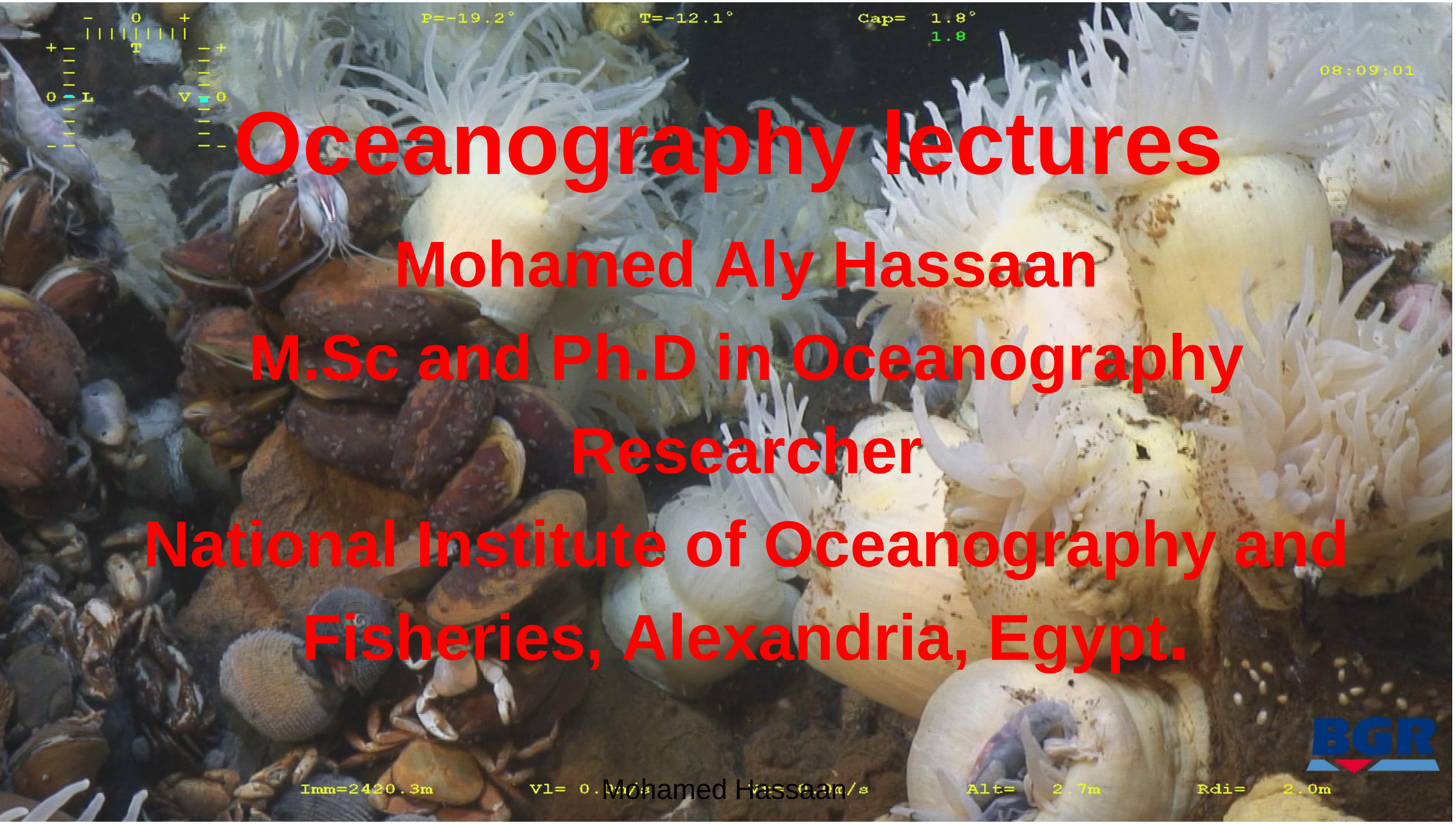

Oceanography lectures

Mohamed Aly Hassaan
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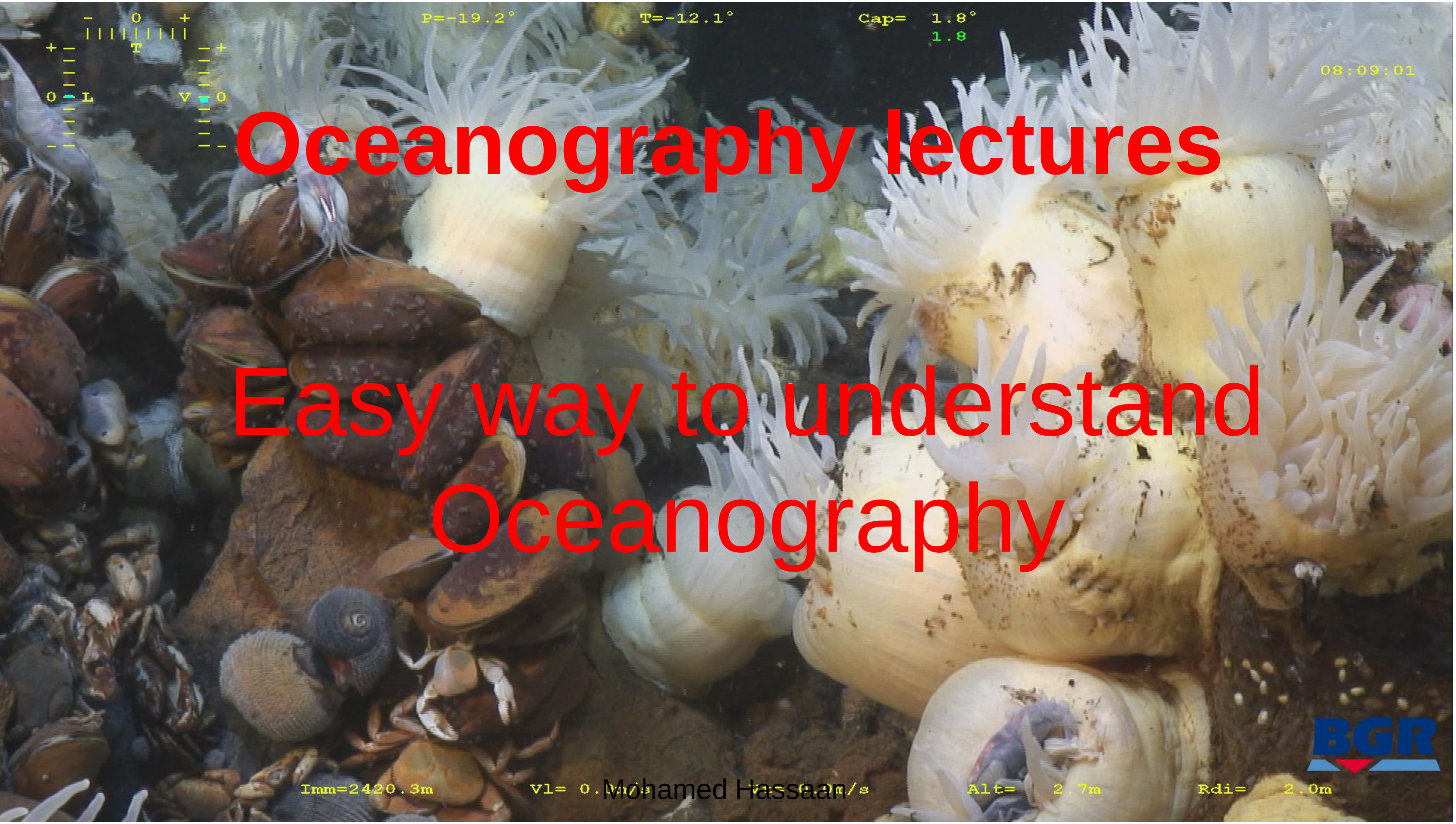
Researcher
National Institute of Oceanography and Fisheries, Alexandria, Egypt.



Oceanography lectures

Easy way to understand Oceanography

Mohamed Hassaan

Preface

Oceanography is a scientific discipline concerned with all aspects of the world's oceans and seas, including their physical and chemical properties, their origin and geologic framework, and the life forms that inhabit the marine environment. Traditionally, oceanography has been divided into four separate but related branches: physical oceanography, chemical oceanography, marine geology, and marine ecology. Physical oceanography deals with the properties of seawater (temperature, density, pressure, and so on), its movement (waves, currents, and tides), and the interactions between the ocean waters and the atmosphere. Chemical oceanography has to do with the composition of seawater and the biogeochemical cycles that affect it. Marine geology focuses on the structure, features, and evolution of the ocean basins. Marine ecology, also called biological oceanography, involves the study of the plants and animals of the sea, including life cycles and food production.

Oceanography is the sum of these several branches. Oceanographic research entails the sampling of seawater and marine life for close study, the remote sensing of oceanic processes with aircraft and Earth-orbiting satellites, and the exploration of the seafloor by means of deep-sea drilling and seismic profiling of the terrestrial crust below the ocean bottom. Greater knowledge of the world's oceans enables scientists to more accurately predict, for example, long-term weather and climatic changes and also leads to more efficient exploitation of the Earth's resources. Oceanography also is vital to understanding the effect of pollutants on ocean waters and to the preservation of the quality of the oceans' waters in the face of increasing human demands made on them.

This book is mainly consisting of fourteen lectures covering most aspects of oceanography. These lectures were collected and edited from the Indiana university site, Britannica, NOAA, Virginia Sea Grant (VIMS), Dive and Discover site and other different pages related to Marine sciences and oceanography. The cover picture and the beginning slide of each lecture was taken from The Federal Institute for Geosciences and Natural Resources of the Federal Republic of Germany (BGR) during the index cruise 2016 in the Indian Ocean. The aim of this book is to give an easy introductory about oceanography for students and researchers through colored slides. The lectures were divided by topics to match all branches of oceanography. This book is a gift to my mother soul ***Mrs.Syria Abd-Elhak***.

Mohamed Aly Hassaan

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Lecture 1	History of Oceanography
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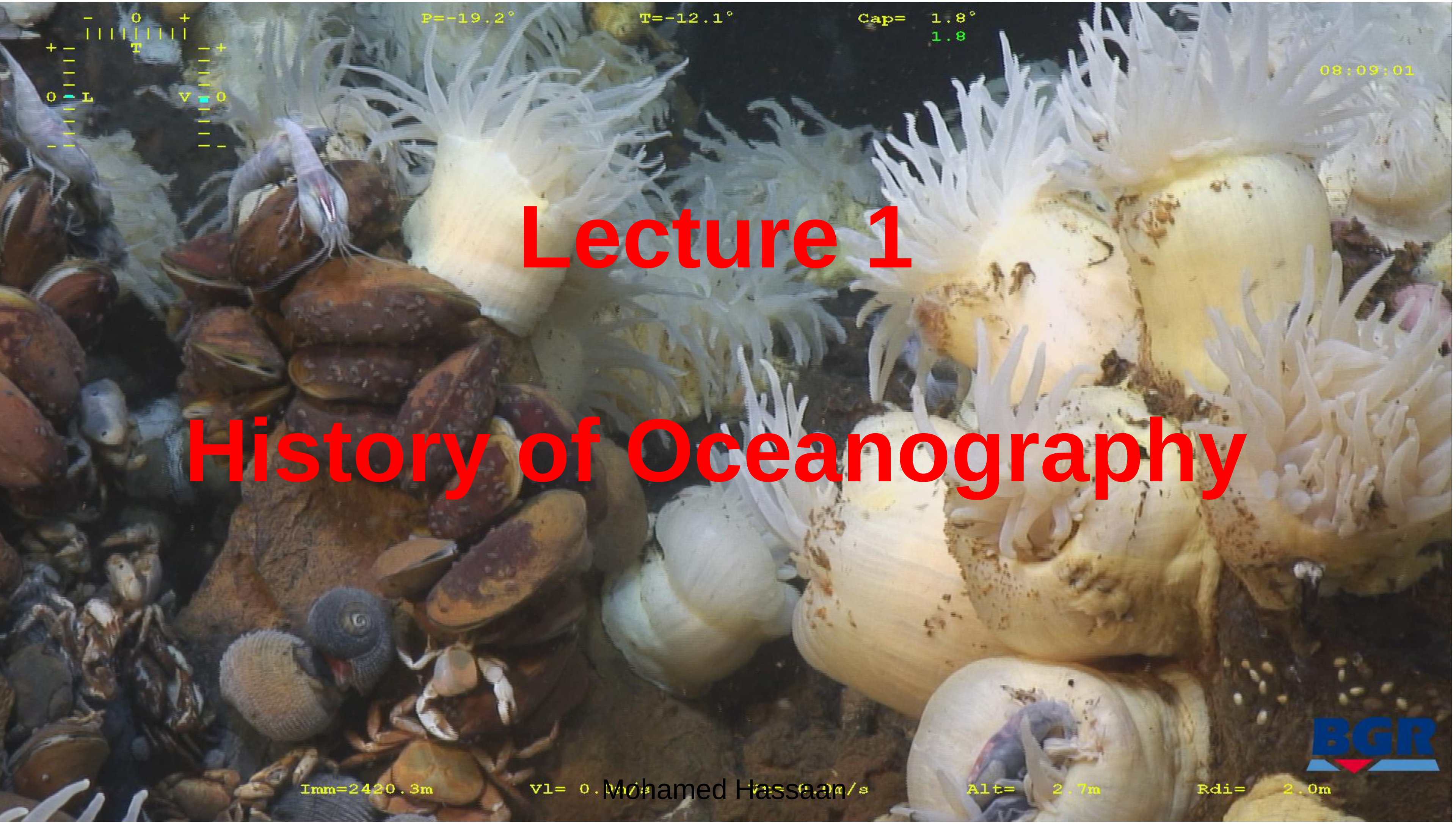
Lecture 11	Coasts, Beaches and Estuaries
Lecture 12	Life in the Ocean
Lecture 13	Hydrothermal Vents
Lecture 14	ROV and Underwater technologies



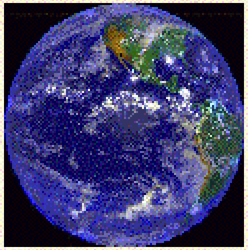
Lecture 1

History of Oceanography

Mohamed Hassaan

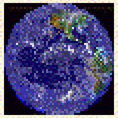
Oceans & Our Global Environment

History of Oceanography



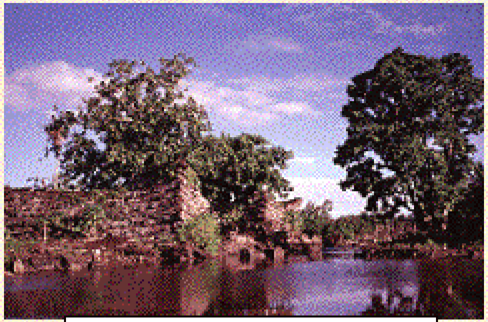
Themes:

- Ancient Use & Understanding of the Oceans
- Voyages of Exploration, Colonization & Exploitation
- Charts and Navigation, Technological Developments
- Oceanic Scientific Expeditions
- Modern Global Ocean Science



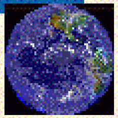
Voyages of Pacific Islanders:

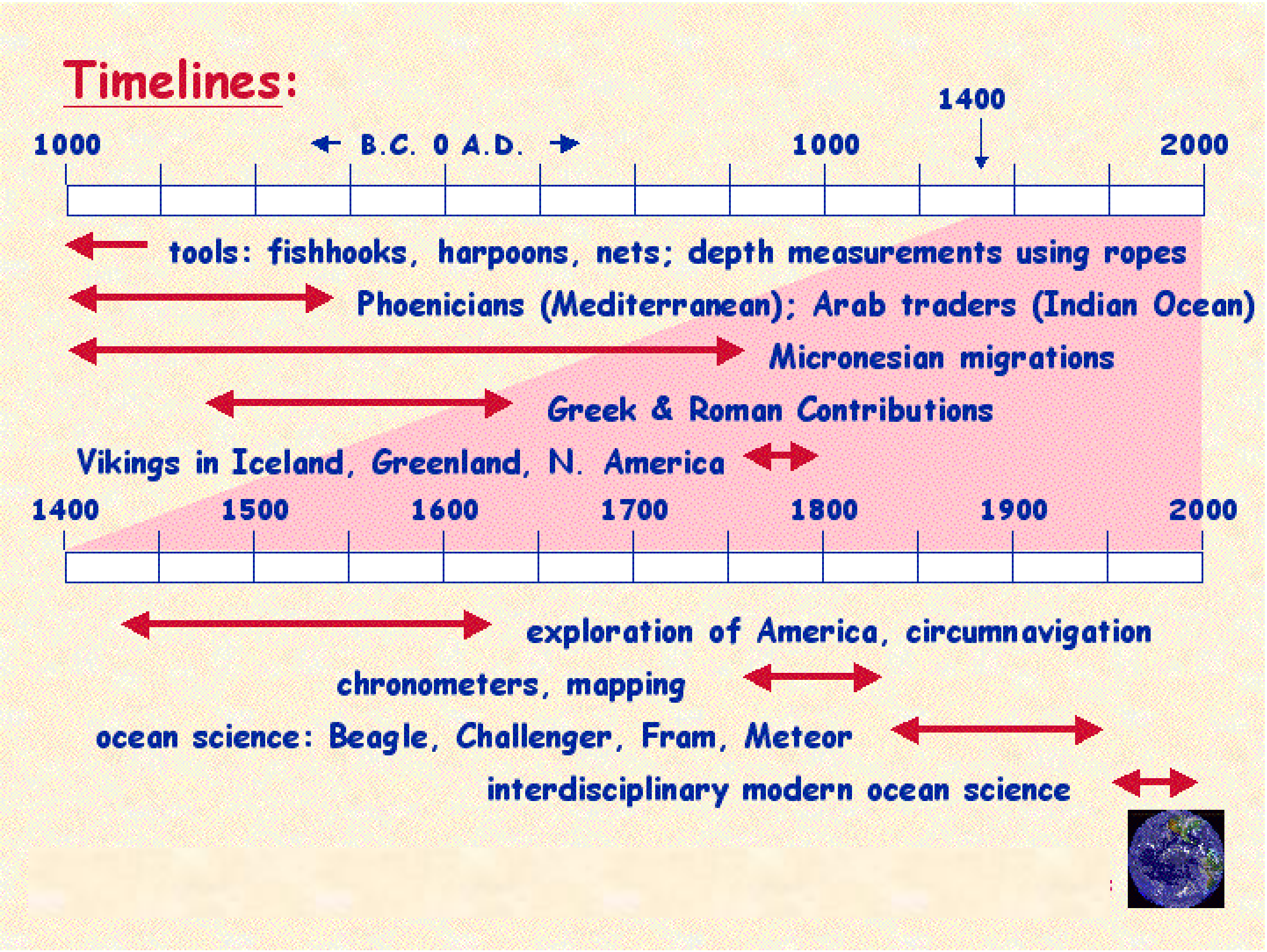
- Island Colonization



Nan Madol, Pohnpei

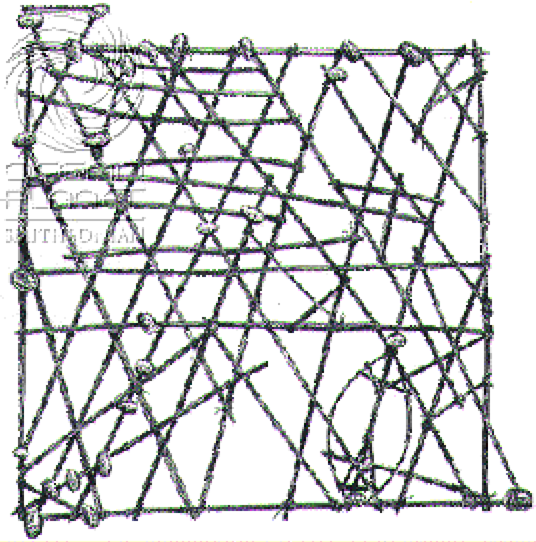
Easter Island, Rapa Nui




Timelines:
1400
1000
← B.C. 0 A.D. →
1000
2000
tools: fishhooks, harpoons, nets; depth measurements using ropes
Phoenicians (Mediterranean); Arab traders (Indian Ocean)
Micronesian migrations
Greek & Roman Contributions
Vikings in Iceland, Greenland, N. America
1400
1500
1600
1700
1800
1900
2000
exploration of America, circumnavigation
chronometers, mapping
ocean science: Beagle, Challenger, Fram, Meteor
interdisciplinary modern ocean science

Ancient Images:

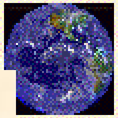
- Fishing
  - Egyptian painting, ca. 2400 B.C.
- Navigational devices: Maps
  - Marshall Island stick map
- Ships: cargo & warships
  - Phoenician vessel



Marshall Islands stick map

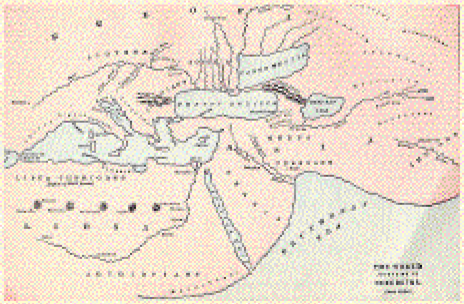
Ancient Egypt: fishing — ca. 2400 B.C.

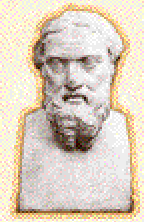
Phoenician ship from the Roman era



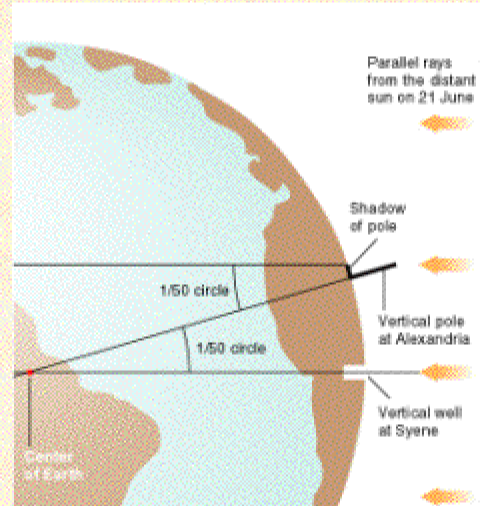
Greek and Roman Contributions:

- Herodotus (*c.* 484 - 430 B.C.)
  - Phoenician voyages to Indian Ocean

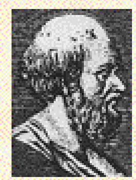


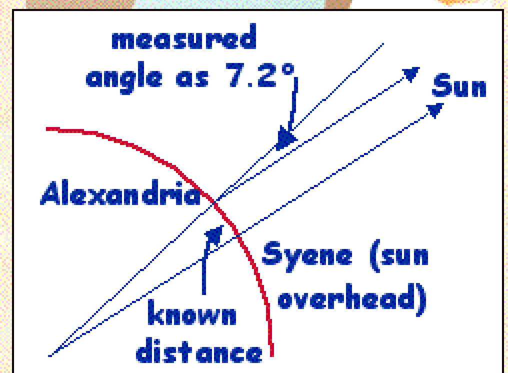


Herodotus' world map

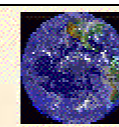


- Pytheas (*c.* 350 - 300 B.C.)
  - navigated by sun, stars & wind
  - traveled to England, Norway
- Eratosthenes (*c.* 264 - 194 B.C.)
  - calculated Earth's circumference as 40,250 km (actual value 40,067km)
  - Alexandria to Syene





Eratosthenes' calculation

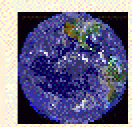


Greek and Roman Contributions:

- Posidonius (*c.* 135 - 50 B.C.)
  - measured depths >550 m off Sardinia
- Pliny the Elder (*c.* 23 - 79 A.D.)
  - related the phase of the Moon to tides

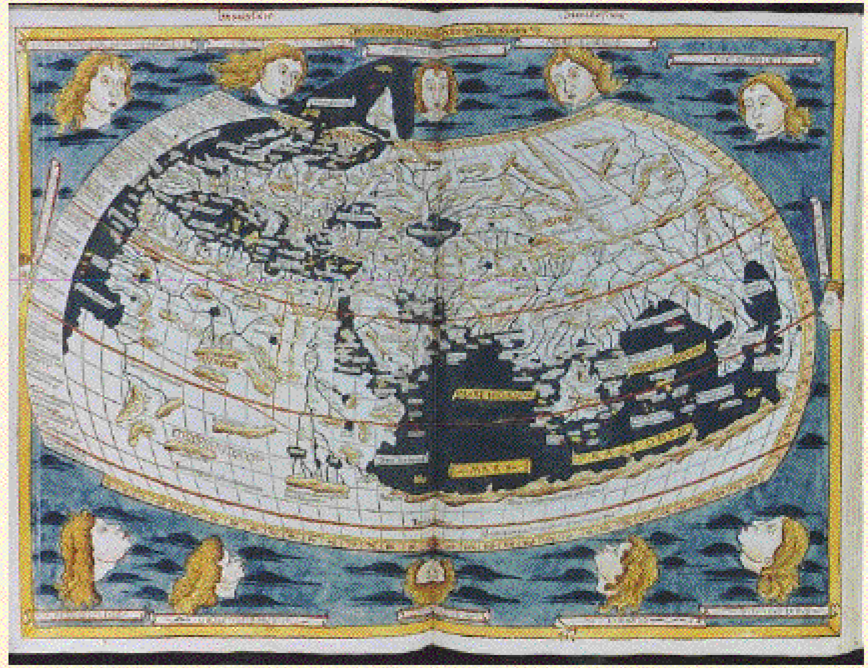
Vesuvius, Italy

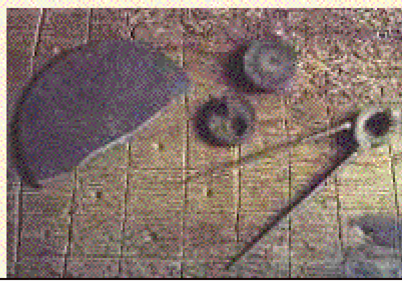
- Ptolemy (*c.* 127 - 51 A.D.)
  - first world atlas, bounded by "Terra Australis Incognita"



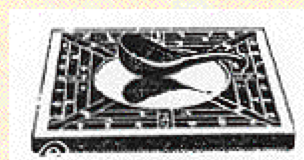
Ancient Use & Understanding of Oceans:

- Maps
  - Ptolemy's world map (1482 copy)
- Navigational devices
  - depth (weights)
  - speed (knots)
  - star charts
  - magnetic compass

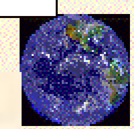




lead weights – 16th century



12th(?) century chinese iron spoon compass



Explorers (*c.* 900's - 1600's):

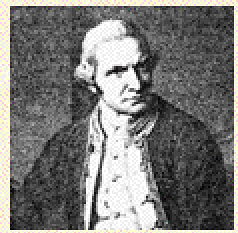
- Vikings: Erik the Red, Leif Eriksson
- Columbus, Vasco da Gama, Magellan
- Cabot, Frobisher, Hudson, Drake

Leif Eriksson

Scientists (*c.* 1750 - 1930):

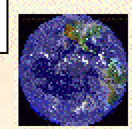
- Harrison (chronometers)
- Cook (Pacific Ocean)
- Ben Franklin (Gulf Stream)
- *H.M.S. Beagle* (Darwin)
- *H.M.S. Challenger* (Thomson)
- Maury (winds & currents)
- Nansen (Arctic)

James Cook



Matthew Maury

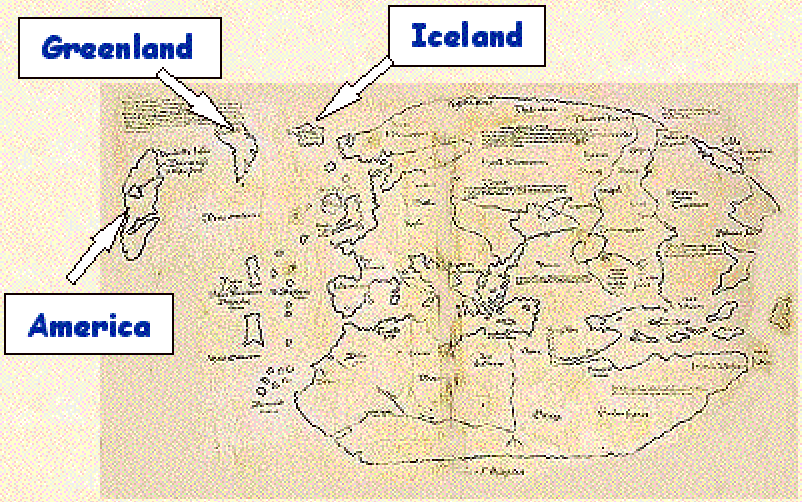
Fridtjof Nansen



Vikings in N. America:

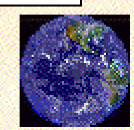
- Settlements in Iceland from *c.* 870 - 930 A.D.
- Erik the Red in Greenland *c.* 980 A.D.
- Leif Ericksson in 'Vinland' for 3+ years, *c.* 1000 A.D.

11th century viking silver penny found in Maine



Vinland map: 1440 copy of original genuine or forgery?

Ruins of viking settlement on Greenland



European Voyages of Exploration:

- Recorded as exploits of ship's captains

1 Indian Ocean
- Bartholomeu Dias
- Vasco da Gama

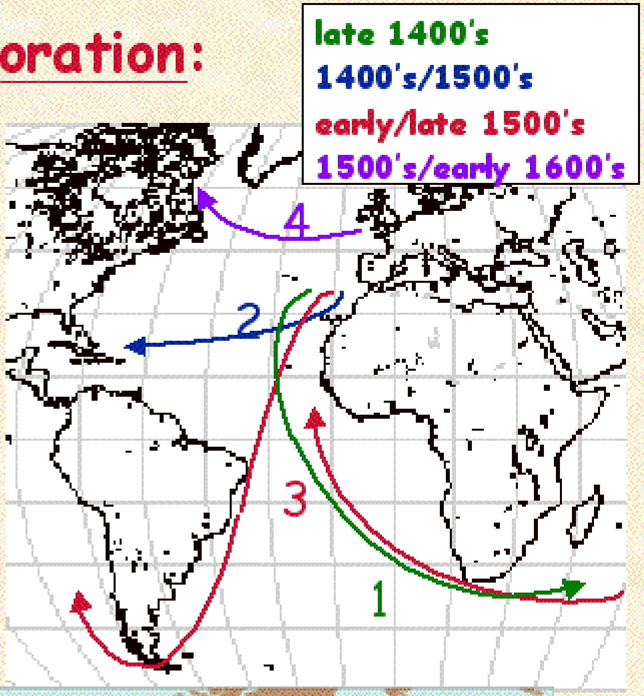
2 Discovery of Americas
- Christopher Columbus
- Amerigo Vespucci
- Vasco de Balboa

3 Circumnavigation
- Ferdinand Magellan
- Francis Drake

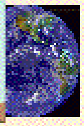
4 Northwest Passage
- John Cabot
- Martin Frobisher
- Henry Hudson
- William Baffin


da Gama


Cabot



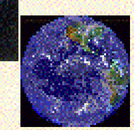
Magellan's voyage



World Map, circa 1570:

- *Coasts well defined, but land areas imprecise*

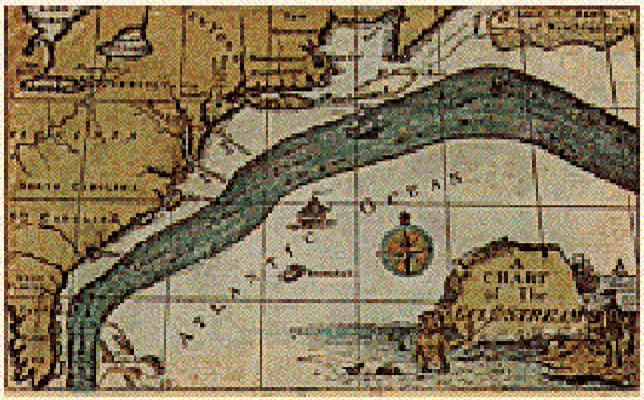
- *Ancient Maps*



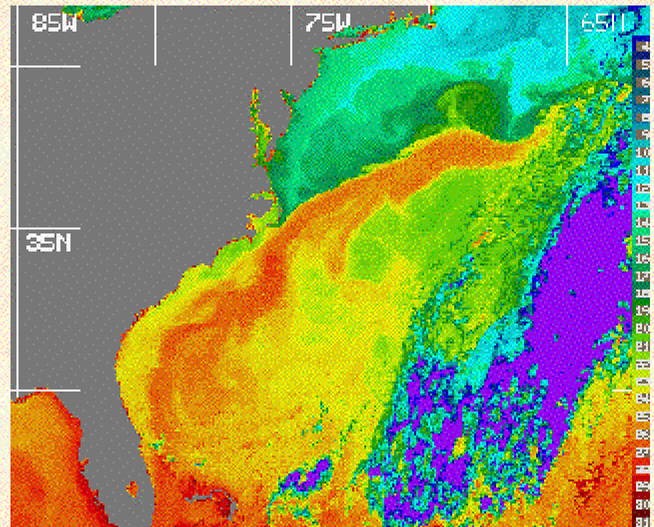
Charts:

- Current maps as navigational aids
- Comparable to modern satellite images
- Benjamin Franklin & Timothy Folger
  - mapped the Gulf Stream (1769)

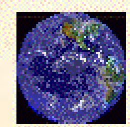
Franklin



Benjamin Franklin's map of the Gulf Stream (1769)



Satellite image of Gulf Stream

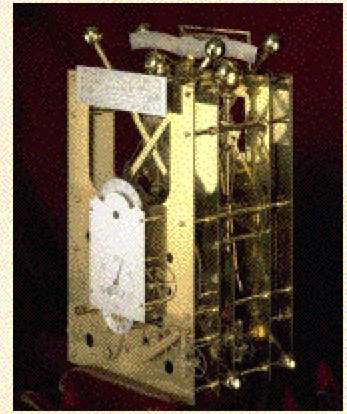


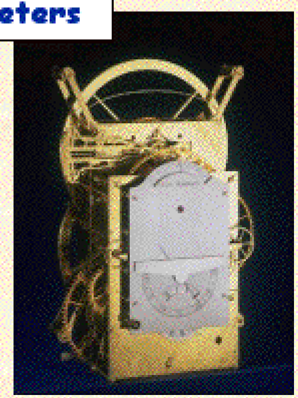
Oceanography and Instruments:

- Technological developments
  - ship design
  - navigational equipment
  - chronometers (Harrison)
  - latitude & longitude

magnetic compass (1790)

quintant (1800)

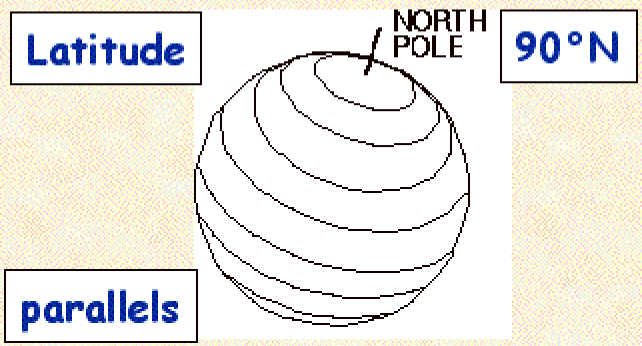


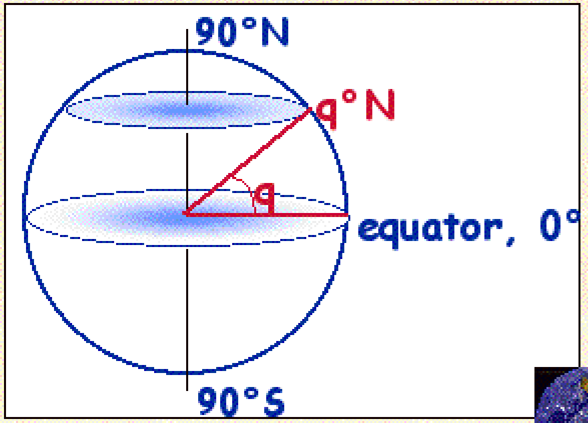


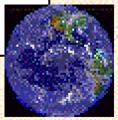
Harrison's chronometers

Earth's Shape and Surface Co-ordinates:

- Flattened sphere (equatorial radius > polar radius)
  - polar radius 6356.9 km, equatorial radius 6378.4 km
- Location System — latitude & longitude
  - aim: a unique description of any point on Earth's surface
- Latitude
  - a series of East-West encircling lines called parallels, measured in °, as angles N or S of equator
  - equator = 0°, poles = 90°
  - 1° = 60 nautical miles

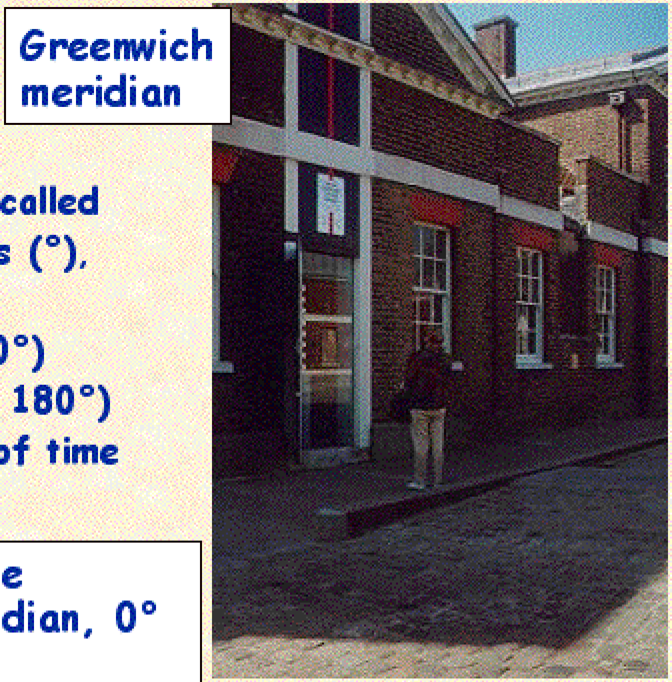


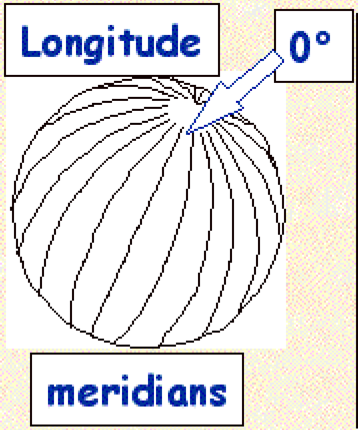


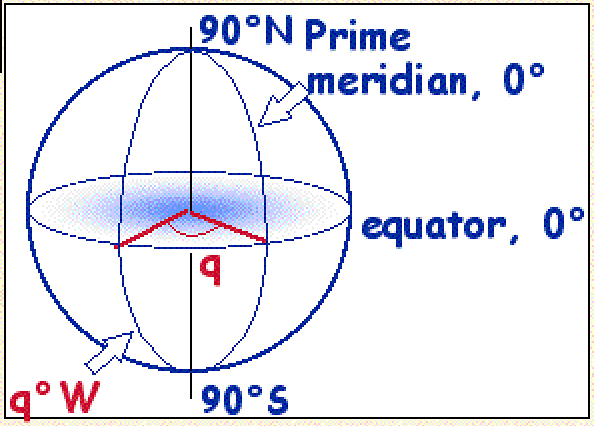


Surface Co-ordinates:

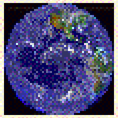
- Longitude
  - a series of North-South lines called meridians, measured in degrees (°), that converge at the poles
  - prime meridian at Greenwich (0°)
  - angles East or West of 0° (to 180°)
  - 360° = 24 hours, 1° = 4 min of time
  - 1 hour = 15° longitude







- prime meridian at Greenwich (0°)
- 180°: international date line

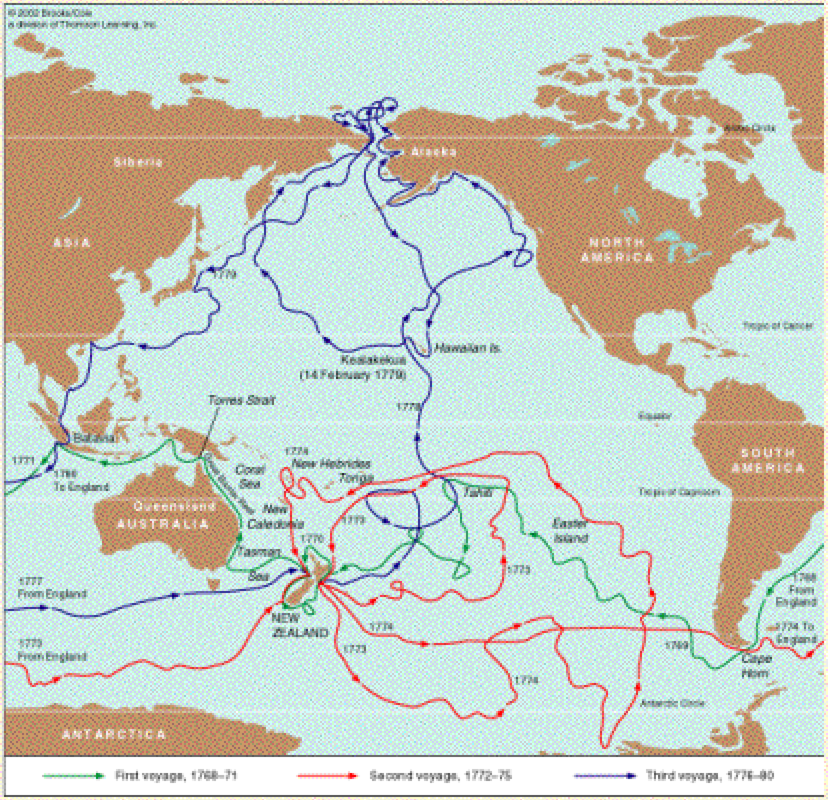


Early Ventures in Ocean Science — I:

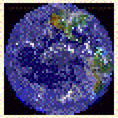
- James Cook
  - *H.M.S. Endeavour*
  - *H.M.S. Resolution*
  - 3 voyages to Pacific
  - (1768 - 1779)
  - charting coastlines

James Cook

Endeavour



- Cook died in a skirmish on Hawai'i



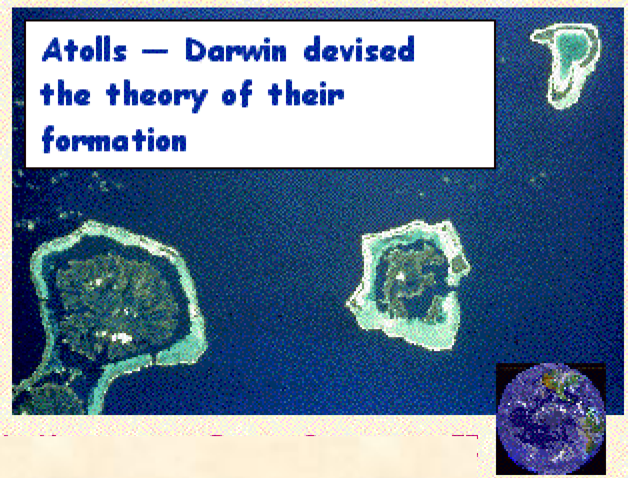
Early Ventures in Ocean Science — II:

- Darwin & *H.M.S. Beagle*
  - circumnavigation 1831-36
  - Darwin as naturalist
  - described, collected & classified organisms from land and sea: observational evidence for his theory of evolution
  - explained how atolls form

H.M.S. Beagle

Darwin (*c.* 1840)

Galapagos finches beaks: adaptations described in "The Origin of Species by means of natural selection"

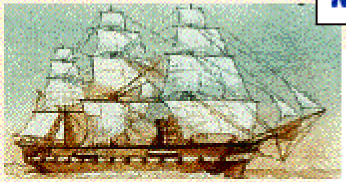


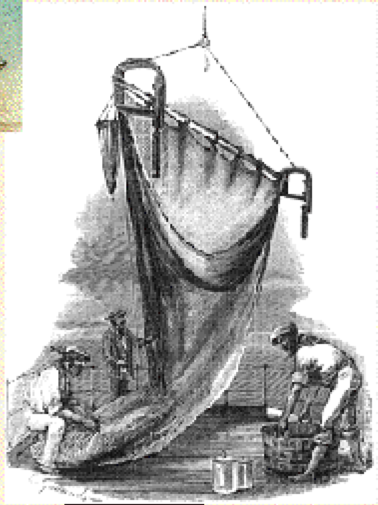
Atolls — Darwin devised the theory of their formation

Early Ventures in Ocean Science – III:

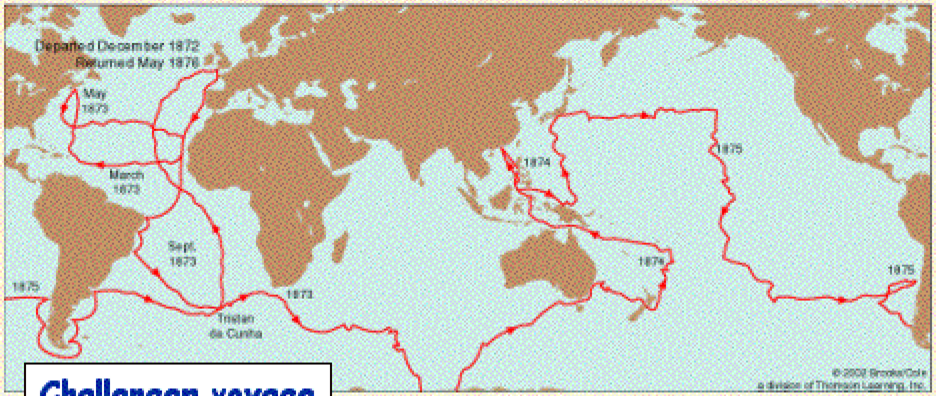
- Matthew Fontaine Maury (US Navy)
  - collected wind and current information
  - "Physical Geography of the Sea" (1855)
- *H.M.S. Challenger* (Thomson & Murray)
  - 1872 - 1876 circumnavigation sponsored by Royal Society
  - collected rocks, plants, animals, and published results (50 vols)
  - deep ocean not "azoic"

Maury

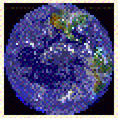


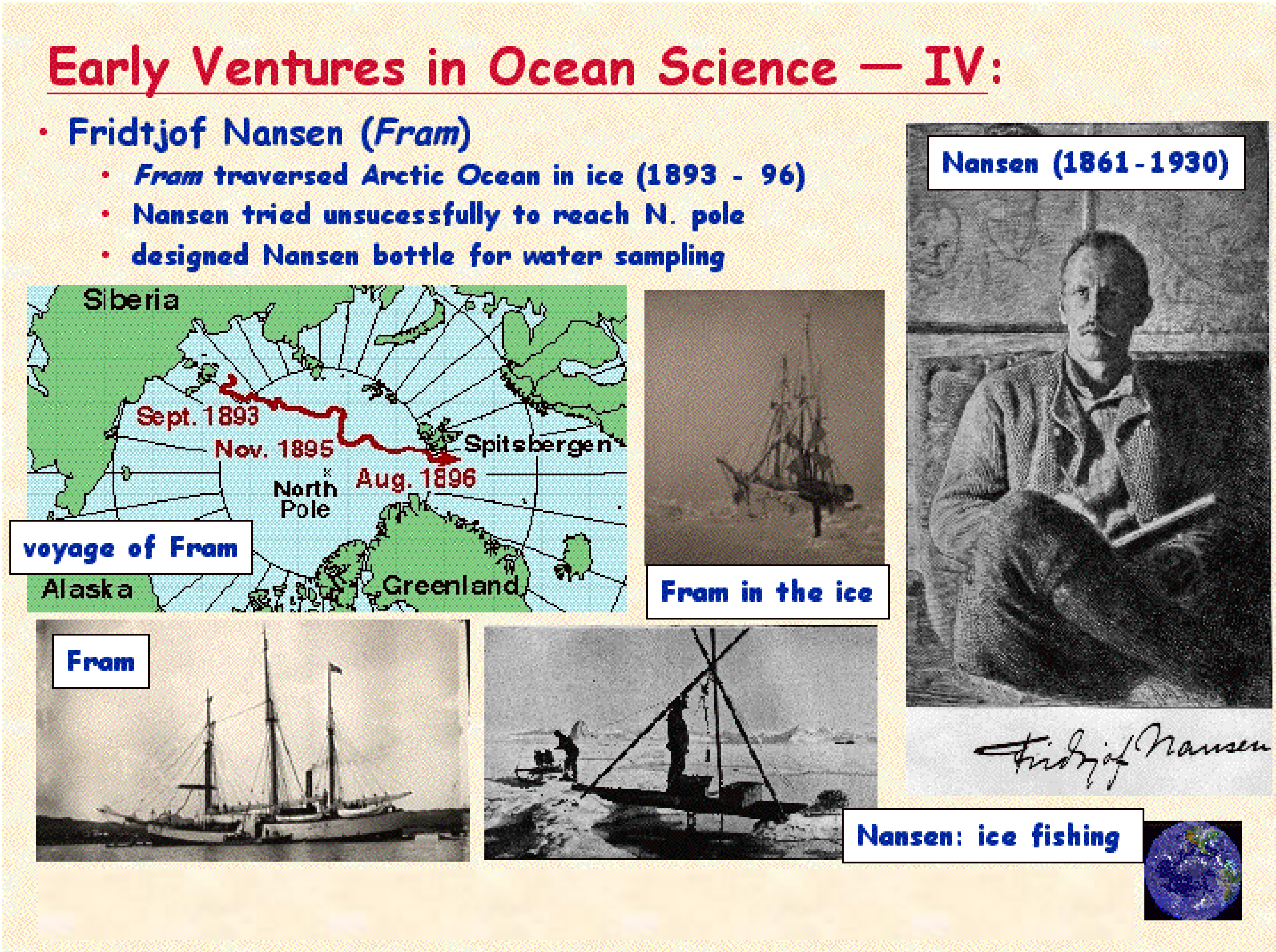


dredge



Challenger voyage




Early Ventures in Ocean Science — IV:
• Fridtjof Nansen (Fram)
• Fram traversed Arctic Ocean in ice (1893 - 96)
• Nansen tried unsucessfully to reach N. pole
• designed Nansen bottle for water sampling
Siberia
Sept. 1893
Nov. 1895
Aug. 1896
Spitsbergen
North Pole
Greenland
Alaska
voyage of Fram
Fram in the ice
Nansen (1861-1930)
Fridtjof Nansen
Fram
Nansen: ice fishing

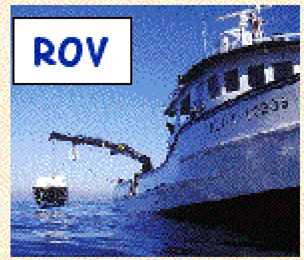
Modern Global Ocean Science:

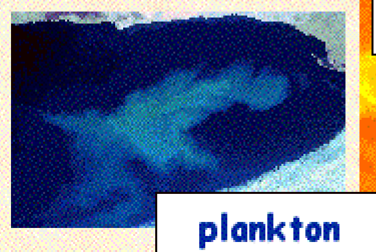
- Ocean Drilling
  - Glomar Challenger
  - JOIDES Resolution

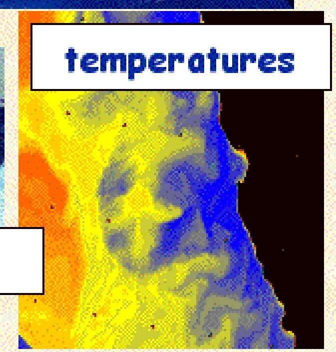
- Submersibles, Alvin, ROV's
  - MBARI vessels (Pt. Lobos)
- Satellite imagery
  - sea temperatures
  - plankton blooms
- Global Climate Change Programs
  - WOCE, JGOFS
  - GLOBEC, RIDGE, GOOS, IGBP

INTERNATIONAL COUNCIL OF SCIENTIFIC UNIONS
Scientific Committee on Oceanic Research

WOCE







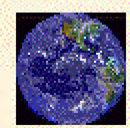
U.S. GLOBEC
GLOBAL OCEAN ECOSYSTEMS DYNAMICS

RIDGE

The Global Ocean Observing System
GOOS

GLOBAL CHANGE
IGBP

JGOFS

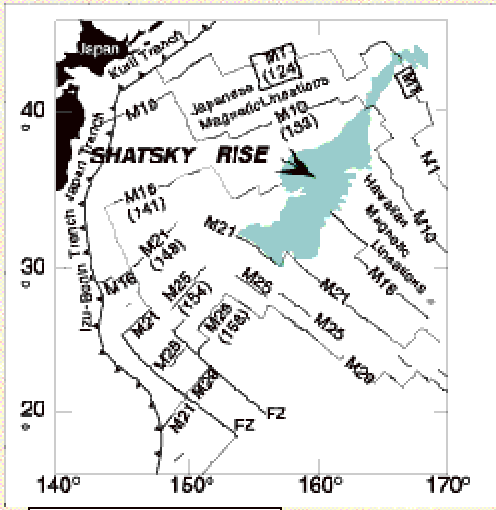


ODP 198 Drilling:

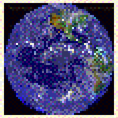
- Simon Brassell (shipboard geochemist)
- Shatsky Rise in West Pacific
- Targeted intervals of extreme warmth

JOIDES Resolution

Sediment cores onboard ship

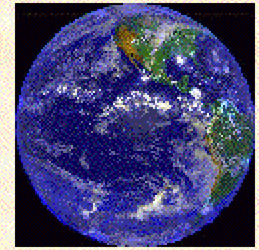


Drilling site



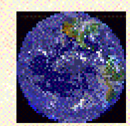
Oceans & Our Global Environment

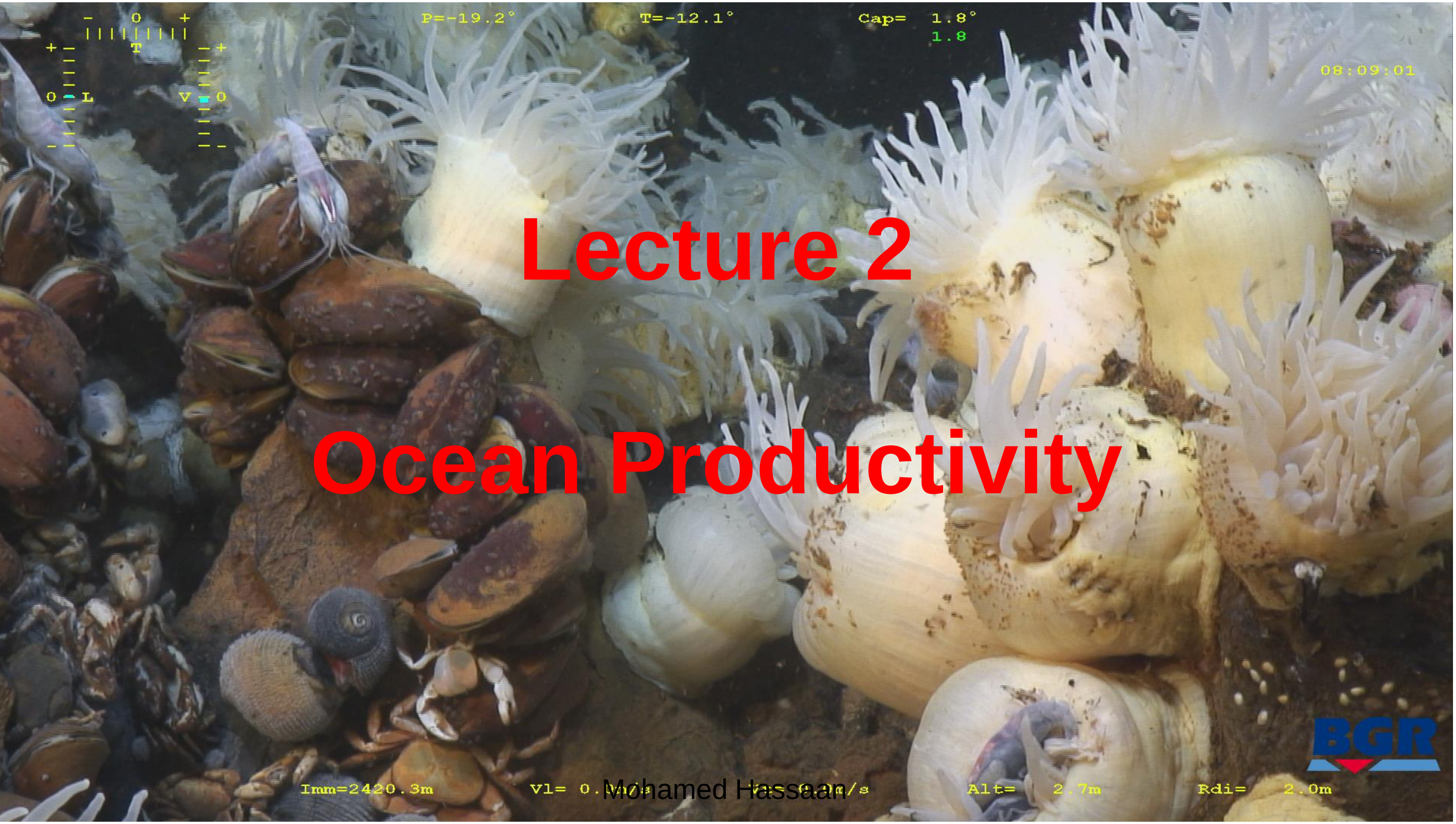
History of Oceanography



Key Concepts:

- Ancient focus on resources, trading, navigation
- Age of discovery by European explorers
- Technological developments improved charts, navigation
- Interest in knowledge of the oceans prompted scientific studies, led to Challenger expedition
- A major interdisciplinary research area, using array of sampling devices, satellite imaging and remote sensing



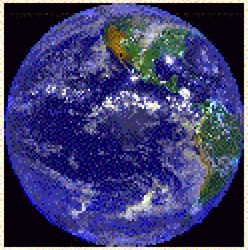


Lecture 2

Ocean Productivity

Mohamed Hassaan

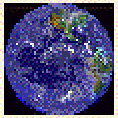
Oceans & Our Global Environment



Life in the Ocean

Topics:

- Primary Production; Food Webs
  - photosynthesis; controls: light and nutrients
  - feeding hierarcy; trophic levels, energy efficiency
- Phytoplankton, Marine Animals and Communities
  - types of phytoplankton, life cycles
  - lifestyles and habitats of organisms:
    - nekton (swimmers) and benthos (bottom dwellers)



Primary Production:

- New Organic Matter:
  - activity of phytoplankton; varies spatially and temporally
  - measured by ^{14}C uptake by water samples, or by satellite color
- Photosynthesis and Respiration:
  - photosynthesis: capture of energy from sunlight by chlorophyll
  - respiration: reverse process, O_2, carbohydrates used for energy
- Production:
  - total photosynthetic production = gross primary production
  - gross primary production – respiration = net primary production
  - mass of organisms = biomass, or standing crop

Photosynthesis: $6\ CO_2 + 6\ H_2O \xrightarrow{\text{sunlight}} C_6H_{12}O_6 + 6\ O_2$

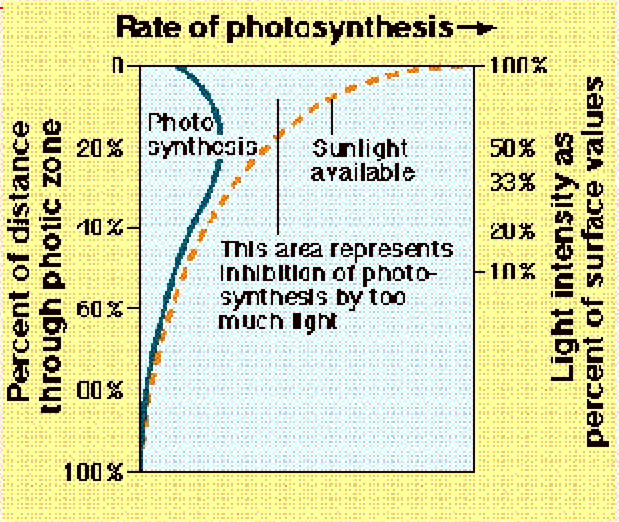
(carbon dioxide + water → glucose + oxygen)

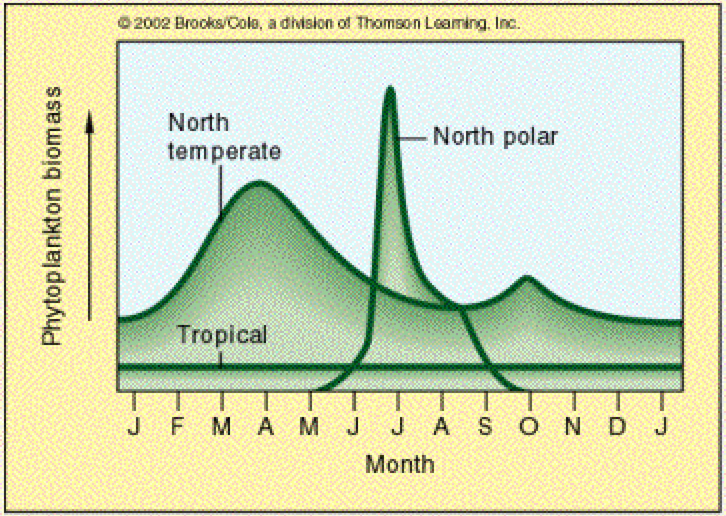
Respiration: $C_6H_{12}O_6 + 6\ O_2 \longrightarrow 6\ CO_2 + 6\ H_2O + \text{energy}$

(glucose + oxygen → carbon dioxide + water + chemical energy)

Controls on Primary Production:

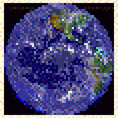
- Light effects:
  - depth (chlorophyll maximum)
  - light availability can restrict primary production
  - seasonal changes in intensity
  - distinct latitudinal variation





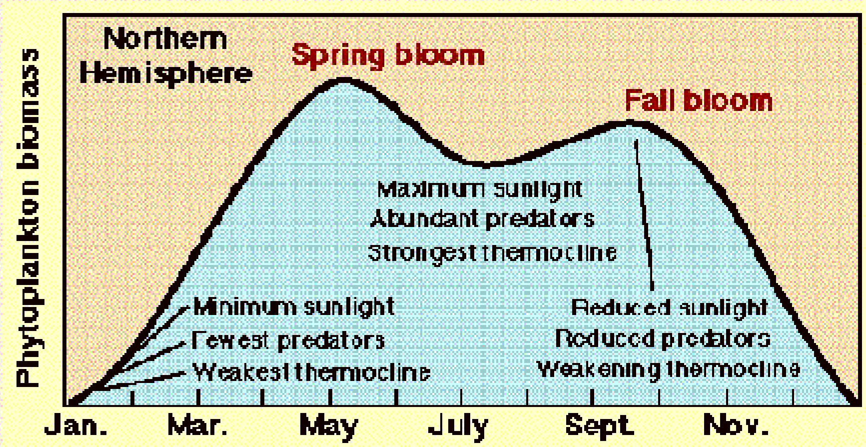
- low latitude: little seasonal variation in light intensity
- mid latitude: marked seasonally in light intensity
- high latitude: extreme seasonal changes in light intensity

Controls on Production

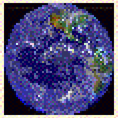


Controls on Primary Production:

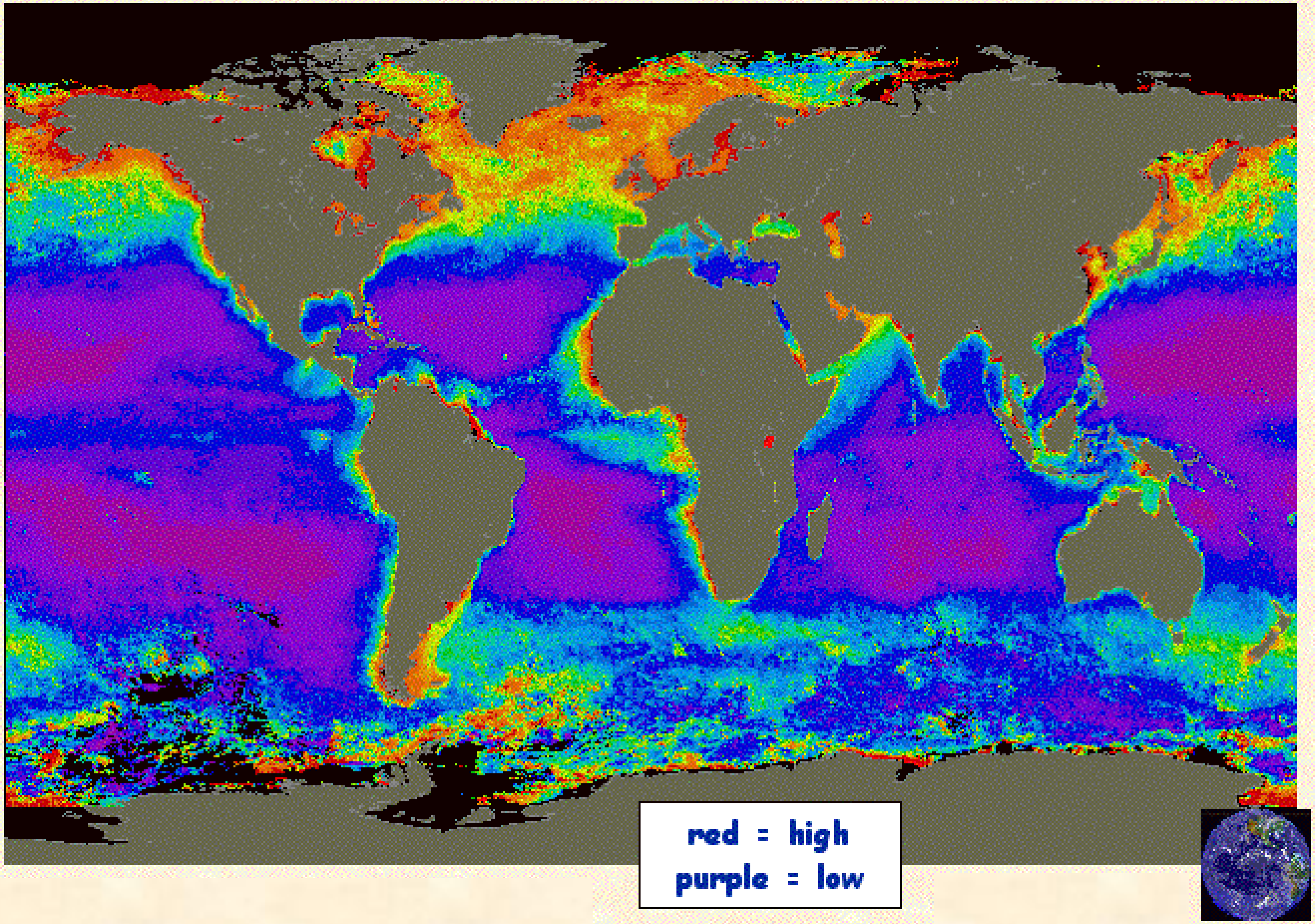
- Nutrients:
  - N, P replenished in surface waters by winter storms
  - restricts plant growth when limiting; vary spatially
- Nutrient Cycling:
  - decomposers aid nutrient regeneration
  - nutrients released when phyto-plankton die



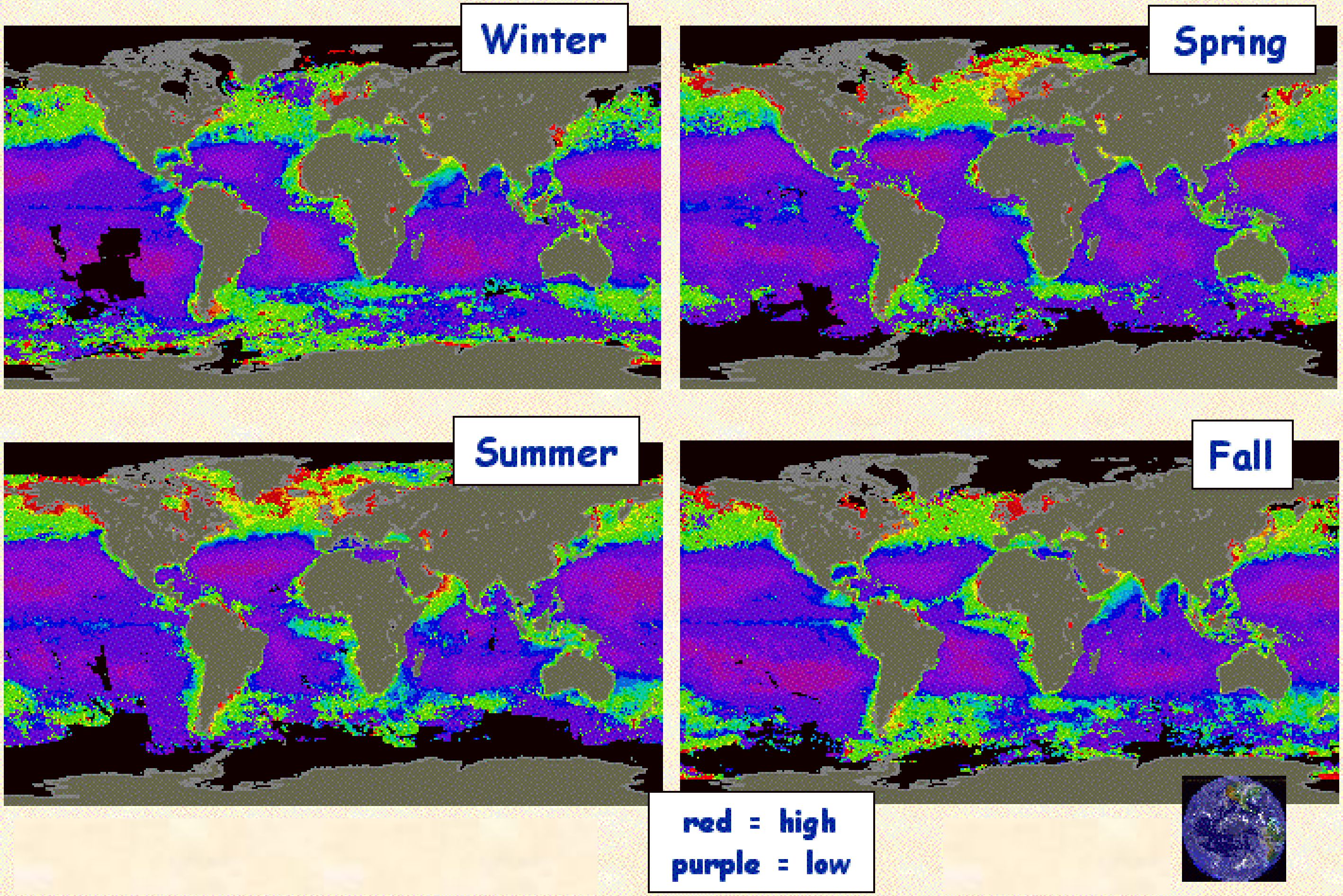
- Blooms:
  - dependent on light, nutrients & overturn, grazing by predators
  - may occur once or twice annually
    - Spring & Fall blooms typical at mid latitudes in the N. hemisphere



Global Annual Primary Production:



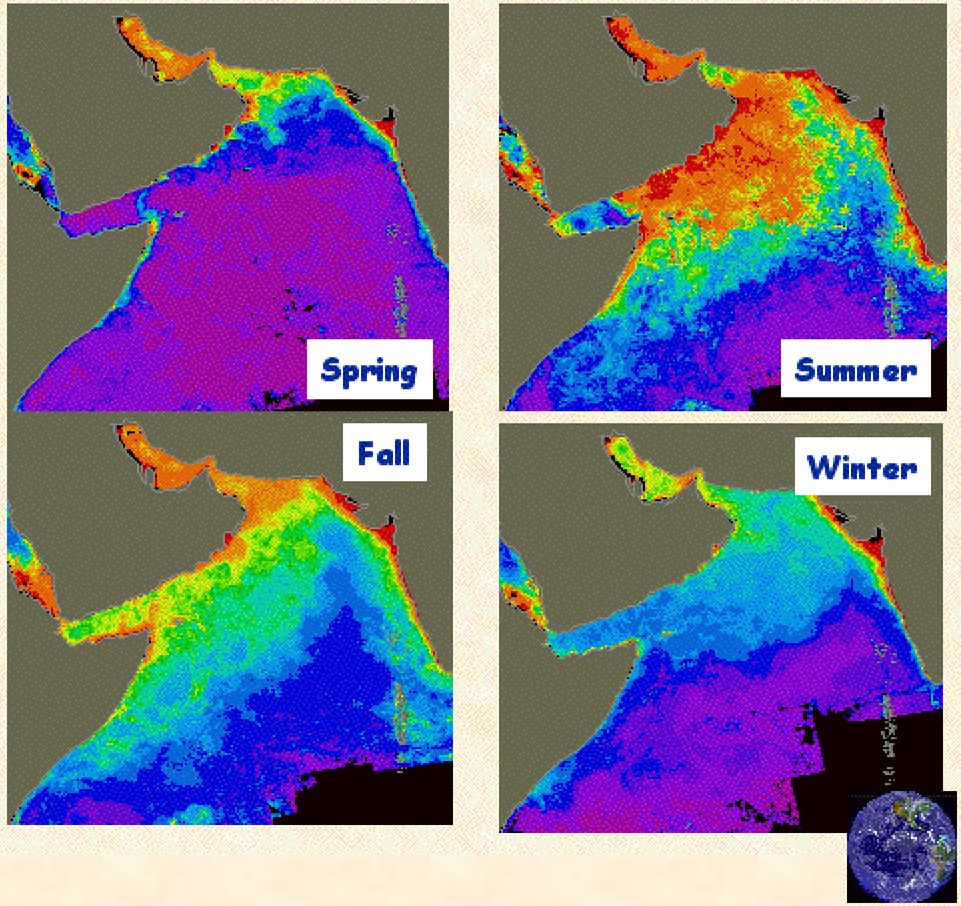
Seasonal Changes in Global Primary Production:



Seasonal Changes in Primary Production:

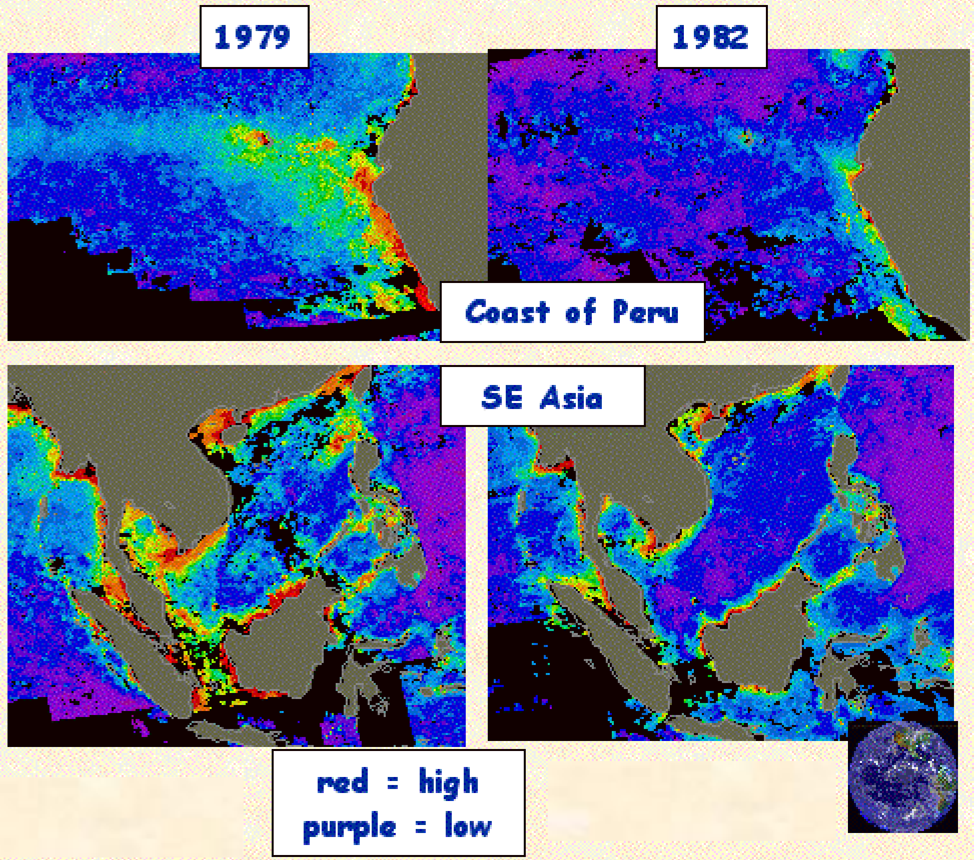
- Arabian Sea
  - seasonal changes influenced by monsoon winds, which induce upwelling during the summer

red = high
purple = low



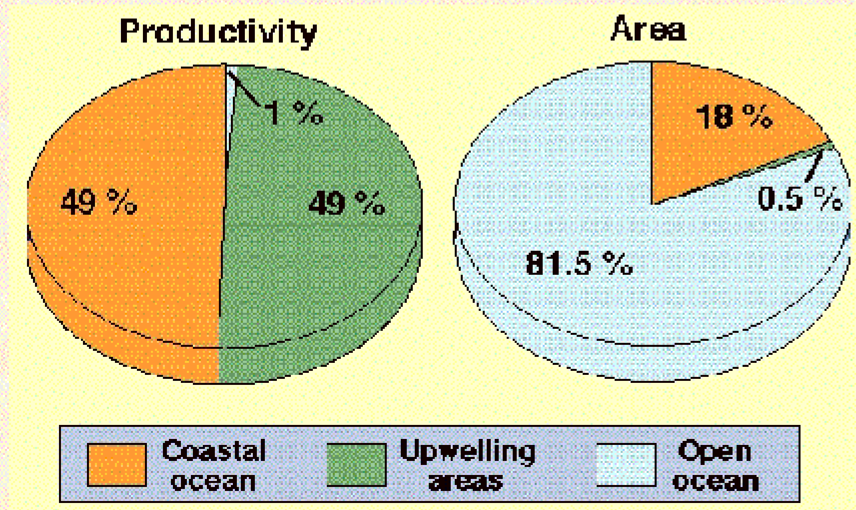
Yearly Changes in Primary Production:

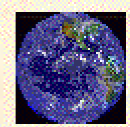
- Variability in intensity of production during the Fall
  - Off Peru
  - SE Asia
- A result of El Niño in 1982/83
  - Peru: nutrient-poor waters upwelling
  - SE Asia: less run-off from lower precipitation



Distribution of Production:

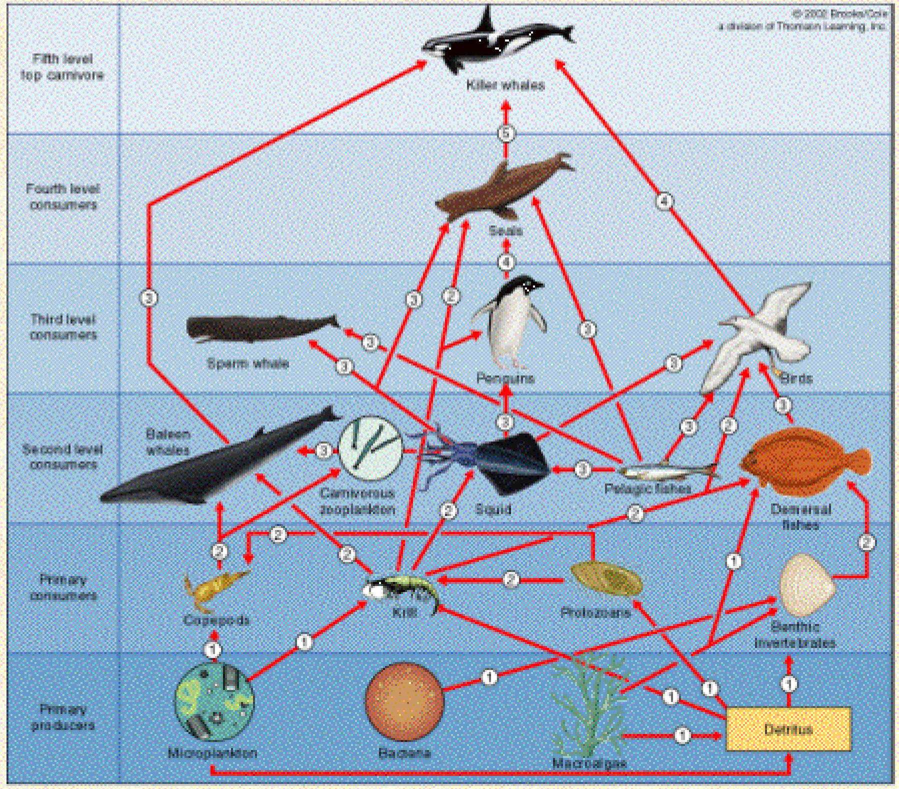
- Open Ocean:
  - 80-85% of total
  - lower amount: 130gC/m²/a
- Coastal Regions:
  - 15-18% of total
  - low amount: 160gC/m²/a
- Upwelling Areas:
  - <1% of total
    high amount: 640gC/m²/a
- Seasonal Variation:
  - latitudinal influences dependent on light intensity





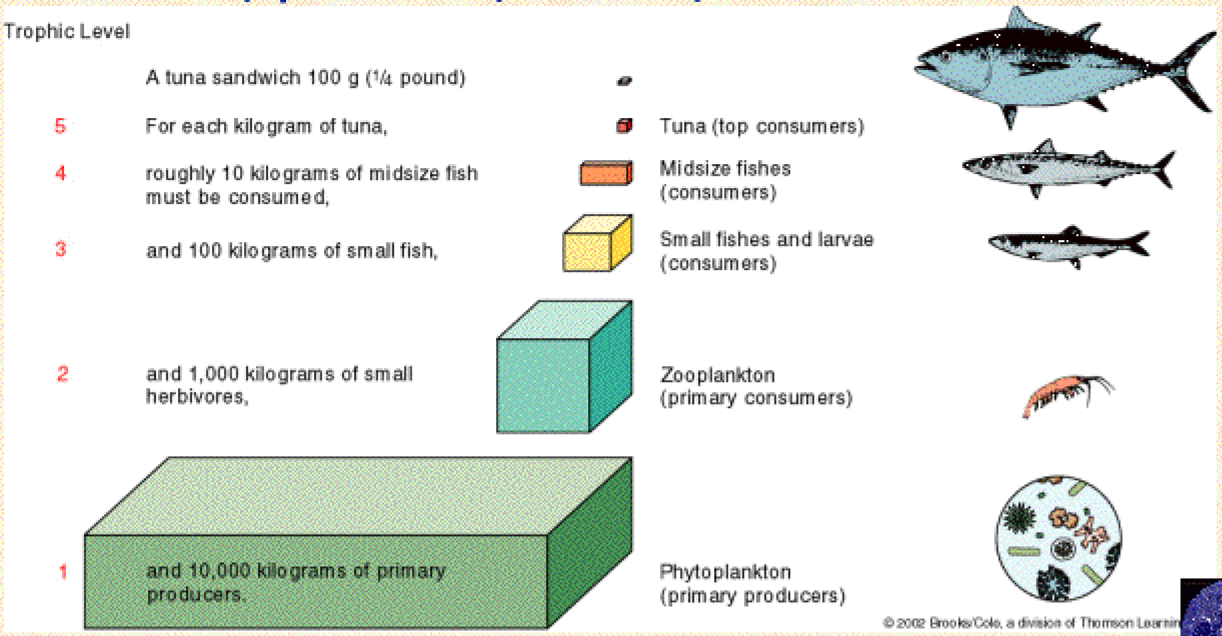
Food Chains and Food Webs:

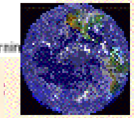
- Hierarchy, grazing:
  - zooplankton production follows phytoplankton production
  - food chains: linear sequence
    - phytoplankton to herbivorous zooplankton to carnivorous zooplankton to fish
  - food webs: interconnected complex inter-relationships between multiple food sources and consumers



Food Chains and Food Webs:

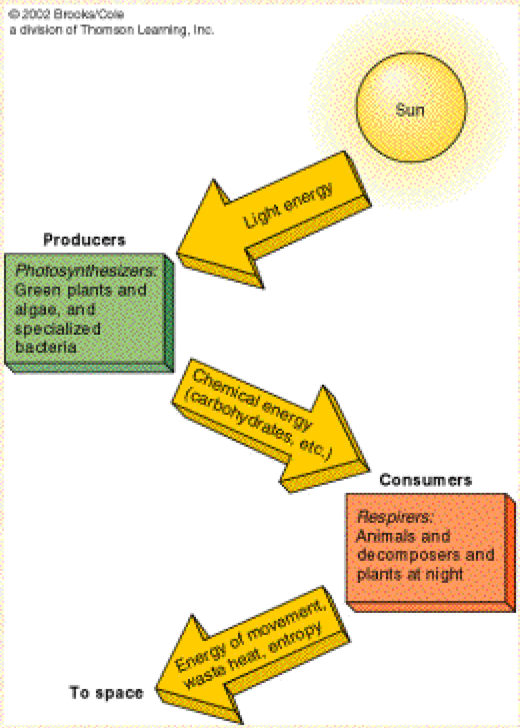
- Trophic Levels:
  - primary producers (plants, bacteria)
  - secondary producers (herbivores)
  - tertiary producers (carnivores)

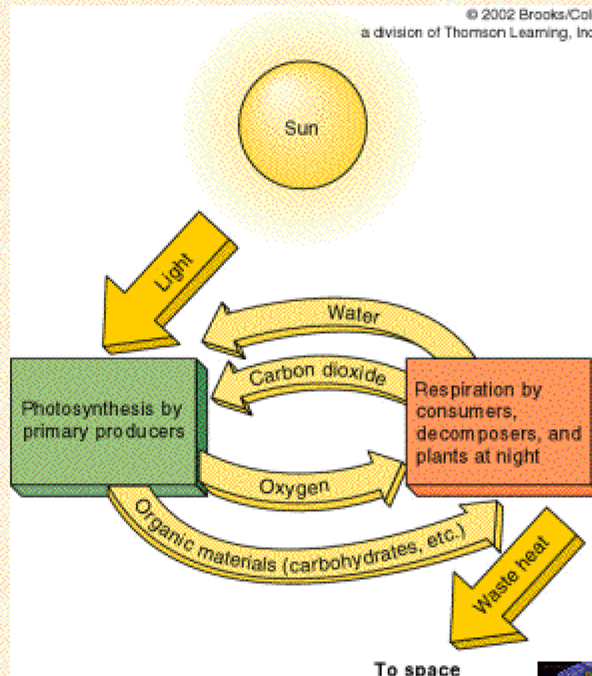


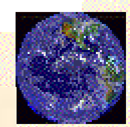


Trophic Pyramids:

- Energy Source:
  - principal source of energy: sunlight

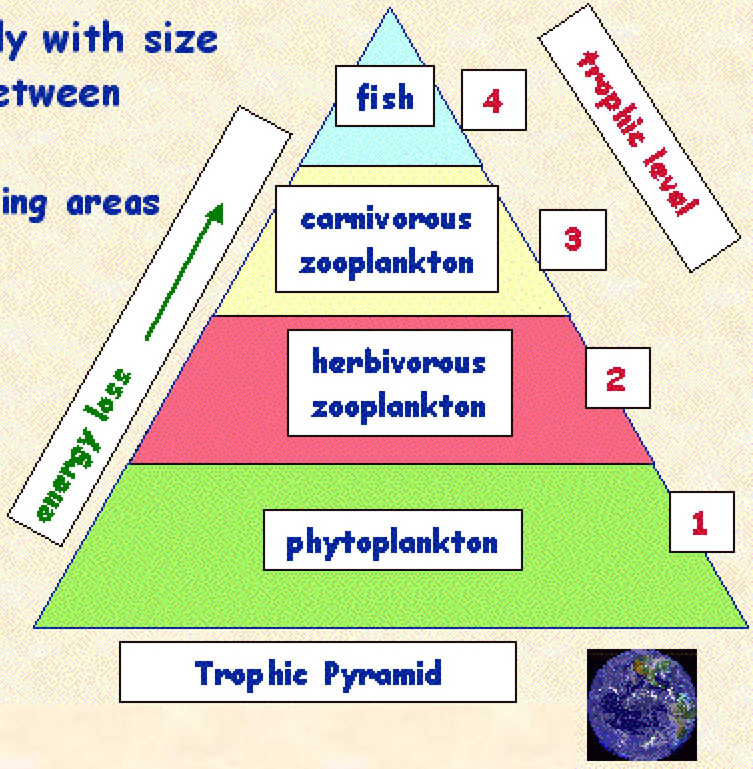






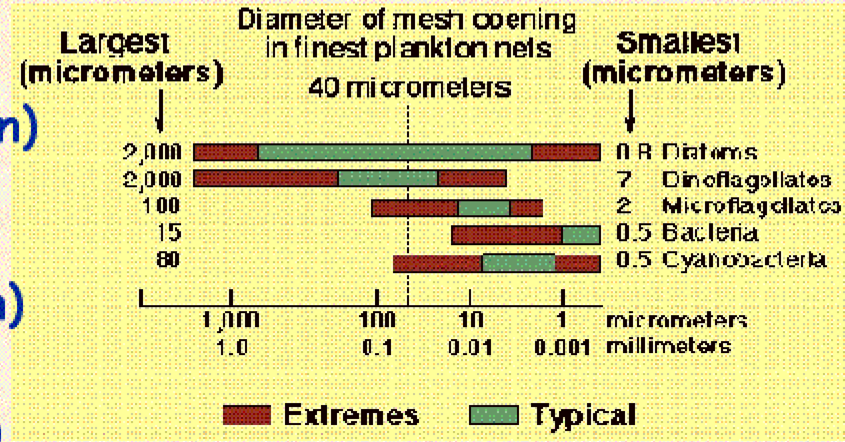
Trophic Pyramids:

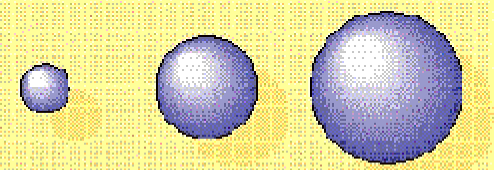
- Trophic Pyramids:
  - inter-relationships of organisms from different trophic levels
    - primary producers to herbivores to carnivores
  - abundance varies inversely with size
  - significant energy loss between trophic levels
    - 20% efficiency in upwelling areas
    - 15% in coastal regions
    - 10% in the open ocean
  - energy is lost at each level of the pyramid
  - decomposers help to recycle nutrients at each level of the pyramid



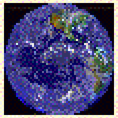
Plankton:

- Plants (phytoplankton)
  - autotrophs
  - heterotrophs
- Animals (zooplankton)
- Size division:
  - ultraplankton (<5μm)
  - microplankton (5-10μm)
  - nannoplankton (<50μm)
  - net plankton
  - range within each group of organisms
  - size affects surface to volume ratio, with implications for
    - buoyancy, light accessibility, intake of CO_2, nutrients



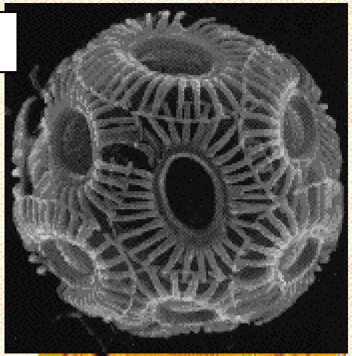


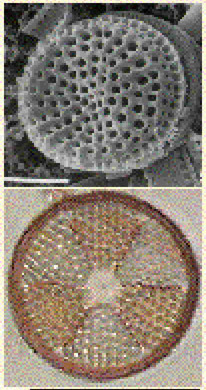
Diameter (cm)	0.5	1.0	1.5
Surface area (cm^2)	0.79	3.14	7.07
Volume (cm^3)	0.06	0.52	1.77
Surface-to-volume ratio	13.17:1	6.04:1	3.99:1



Phytoplankton:

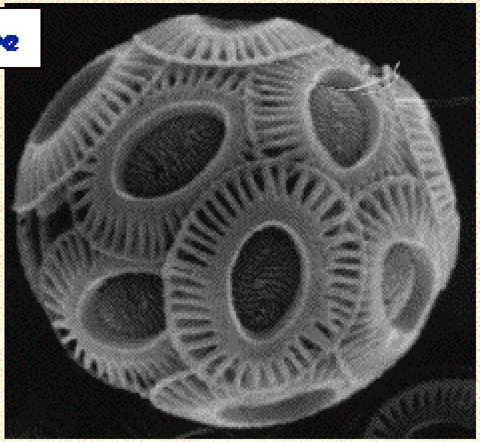
- Phytoplankton:
  - unicellular plants, autotrophs (photosynthetic)
  - some heterotrophs, some filamentous
- Coccolithophorids:
  - calcareous photoautotrophs
- Diatoms:
  - siliceous photoautotrophs
  - radial (centric) or pennate frustules
  - divides for reproduction
- Dinoflagellates:
  - organic-walled auto-, heterotrophs
  - possess flagella, can cause red tides
- Bacteria:
  - photoautotrophic cyanobacteria
  - other heterotrophs

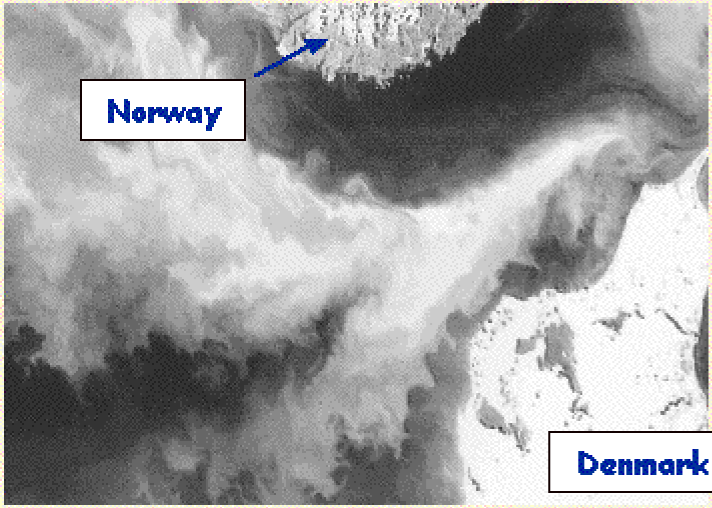


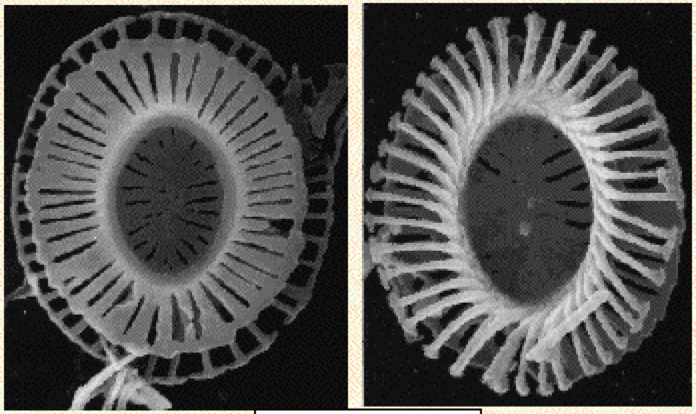


Coccolithophorids:

- Calcareous Photoautotrophs
  - abundant, widespread, unicellular algae (microplankton)
  - produce calcite coccosphere consisting of individual placoliths
  - seasonal blooms create "milky water"

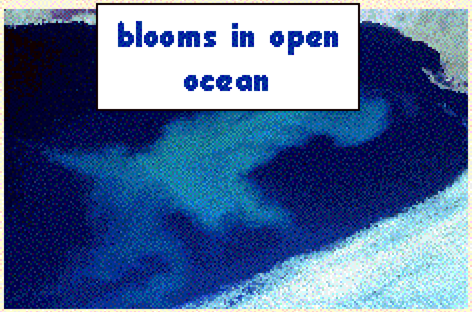


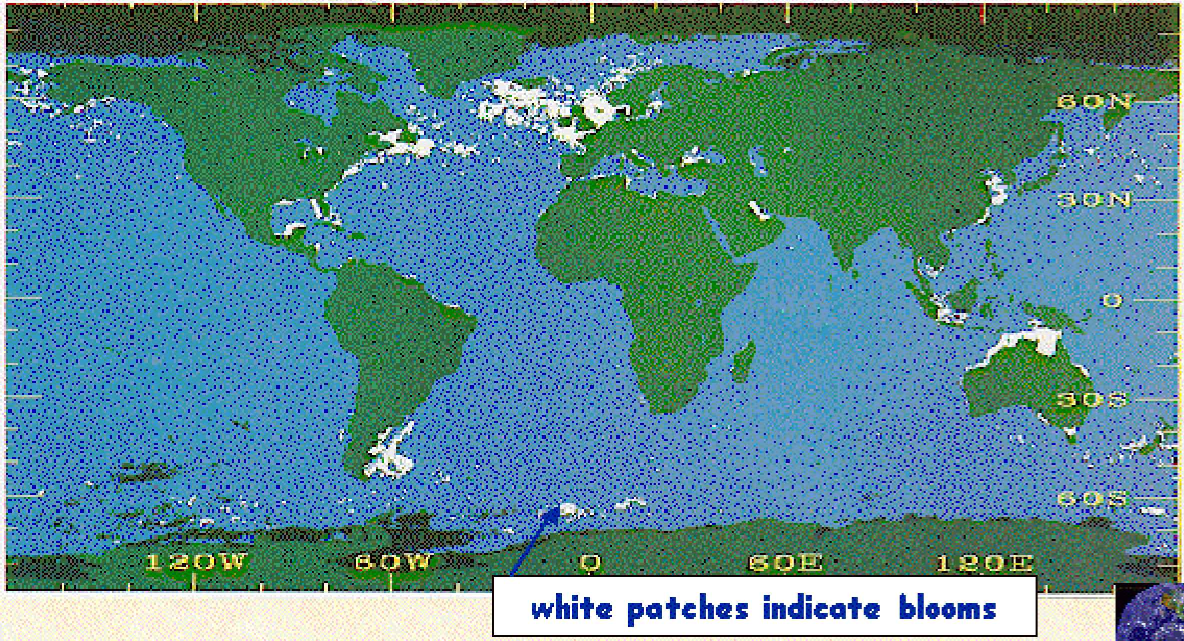


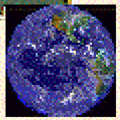


Coccolithophorid Blooms:

- Visible in Satellite Images
  - Emiliania huxleyi seasonal blooms
  - discolor ocean
  - create intense light scattering







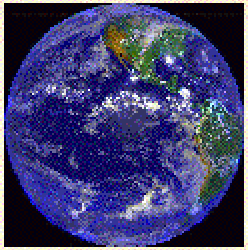
Lecture 3

Plate Tectonic

Mohamed Hassaan

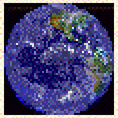
Oceans & Our Global Environment

Plate Tectonics



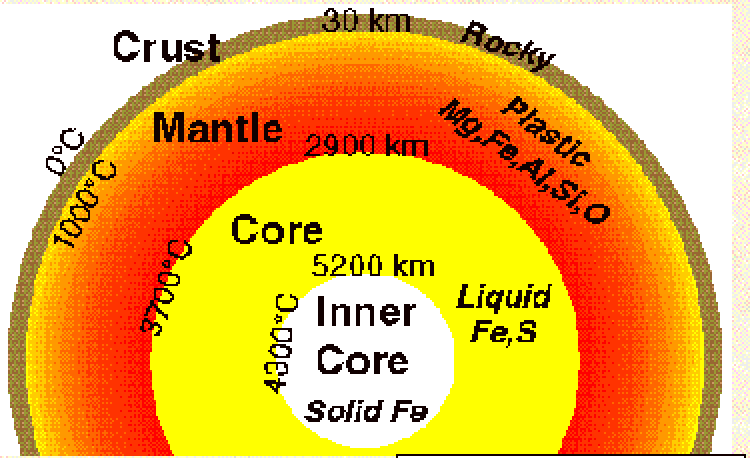
Topics:

- Internal Structure of the Earth
- Lithosphere — Structure and Isostasy
- Movement of Continents
  - continental configurations: history of an idea
  - rifting, ridge structure, subduction
- Plate Boundaries and Hot Spots - Processes
- History of Ocean Basins and Continents



Interior of the Earth:

- Series of concentric spheres create layered structure
- Layers (core, mantle, crust) differ in composition
- Minor divisions differ in phase (solid vs. liquid)
  - core (metallic: Fe, Ni)
    - inner (solid, 1070km)
    - outer (liquid, 2400km)
  - mantle (Fe/Mg silicates)
    - lower mantle (solid)
    - upper mantle (plastic/ partially molten, asthenosphere)
  - crust (rigid, silicates)
    - oceanic (thin: 7km, Mg, Fe silicates)
    - continental (thick: 45km; Mg, Al silicates)



Interior structure

Earthquakes:

- Ground-shaking produced by seismic waves
- Examples from California

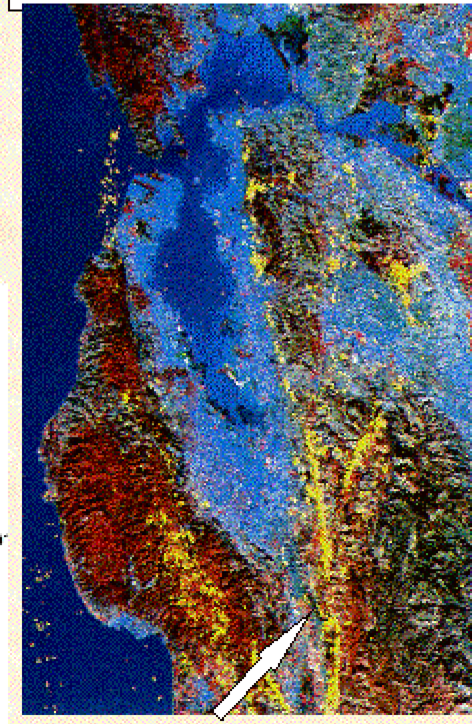
Loma Prieta, 1989

Northridge, CA

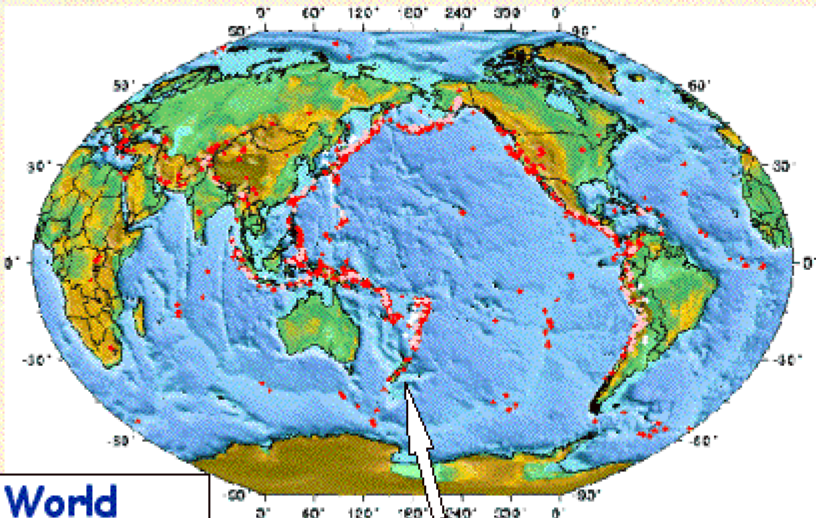
Earthquakes:

- Spatially restricted occurrence
  - typically occur along linear belts
- Occur globally in specific regions
  - continents & oceans, ocean margins

San Francisco Bay area

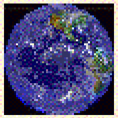


earthquakes in yellow



World (1990-1996)

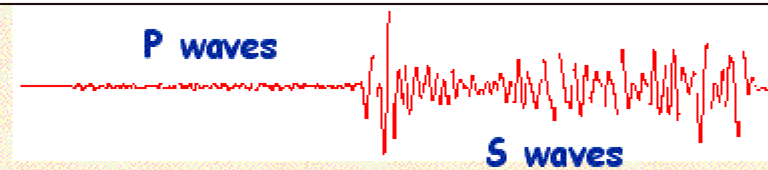
earthquakes in red, pink, white



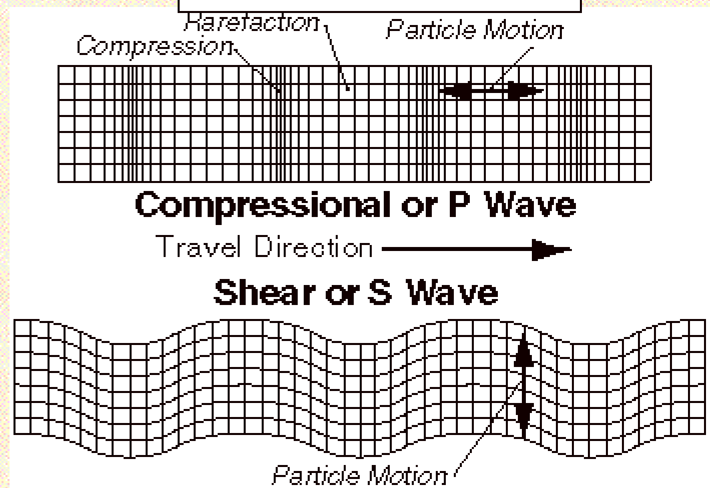
Seismic Waves — I:

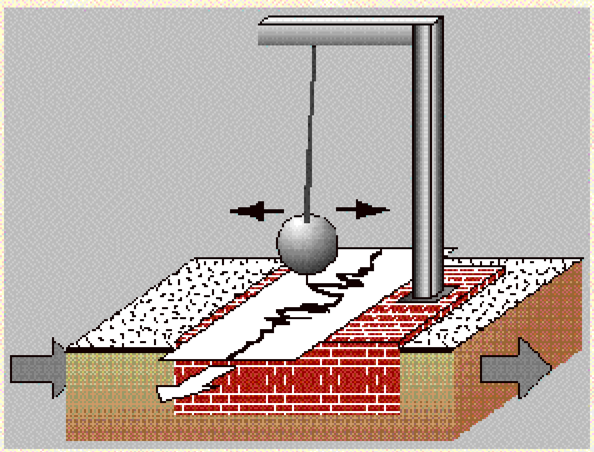
- 2 types of waves
  - Primary or P waves
    - compressional, fast
  - Secondary or S waves
    - shear, slow
    - cannot travel in liquids

Seismogram of 1906 San Francisco earthquake

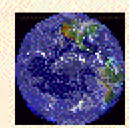


Wave characteristics



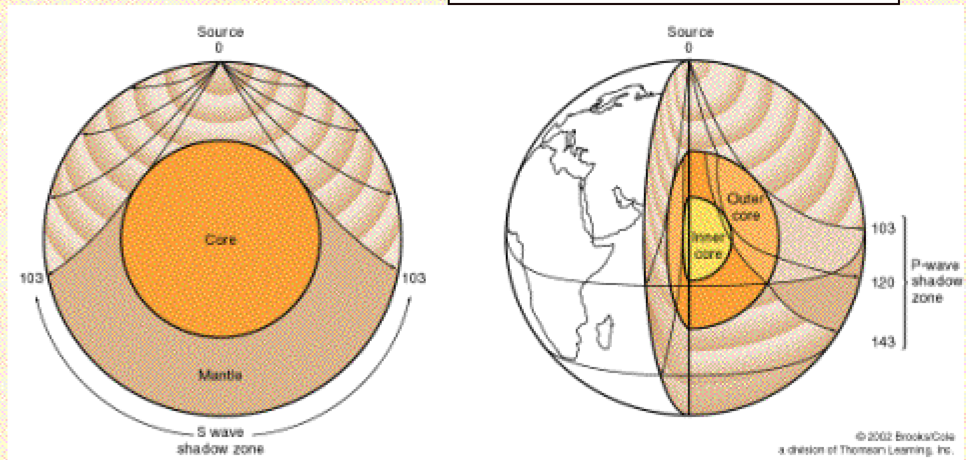


Seismographs used to measure earthquakes

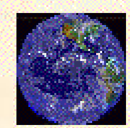


Seismic Waves — II:

Seismic wave refraction

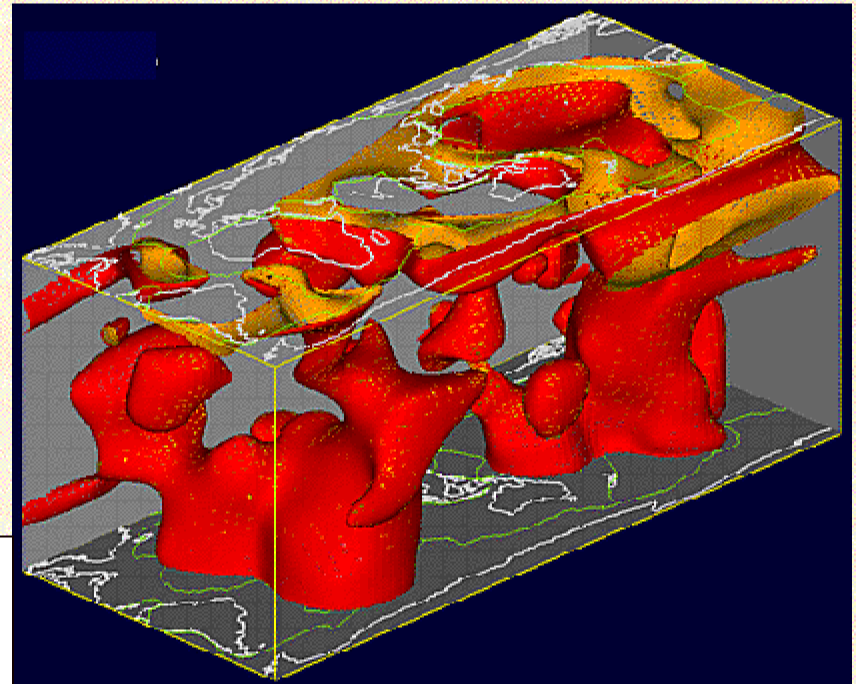


- Clues about Earth's Interior
  - Primary or P waves (pass through liquids)
  - Secondary or S waves (cannot travel in liquids)
  - Refracted by differences in density, which creates shadows in the occurrence of seismic waves
  - Earthquake locations are assessed by triangulation
  - Seismic wave speed depends on rock temperature (hot: slow, cold: fast)

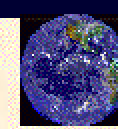


Mantle Imaging:

- Seismic Tomography, assessed from wave velocities
  - hot: slow waves
  - cold: fast waves
- Mantle uniformity?
  - inhomogeneous
  - cold zones
  - warm zones
  - variable with depth

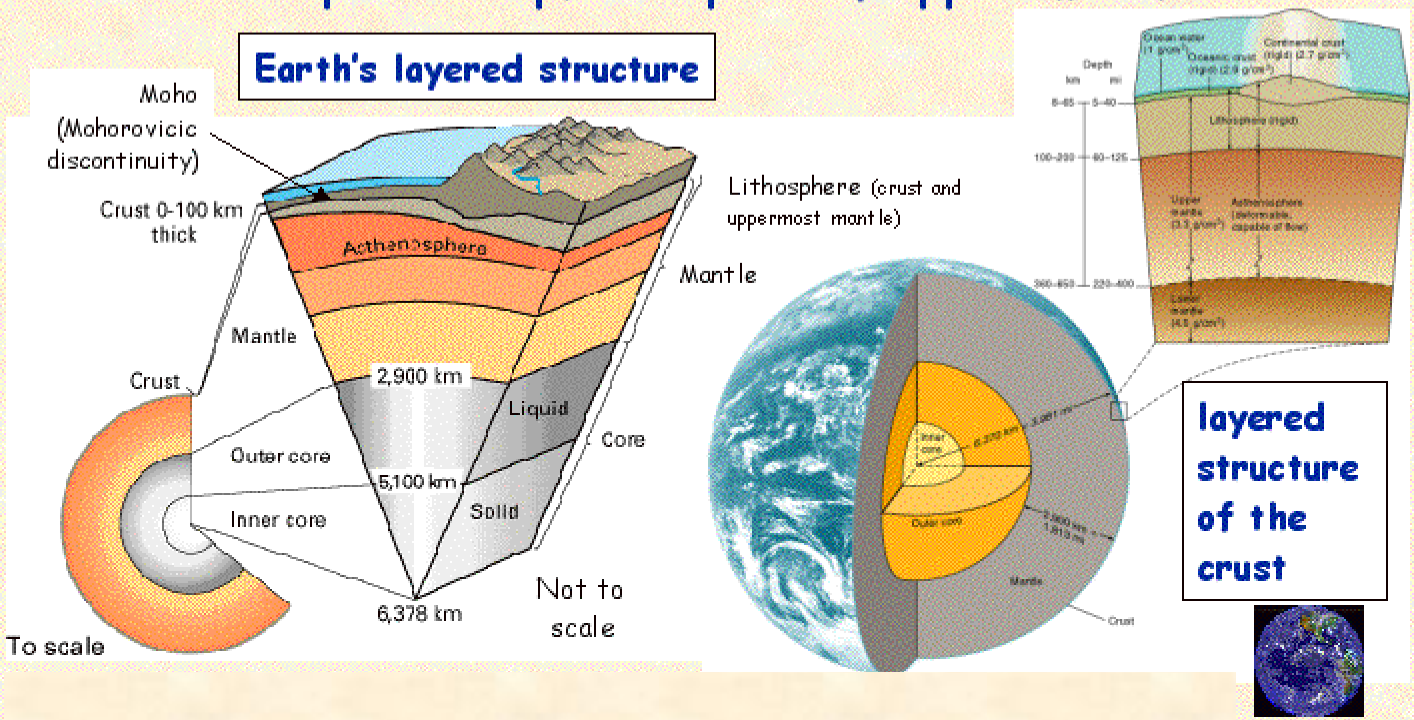


tomographic image of heat in Earth's mantle



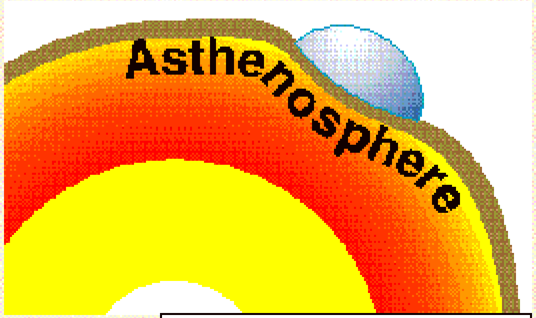
Earth's Lithosphere:

- Lithosphere — crust + rigid, solid upper mantle
- Floats on plastic/partially molten asthenosphere
- Asthenosphere — plastic part of upper mantle

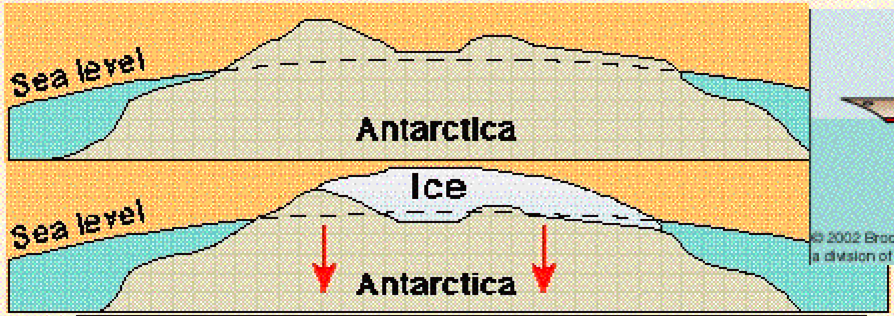


Isostasy:

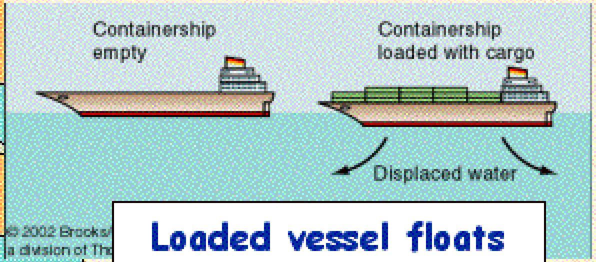
- Lithosphere floats on plastic asthenosphere
- Asthenosphere buckled by continental crust, dependent on density and thickness
- Continent can be loaded by volcanic sediments or by ice (e.g. Canadian Shield)



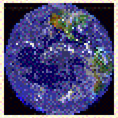
continents depress asthenosphere



Antarctica lowered by ice sheet build-up



Loaded vessel floats lower in the water



Continental Drift - I:

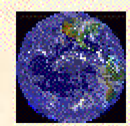
- 1858: Antonio Snider-Pellegrini
  - demonstrated "fit" of Africa and Europe with Americas
- 1920's Alfred Wegener argued for supercontinent Pangaea


Snider's fit


Alfred Wegener

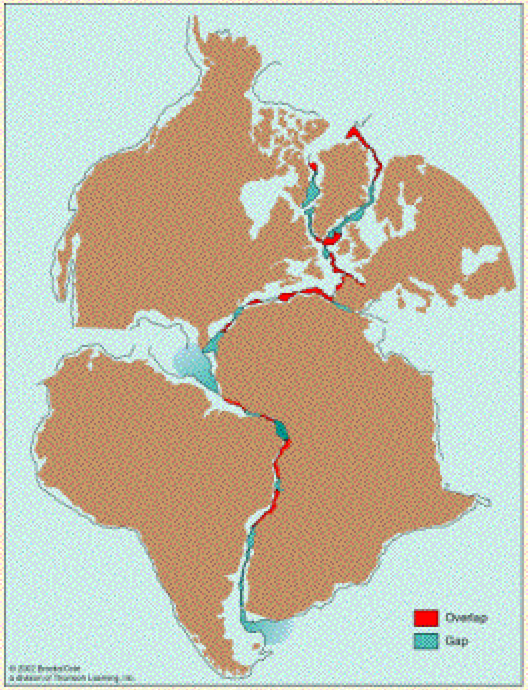
- continental 'fit'
- driven by gravity?
- consistent geological features
  - glaciated regions
  - fossil occurrences (fauna & flora)

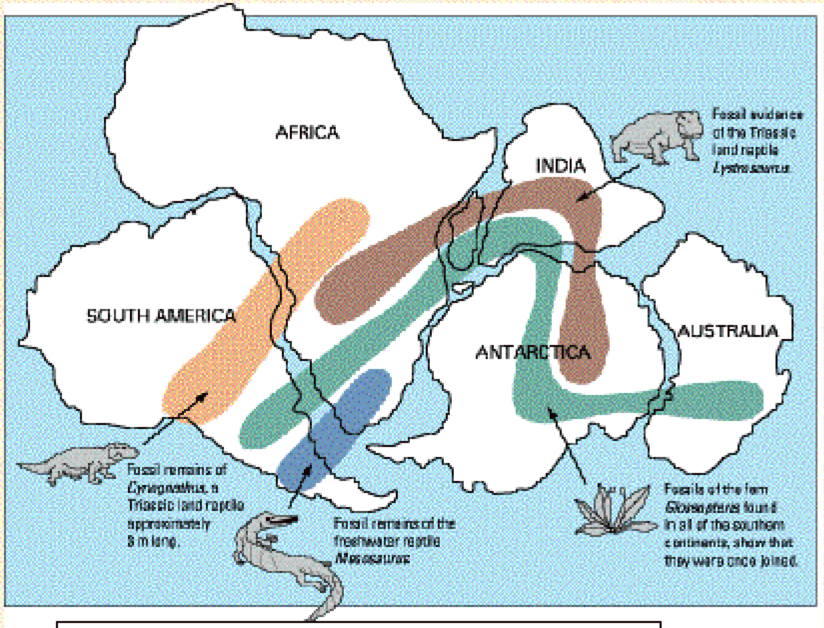
Pangaea



Continental Drift - II: Evidence for Pangaea

- Physical and geological similarities
  - continental 'fit' matched by Triassic flora and fauna





Comparability of flora and fauna

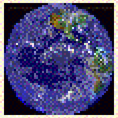
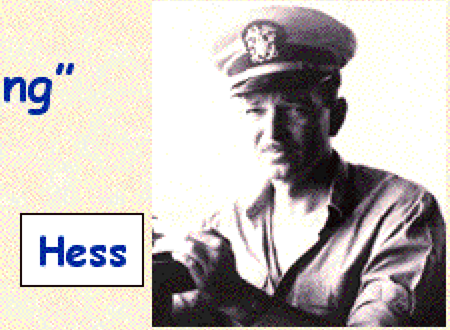


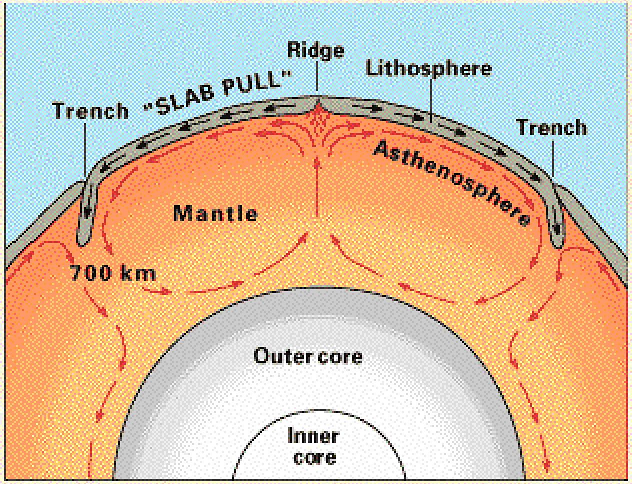
Plate Tectonics History:

- Harry Hess coined "sea floor spreading"
  - crust formed at mid-ocean ridges
  - crust consumed at trenches
  - driven by mantle convection



Mantle Convection:

- Process of thermal overturn
  - drives plates
- Mantle thermics
  - heated by core
  - cooled by volcanic eruptions, crust formation and seawater infiltration



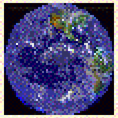


Plate Boundaries:

Transform: ocean/continent (San Andreas)

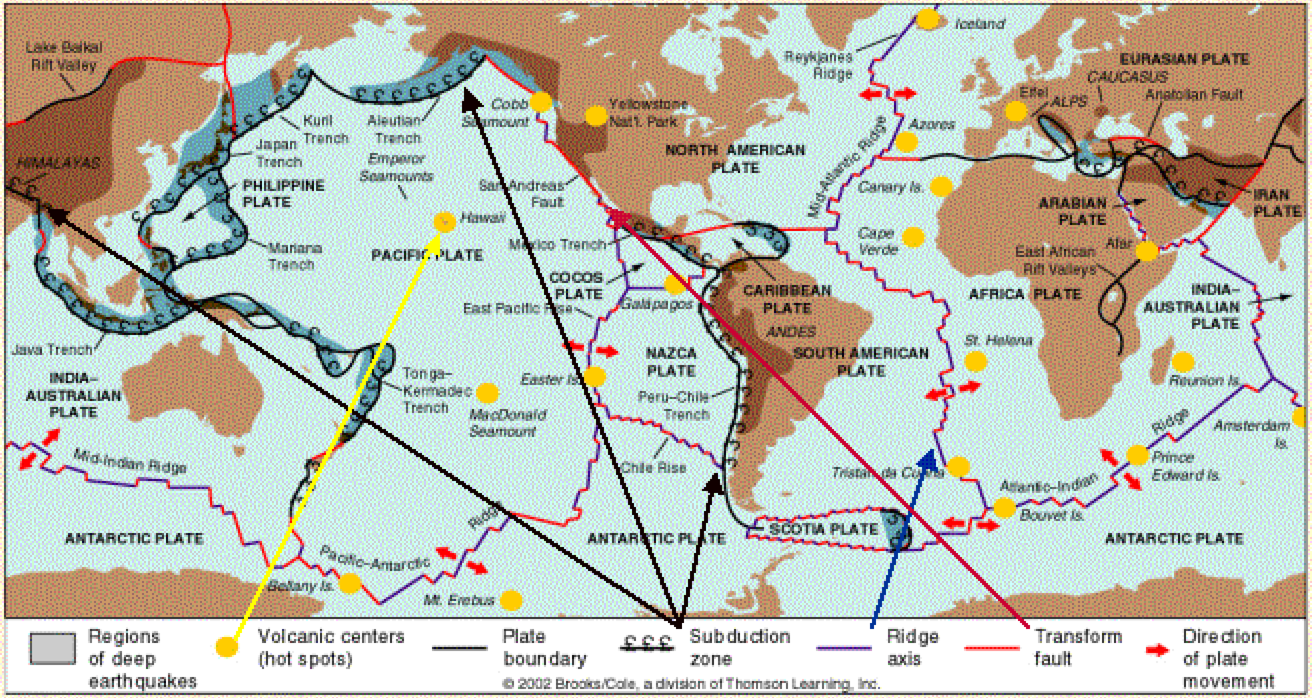
Hot spot: oceanic (Hawai'i)

Convergent: ocean/continent (W coast S. America)

Convergent: ocean/ocean (Aleutians)

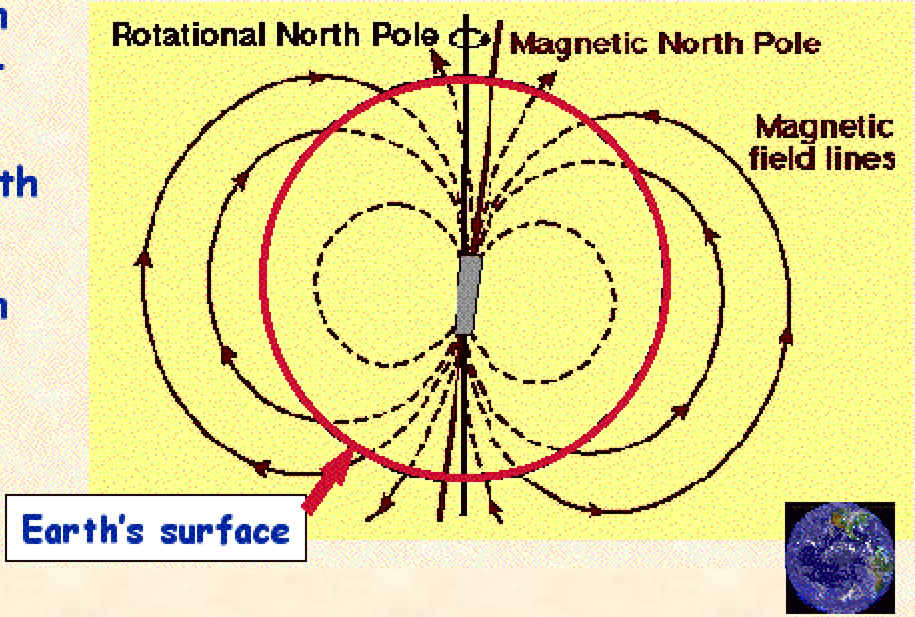
Convergent: continent/continent (Himalayas)

Divergent: mid ocean ridge (Atlantic, E. Pacific)



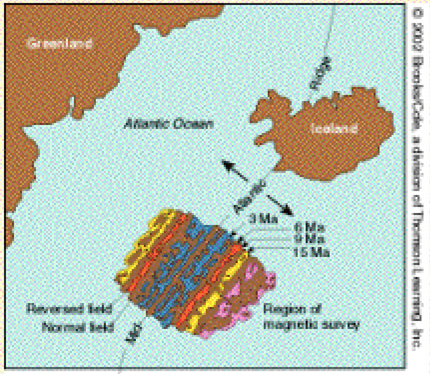
The Earth's Magnetic Field:

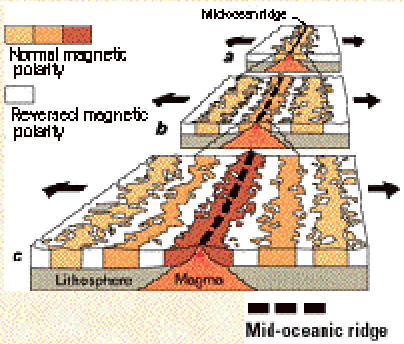
- Earth acts like a bar magnet
  - minerals in rocks record Earth's magnetic field as they cool
  - they become orientated with the magnetic north pole
  - Earth's magnetic orientation periodically reverses
  - magnetic north pole is distinct from the rotational North Pole
  - magnetic north pole migrates

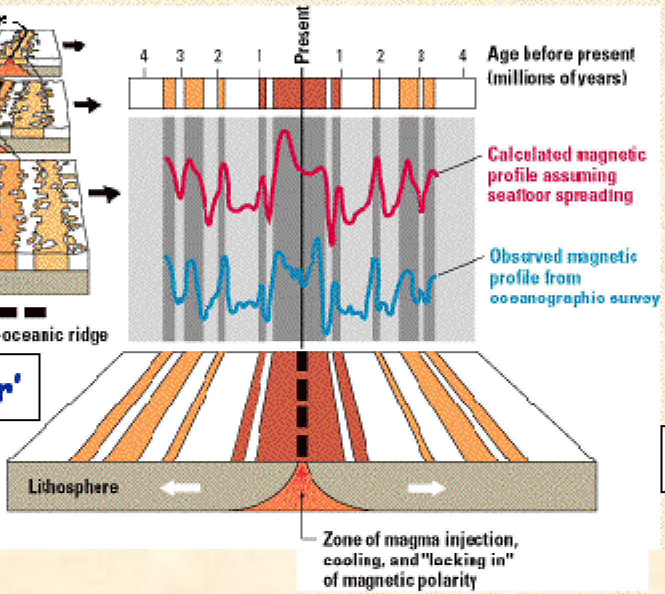


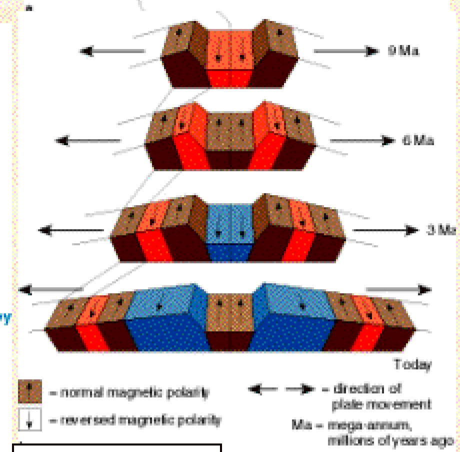
Magnetic Reversals:

- Fred Vine & Drummond Matthews
  - shifts in Earth's polarity (reversals)
  - recognized in signals of the sea floor
  - symmetric anomalies across ridge axis
  - Alternation of normal and reverse fields



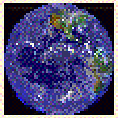






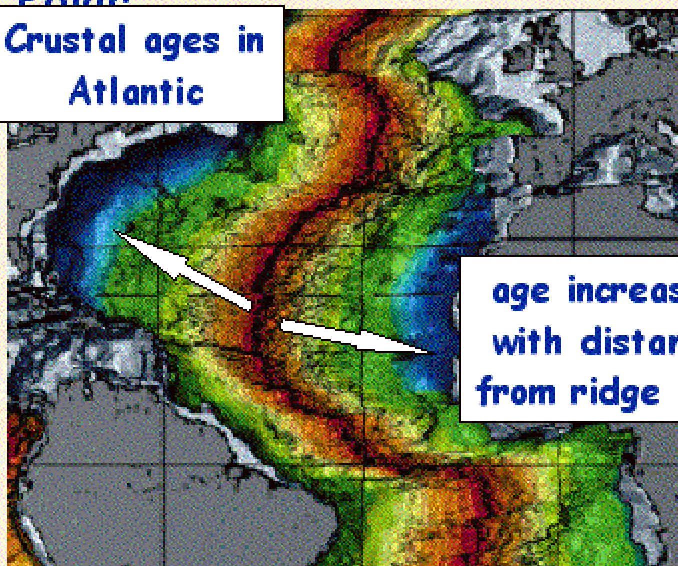
a 'tape recorder'

symmetric



Magnetic Features:

- Magnetic reversals
  - orientation of Earth's magnetic field has changed irregularly over time
- Polar



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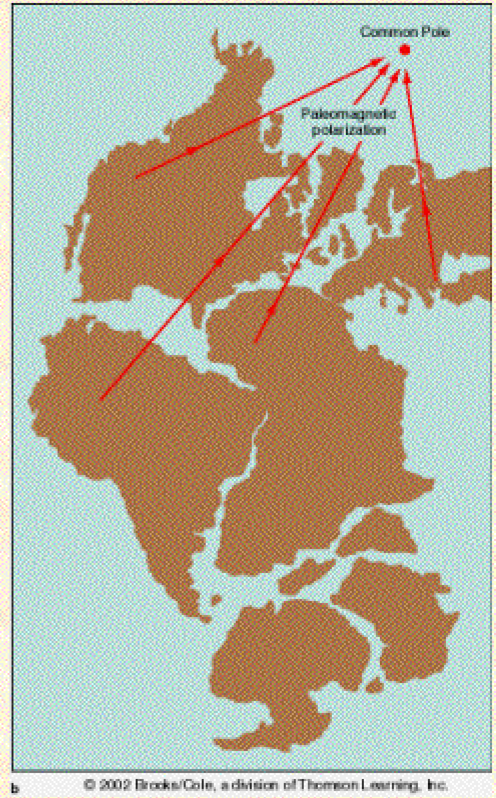
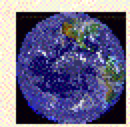


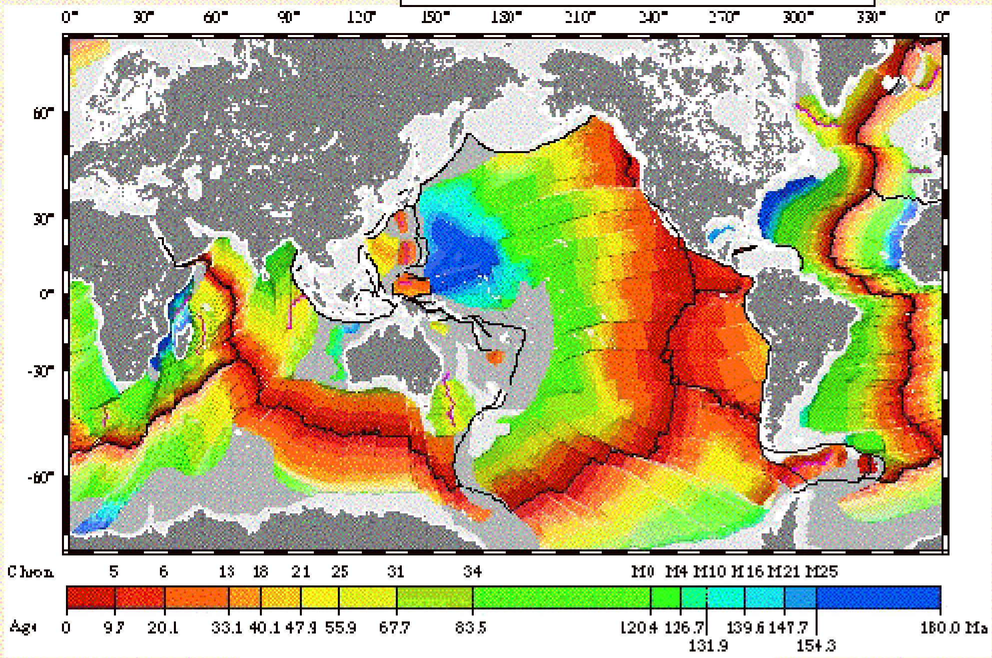
magnetic field



Ages of Ocean Crust:

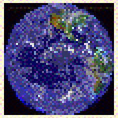
age increases with
distance from ridge axis

- Youngest crust at mid-ocean ridges
- Oldest crust in Western Pacific
- Crust ages away from ridge
- Supports idea of seafloor spreading

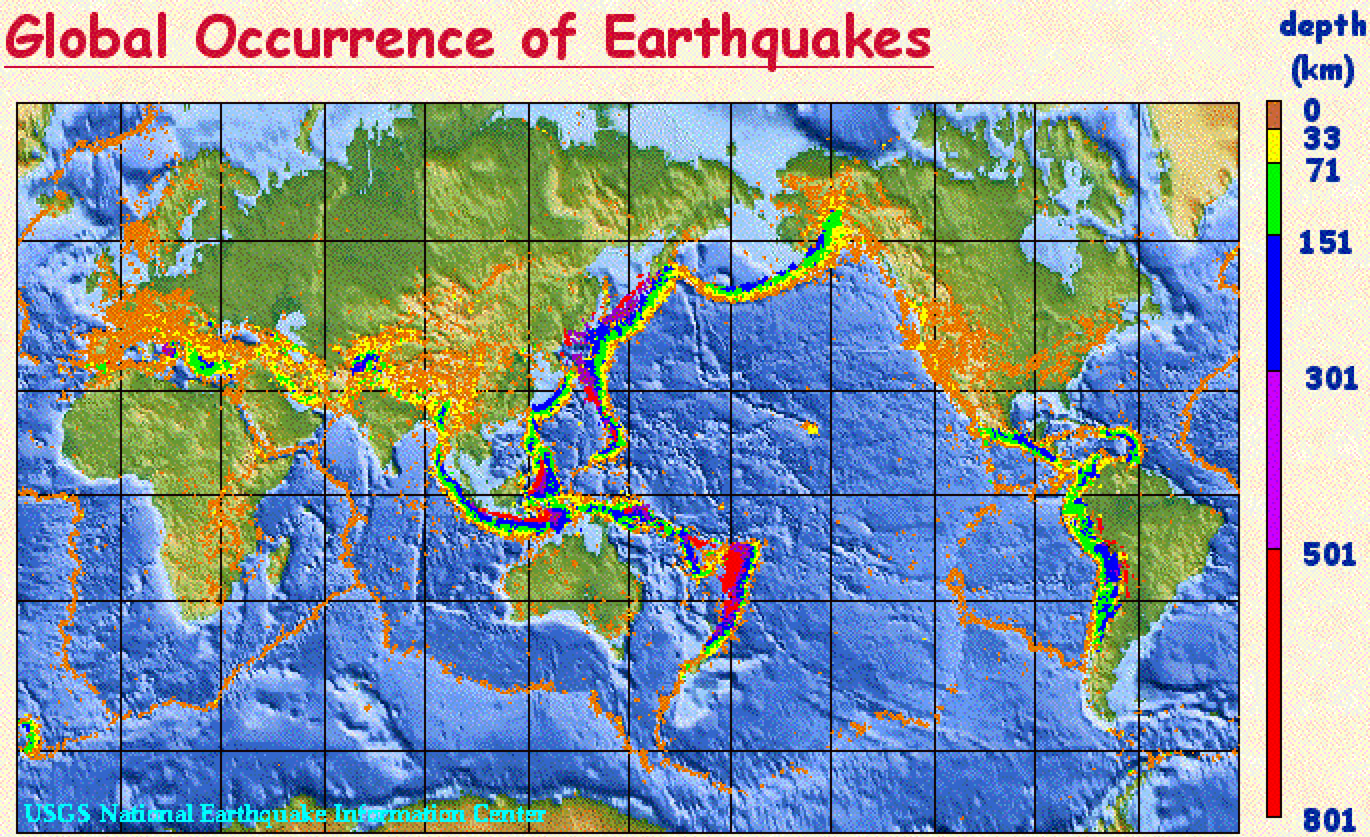


younger older

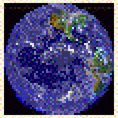
timescale of crustal ages



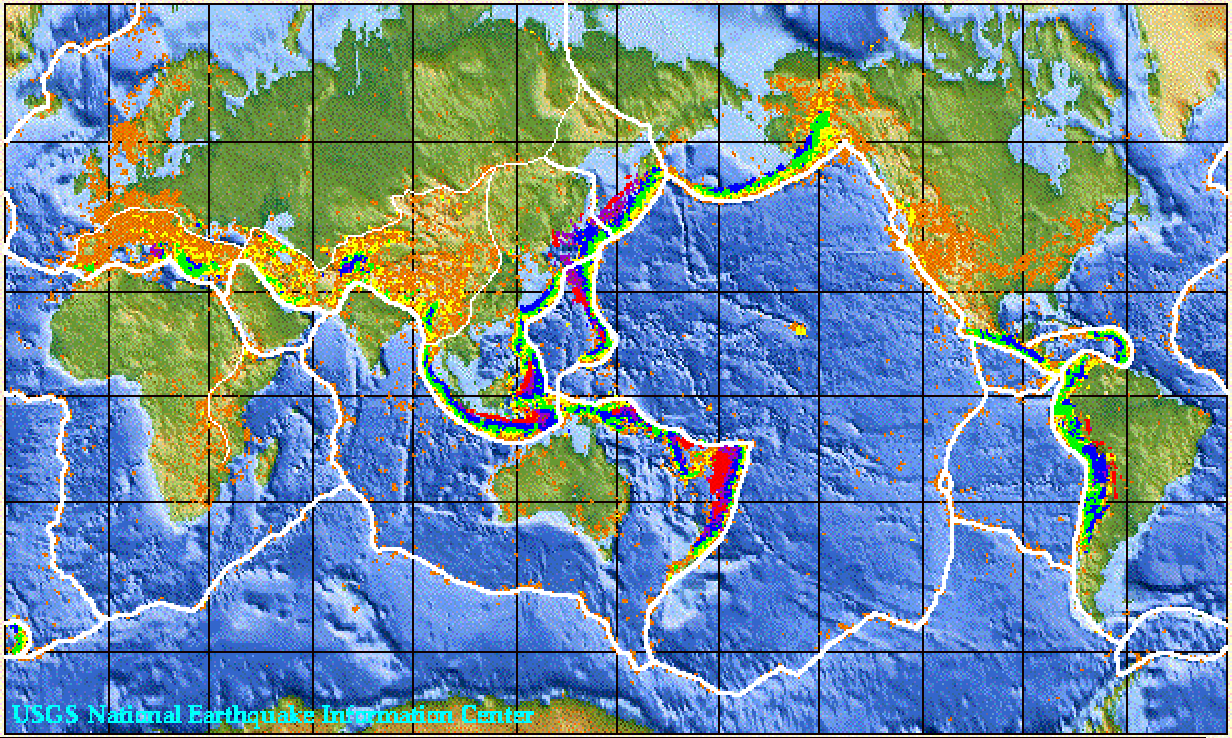
Global Occurrence of Earthquakes

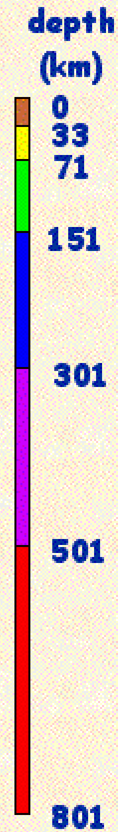


Earthquakes occur in specific regions, often in linear belts

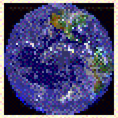


Occurrence of Earthquakes





Earthquakes divide the earth into distinct regions, or plates



Global Configuration of Crustal Plates:

- a mosaic of plates defined by earthquake activity
- either oceanic crust, or oceanic & continental crust

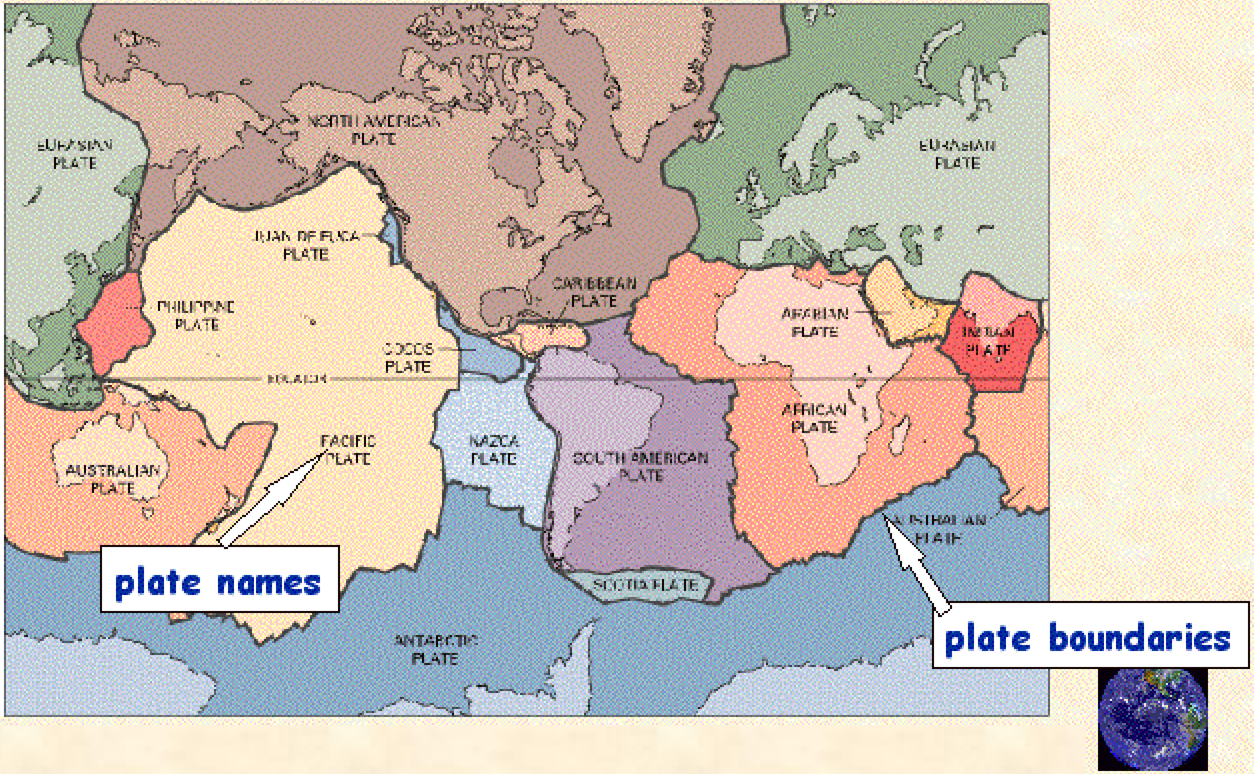
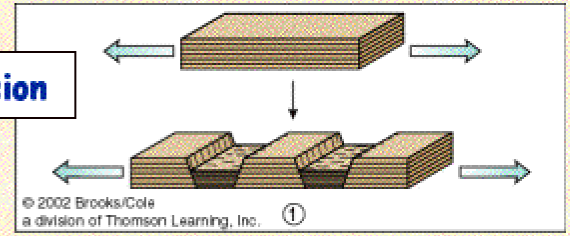
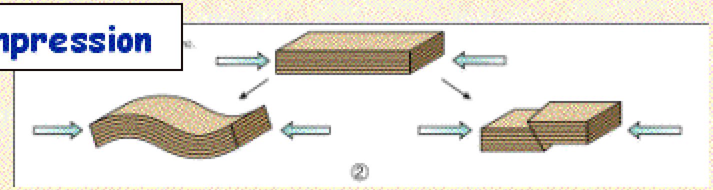


Plate Boundaries — 3 Types:

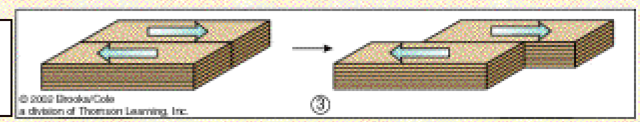
- Divergent



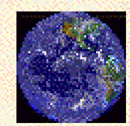
  - extensional, stretching, spreading
  - spreading centers where new crust is formed, generating shallow earthquakes
  - mid-ocean ridges, e.g. Mid-Atlantic Ridge, E. Pacific Rise
- Convergent



  - compression, collision
  - ocean crust is subducted, generating deep earthquakes
  - form trenches, mountain belts (e.g. Aleutians, W. coast S. America, Tibet)
- Transform

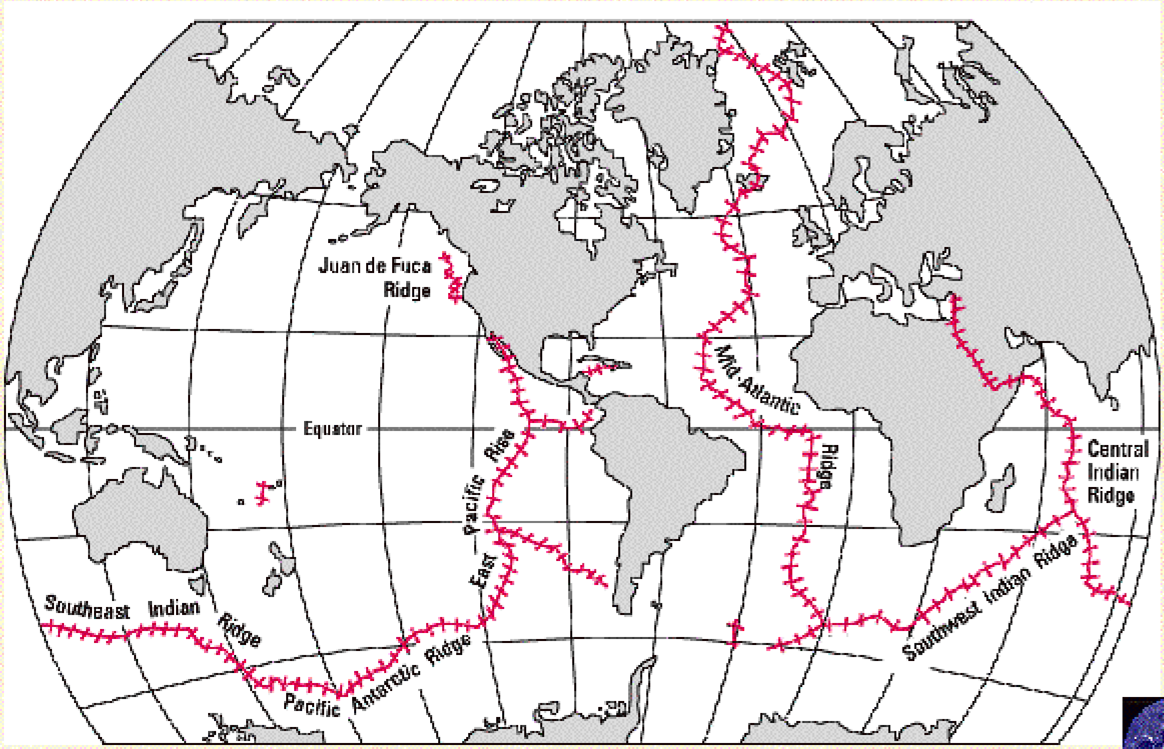


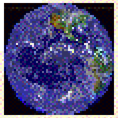
  - sliding, shearing
  - offset mid-ocean ridges, form fracture zones (e.g. Mendocino FZ, San Andreas)



Mid-Ocean Ridges:

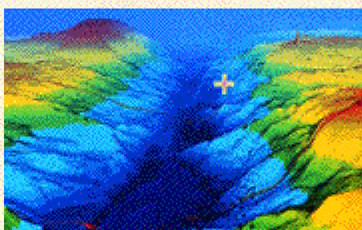
- Divergent, spreading centers where new crust forms





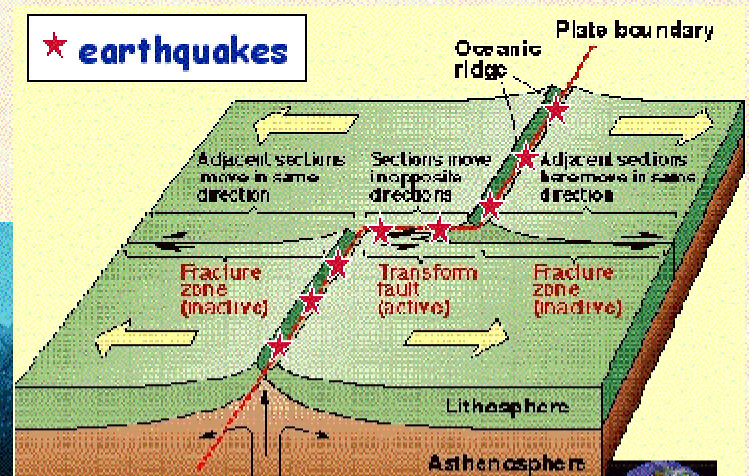
Anatomy of a Mid-Ocean Ridge:

- divergent boundaries, spreading centers, central rift
  - initially block faulting to create grabens (East Africa)
  - widen, deepen, pillow lavas erupt, seawater enters (Red Sea)
  - thin lithosphere, new ocean crust forms as layered sequence
- ocean/ocean transform faults
  - fracture zones offset mid-ocean ridges



central rift

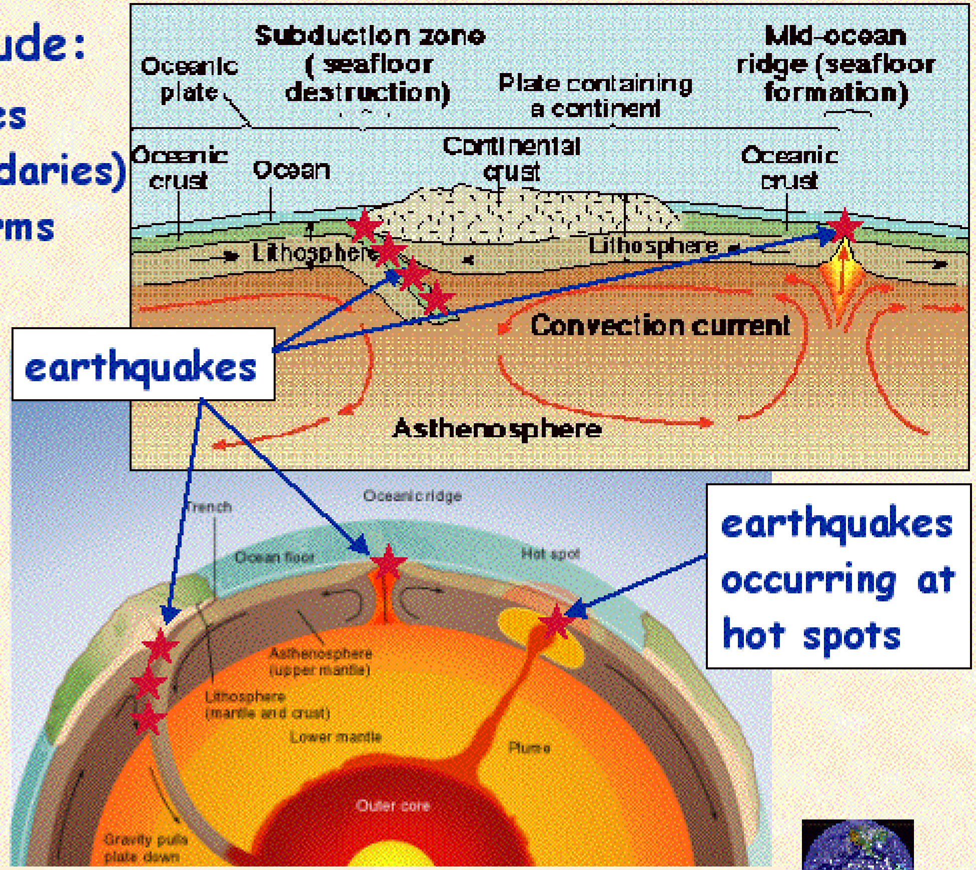
pillow lava

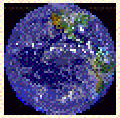


layered sequence in lithosphere

Plate Tectonics and Plate Boundaries:

- Boundaries include:
  - mid-ocean ridges (divergent boundaries) where crust forms
  - trenches (convergent boundaries) where crust is consumed
  - earthquakes occur along these boundaries

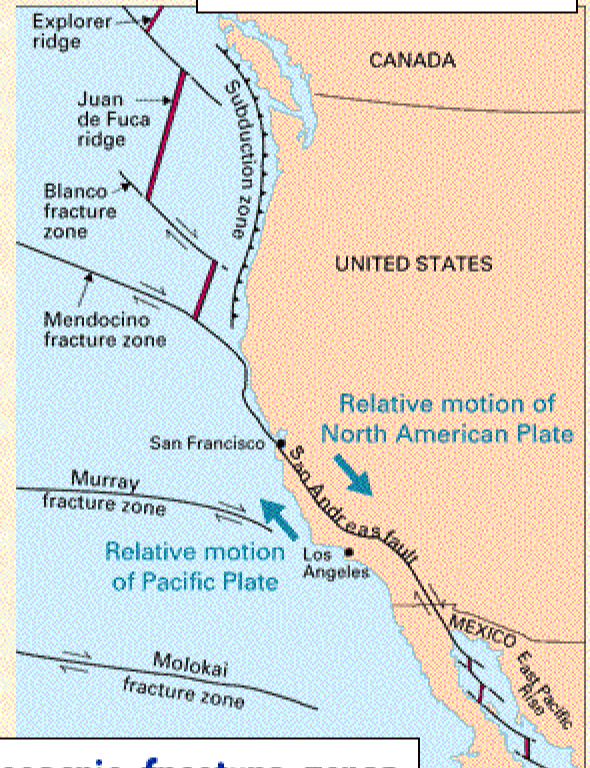




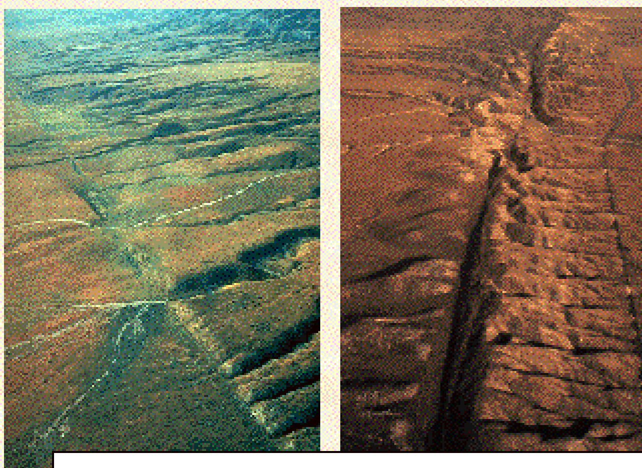
Transform Plate Boundaries:

- ocean/ocean fracture zones
  - Mendocino, Murray
  - accommodate spreading on the surface of a sphere
- continent/continent
  - San Andreas fault system

U.S. West coast



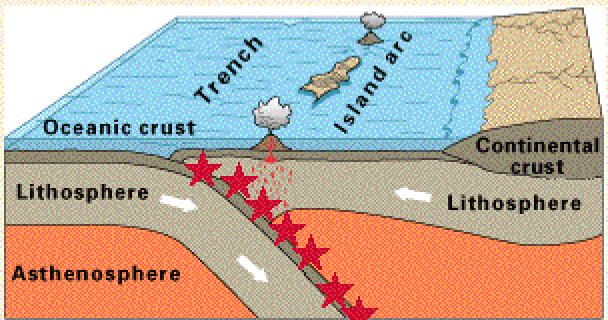
oceanic fracture zones

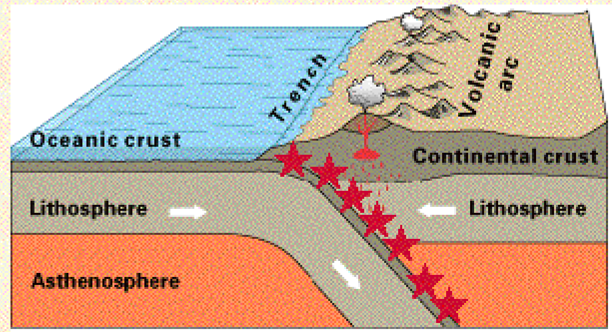


San Andreas fault: a scar on the landscape

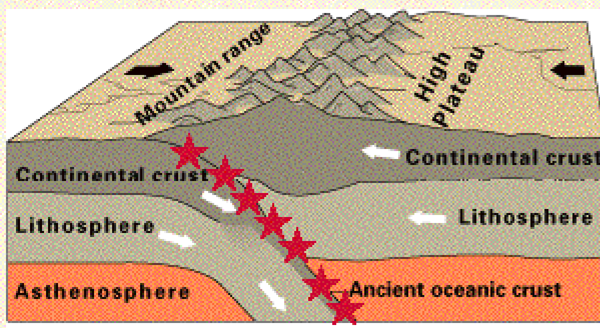
Convergent Plate Boundaries: Cross Sections

- Types: ocean/ocean,ocean/continent,continent/continent





ocean/ocean
island arcs
e.g.
Aleutians,
Japan



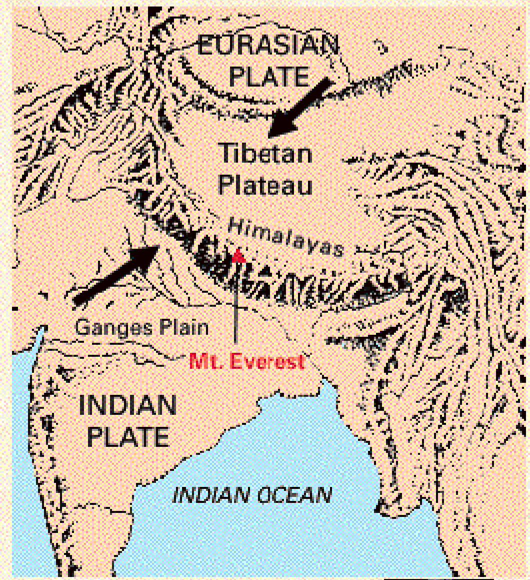
ocean/continent
volcanic arcs
e.g. Andes,
Cascades

continent/continent
e.g. Himalayas

Convergent Boundaries: Continental Collision

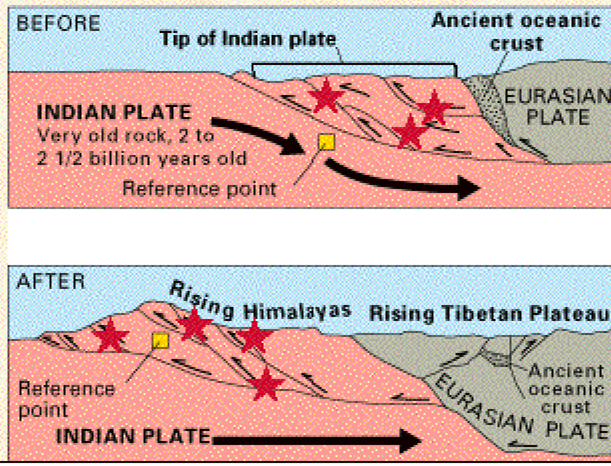
- continent/continent convergence
- example: collision of Eurasian and Indian plates
- crustal crumpling leads to mountain building
  - Himalayas and Tibetan plateau, elevated highlands

Mt. Everest: summit is composed of marine rocks

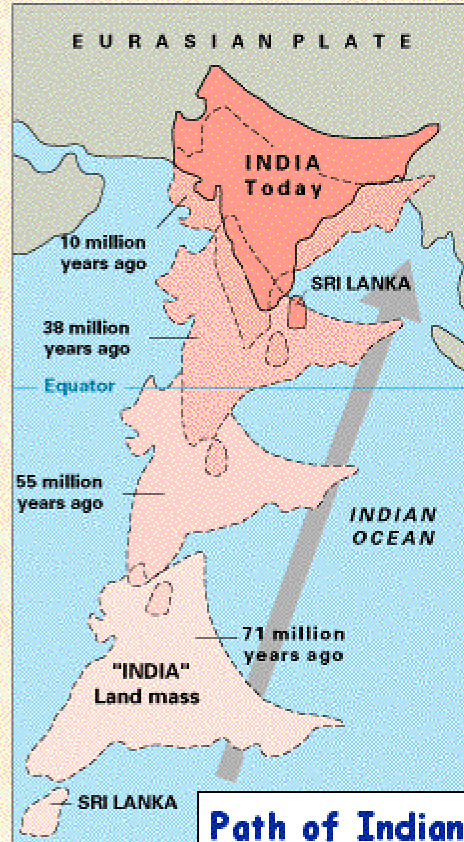


Convergent Plate Boundaries:

- collision of Eurasian/Indian plates
- ocean closure (Tethys)
- building of Himalayas



continental collision: thrusting, buckling & thickening of crust with earthquakes wherever movement occurs



Path of Indian subcontinent

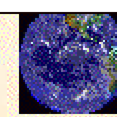
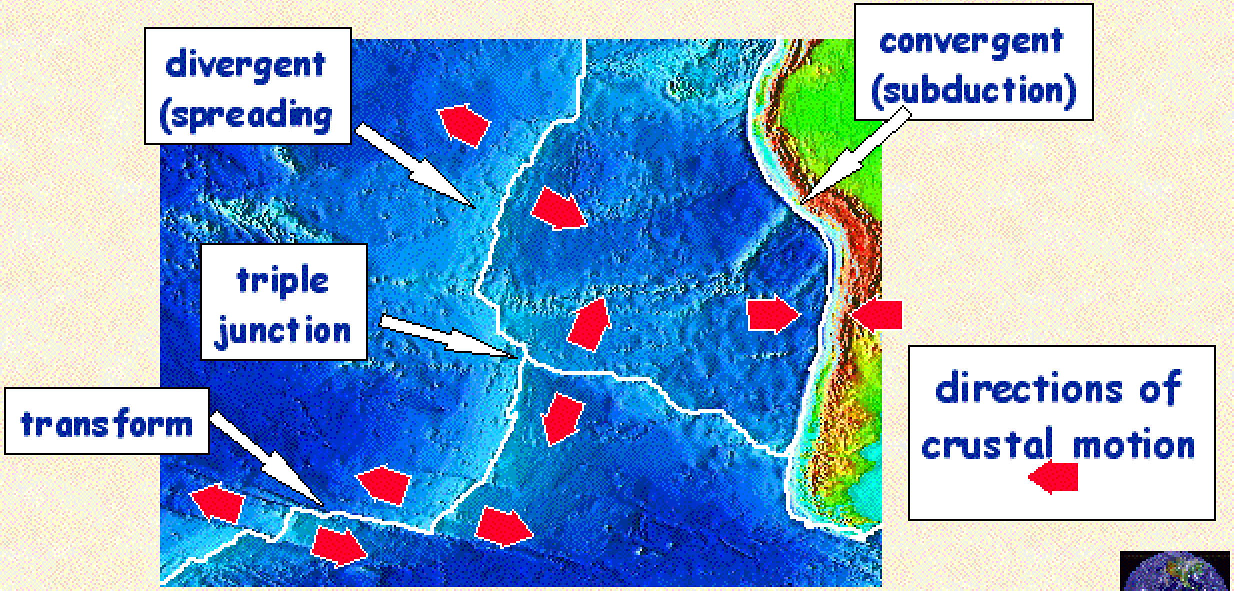


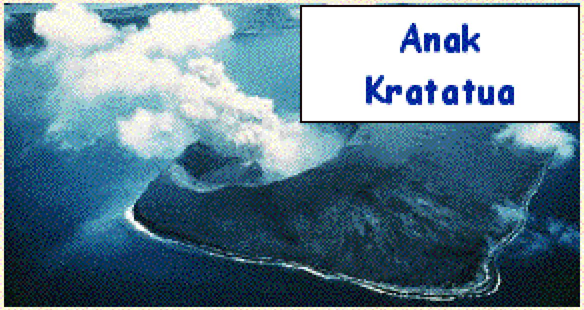
Plate Boundaries — 3 Types:

- divergent, convergent and transform
- linear boundaries of spreading, colliding, sliding
- triple junctions where 3 plates meet



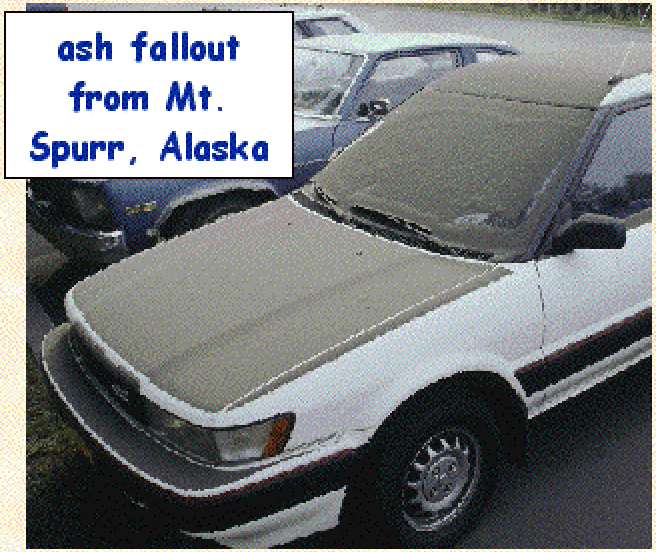
Volcanism

- Three principal settings
  - island arcs and volcanic arcs
    - violent ash eruptions linked to subduction of oceanic crust forms steep-sided volcanoes
  - mid-ocean ridges:
    - underwater activity forms pillow lavas
  - hot spots:
    - build gentle-sloped shield volcanoes

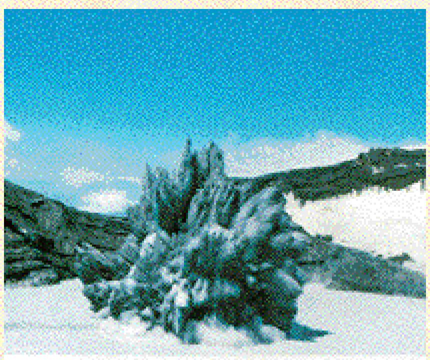


Arc Volcanoes — I:

- Steep-sided cone-shaped andesite volcanoes
  - Often violent, explosive eruptions of volcanic ash
  - Ash plumes may reach upper atmosphere, affecting local and global climate
  - Form craters after eruptions



ash fallout from Mt. Spurr, Alaska



Ruapehu, N.Z.

Arc Volcanoes — II:

- Ocean/ocean convergence: island arc volcanism
  - Tambora (1815), Krakatua (1883), Pinatubo (1991), Ruapehu (1996), Bezymianny (1997)

- Ocean/continent convergence: volcanic arc volcanism
  - Mt. Mazama (6600 b.p.), now Crater Lake, OR
  - Mt. St. Helens (1980)

Pacific Ocean: Ring of Fire

- Combination of active volcanoes & deep sea trenches

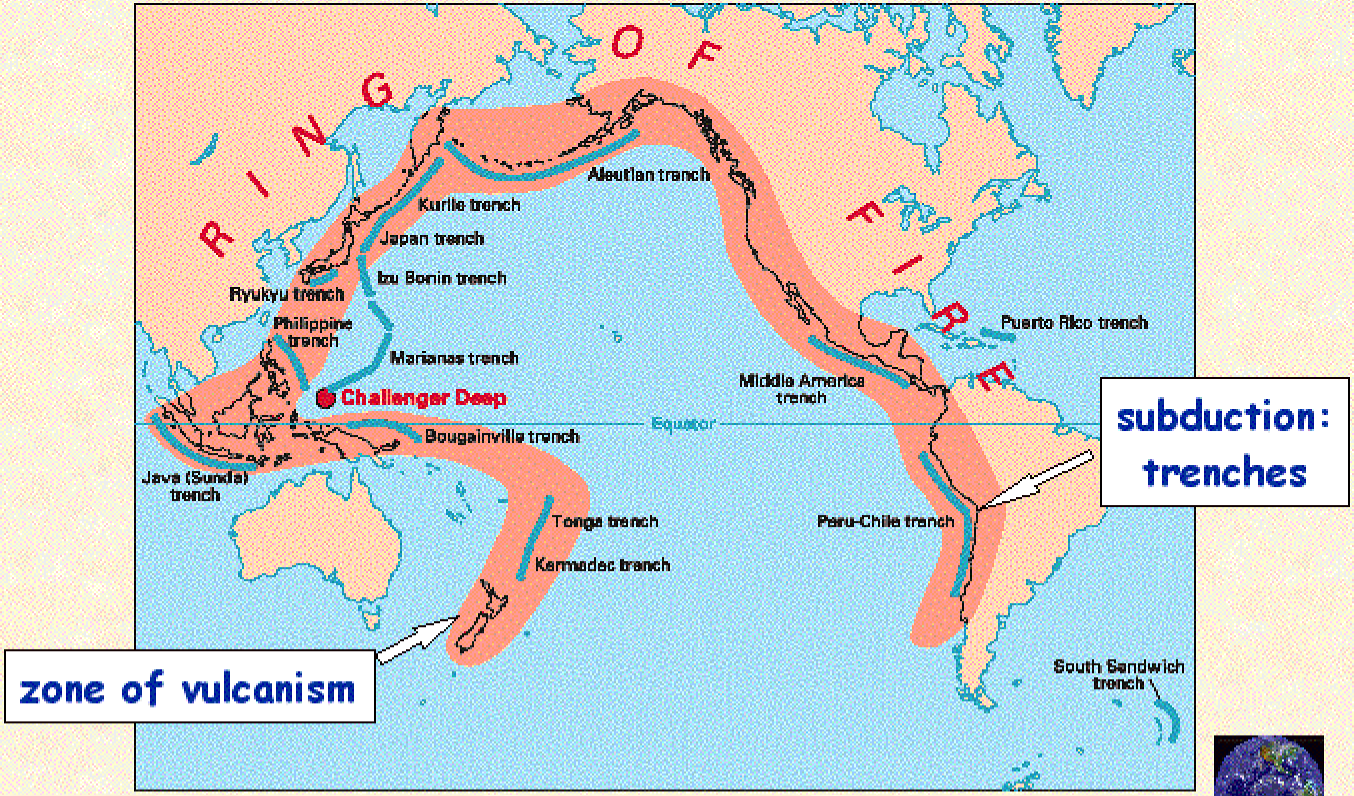
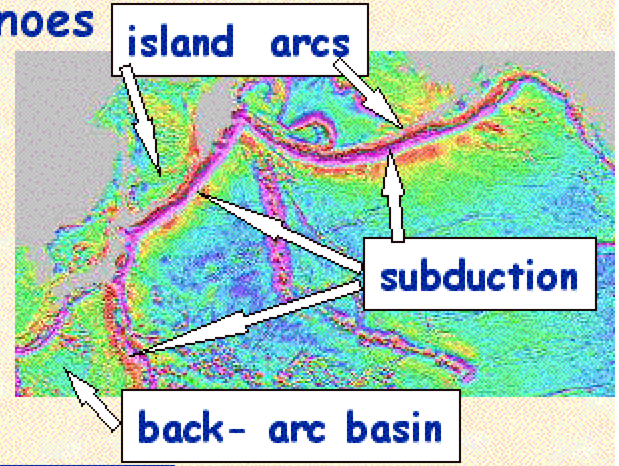
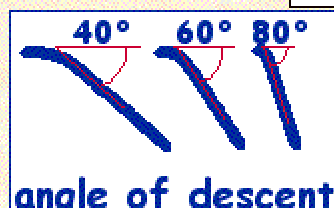
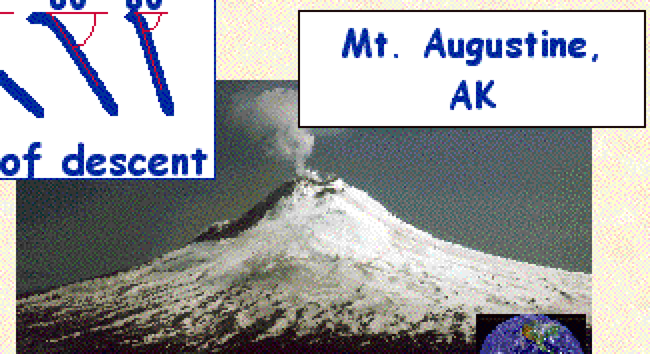


Plate Boundaries: Active Continental Margins

- Sites of earthquakes and volcanoes
- Convergent, Pacific-type
  - subduction of oceanic crust
  - volcanism in island and volcanic arcs
  - back-arc basins:
    - crust formed by spreading behind subduction zone
  - angle of subduction:
    - Shallow: young, hot
    - Steep: old, cold
- Continental Collision
  - crustal folding, thrusting, thickening (e.g. Himalayas)
  - accretion of exotic terranes

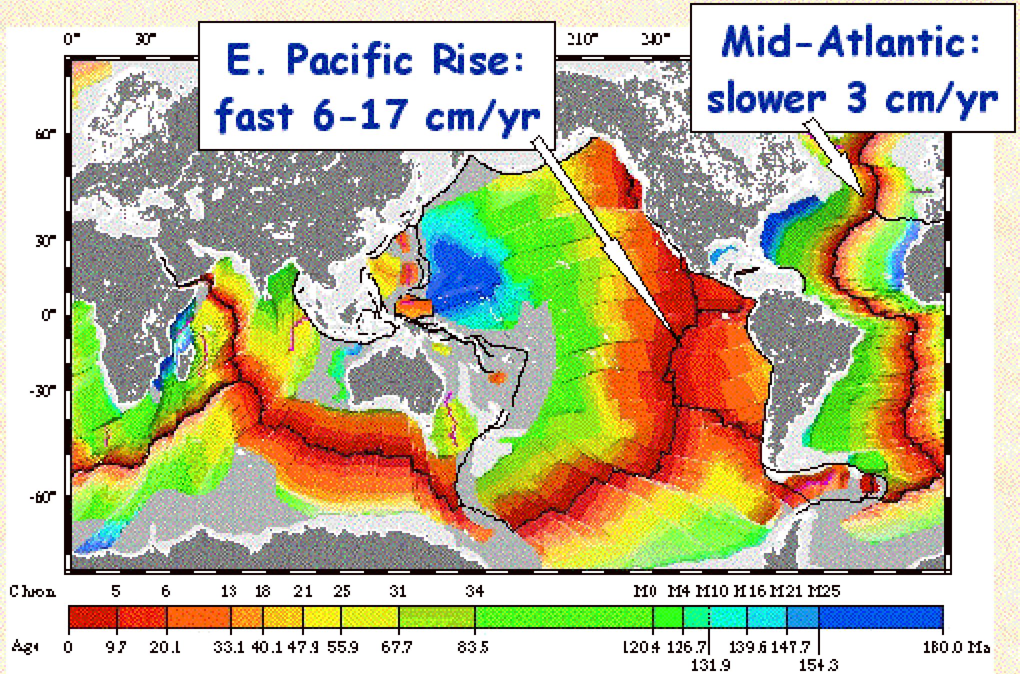






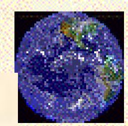
Ages and Spreading Rates of Ocean Crust:

- Youngest crust at mid-ocean ridges
- Oldest crust in Western Pacific
- Crust ages away from ridge
- Rates vary (1 -17 cm/yr)



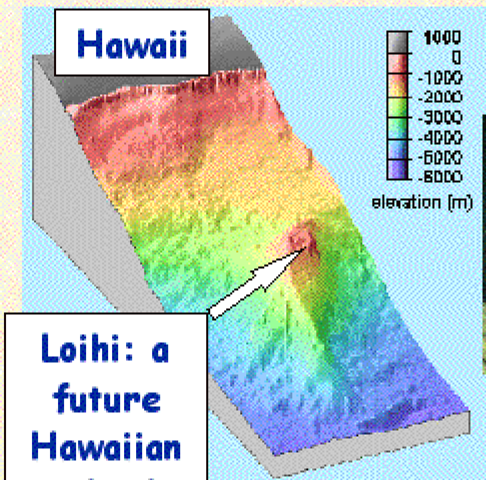
younger older

timescale of crustal ages



Volcanoes — Hot Spots:

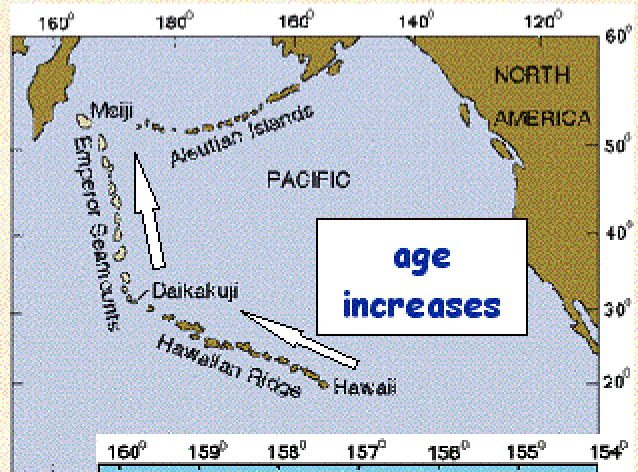
- Formation of Hawaiian islands
  - age increases to northwest
  - eroded as they age
  - new island of Loihi



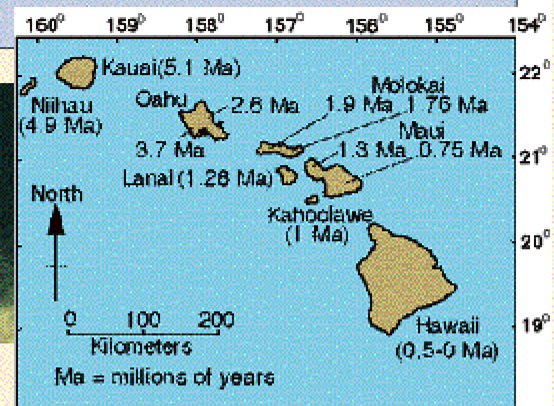
Hawaii

Loihi: a future Hawaiian island

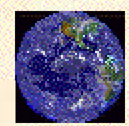
pillow lava from Loihi



age increases

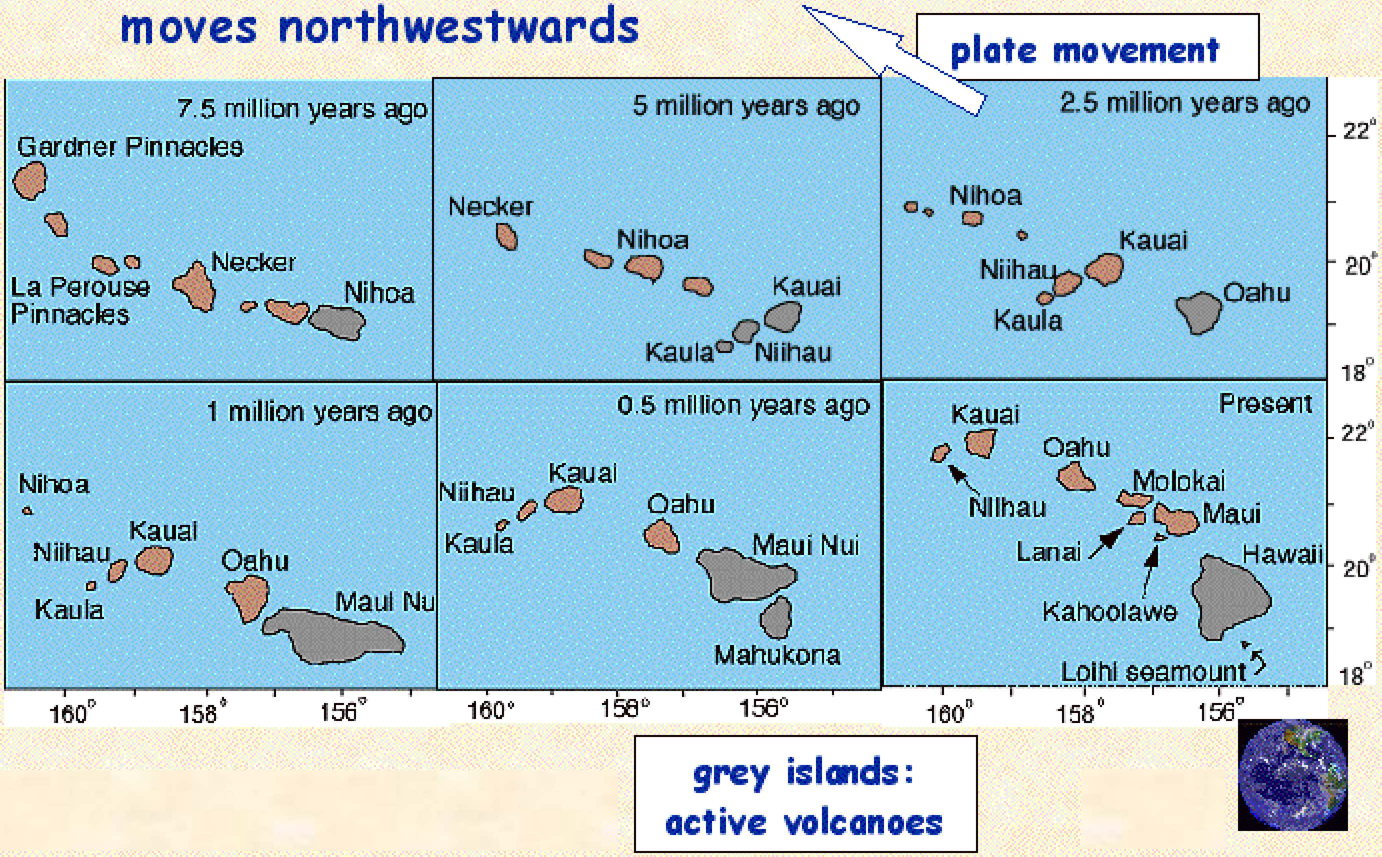


Hawaiian islands



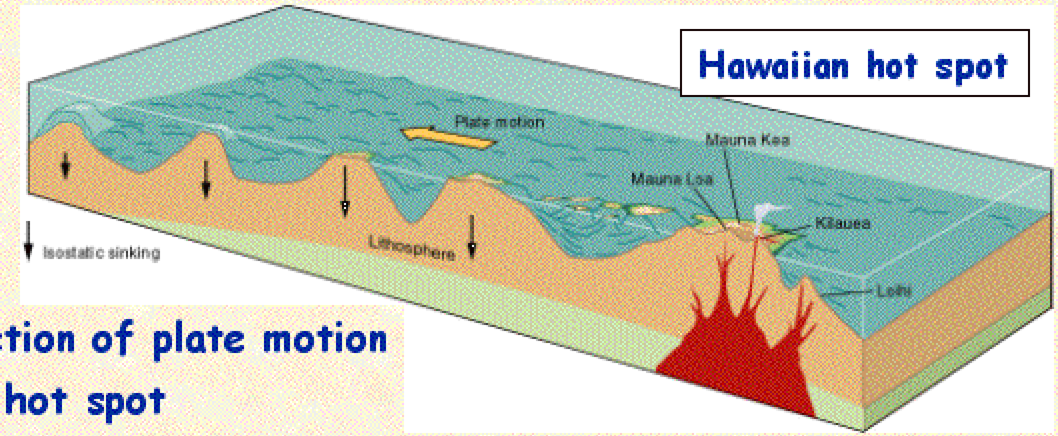
Evolution of the Hawaiian Islands:

- Sequence of formation and erosion as Pacific plate moves northwestwards



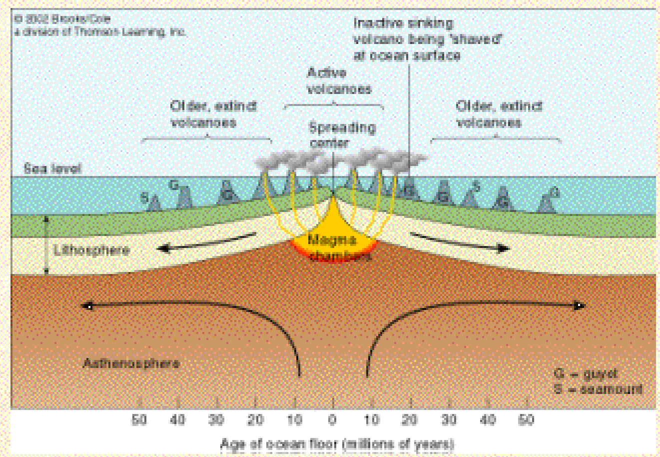
Hot Spots:

- Form island chains
  - increase in age in direction of plate motion
  - active over hot spot
  - older islands inactive



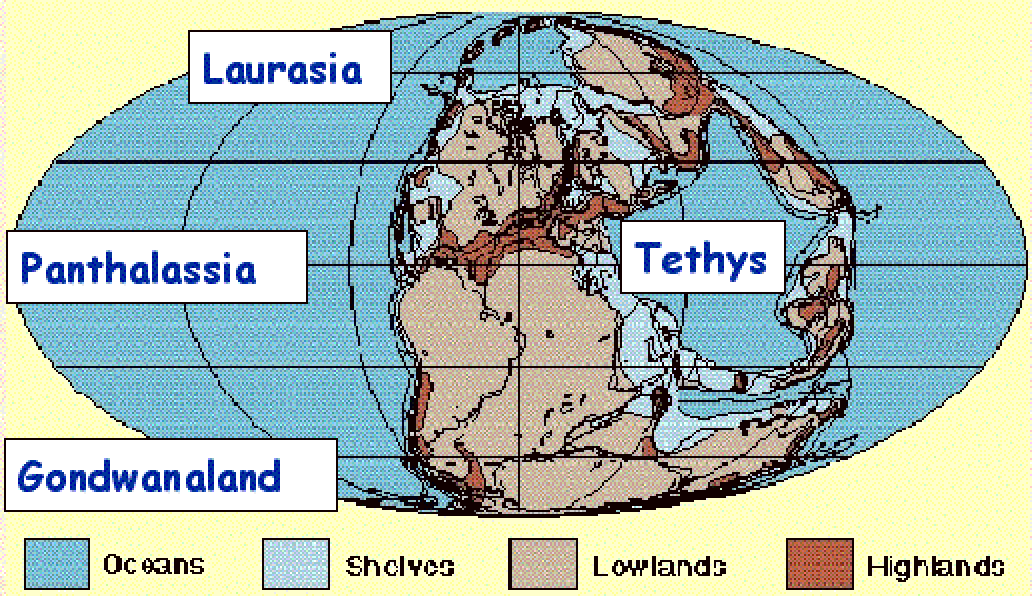
Seamounts:

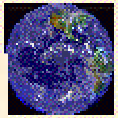
- Chains of remnant volcanoes
  - Wave erosion forms flat-topped guyots
  - Or, transverse ridge may be formed



History of the Ocean Basins: 255Ma (Permian)

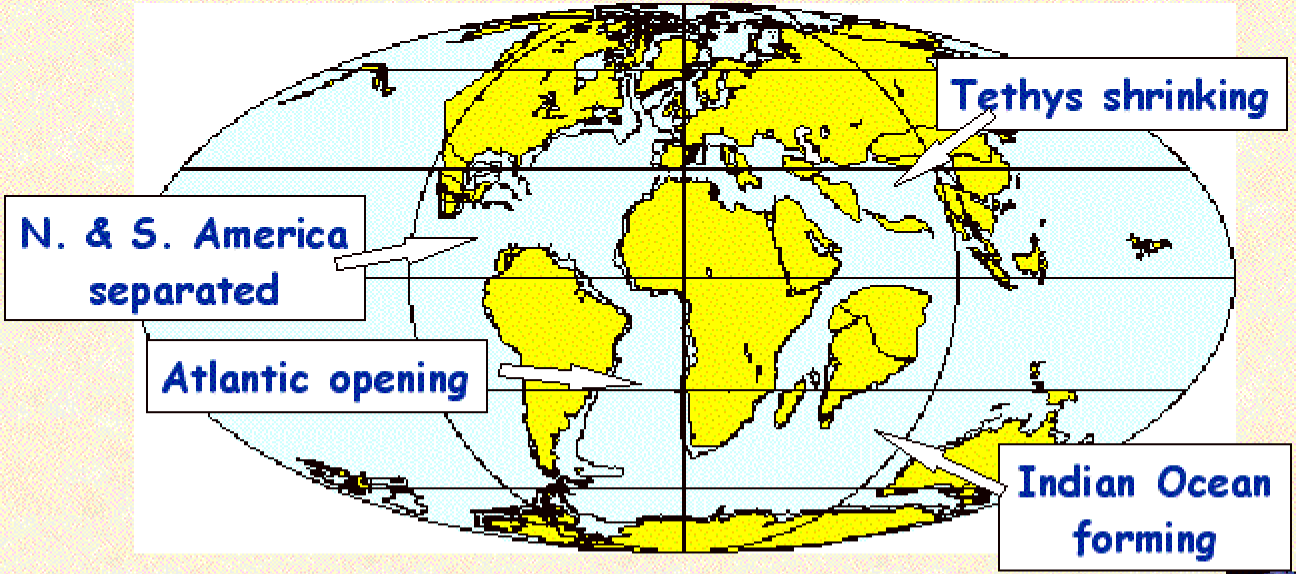
- Supercontinent (Pangaea)
- Superocean (Panthalassia)
  - Tethys embayment separates Gondwanaland and Laurasia





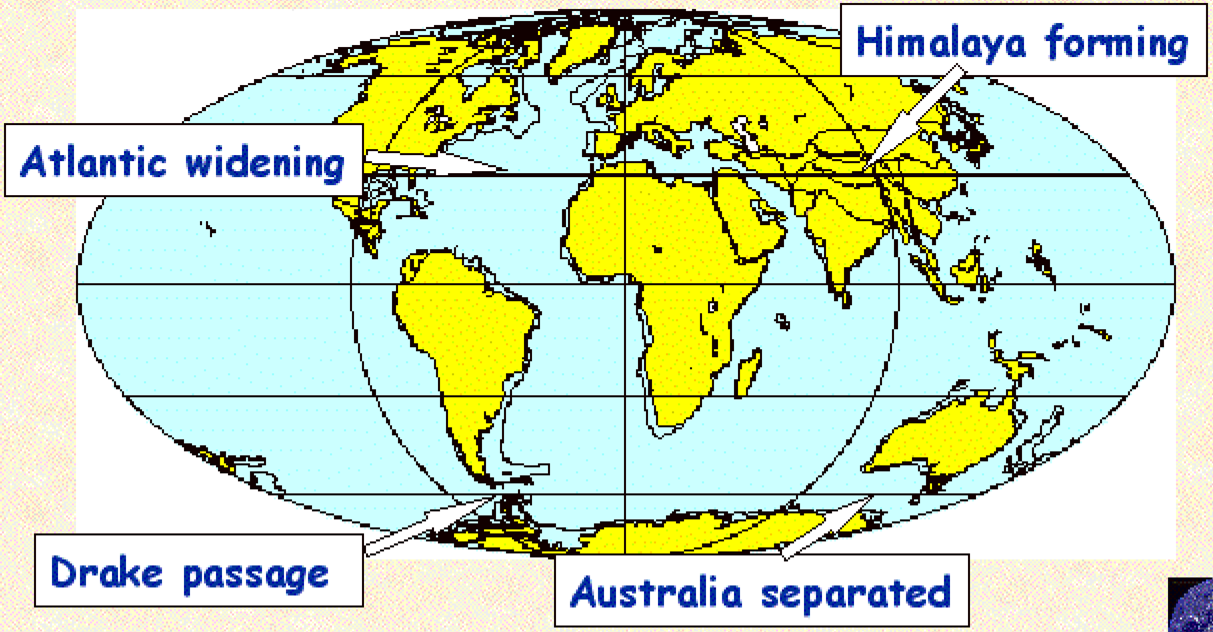
History of the Ocean Basins: 70Ma (Cretaceous)

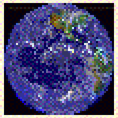
- Supercontinent Pangaea fragmented
  - Atlantic Ocean opens and spreads, Indian Ocean forming
  - India separates from Antarctica and Africa



History of the Ocean Basins: 30Ma (Oligocene)

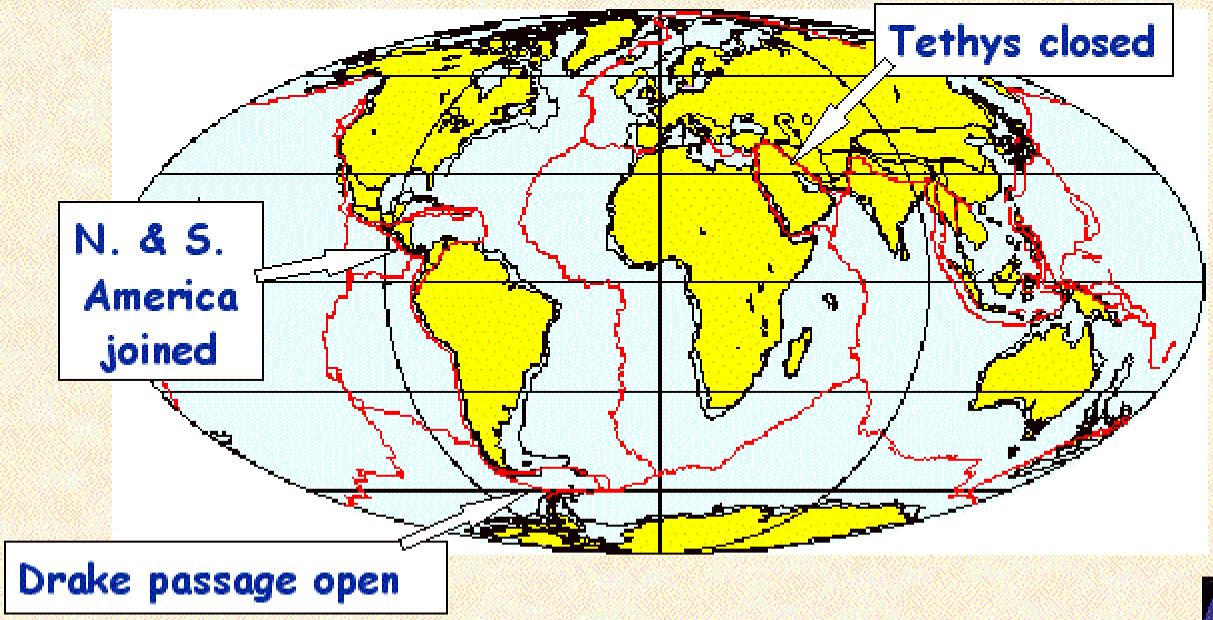
- Continued fragmentation of Pangaea
  - Atlantic widens, India collides with Asia
  - Australia separates from Antarctica

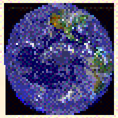




History of the Ocean Basins: Present Day

- Fragmentation of Pangaea complete, Asia formed
  - Atlantic continues to widen, Tethys closed
  - Americas joined, Antarctica isolated

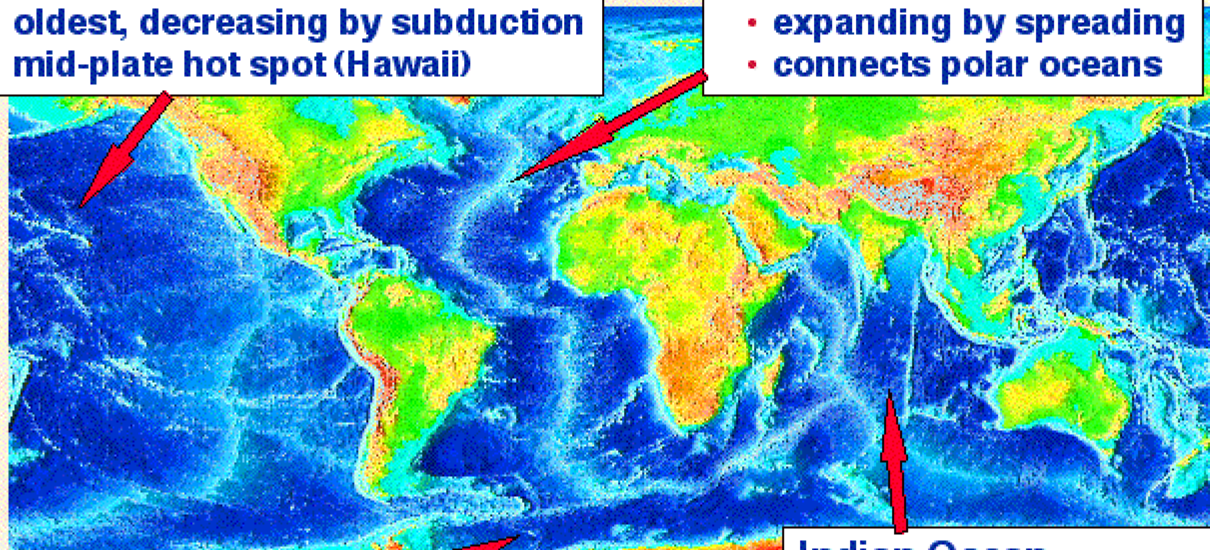




Formation/Destruction of Ocean Basins

Pacific Ocean
- oldest, decreasing by subduction
- mid-plate hot spot (Hawaii)

Atlantic Ocean
- expanding by spreading
- connects polar oceans



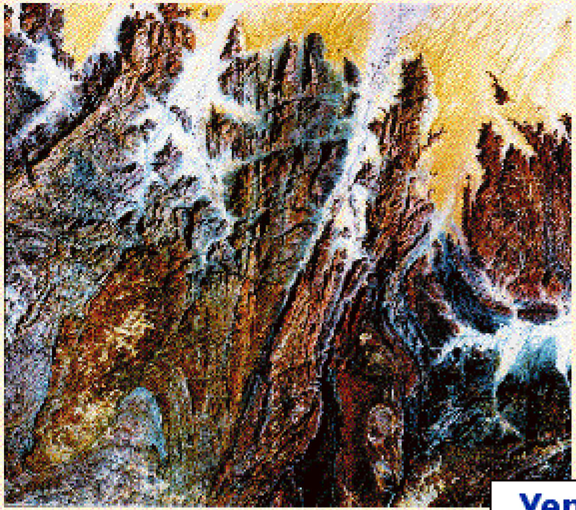
Southern Ocean
- youngest, from Gondwanaland break-up
- formed as Australia moved north (~50Ma)
- completed as Drake passage opened (~20Ma)

Indian Ocean
- young, formed by Gondwanaland break-up

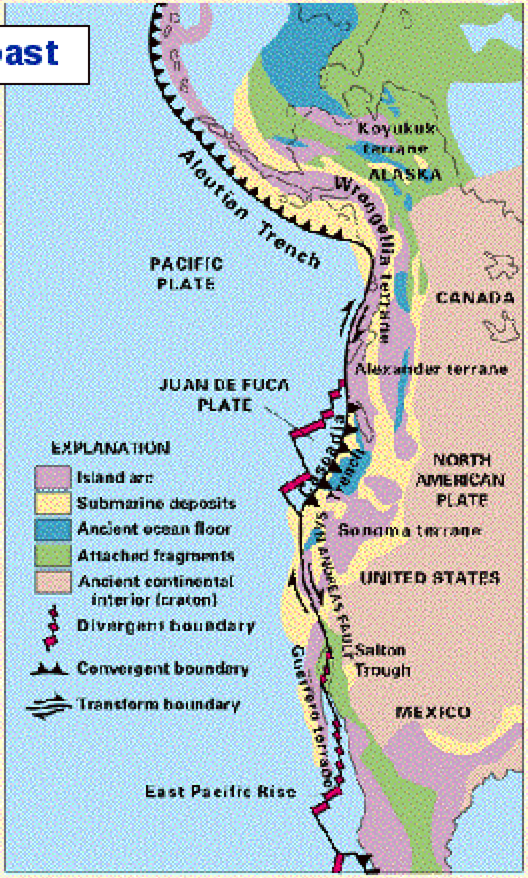
Terranes

- Fragments added by subduction
  - island arcs, submarine deposits, ancient ocean floor
- Recognized from geology and by satellite imagery

W. coast

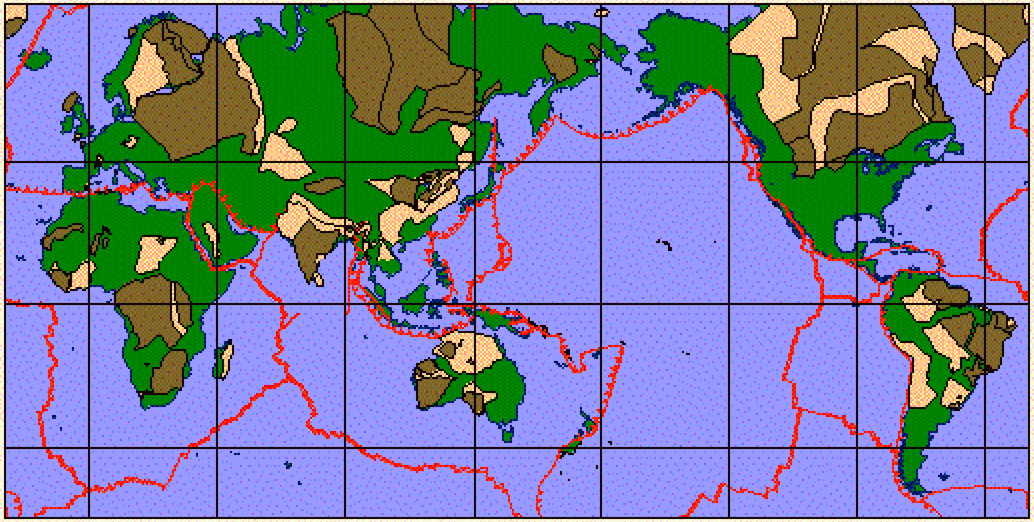


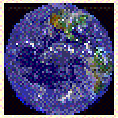
Yemen



Formation of Continents

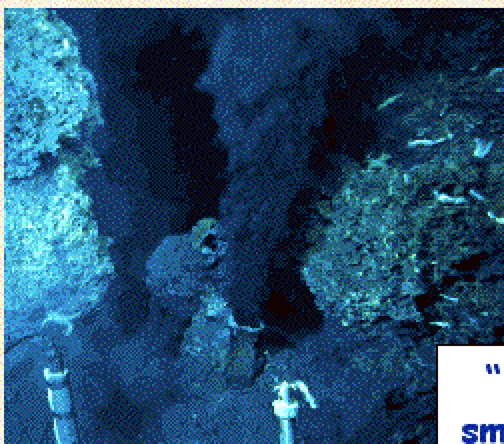
- A progressive building of continental landmasses
  - cratons (brown: most ancient & yellow: younger)
  - terranes (green, various ages) added during subduction

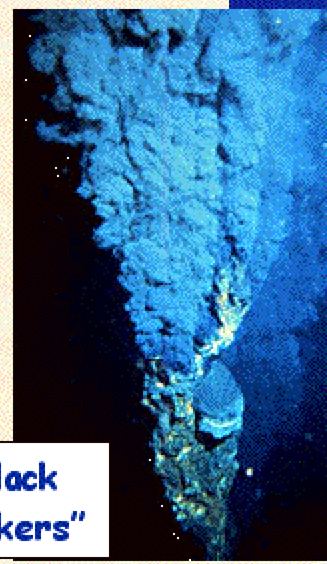




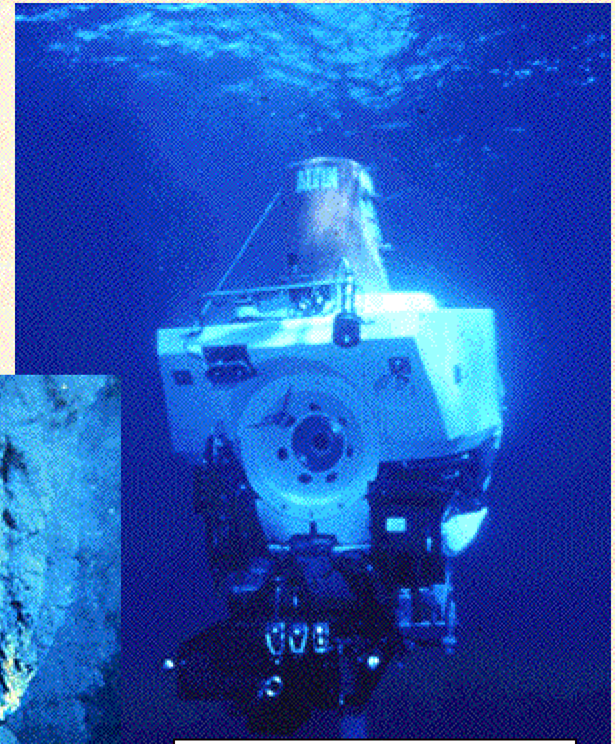
Hydrothermal Vents — I:

- Discovered by submersibles
- Submarine vents, fissures
  - 'black smokers' (300-400°C)
    - metal sulfides
    - gases (e.g. CH_4)





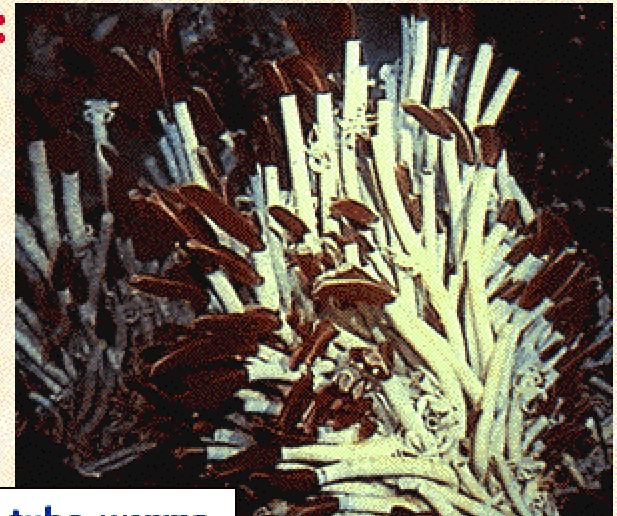
"black smokers"



Submersible: Alvin

Hydrothermal Vents — II:

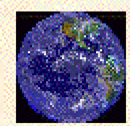
- Mid-ocean ridges
  - fluids expelled at vents
  - communities of organisms



tube worms

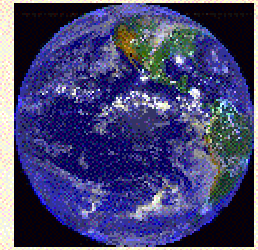
giant clams

- vent fluids contain metals, sulfur that provide energy source for chemosynthetic bacteria
- bacteria support clams, worms, crabs, etc.



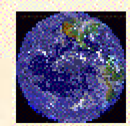
Oceans & Our Global Environment

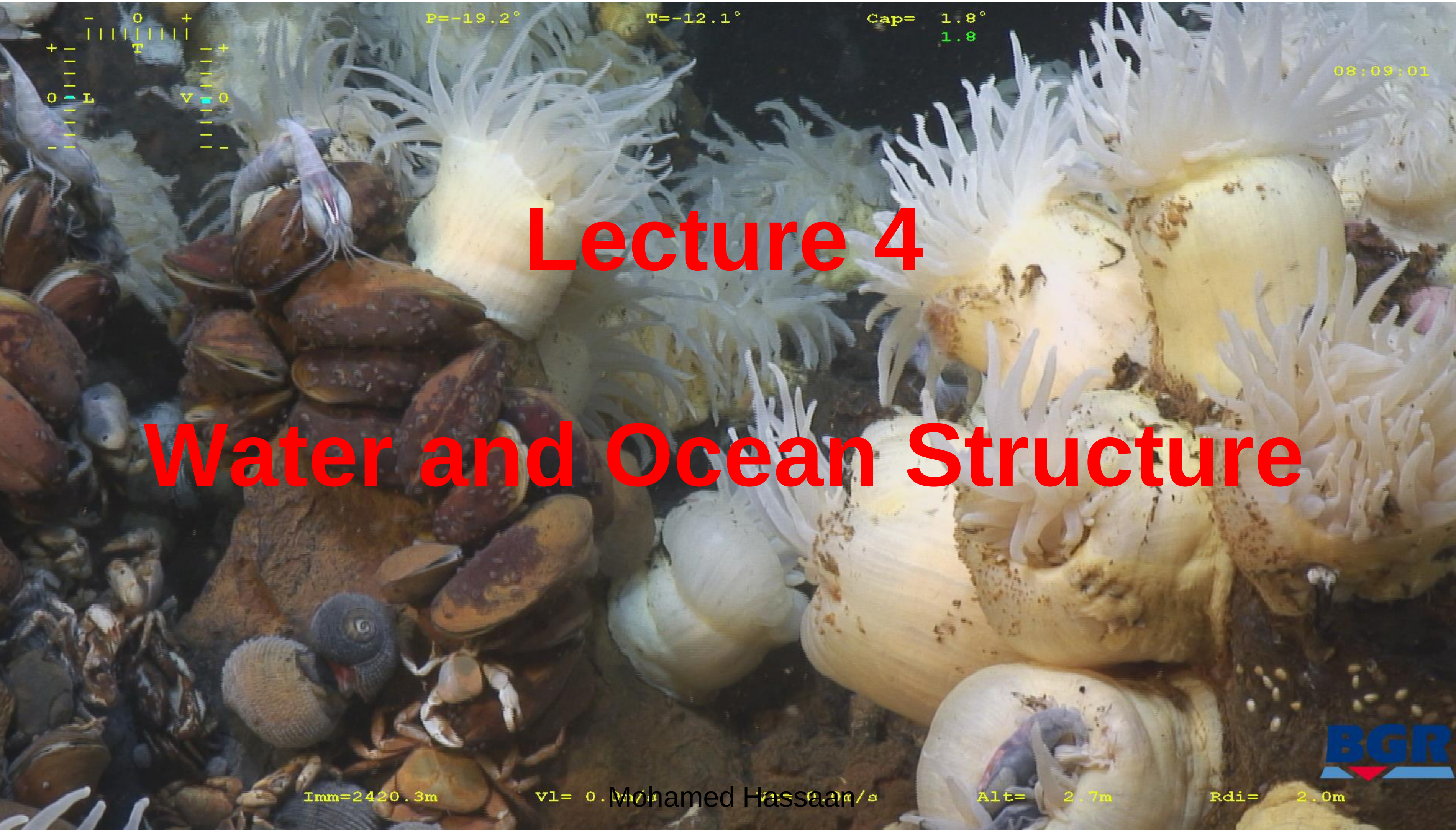
Plate Tectonics



Key Concepts:

- Internal Structure of the Earth
- Plate Tectonic Characteristics and Processes
  - processes of rifting, collision and subduction
  - mechanisms & rates of plate motion, hot spots
  - active & passive continental margins, hydrothermal vents
- History of Ocean Basins and Continents
  - Pangaea break-up, exotic terranes



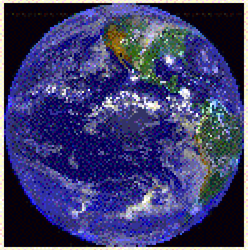


Lecture 4

Water and Ocean Structure

Mohamed Hassaan

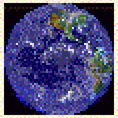
Oceans & Our Global Environment



Water and Ocean Structure

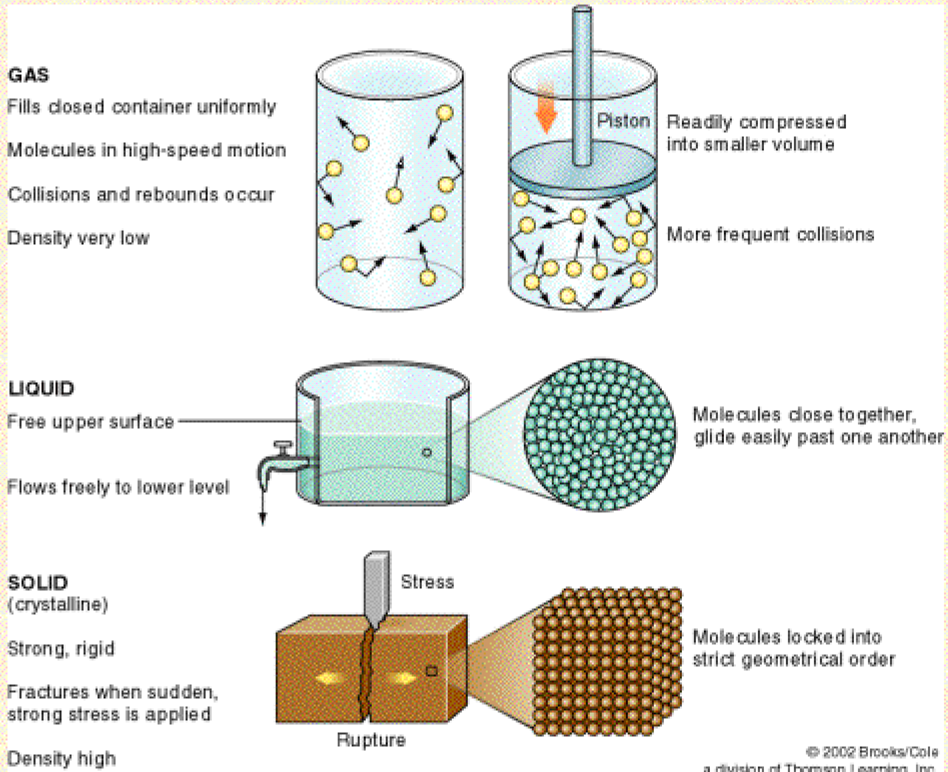
Topics:

- The Water Molecule
  - structure (water and ice), bonds
  - changes of state: heat energy required, calories
- Sea Ice and Icebergs
- Physical Properties of Water
  - heat capacity, cohesion, surface tension, viscosity
  - compressibility, density, dissolving ability
- Energy Transmission
  - conduction, convection, radiation; light, heat, sound



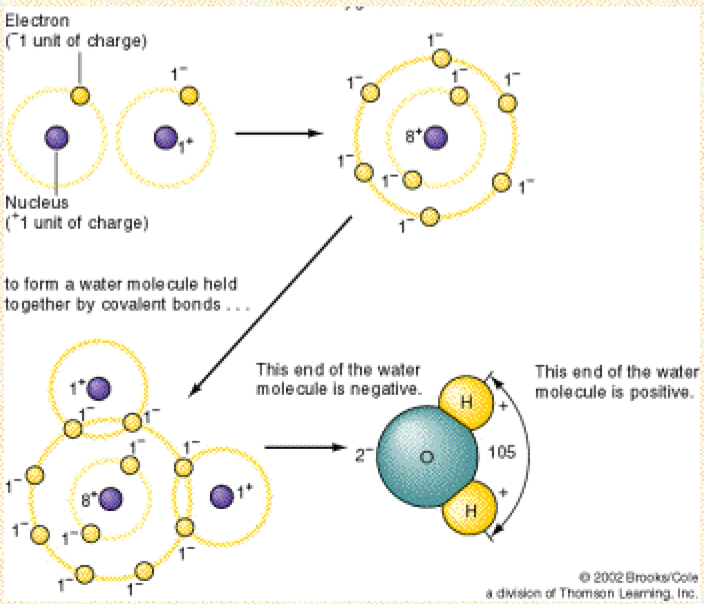
Physical States of Water:

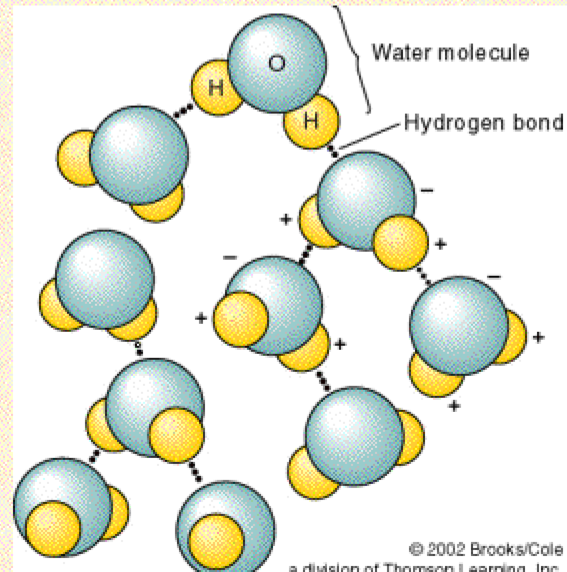
- Gas
  - random molecules
- Liquid
  - molecules close together
- Solid
  - molecules locked into fixed arrangement



Water Molecule:

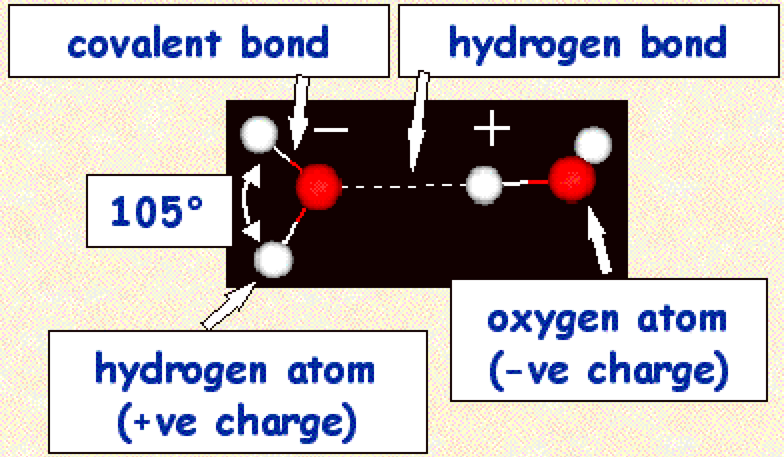
- Hydrogen and oxygen atoms share electrons in strong covalent bond (105° angle)
  - Oxygen atom: negative. Hydrogen atoms: positive
  - Polar, asymmetric, molecules linked by H-bonds (weak)



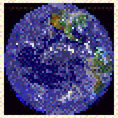


Water Molecule:

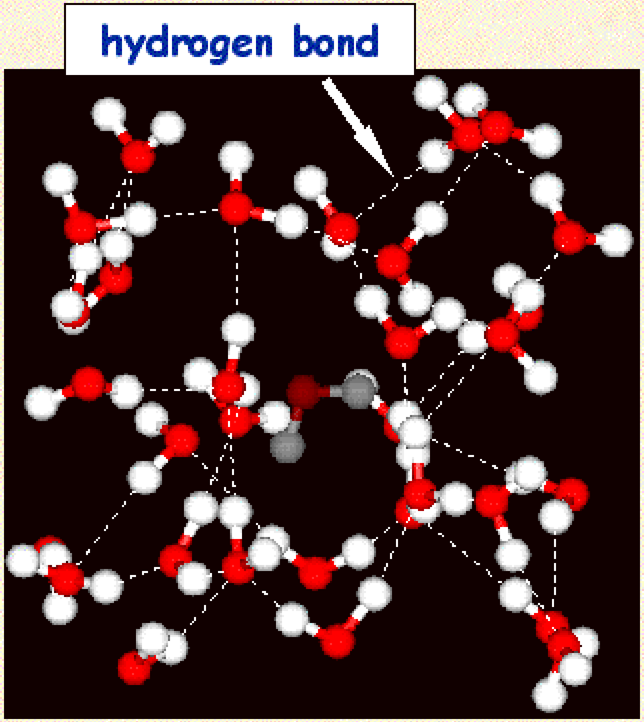
- Chemical Character
  - Strong intramolecular covalent bond between O and H atoms of the same molecule
  - Weak intermolecular H-bonds between O and H atoms of adjacent molecules



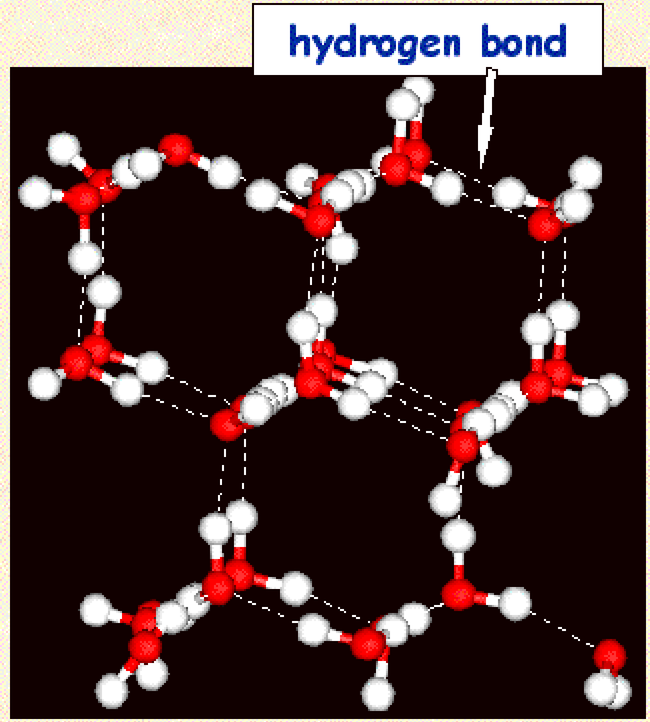
- Many unusual thermal and physical properties
- Other forms of bonds
  - ionic: transfer of electrons (e.g. salt, sodium chloride, NaCl)
  - Van der Waals: electrostatic attraction (e.g. graphite)



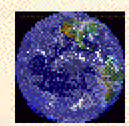
Water and Ice Structures:



water: clusters linked by H-bonds

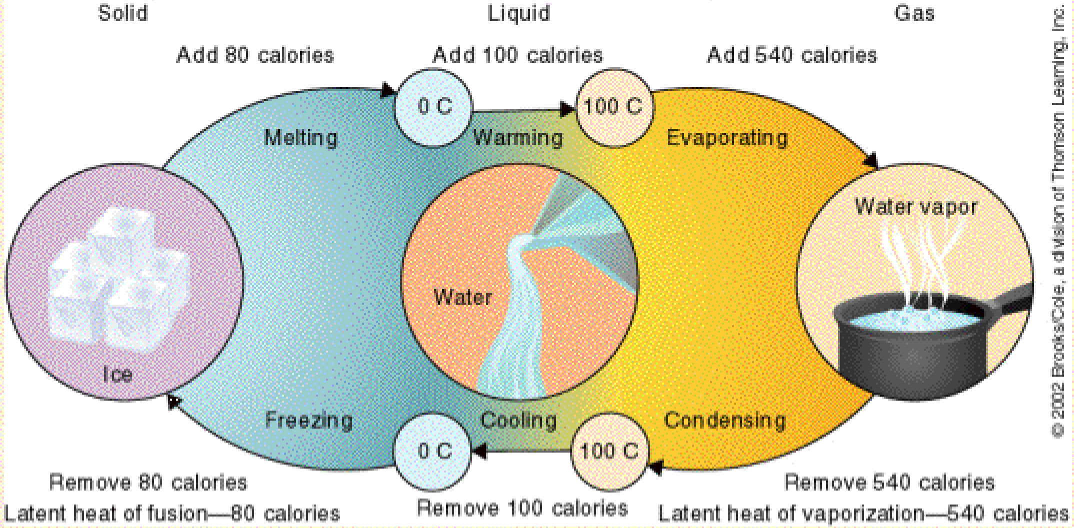


ice: open network held by H-bonds



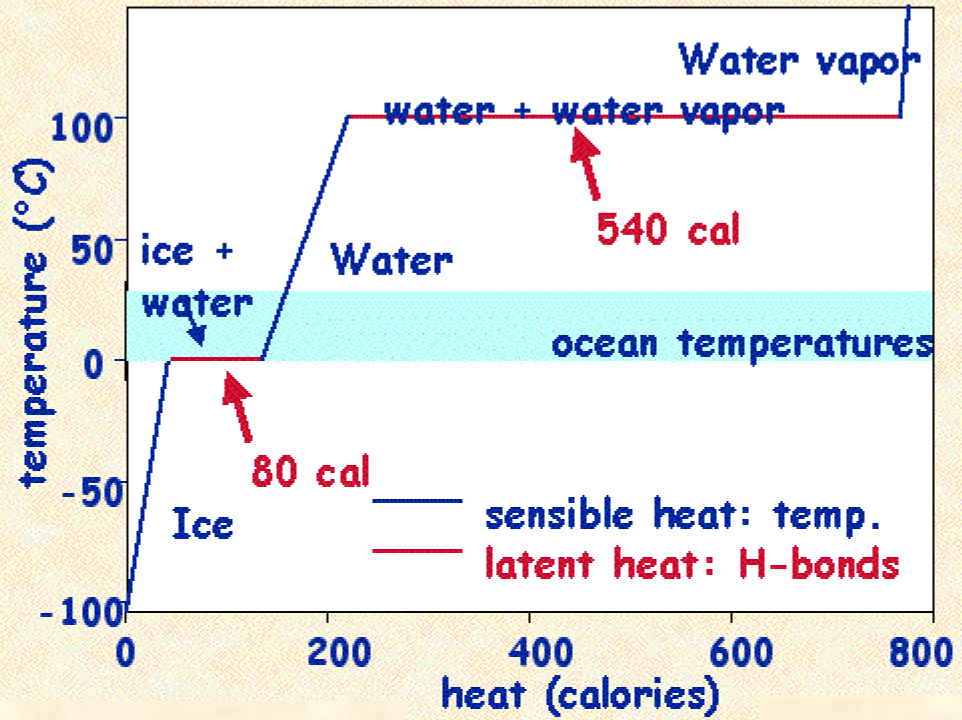
Changes of State:

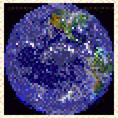
- Energy: measured in calories
  - 1 cal = heat required to raise 1g of water by 1°C
- Hydrogen bonds
  - form in condensation break in evaporation (540cal)



Changes of State — Role of Heat Energy:

- Heat absorption:
  - latent heat (H-bonds) and sensible heat (temperature)

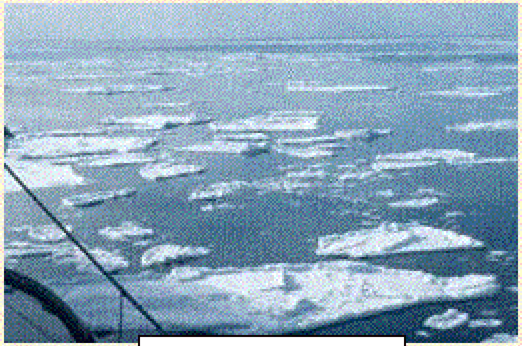




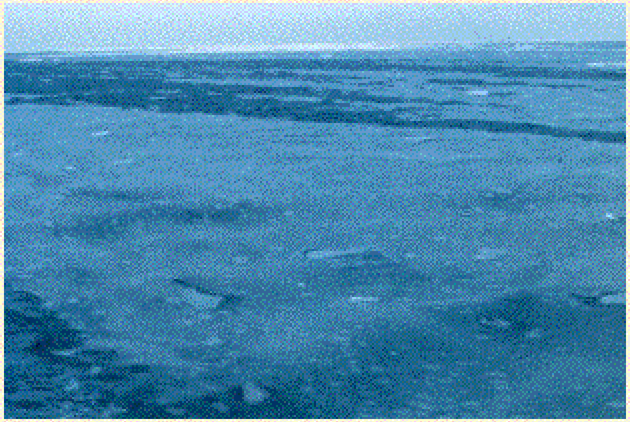
Sea Ice:

- Freezing excludes salts
- Sequence
  - slush (grease ice)
  - pancake ice
  - floes
- Fast ice attached to land

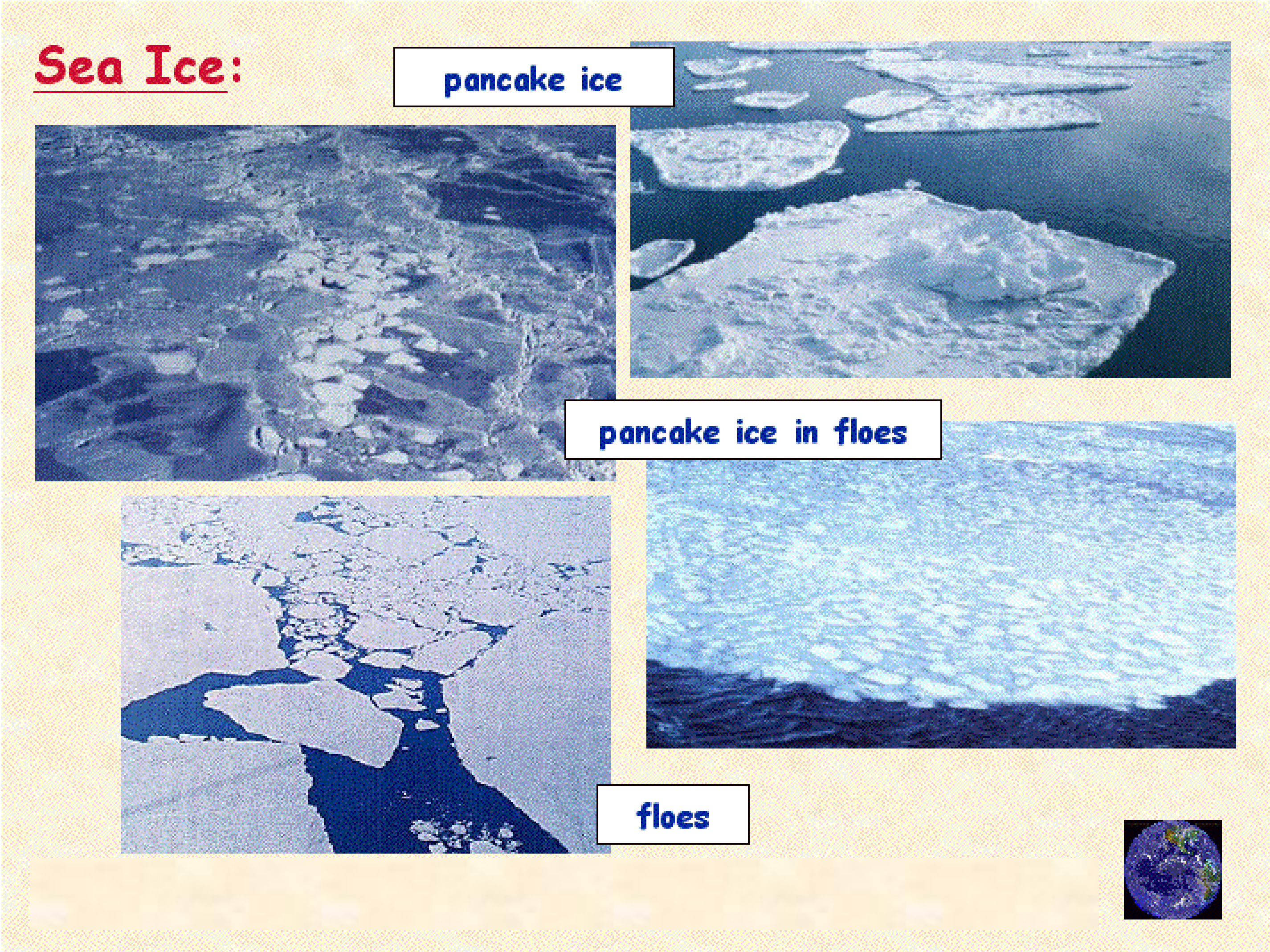
slush



pancake ice

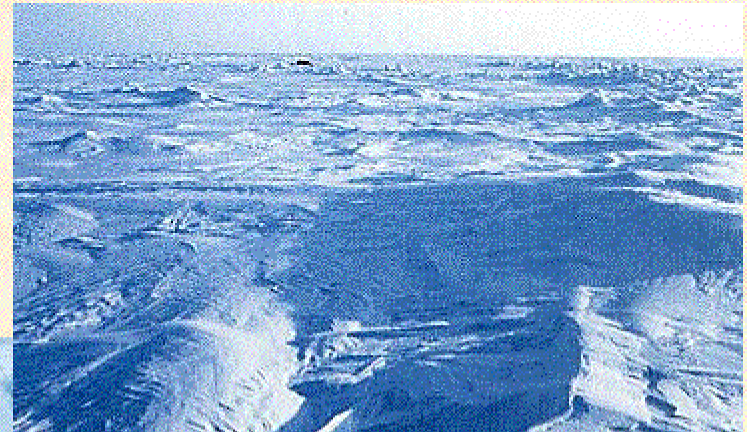


grease ice


Sea Ice:
pancake ice
pancake ice in floes
floes

Sea Ice:

- Multiyear ice
  - hummocks
  - ridges
  - formed by compression

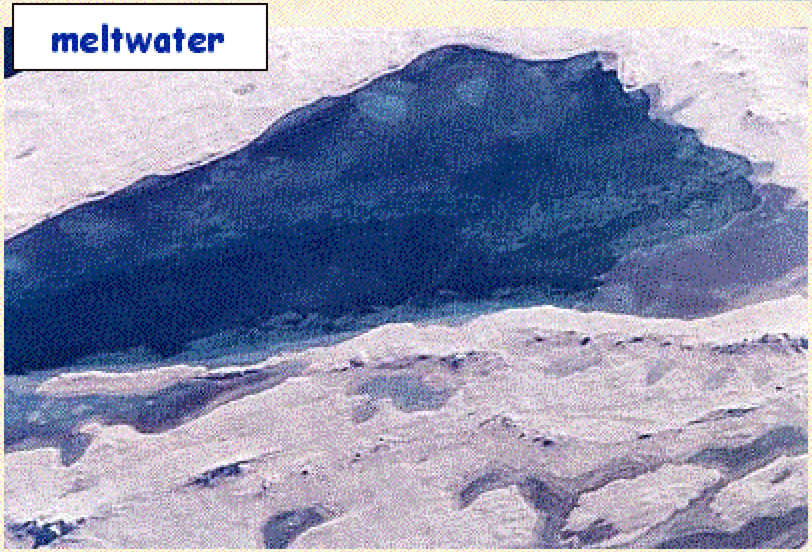


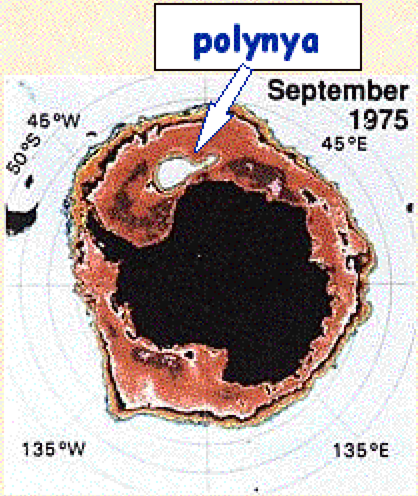
multiyear ice

ridges

Sea Ice:

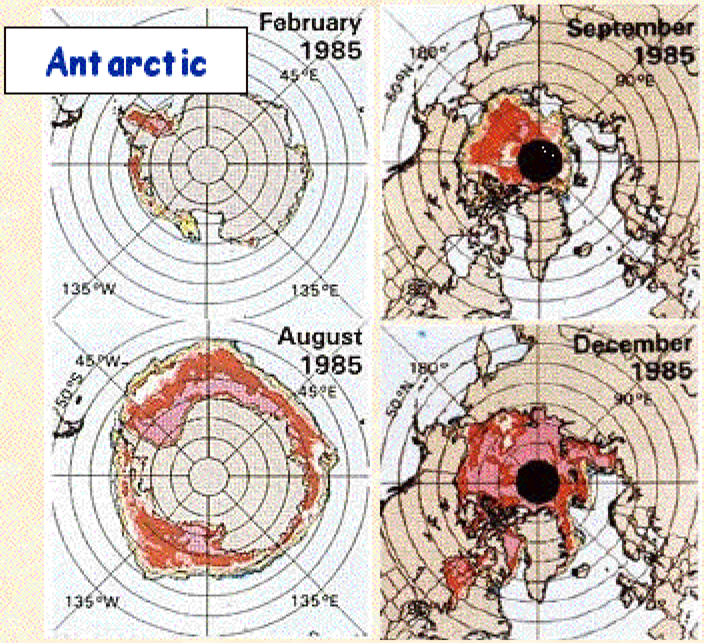
- Openings
  - small: leads
  - large: polynyas
  - surface meltwater

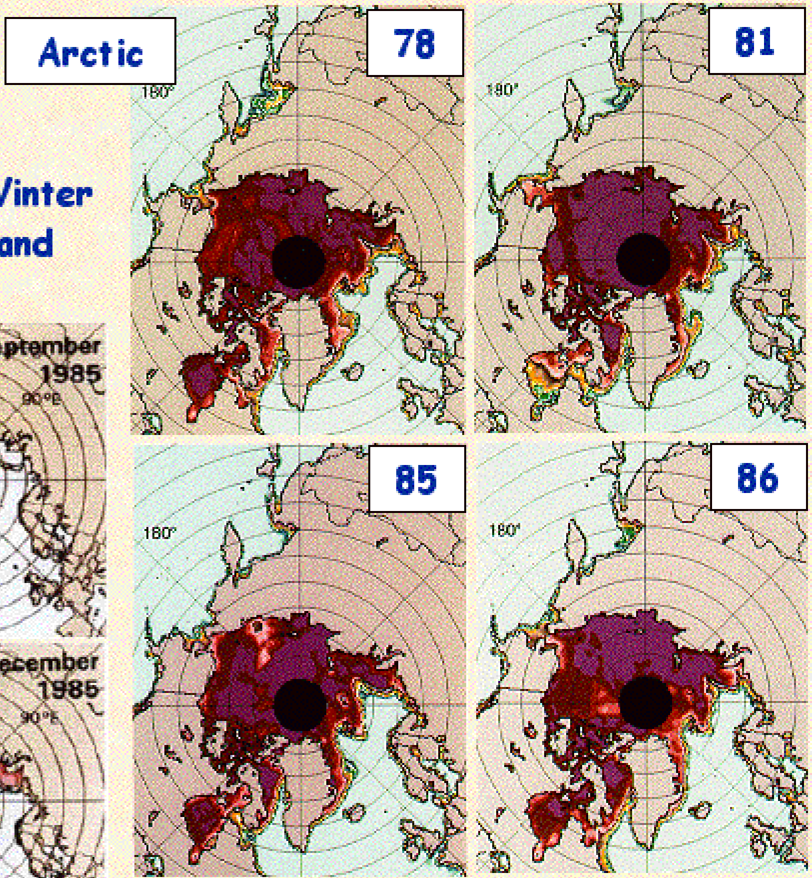


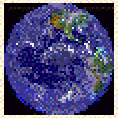


Sea Ice:

- Satellite images
  - measure thickness
  - show seasonal cycles of Winter build-up/Summer melting and annual variations

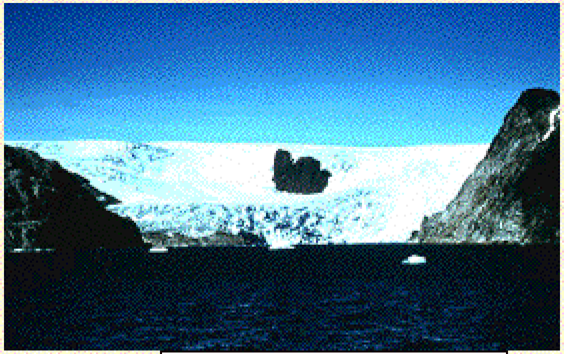






Icebergs — I:

- Formed from glaciers by calving
  - carry sediment load at their base (gouged from land)
  - 12% volume above sea surface
  - castle (cathedral) bergs from valley glaciers



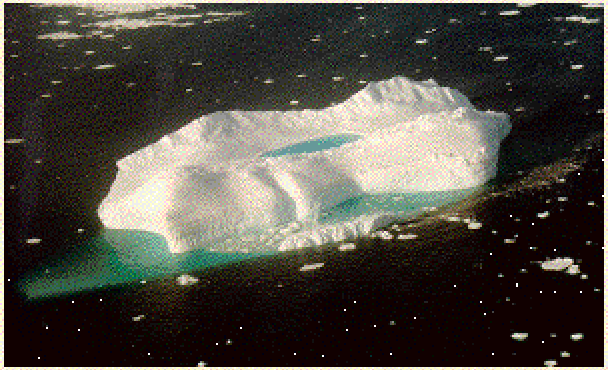
valley glacier

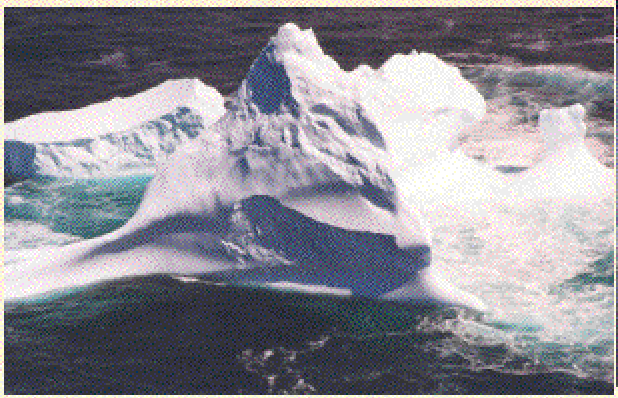
cathedral berg

castle berg

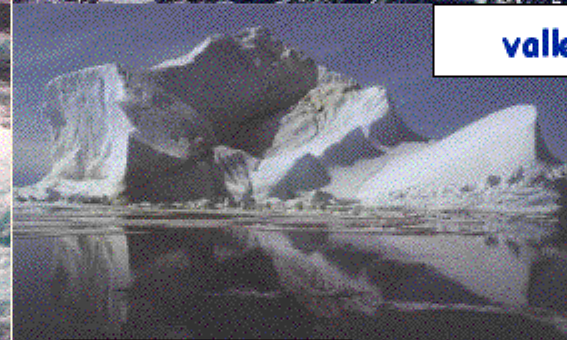
Icebergs — II:

- Glaciers and Bergs





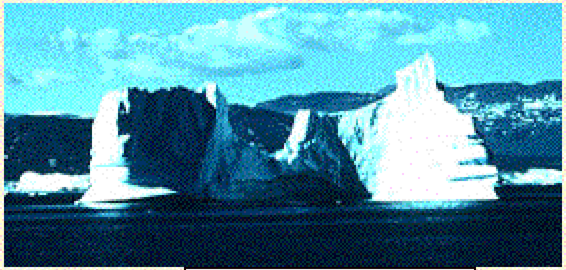
valley glacier



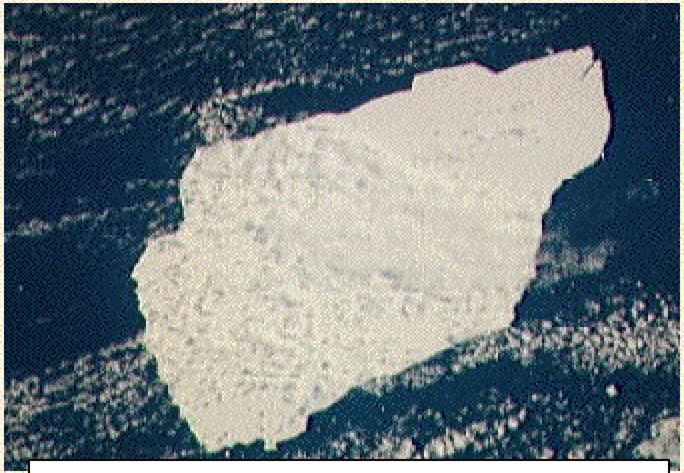
castle berg

Icebergs — III:

- Calved from glaciers
  - tabular bergs from continental ice sheets (vast size)
  - green icebergs with organic materials, or blue



castle berg

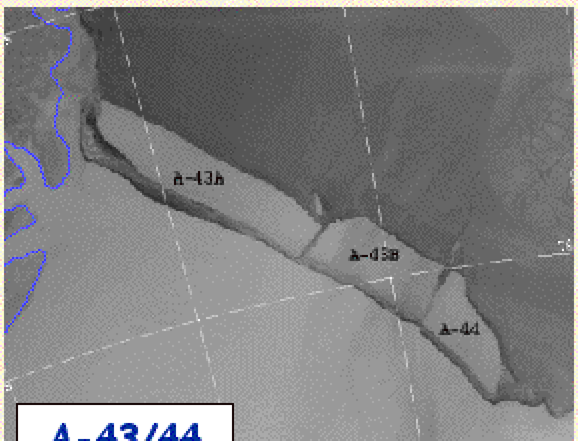


tabular iceberg (65 x 35km)

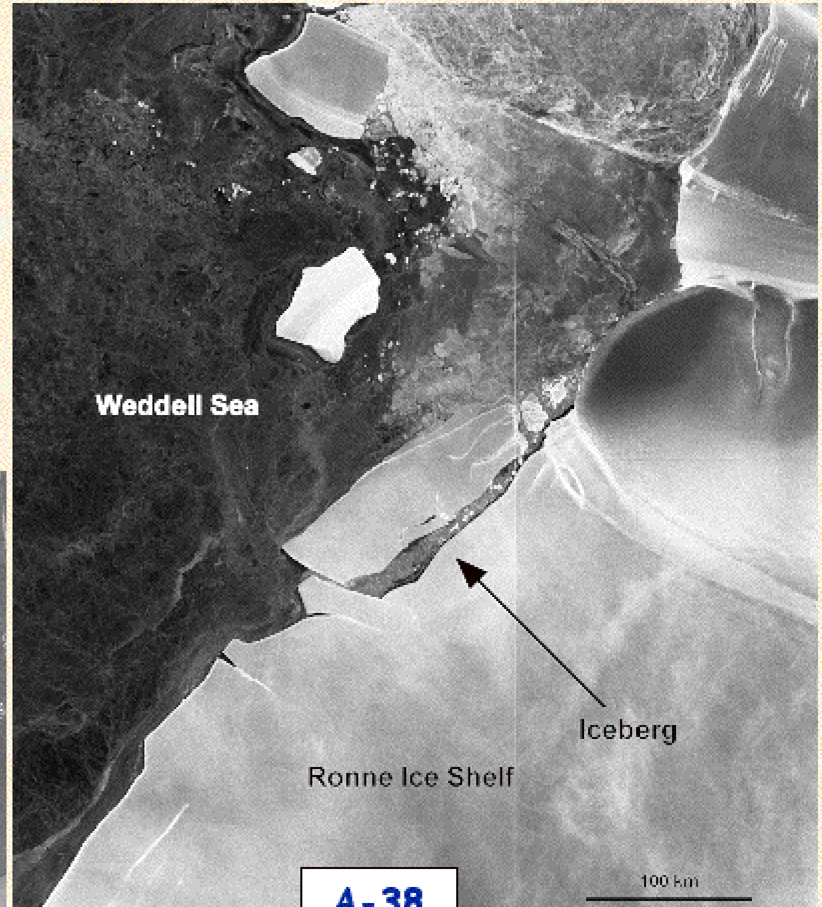
blue iceberg

Icebergs — IV:

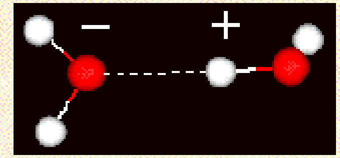
- Tabular Bergs
  - A-38, 10/5/98
  - 92 x 30 mi
  - 3500 km^2
  - A-43/A-44
  - combined: 4200 km^2



A-43/44

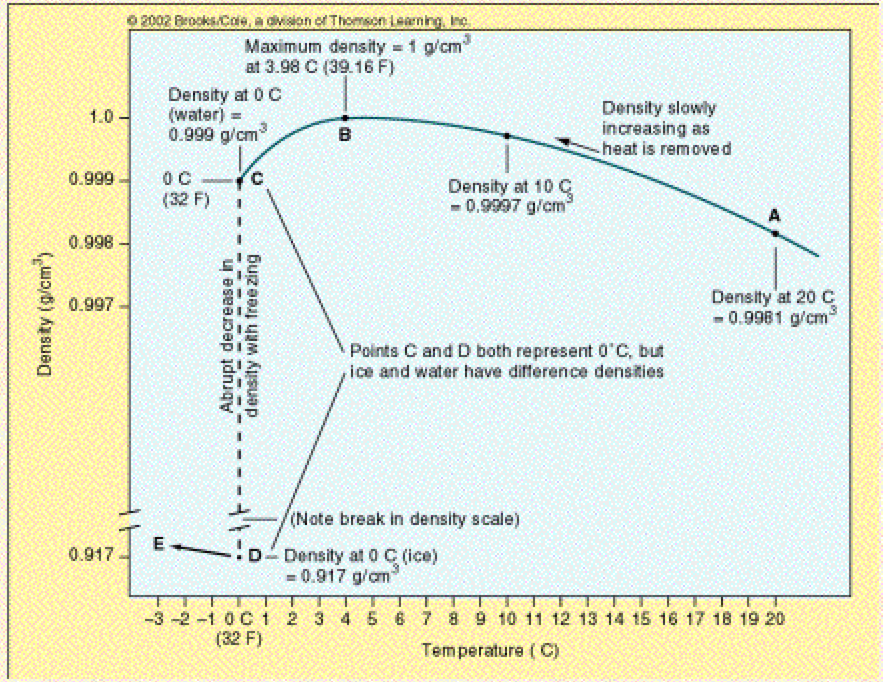


A-38



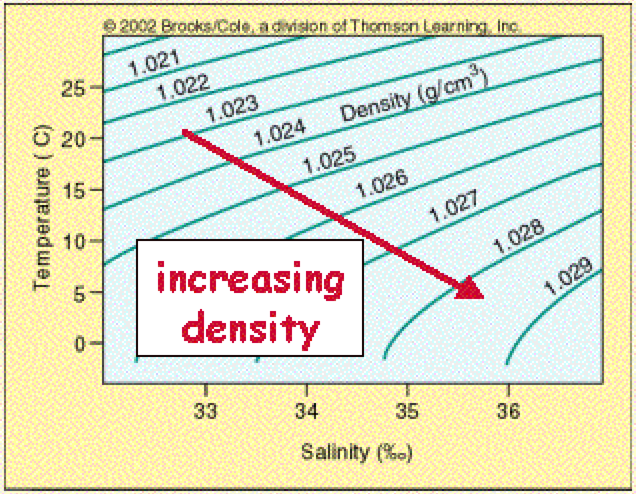
Physical Properties of Water:

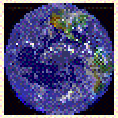
- Density
  - Ice is less dense than water
  - maximum density is at 3.98°C, where it is 1 g/cm^3 (seawater is 1.0278 g/cm^3)
  - density increases with salts, seawater sinks when it cools



Seawater Density:

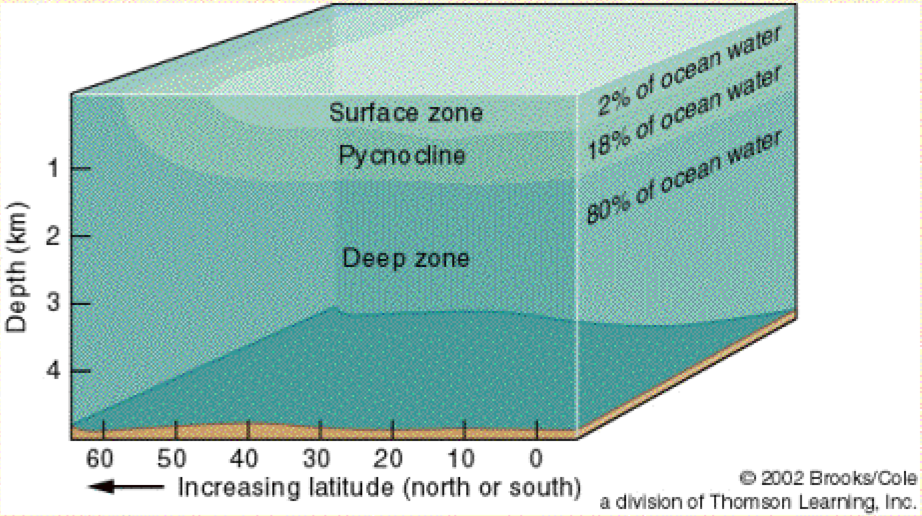
- Density
  - controlled by temperature and salinity
  - salinity increase leads to density increase
- Sigma-t
  - convenient measure for seawater density
  - termed σ_t = (density - 1)/1000
- Range of densities
  - high temperature, low salinity = low density
  - high temperature, high salinity or low temperature, low salinity = intermediate density
  - low temperature, high salinity = high density

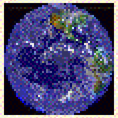




Density Structure:

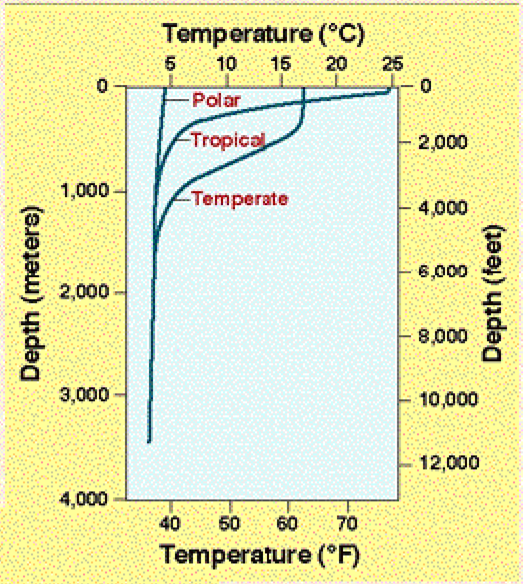
- Three depth zones within the ocean:
  - Surface: 0-100m (2% of ocean water)
  - Pycnocline: 100m - 1km (18 % of ocean water)
  - Deep ocean: below 1km (80 % of ocean water)

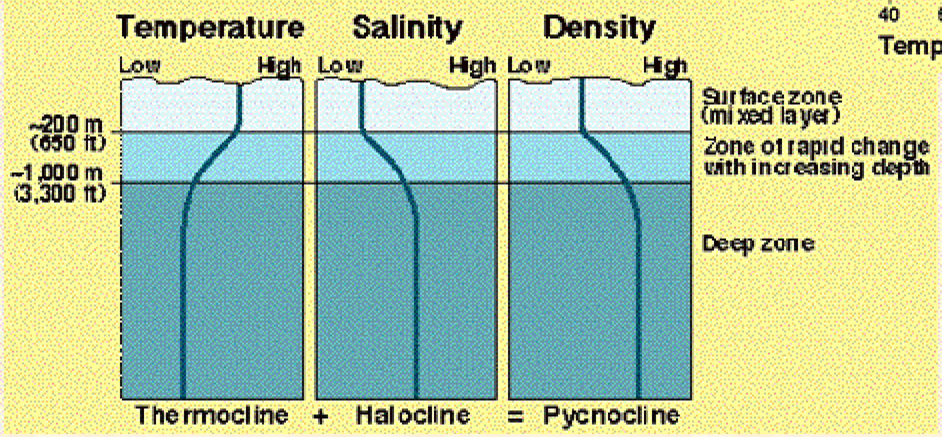


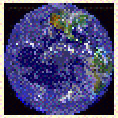


Ocean Structure:

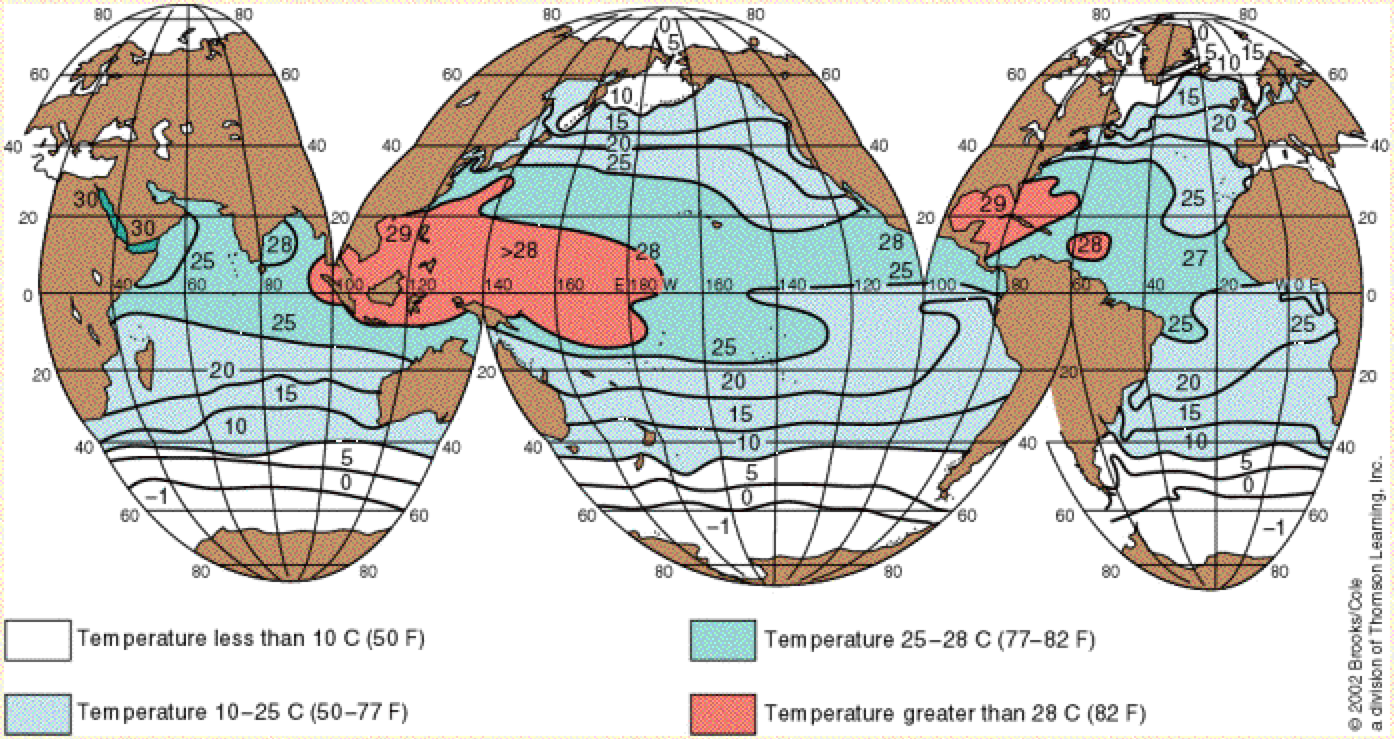
- Changes with depth
  - density increases in pycnocline
  - temperature decreases with depth
  - salinity increases with depth
  - layers called:
    - pycnocline, thermocline, halocline

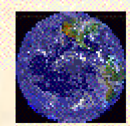


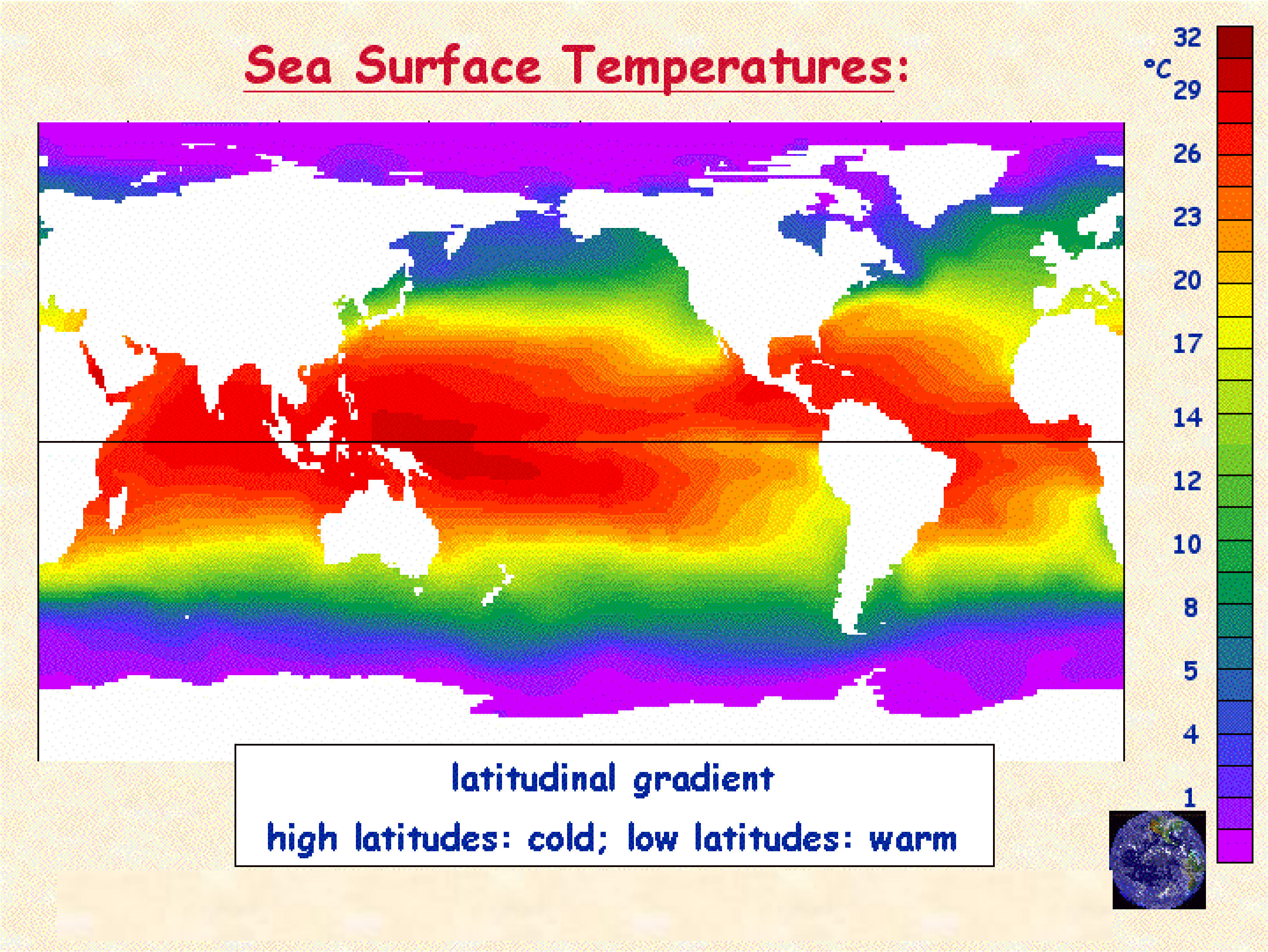




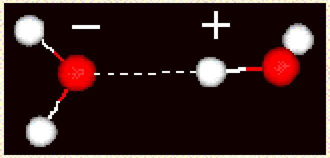
Sea Surface Temperatures:






Sea Surface Temperatures:
°C
32
29
26
23
20
17
14
12
10
8
5
4
1
latitudinal gradient
high latitudes: cold; low latitudes: warm

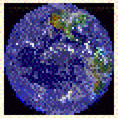
Physical Properties of Water:



- Cohesion, Surface Tension, Viscosity
  - H-bonds hold water together
  - order structure at air/water interface
  - low resistance to flow
- Heat Capacity
  - high, 1 cal/g/°C
  - Critical for Earth's temperature regulation
- Compressibility
  - very low
  - volume reduced by 1.7% at 400atm (4km deep)
- Dissolving Ability
  - separates charged ions, continually transports salts to ocean

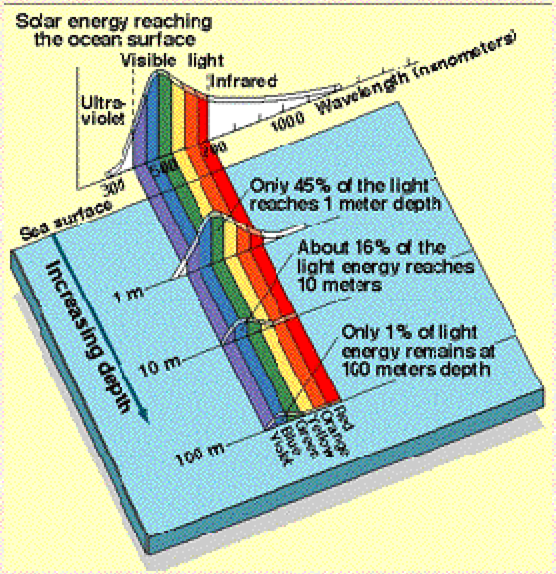
Heat Capacities

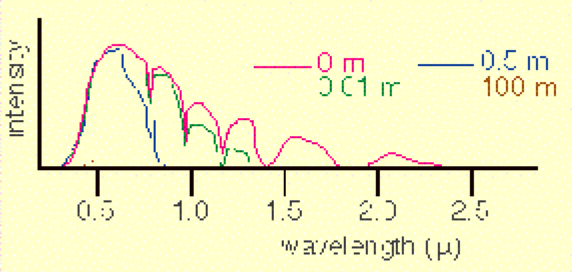
Substance	cal/g/°C
silver	0.06
aluminum	0.22
gasoline	0.50
water	1.00
ammonia	1.13

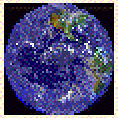


Transmission of Energy:

- Heat
  - by conduction (direct)
  - convection (movement)
  - radiation (transfer through space)
- Light
  - Sun's heat as electromagnetic radiation
  - gamma rays, X-rays, Ultraviolet (UV), visible, infrared (IR), microwave, radar, shortwave (TV, FM), broadcast, long wave
  - part absorbed by atmospheric gases, especially water vapor and carbon dioxide (CO_2)
  - further absorption by ocean, limiting penetration



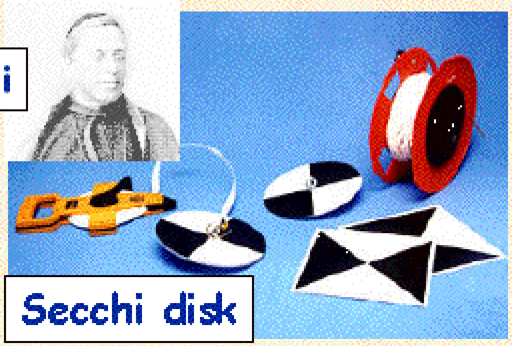




Transmission of Energy:

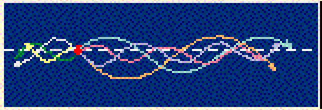
- Light
  - seawater transmits only visible light
  - light refracted on entering water
  - absorbed and scattered (attenuated)
  - measured by light meters or using a Secchi disk

Fr. Secchi

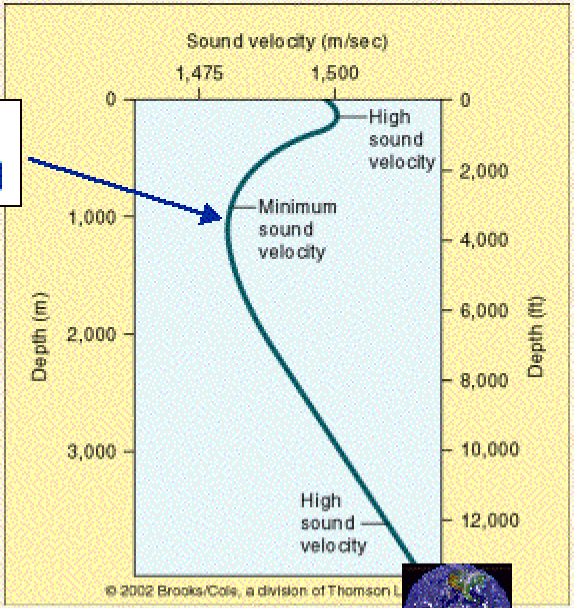


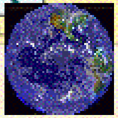
Secchi disk

- Sound
  - echo sounders or precision depth recorders used to measure depths
  - speed of sound increases with temperature, pressure, salts
  - minimum velocity at 1km
  - Sound waves are contained within Sofar channel



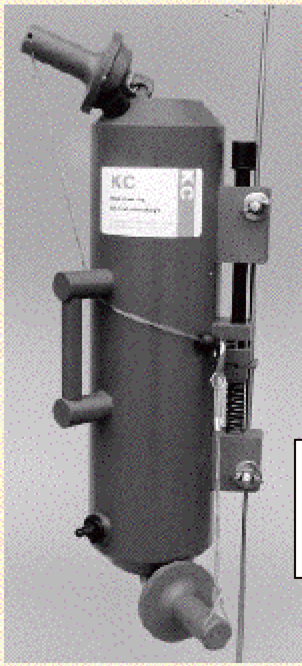
sofar channel

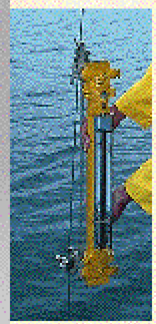




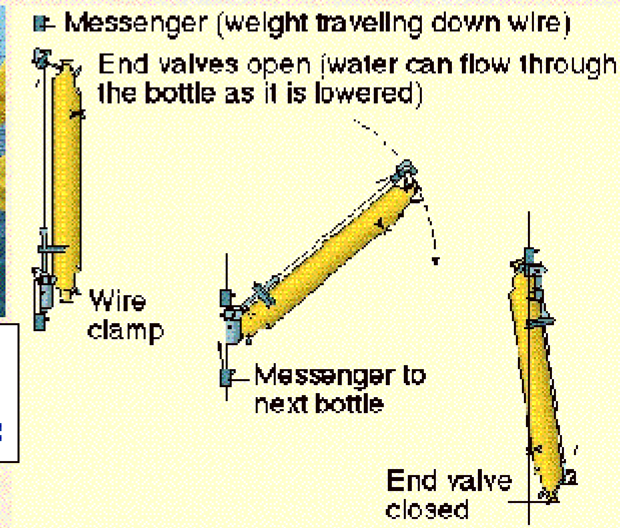
Measurement Techniques:

- Water Properties
  - water bottle samples (triggered by messenger)
  - CTD (conductivity-temperature-depth) sensors





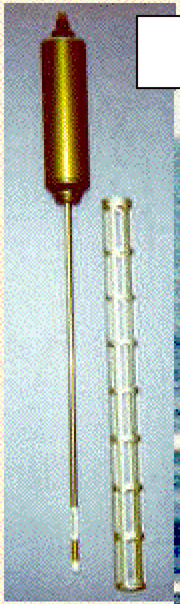
water bottles



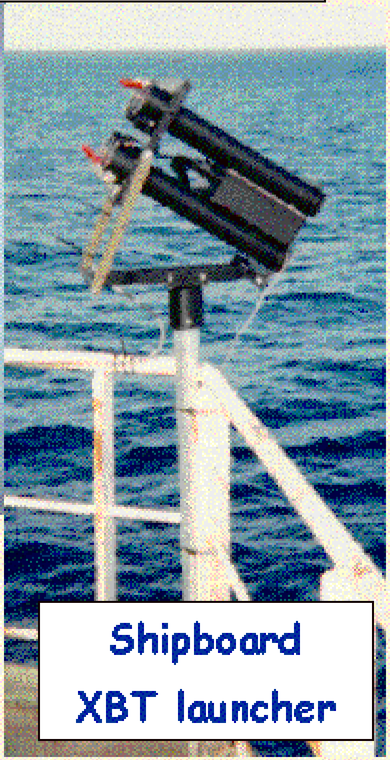
CTD

Measurement Techniques:

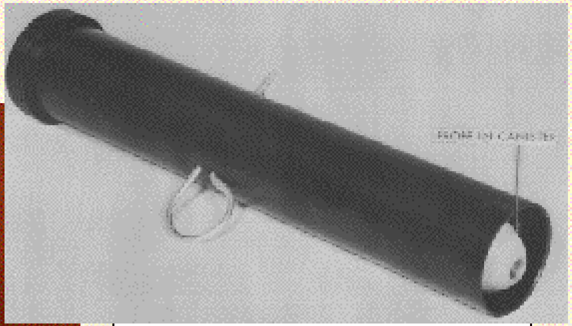
- Temperature
  - CTD, thermometer, mechanical bathythermographs, expendable bathythermographs (XBT)



mechanical BT

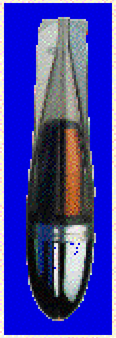


Shipboard XBT launcher



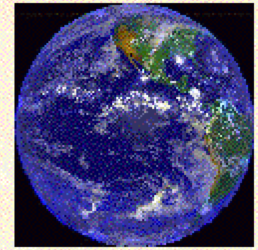
XBT in cannister

airborne XBT



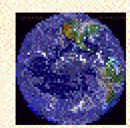
XBT

Oceans & Our Global Environment
Water and Ocean Structure



Key Concepts:

- Water Molecule
  - structure, chemical bonds, changes of state, density
- Physical Relationships and Properties
  - energy and temperature, latent and sensible heat
  - heat, light and sound in seawater
- Sea Ice and Icebergs
- Vertical Structure of the Oceans
  - surface mixed layer, pycnocline, deep ocean



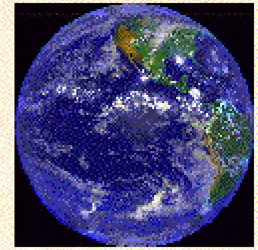
Lecture 5

Chemical Oceanography

Mohamed Hassaan

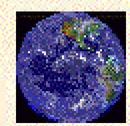
Oceans & Our Global Environment

The Chemistry of Seawater



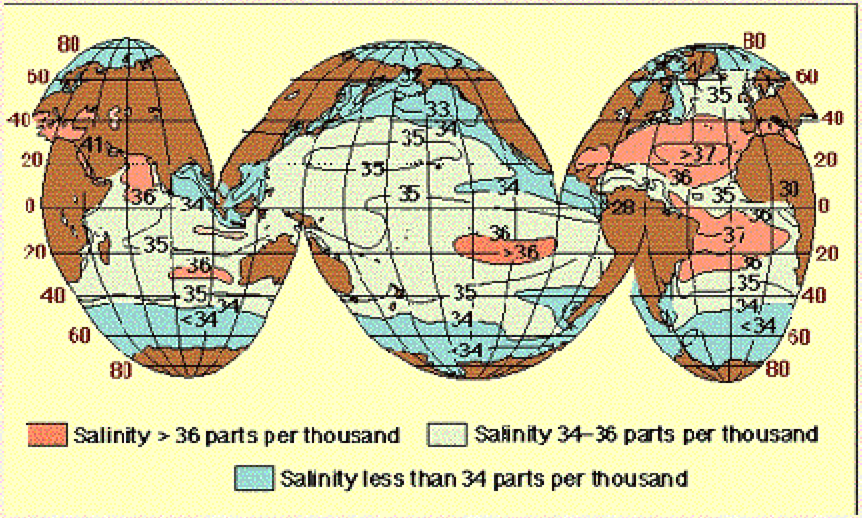
Topics:

- The Salts
  - ocean salinity and dissolved salts
  - sources of salts, salt balance, residence times, etc.
- The gases
  - types, depth distribution, CO_2 as buffer, carbon cycle, etc.
- Other Substances
  - nutrients, organics
- Practical Considerations
  - salt and water: desalination

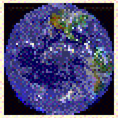


Seawater Surface Salinity

- High salinites
  - Mid latitudes in the N. Atlantic, S. Atlantic, S. Pacific & Indian Oceans
  - Arabian Sea
  - Red Sea
  - Mediterranean

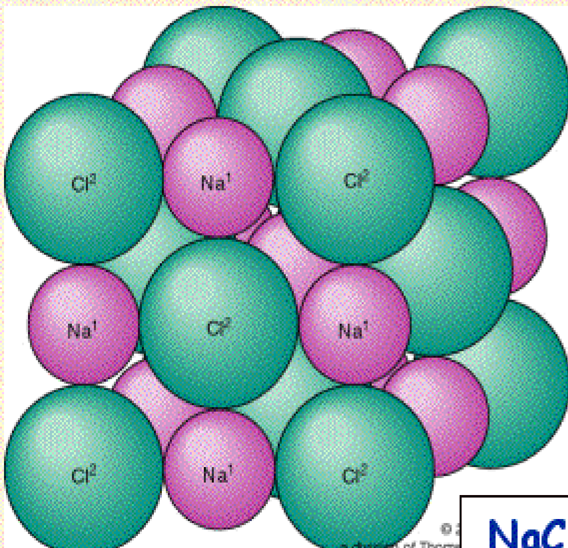


- Low Salinities
  - high latitudes: around Antarctica, Arctic Ocean
  - S.E. Asia
  - Western coasts of N. America and central America
- Seasonal Changes
  - pronounced in polar regions (effects of ice formation)

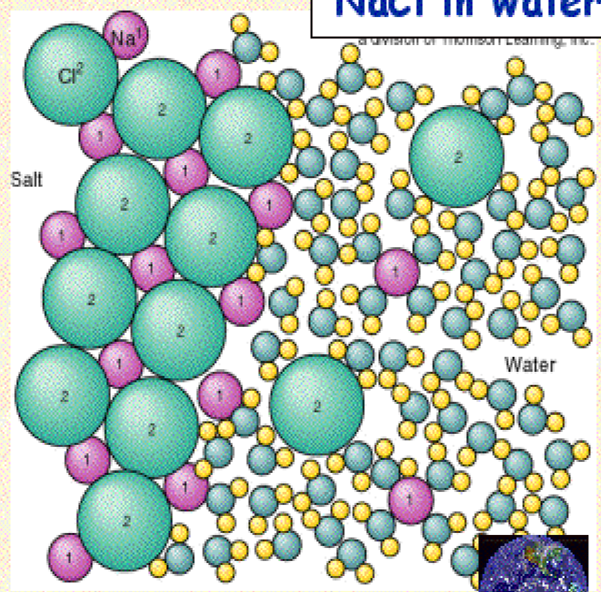


Dissolution of Salt:

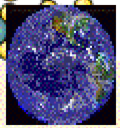
- Common salt, sodium chloride, NaCl
  - ionic bonds, electrons are transferred Na to Cl
  - cations with +ve charge (Na^+), anions with -ve charge (Cl^-)
  - in solution solvated by water molecules, H atoms suround Cl^- O atoms around Na^+



NaCl

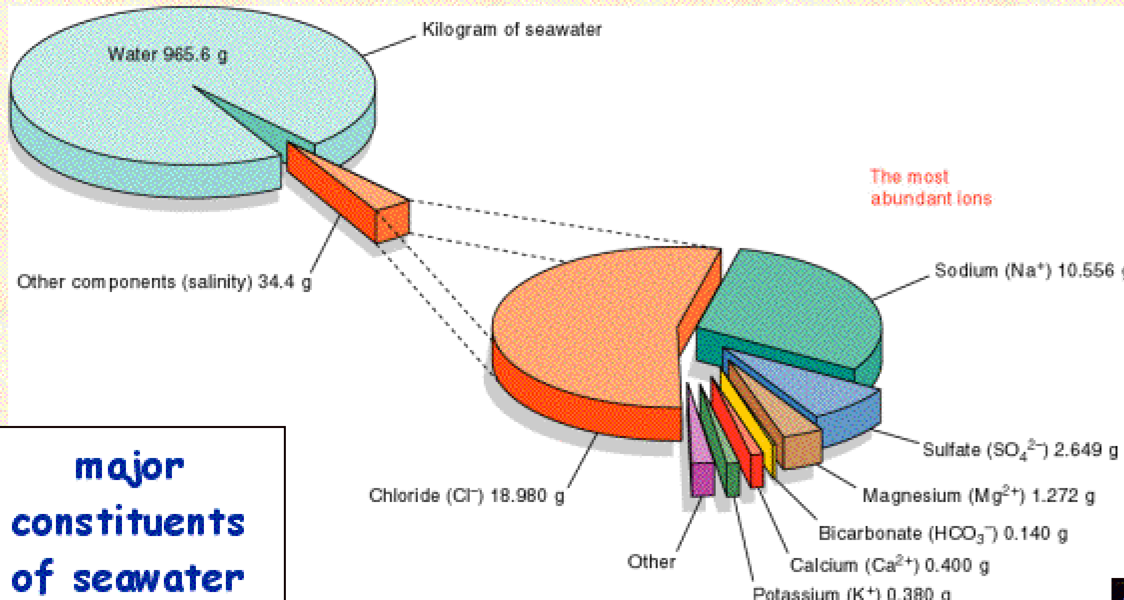


NaCl in water

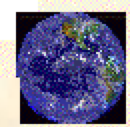


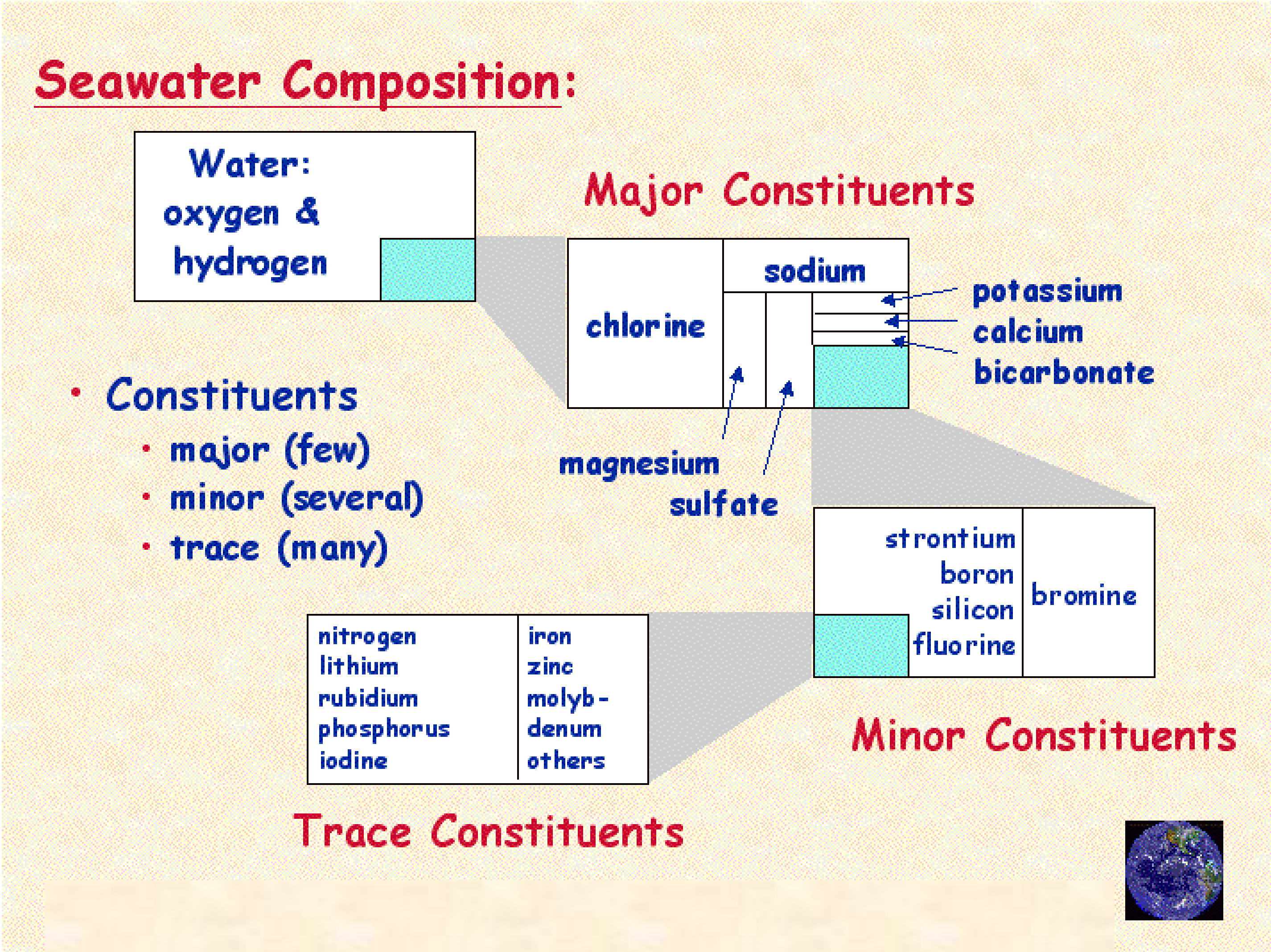
Seawater Composition:

- Dissolved salts, about 35 parts per thousand, 35‰
  - form electrically charged particles, ions
  - major constituents (Cl^-, Na^+, SO_4^{2-}, Mg^{2+}, Ca^{2+}, K^+, HCO_3^-) make up >>99% of dissolved salts



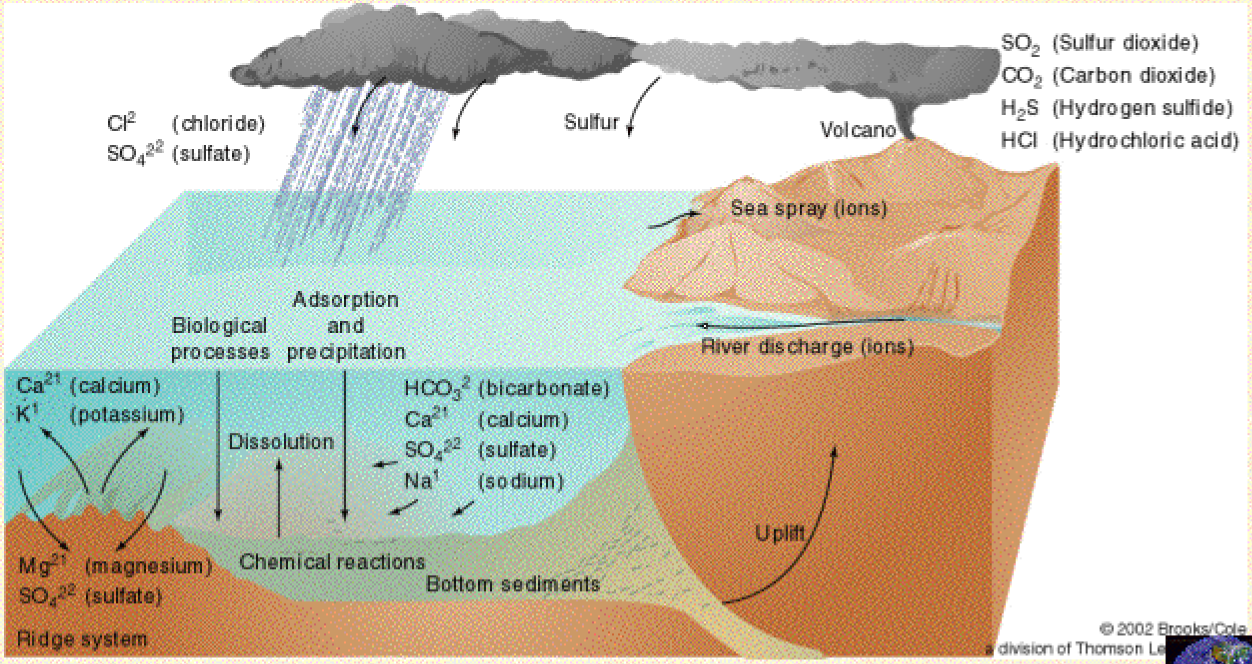
major constituents of seawater




Seawater Composition:
Water: oxygen & hydrogen
Major Constituents
chlorine
sodium
potassium
calcium
bicarbonate
magnesium
sulfate
• Constituents
• major (few)
• minor (several)
• trace (many)
strontium
boron
silicon
fluorine
bromine
Minor Constituents
nitrogen
lithium
rubidium
phosphorus
iodine
iron
zinc
molyb-
denum
others
Trace Constituents

Sources and Sinks of Seawater Salts:

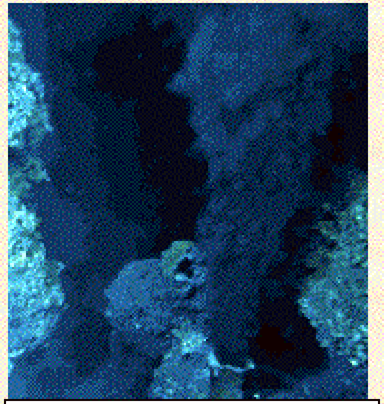
- Balance of inputs and outputs
  - seawater composition uniform through time over last 1.5Ga



Sources of Salts:

- Processes Regulating Seawater Salts
  - primordial source from Earth's interior
  - volcanic gases that fallout as rain
  - fluids introduced at ridge crests, vents
  - river outflow into the ocean
  - dusts from land (eolian transport)

river outflow

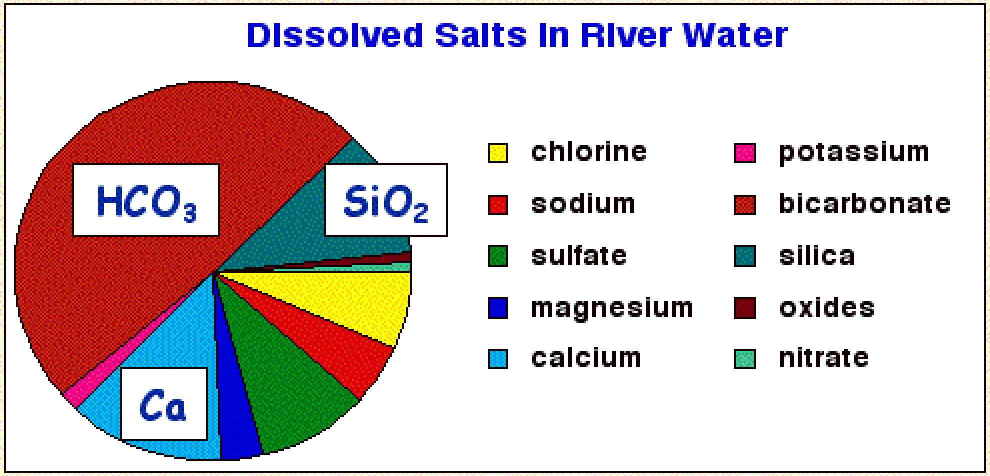


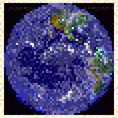
vent emanations

volcanic gases

Sources of Salt:

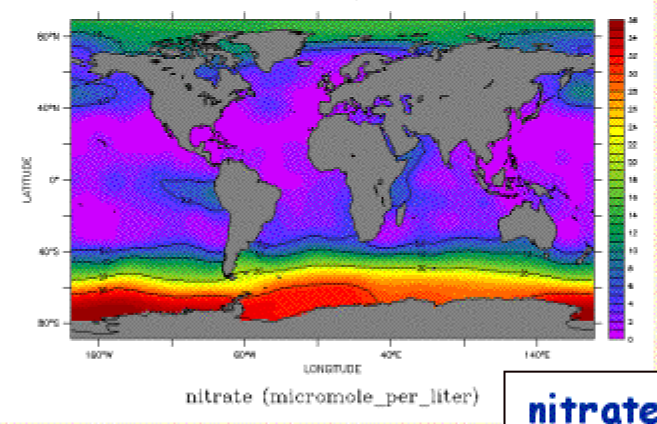
- Recycling
  - **occurs with uplift, erosion of marine sediments**
- River constituents
  - **dissolved constituents from chemical weathering of rocks**
  - **distinct from ocean constituents**



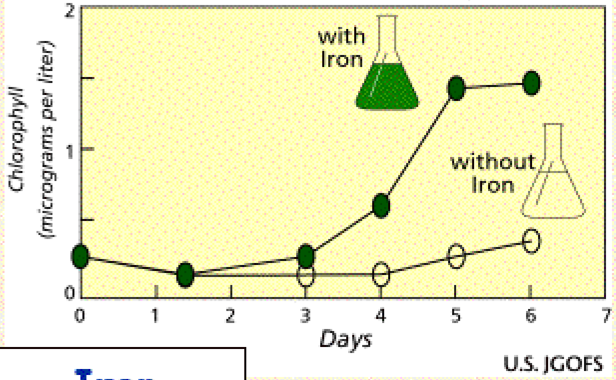


Behavior of Salts:

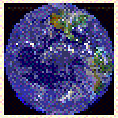
- Conservative and Non-Conservative
  - conservative, unaffected by biological processes
    - most elemental constituents
  - non-conservative, elements taken or required by b processes (essential nutrients)
    - nitrogen, phosphorus, silicon, oxygen, carbon, iron
    - often depleted or limiting



nitrate



Iron fertilization



Residence Times:

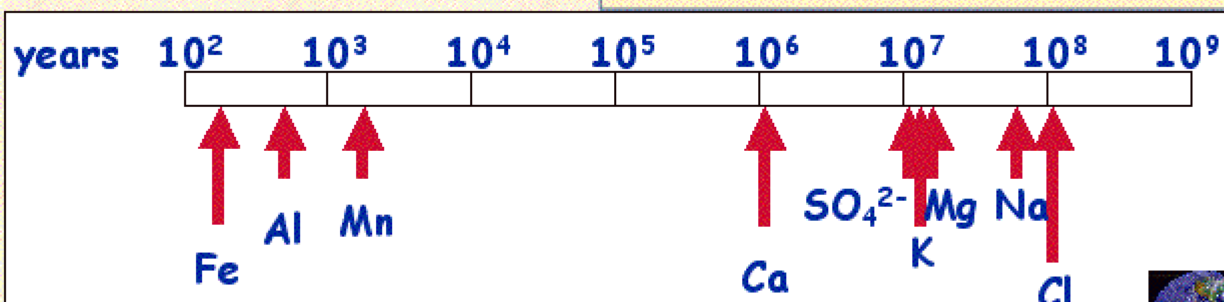
- Residence Times
  - defined as: amount present/removal rate
  - wide time range: aluminum = 600 years; calcium = 1 Ma sodium = 68Ma

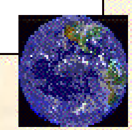
Table 7.3 Approximate Residence Times for Constituents of Seawater

Constituent	Residence Time (years)
Chloride (Cl^{2})	100,000,000
Sodium (Na^{1})	68,000,000
Magnesium (Mg^{21})	13,000,000
Potassium (K^{1})	12,000,000
Sulfate (SO_4^{22})	11,000,000
Calcium (Ca^{21})	1,000,000
Carbonate (CO_3^{22})	110,000
Silicon (Si)	20,000
Water (H_2O)	4,100
Manganese (Mn)	1,300
Aluminum (Al)	600
Iron (Fe)	200

Skirrow,

Residence Times

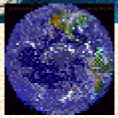




Constant Proportions, Determining Salinity:

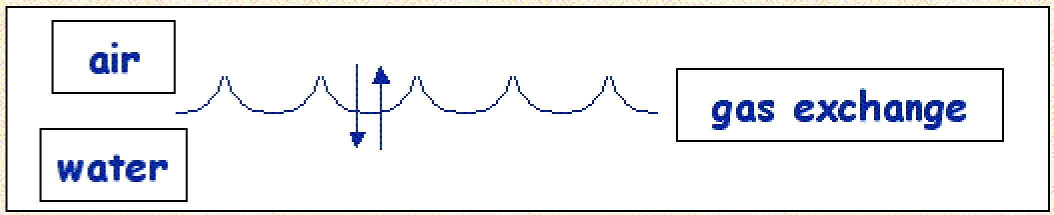
- Constant Proportions
  - seawater is well mixed, ionic concentrations vary little
  - elements in constant proportion, except for biological usage
- Determining Salinity
  - measured using $AgNO_3$ by titration
    - removes halogens (F, Cl, Br, I)
    - halogen content known as chlorinity (Cl^- equivalence)
  - salinity (in ‰) proportional to chlorinity
    - salinity = 1.80655 x chlorinity
  - can be measured by electrical conductivity (salinometer)
    - conductance is related to salt content

salinometer

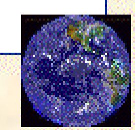


Dissolved Gases in Seawater:

- Gases dissolve and exsolve at air/water interface
  - surface water is saturated with atmospheric gases
  - equilibrium concentrations
    - different values for individual gases
  - major gases: nitrogen N_2, carbon dioxide CO_2, oxygen O_2
  - saturation affected by temperature, salinity and pressure



Gas	atm. (vol)	Seawater (vol)	Concn. (mass)
N_2	78%	48%	1-18 ppm
O_2	21%	36%	0-13 ppm
CO_2	0.035%	15%	64-107 ppm
Ar, He, Ne	0.95%	1%	



Distribution of Dissolved Gases with Depth:

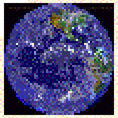
- Plant photosynthesis:
  - uses CO_2, produces O_2 and carbohydrates (e.g. glucose)
  - requires light as energy source
  - occurs in surface waters (photic zone)
  - decreases with depth
- Respiration: uses O_2 and organics, produces CO_2
  - uses O_2 and carbohydrates (e.g. glucose) to produce CO_2
  - occurs throughout the water column

Photosynthesis:

$$\underset{\text{carbon dioxide}}{6\,CO_2} + \underset{\text{water}}{6\,H_2O} \xrightarrow{\text{sunlight}} \underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6\,O_2}$$

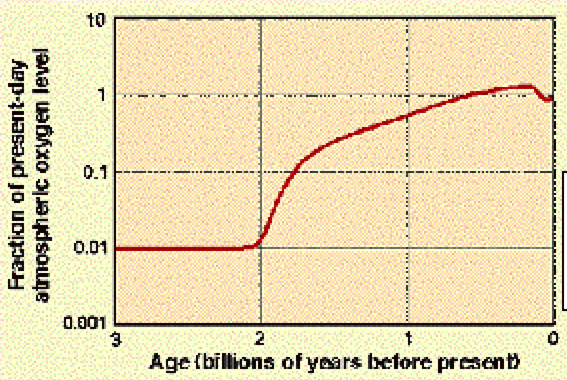
Respiration:

$$\underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6\,O_2} \longrightarrow \underset{\text{carbon dioxide}}{6\,CO_2} + \underset{\text{water}}{6\,H_2O} + \underset{\text{chemical energy}}{\text{energy}}$$

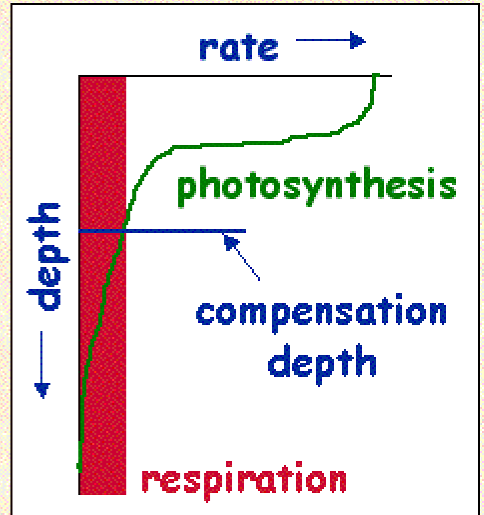


Biological Effects on Dissolved Gases:

- Photosynthetic Compensation Depth
  - rate of production = rate of respiration
  - above O_2 produced, CO_2 consumed
  - below CO_2 produced, O_2 consumed

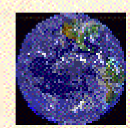


O_2 build-up

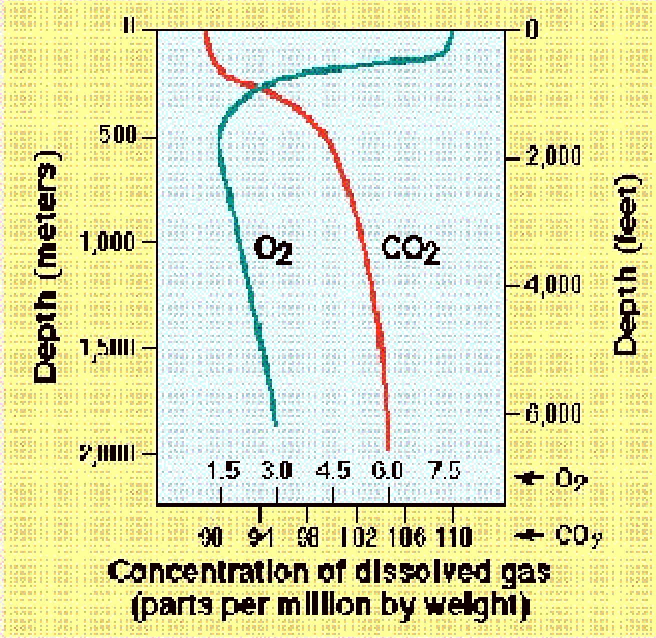


photosynthesis & respiration

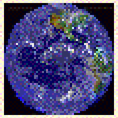
- Oxygen Balance
  - excess O_2 enters atmosphere
  - gradual build-up over geological time
  - atmospheric O_2 weathers and oxidizes rocks



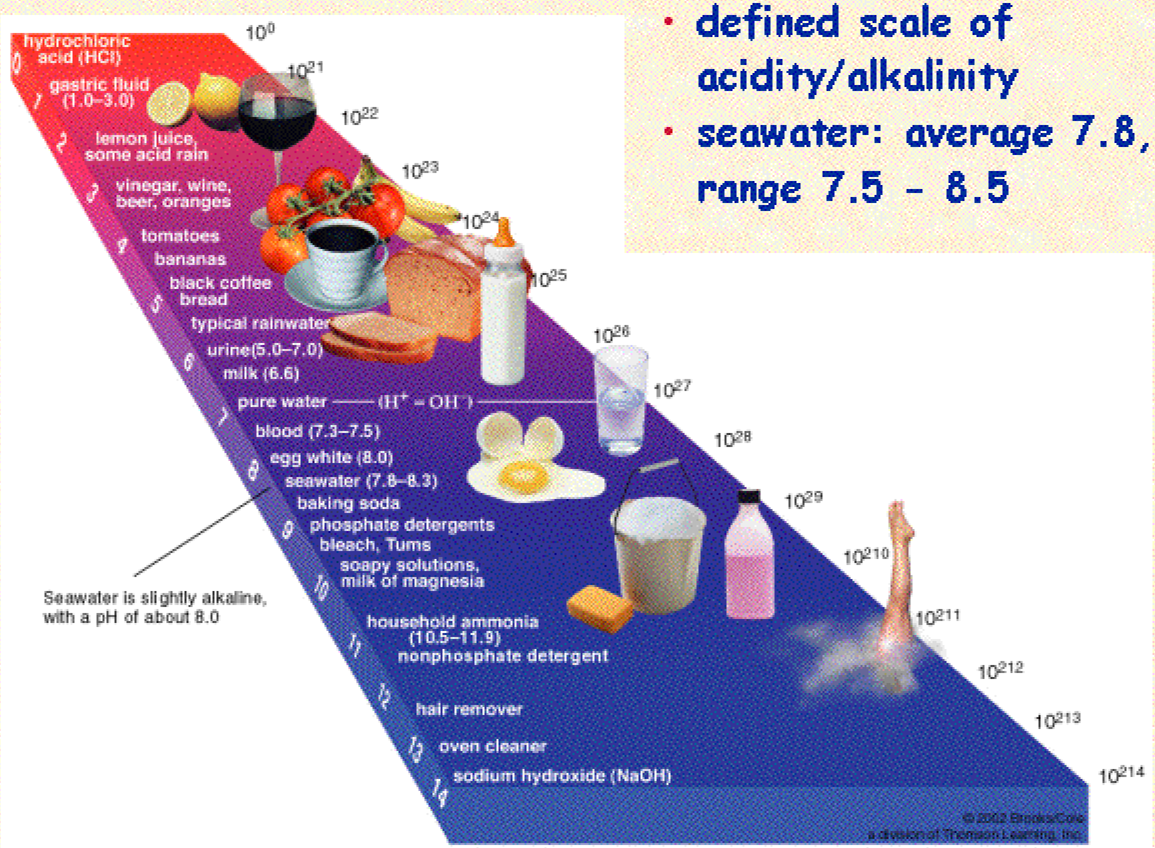
Gas Concentrations:



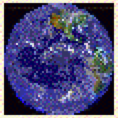
- Dissolved O_2
  - typically 0-10 mL/L in ocean
  - zero O_2 = anoxic conditions
  - at intermediate depths (~800m) O_2 minimum zone occurs
  - O_2 enriched in surface, depleted in intermediate waters, replenished at depth
- Dissolved CO_2
  - CO_2 depleted in surface waters, replenished at depth
  - biological pump cycles CO_2 to deep ocean



pH:



- defined scale of acidity/alkalinity
- seawater: average 7.8, range 7.5 - 8.5

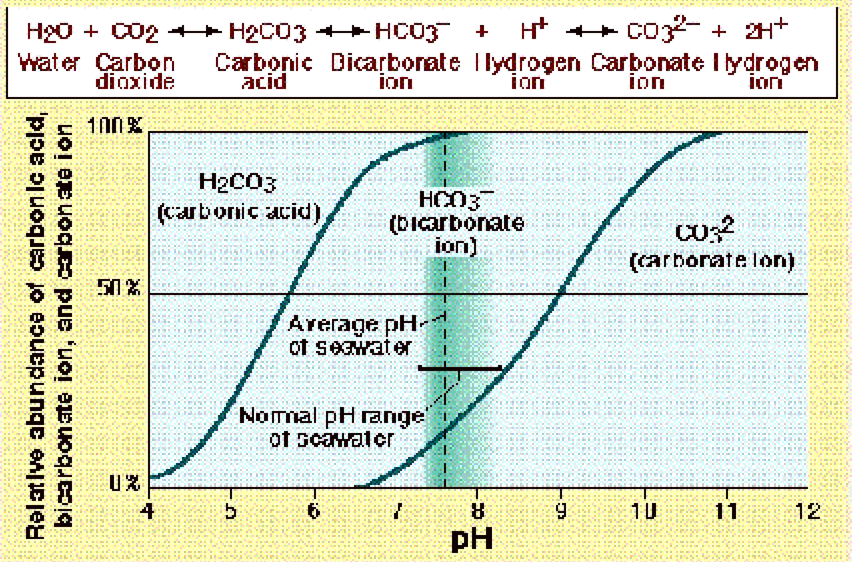


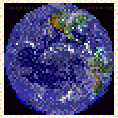
Carbon Dioxide, Buffers:

- CO_2 as a buffer
  - $CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons HCO_3^- + H^+$
  - prevents sudden changes in pH

position of equilibrium of CO_2 dissolution is pH dependent

- CO_2 cycle
  - contributions:
    - fires
    - plant decay
    - respiration
  - storage in:
    - living matter
    - atmosphere
    - oceans
    - carbonate rocks
    - petroleum, coals and natural gas

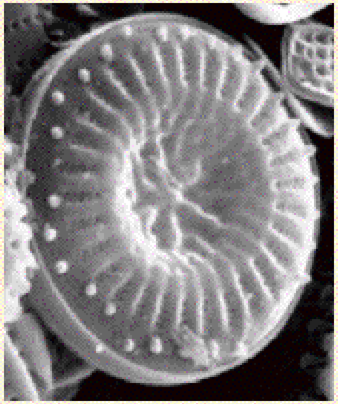


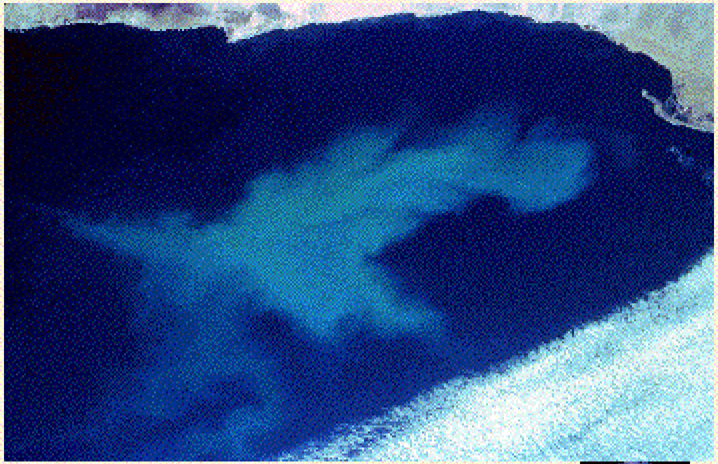


Other Substances:

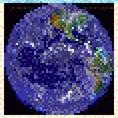
- Nutrients
  - nitrate (NO_3^-), phosphate (PO_4^{3-})
    - required by all organisms
  - silicate (SiO_4^-)
    - required by siliceous organisms
  - removed from seawater during growth
  - recycled during decay
  - non-conservative
- Organics
  - proteins, carbohydrates, lipids (fats)
  - made by organisms
  - or obtained from surroundings or diet
  - may accumulate in sediments

siliceous diatom



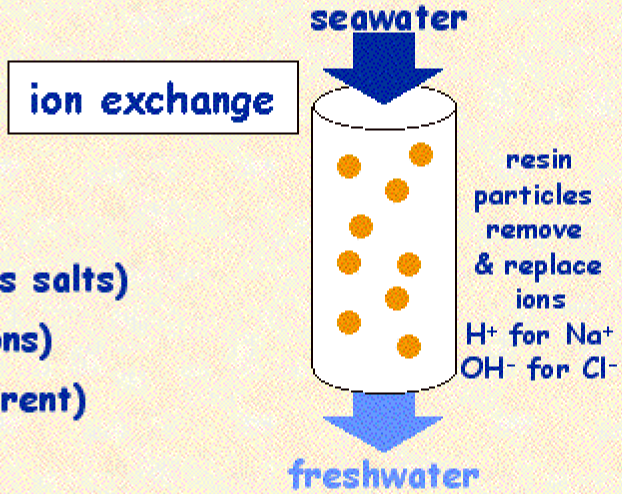


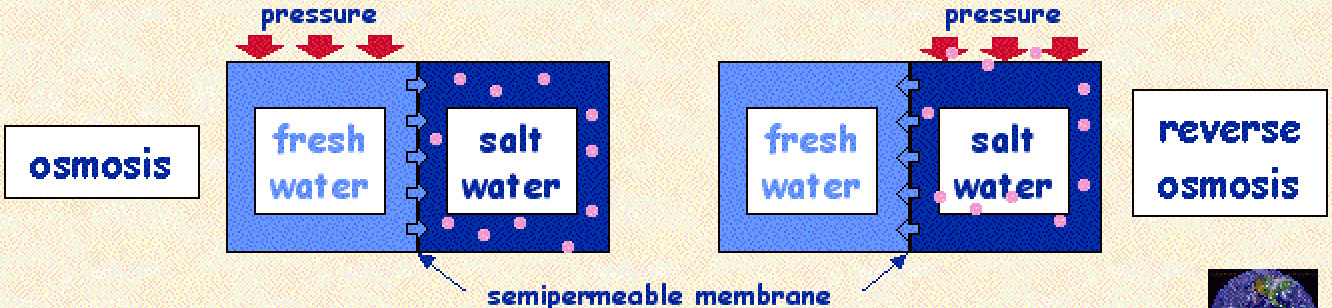
algal bloom

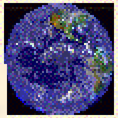


Practical Considerations: Salt and Water:

- Chemical resources
  - salt, Mg, Br
- Desalination
  - freshwater
    - freezing or evaporation (excludes salts)
    - ion exchange (resin exchanges ions)
    - electrodialysis (uses electric current)
    - reverse osmosis





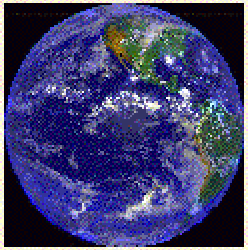


Lecture 6

Sediments

Mohamed Hassaan

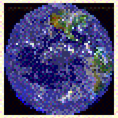
Oceans & Our Global Environment



Sediments

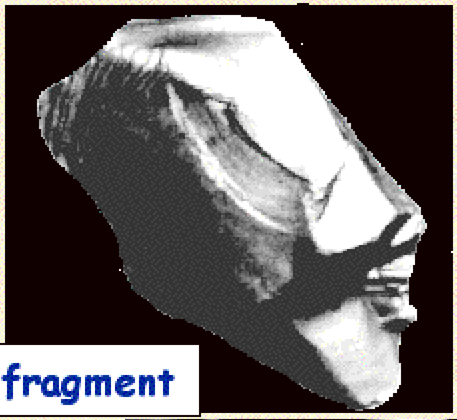
Topics:

- Sediments and their Sources
  - terrigenous, biogenous, hydrogenous, cosmogenous
  - biogenic oozes, red clays
- Patterns of Sediment Deposits
  - terrigenous sediments, particles sizes, rates of deposition
  - sampling methods
- Seabed Deposits as Resources
  - sand & gravel, phosphorites, sulfur

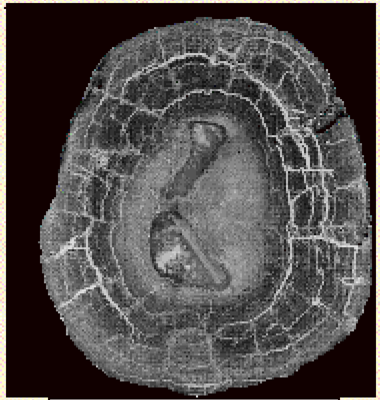


Types of Ocean Sediments:

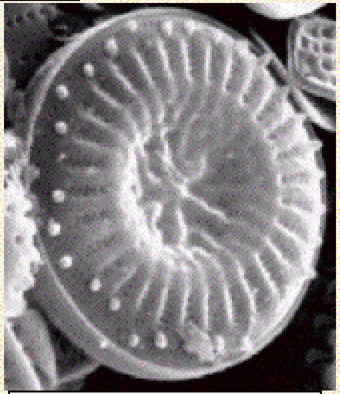
- Terrigenous
  - rock fragments from land, volcanic ash
  - broken down by physical weathering
  - altered by chemical weathering
- Biogenous
  - hard skeletal parts (minerals)
  - silica or carbonate
- Hydrogenous
  - chemical deposits, evaporites, phosphorites
  - Mn nodules (Mn, Fe, Cu, Co, Ni) grow slowly, nucleate on fish teeth, etc.
- Cosmogenous
  - particles from space, tektites, meteorites (Fe-rich)



rock fragment



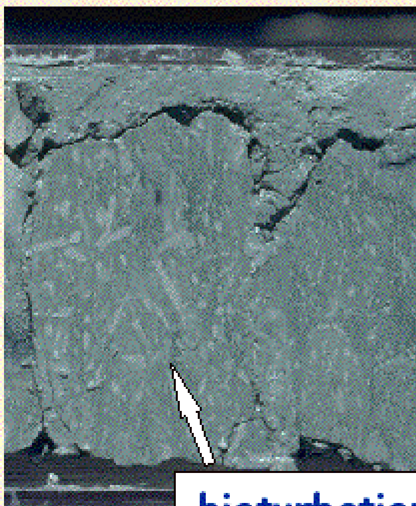
Mn nodule

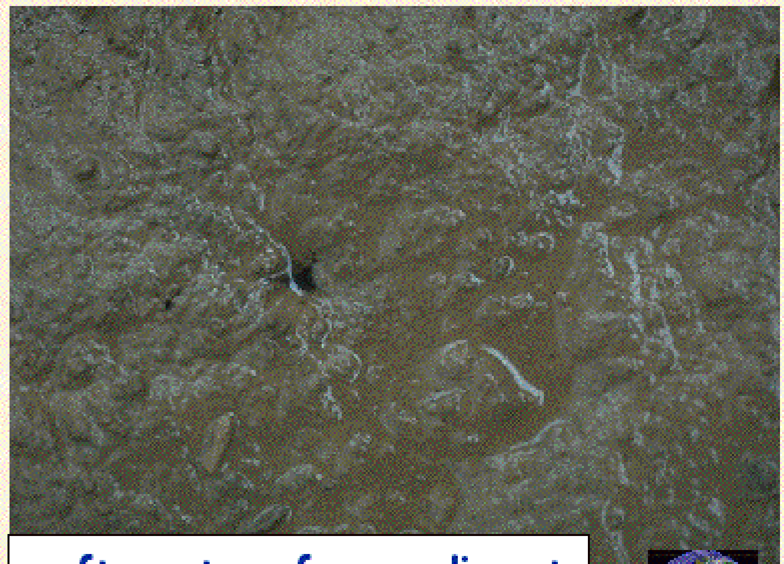


silica: diatom

Sediment Textures:

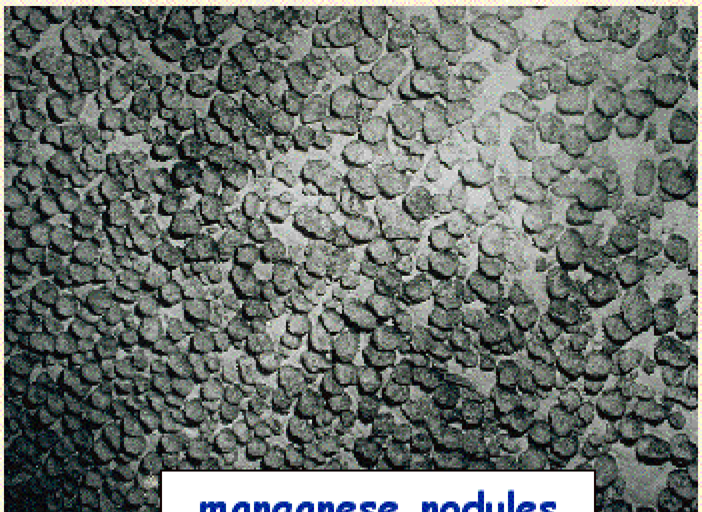
- Fine to coarse
  - wet, soft
  - hard, consolidated
  - bioturbated by organisms



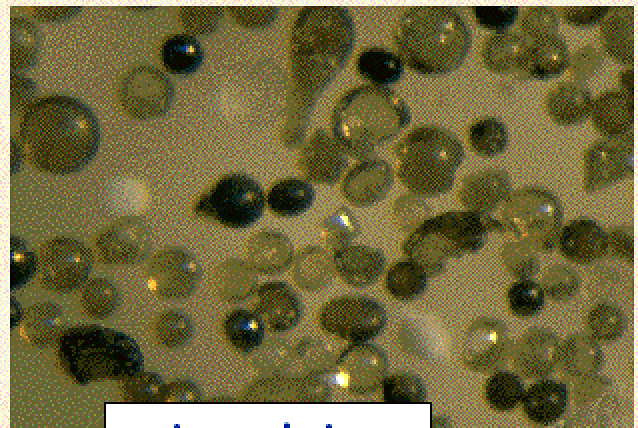


Hydrogenous and Cosmogenous Sediments:

- Hydrogenous:
  - surficial covering of Mn nodules, densely packed in places
  - grow slowly, nucleate on particles, fish teeth, etc.
- Cosmogenous:
  - trace constituents, recognized as glassy spherules



manganese nodules



microtektites

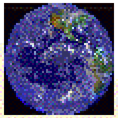
Major Types of Marine Sediments: Summary

- Four Principal Types:
  - Terrigenous, Biogenous, Hydrogenous, Cosmogenous:
  - Differ in terms of their source, character (examples), distribution and extent (% of ocean floor)

Table 5.2 Classification of Marine Sediments by Source of Particles

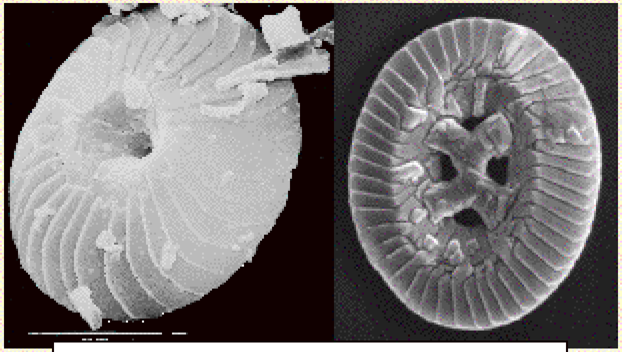
Sediment Type	Source	Examples	Distribution	Percent of All Ocean Floor Area Covered
Terrigenous	Erosion of land, volcanic eruptions, blown dust	Quartz sand, clays, estuarine mud	Dominant on continental margins, abyssal plains, polar ocean oors	~45%
Biogenous	Organic; accumulation of hard parts of some marine organisms	Calcareous and siliceous oozes	Dominant on deep-ocean oor (siliceous ooze below about 5 km)	~55%
Hydrogenous (authigenic)	Precipitation of dissolved minerals *from* water, often by bacteria	Manganese nodules, phosphorite deposits	*Present* with other, more dominant sediments	< 1%
Cosmogenous	Dust *from* space, meteorite debris	Tektite spheres, glassy nodules	Mixed in very small *proportion* with more dominant sediments	0%

Sources: Kennett, 1982; Weihaupt, 1979; Sverdrup, Johnson, and Fleming, 1942.



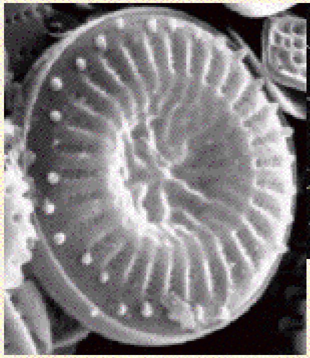
Biogenous Oozes:

- Sediments >30% biogenous
  - diluted by other particles
- Calcareous oozes: carbonate
  - dissolve in deep ocean at low temperatures and high pressures (below CCD < 20% carbonate)
  - dominant in shallow ocean
  - foraminifera (animals), coccoliths (calcareous plants), pteropods (snails)
- Siliceous oozes
  - dissolve slowly
  - diatoms (plants) in nutrient-rich waters (N. Pacific and Antarctica)
  - radiolaria (animals) (equatorial Pacific)

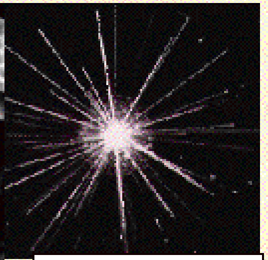


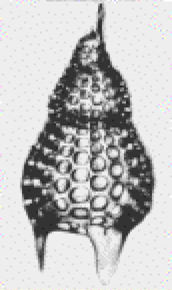
carbonate: coccoliths

pteropod

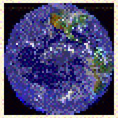


silica: diatom



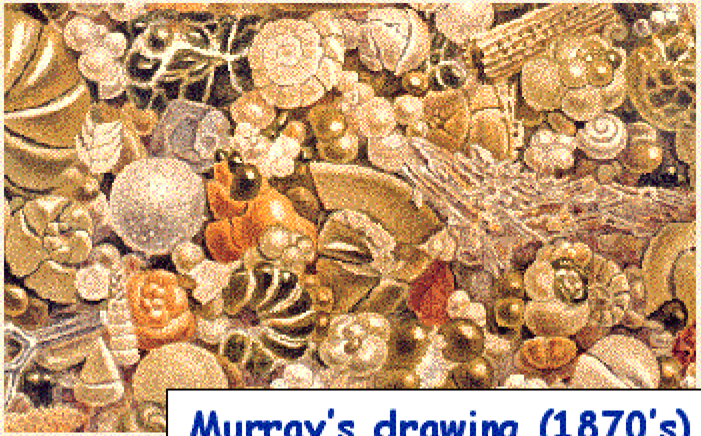


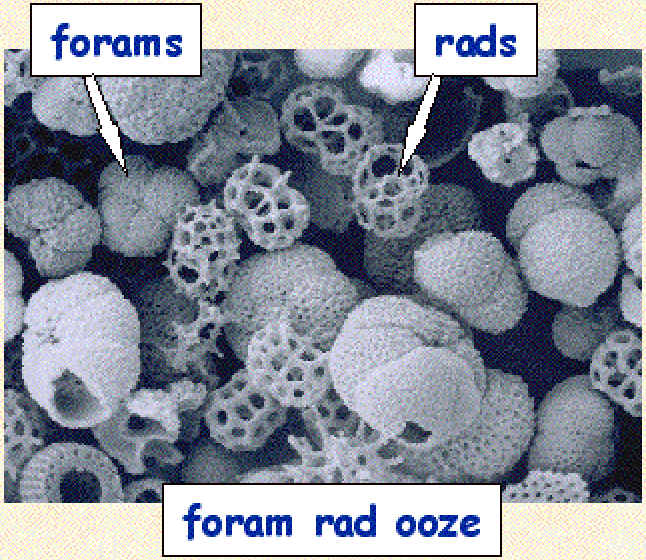
silica: radiolaria



Biogenous Oozes:

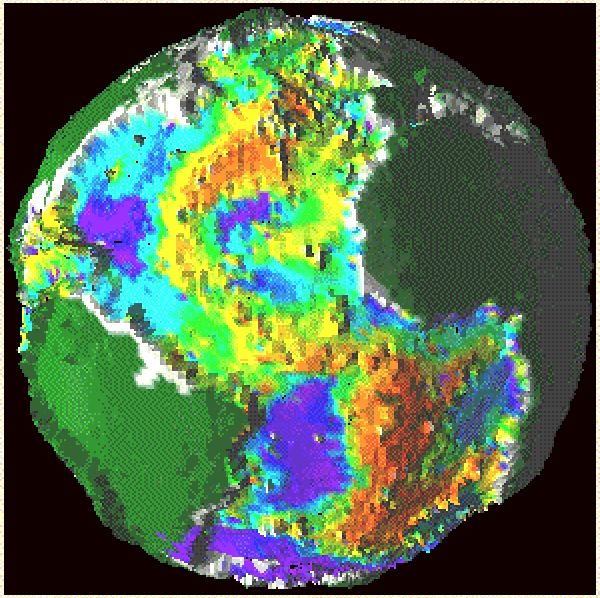
- Various components
  - foraminifera (calcareous)
  - radiolaria (siliceous)
  - diatoms (siliceous)
- Named accordingly

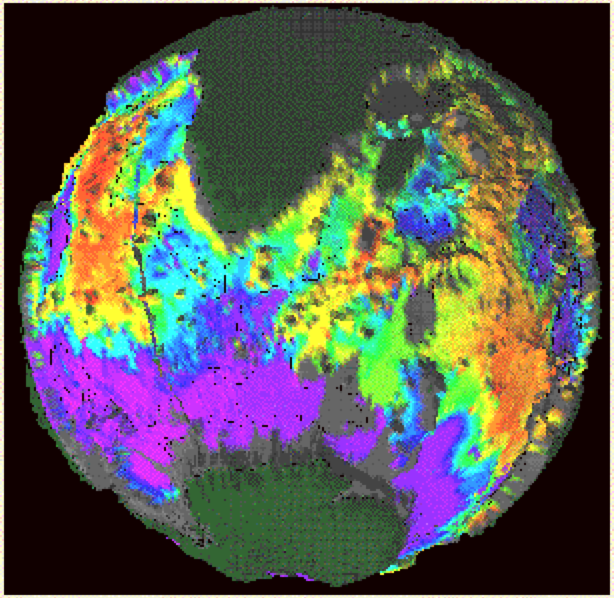


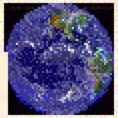


Carbonate Sediments:

- Biogenous, dominant in shallow oceans (e.g. ridges)
- Carbonate is dissolved in deep ocean

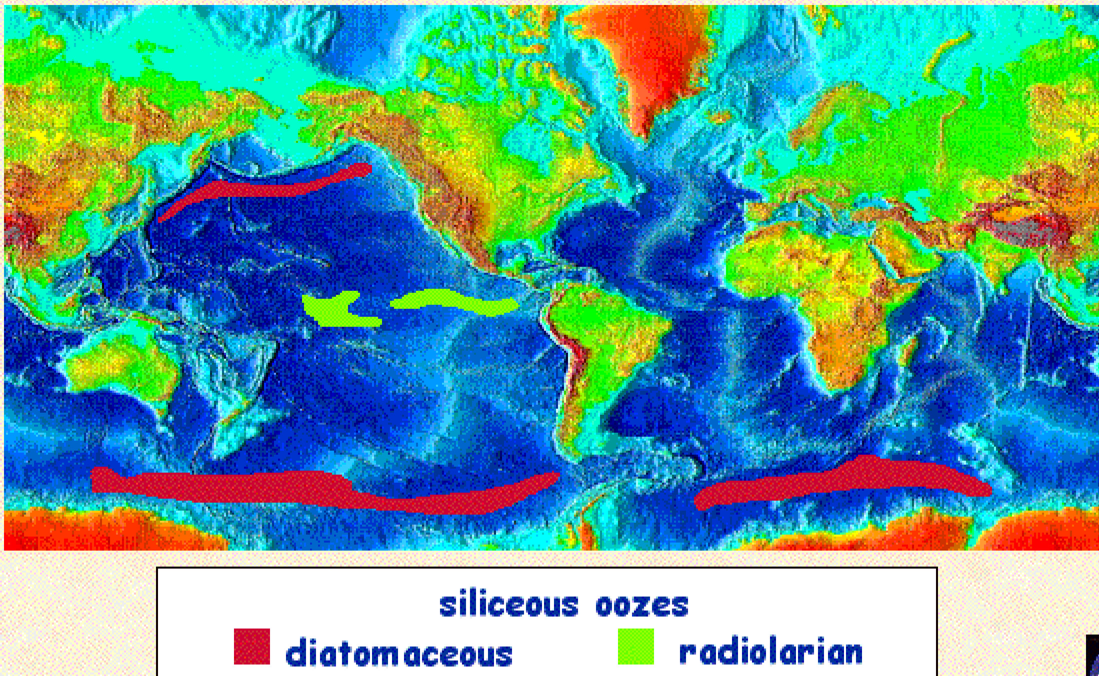






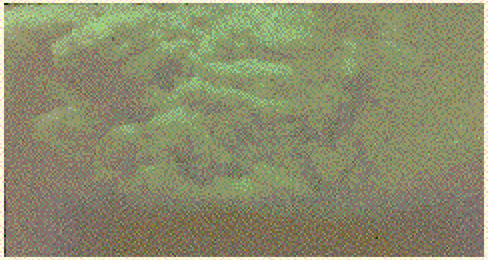
Siliceous Oozes:

- Areas of high nutrients, cold waters
  - two types: diatomaceous oozes, radiolarian oozes

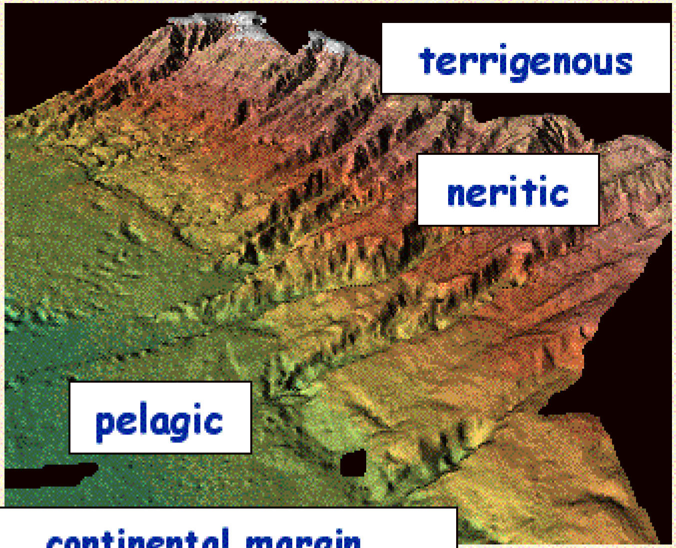


Red Clays and Types of Sediment Deposits:

- Red clays
  - very fine, oxidized lithogenous sediments in Pacific
- Three terms applied to sediments
  - terrigenous
    - land-derived sediments
  - neritic (mixed)
    - shallow water deposits
  - pelagic
    - deep sea sediments



transport by turbidity currents

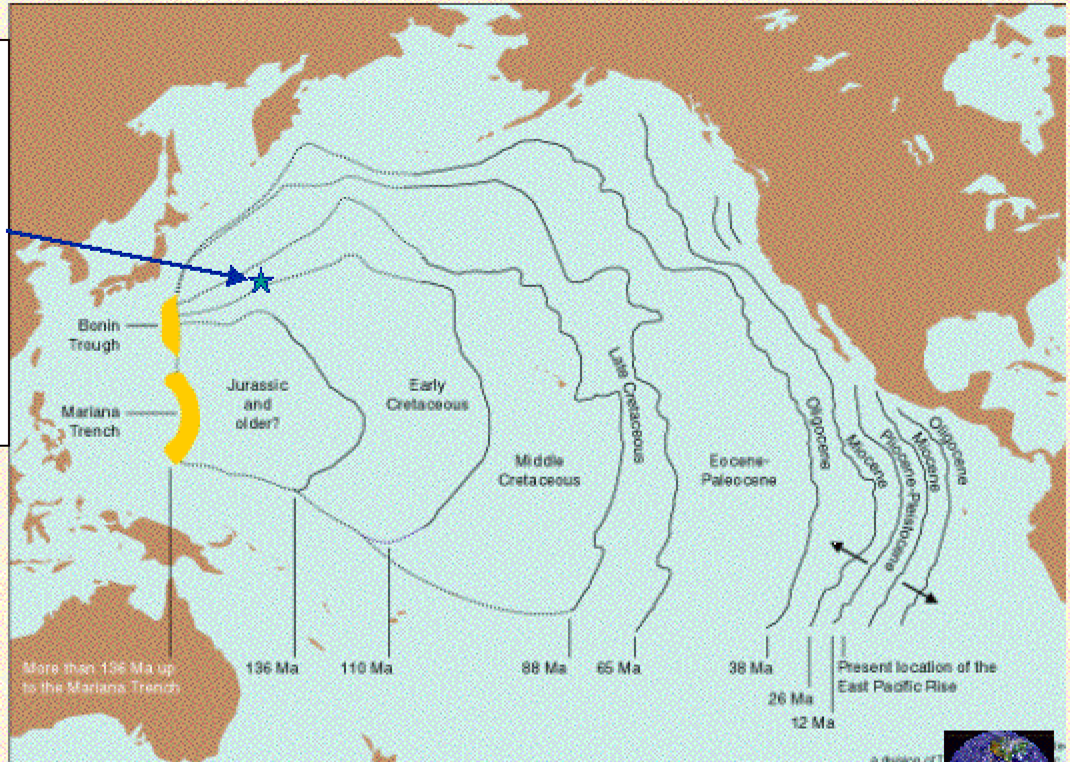


continental margin sediments change from shallow to deep waters

Age of Sediments:

- Increases westward from East Pacific Rise

Early Cretaceous sediments recovered on Shatsky Rise (ODP Leg 198)



Sediment Transport:

- Balance between Erosion, Transport and Deposition
  - depends on size and current velocity
- Sediment Thickness
  - depends on transport processes, sites of accumulation

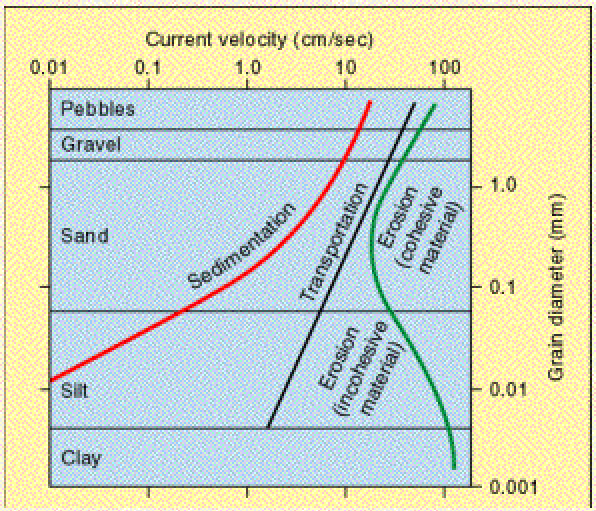


Table 5.3 The Distribution and Average Thickness of Marine Sediments

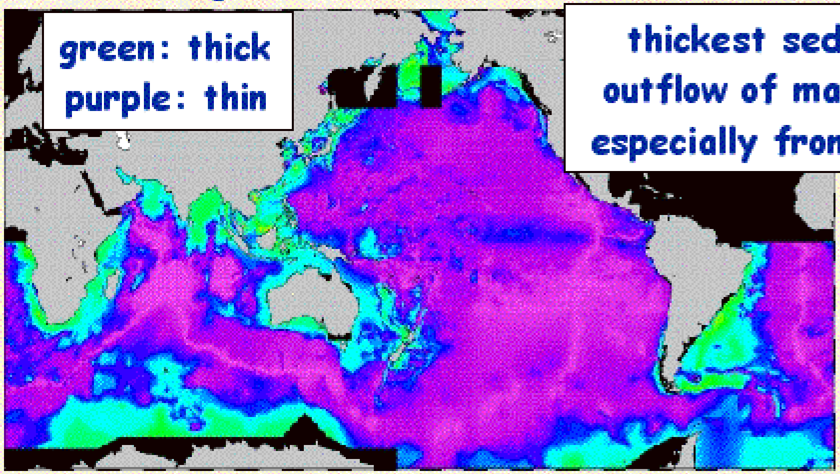
Region	Percent of Ocean Area	Percent of Total Volume of Marine Sediments	Average Thickness
Continental shelves	9%	15%	2.5 km (1.6 mi)
Continental slopes	6%	41%	9 km (5.6 mi)
Continental rises	6%	31%	8 km (5 mi)
Deep-ocean *floor*	78%	13%	0.6 km (0.4 mi)

Sources: Emery in Kennett, *Marine Geology*, 1982 (Table 11.1); Weihaupt, *Exploration of the Oceans*, 1979; Sverdrup, Johnson, and Fleming, *The Oceans: Their Physics, Chemistry and General Biology*, 1942

Sediment Thickness:

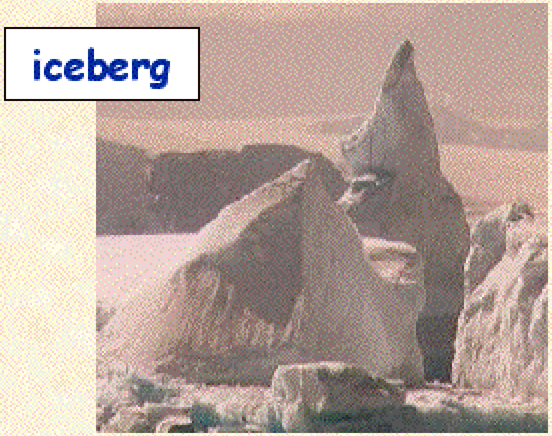
- Terrigenous sediments transported to ocean
  - rivers, ice, wind, dusts, fine particles, volcanoes
- Dependent on crustal age, accumulation rate
  - range: <1 cm/ka to 8 m/a

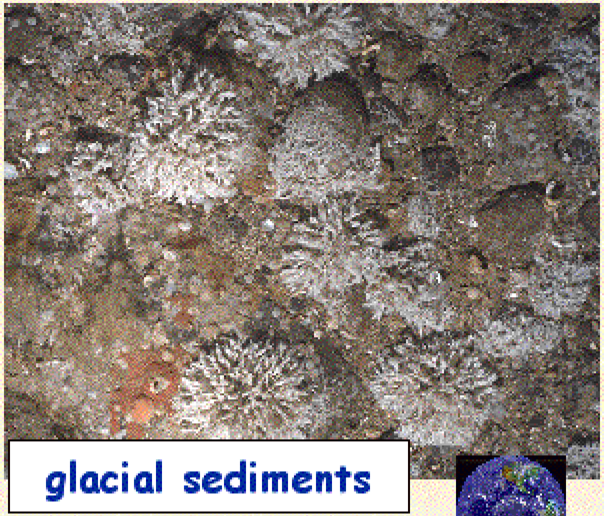
Input source	Input amount (10^9 tons/yr)
Rivers	18.3
Glaciers and ice sheets	2.0
Wind-blown dust	0.6
Coastal erosion	0.25
Volcanic debris	0.15
Groundwater	<0.48



Glacial Sediments:

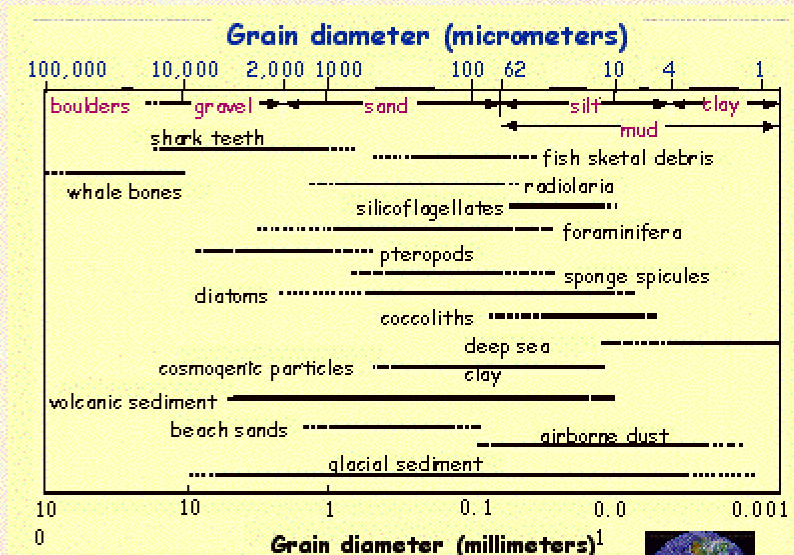
- Terrigenous deposits:
  - scoured from land by glaciers
  - ice-rafted into the ocean
  - deposited when iceberg melts
  - mixed sizes of particles

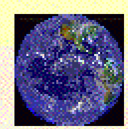




Particle Size:

- Size categories (terrigenous materials):
  - gravel (boulders, cobbles, pebbles, granules) >2 mm
  - sand (very coarse to very fine) 0.06 - 2 mm
  - silt 0.004 - 0.06 mm
  - clay < 0.004 mm
- Biogenous materials vary dependent on organism
  - coccoliths < forams < rads < pteropods
- Wide range of sizes for glacial and volcanic particles
- Fine-grained dusts





Sediment Sorting and Settling Rates:

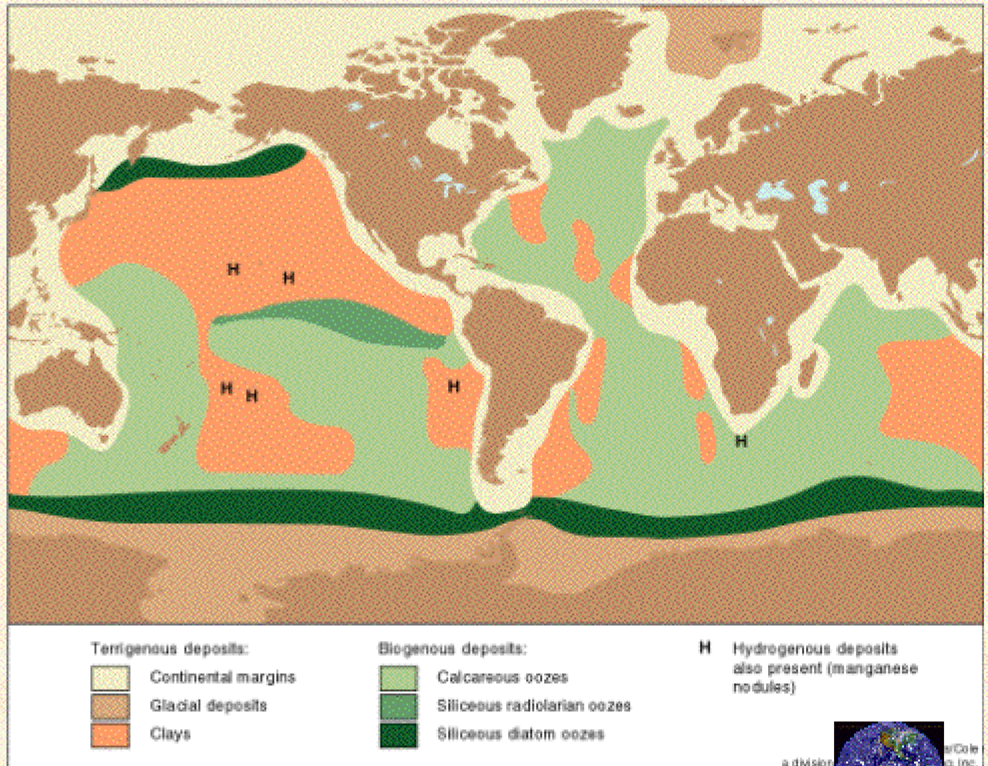
- Size of sediment particles
  - similar: well sorted, mixed: poorly sorted
- Settling rates of sediment particles
  - larger particles settle faster
    - sand: ~2.5 cm/s, silt: ~0.025 cm/s, clay: < 0.00025 cm/s
  - aided by aggregation and as fecal pellets

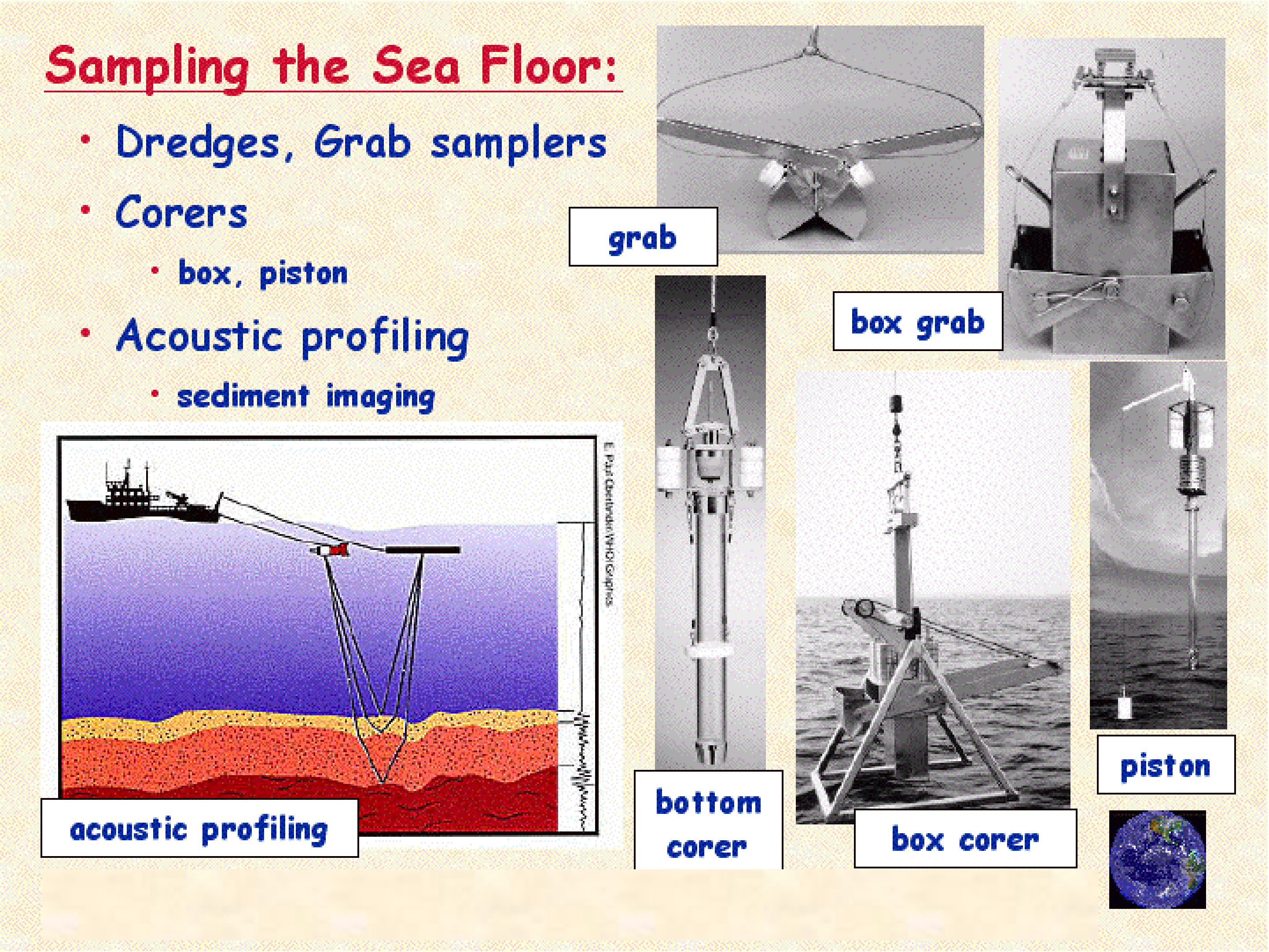
Particle	Diameter	Settling velocity	Time needed to settle 4 km
Boulder	> 256 mm	—	—
Cobble	64-256 mm	—	—
Pebble	4-64 mm	—	—
Granule	2-4 mm	—	—
Sand	0.062-2 mm	2.5 cm/sec	1.8 days
Silt	0.004-0.062 mm	0.025 cm/sec	6 months
Clay	< 0.004 mm	0.00025 cm/sec	50 years*

poorly sorted sand/gravel

Global Distributions of Sediments:

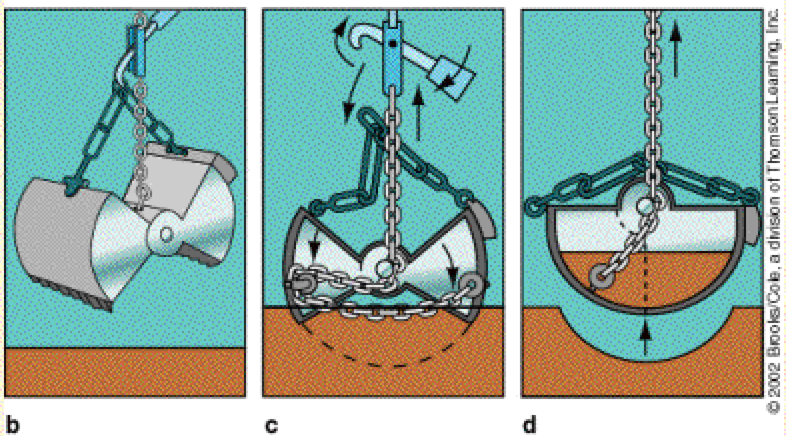
- Terrigenous:
  - continental, glacial, clays
- Biogenous:
  - calcareous, radiolarian & diatomaceous oozes
- Hydrogenous:
  Mn nodules



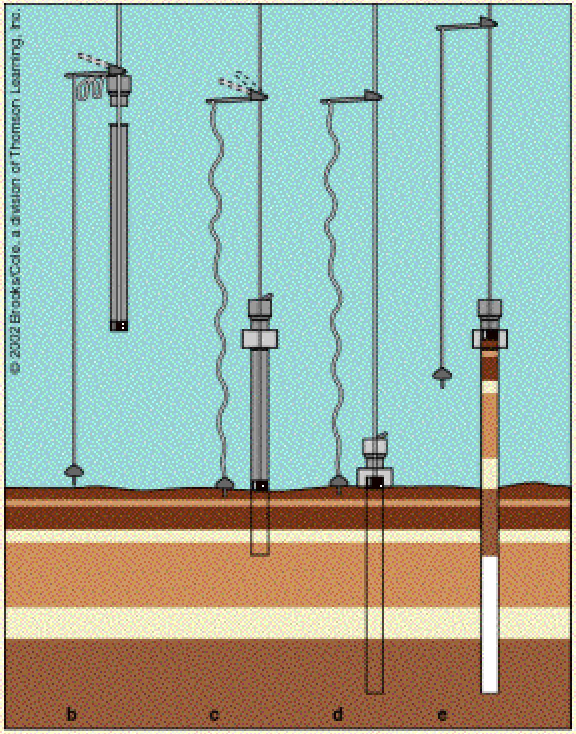

Sampling the Sea Floor:
• Dredges, Grab samplers
• Corers
• box, piston
• Acoustic profiling
• sediment imaging
grab
box grab
bottom corer
box corer
piston
acoustic profiling

Grab and Core Samples:

- Grab samplers
  - recover sediment in bulk
- Piston Coring
  - recover sediment undisturbed
  - layering sequence preserved



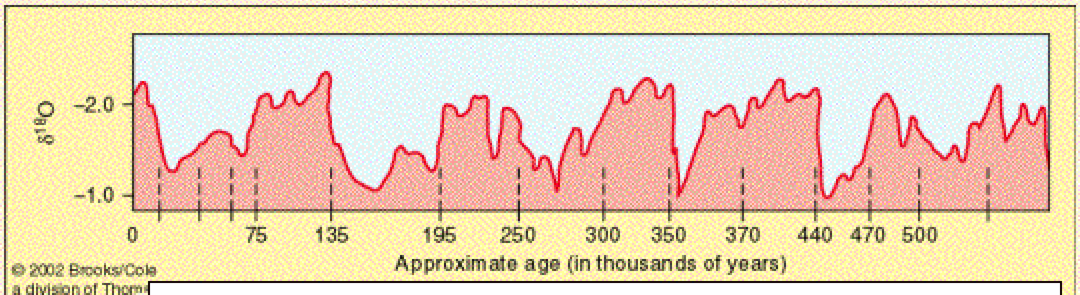
grab sampling



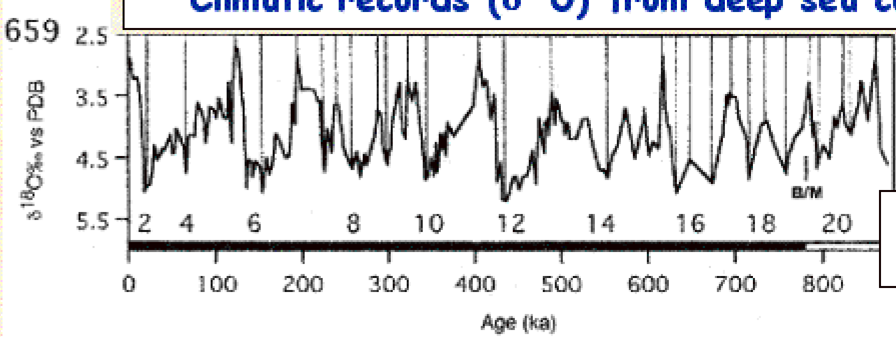
piston coring: recovers sediment layers in sequence

Climate Records:

- oxygen isotopes in planktic foraminifera record temperature changes
  - high resolution climate records

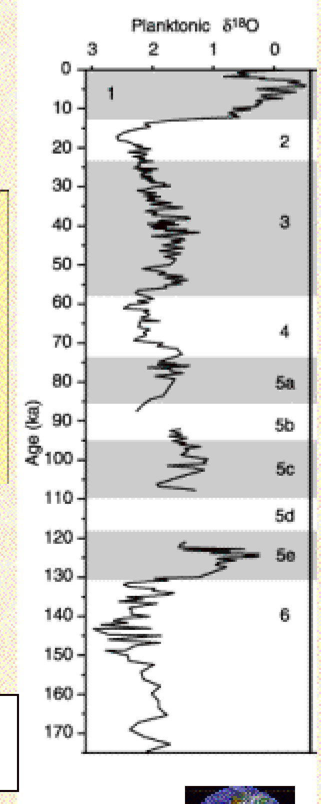


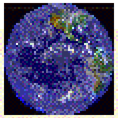
Climatic records (δ18O) from deep sea cores



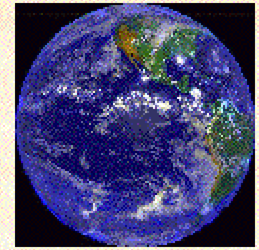
isotopic stages

high resolution





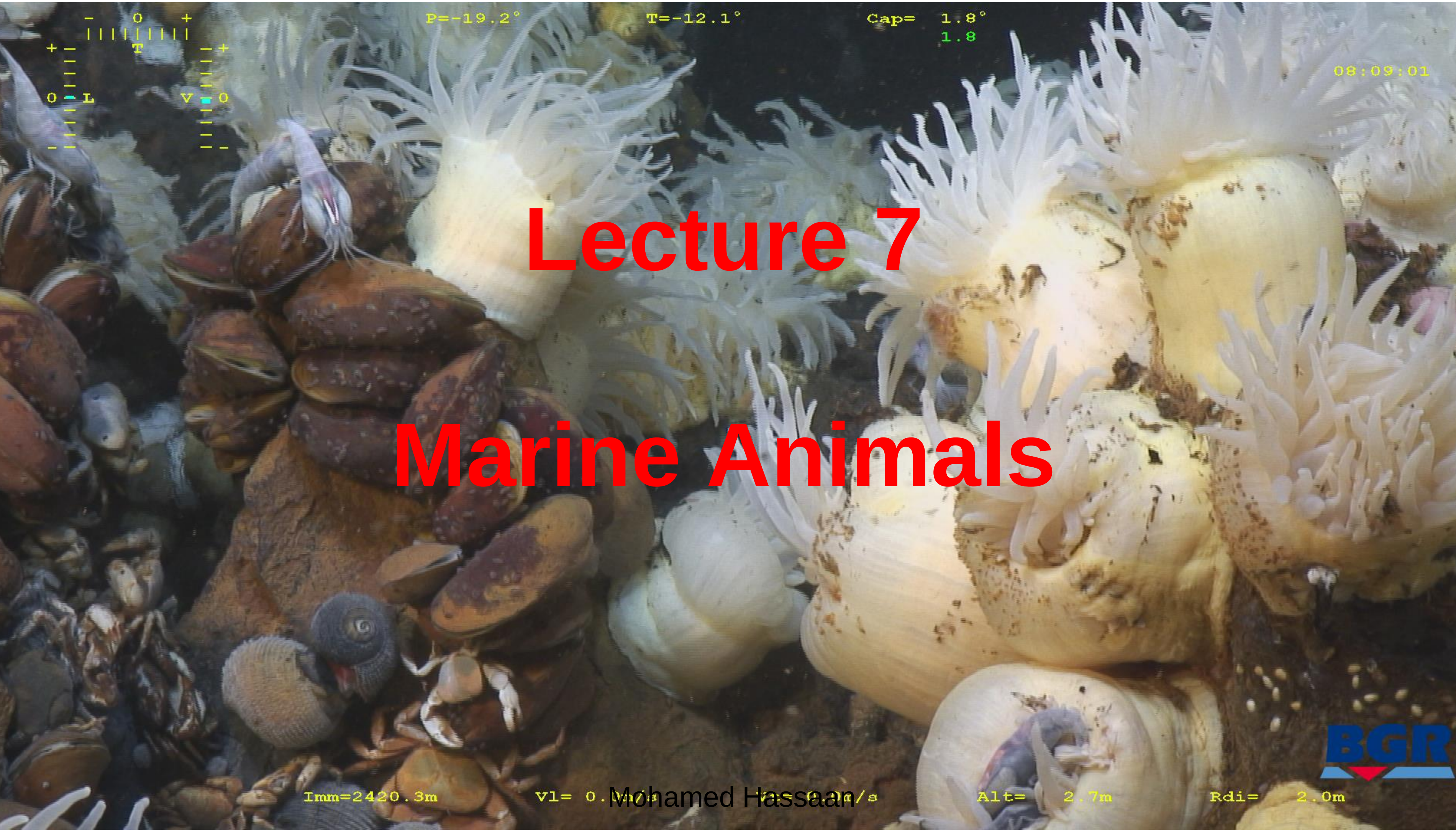
Oceans & Our Global Environment



Sea Floor Sediments

Key Concepts:

- Major Types of Sediments and their Sources
  - terrigenous, biogenous, hydrogenous, cosmogenous
  - biogenic oozes, red clays
  - modes of transportation: turbidity currents, wind, ice
- Patterns of Sediment Deposits
  - global occurrences of sediment types, particles sizes, sorting, settling rates
- Approaches to Sediment Sampling



Lecture 7

Marine Animals

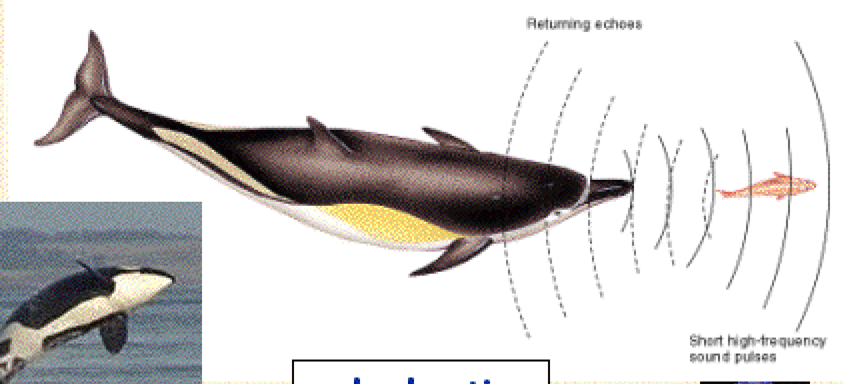
Mohamed Hassaan

Cetaceans:

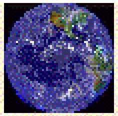
- Whales, Dolphins, Porpoises
  - warm-blooded, air-breathing mammals
  - herbivores and carnivores
  - baleen whales and toothed whales
    - baleen: filter feeders on zooplankton (e.g. krill)
    - toothed: feed on fish, squid, crustacea, seals
  - use echo-location to find prey, emitting high & low frequency sound clicks, receiving echoes

gray whale: a baleen whale

killer whale (Orca): a toothed whale

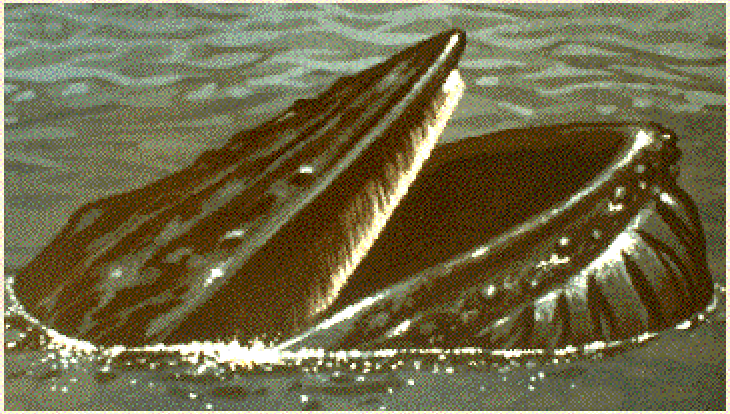


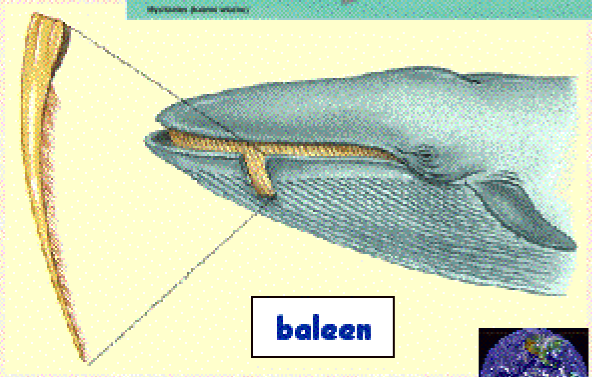
echo-location

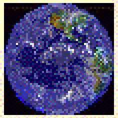


Baleen Whales (Mysticetes):

- Feeding Strategy
  - several swim open-mouthed
  - filter feed on abundant zooplankton trapped by baleen, aided by tongue
  - some migrate great distances
  - large size; all 'great' whales are baleen whales, except sperm whales

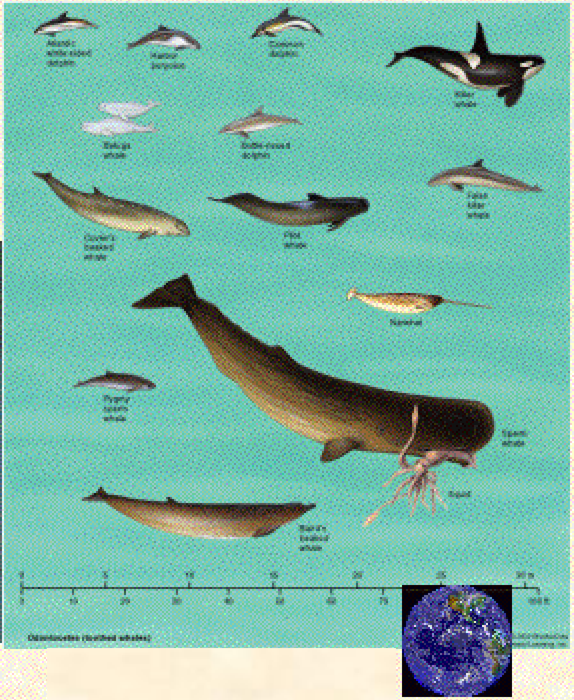






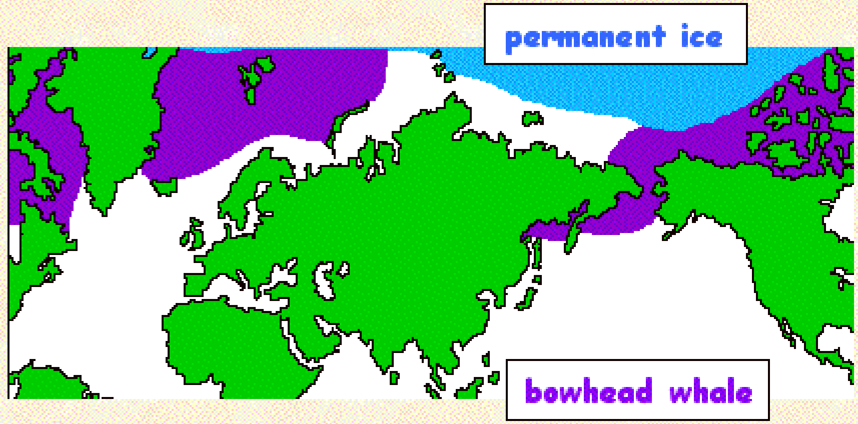
Toothed Whales (Odontocetes):

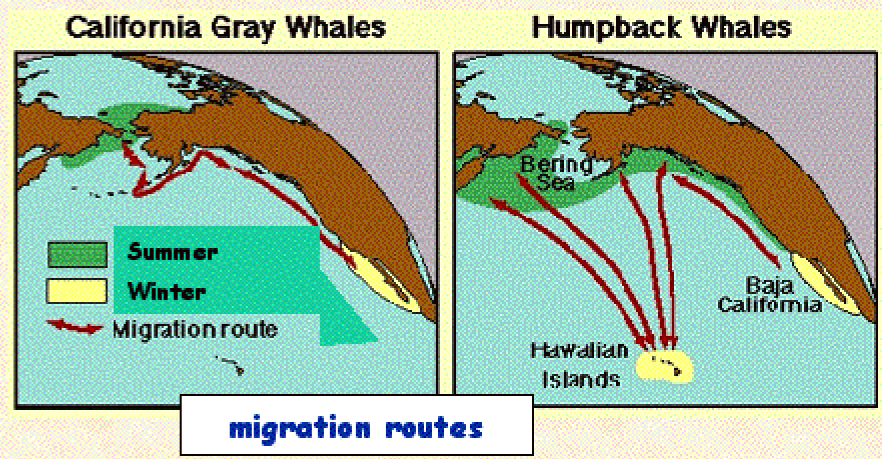
- Feeding Strategy
  - Pursue, catch prey
  - Feed on fish, seals, squid
  - inhabit polar, temperate and tropical regions
  - mainly small, except sperm whale

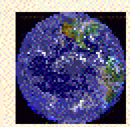


Whale Migrations:

- Distances
  - short or long
- Bowhead Whales
  - year-long arctic residents
- Gray Whales
  - Summer:
    - Arctic Ocean, Bering Sea
  - Winter:
    - Baja California
- Humpback Whales
  - Summer:
    - Bering Sea
  - Winter: Baja California, Hawaii





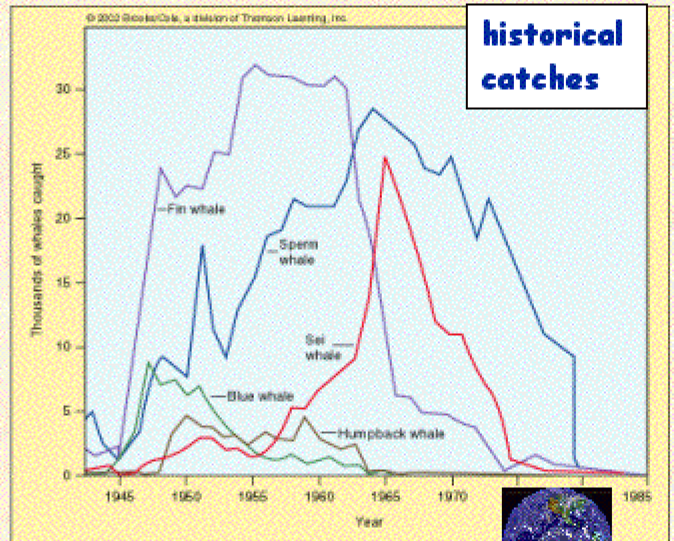


Whaling:

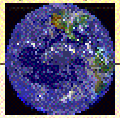
- Consequence of Unrestricted Whaling
  - populations decimated until harvest limited by scarcity
  - catches reflect trends: blue, then fin, then sperm and sei
  - international restrictions now in place (Norway in dispute)
  - all 'great' whales severely depleted, except:
    - gray whale (recovered)
    - minke whale (sustained)

Number of Whales	Species	Nation	Total Value (US$ millions)
276	Minke	Japan	55.2
130	Minke	Greenland	26.0
68	Finback	Iceland	68.0
10	Sei	Iceland	5.0
168	Gray	U.S.S.R.	Subsistence
3	Humpback	Bequia	Subsistence
29	Bowhead	U.S.A.	Subsistence
684			$154.2

annual harvests



historical catches

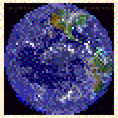


Pinnipeds (Possess Flippers):

- Seals, Sea Lions, Walruses:
  - feed on shells, fish, penguins
  - seals have no external ears
  - walruses have tusks
- Human Influences:
  - fur seal hunted for coats
  - walruses for ivory
  - populations affected by pollutants

California sea lions

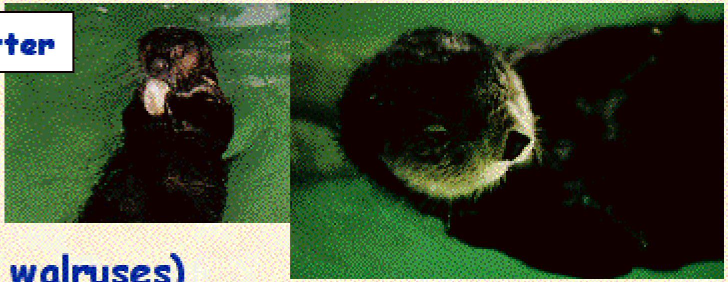
walruses



Marine Mammals:

- Major Groups:
  - cetaceans (whales, dolphins, porpoises)
  - pinnipeds (seals, sea lions, walruses)
  - sea otters (Alaska to California)
    - feed on abalone, clams, urchins
  - sea cows (manatees, dugongs)
    - herbivores living in warm waters
    - Caribbean, Asia, Australia, Africa
    - boat collisions kill or injure many

sea otter



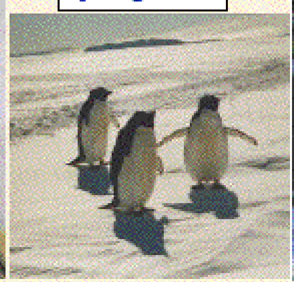
manatee

Marine Birds:

- Lifestyle
  - adaptations: webbed feet, waterproofing (preen)
  - nest on land, near ocean food supply
  - feed on fish, shellfish
  - wading: herons, egrets
  - diving: pelicans, cormorants
  - swimming: penguins

sandlings

pelican

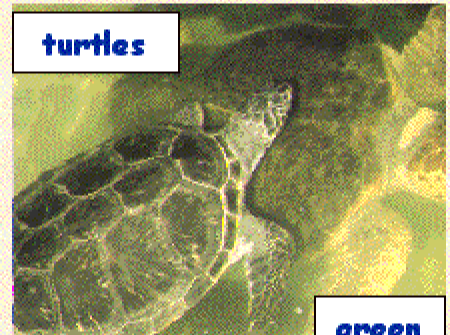


penguins

Marine Reptiles:

- Marine Reptiles:
  - sea turtles: migrating herbivores
  - sea snakes
  - marine iguanas (Galapagos) feed on algae

leatherback



turtles

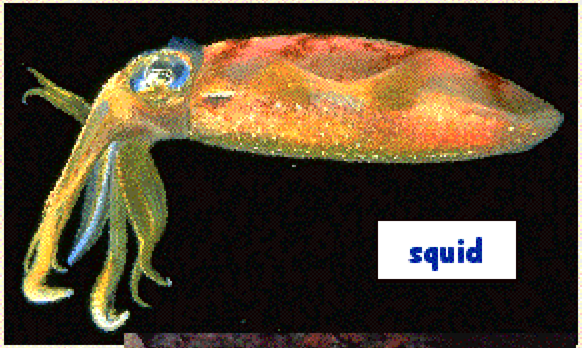
green

marine iguana

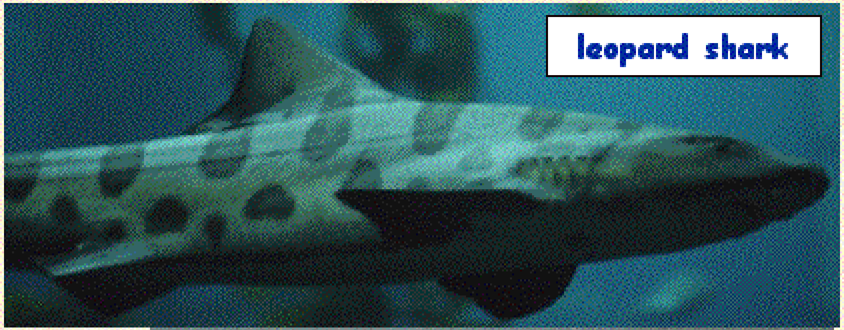
sea snake

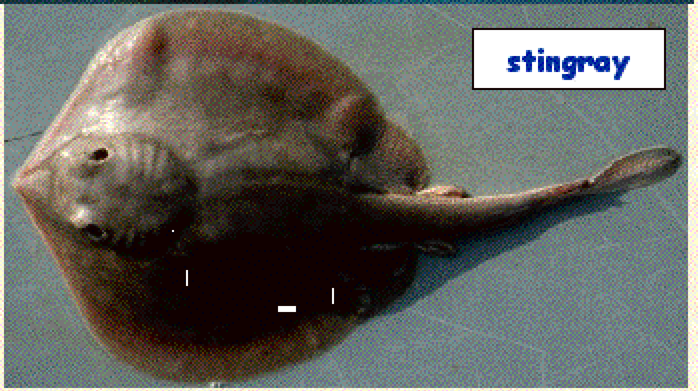
Squid & Fish:

- Squid (Swimming Mollusks):
  - live at mid-depth and migrate to surface at night
  - expel water via funnel to swim
  - catch prey with tentacles
- Fish: Two Major Groups
  - cartilaginous fish: cartilage skeletons — sharks & rays
  - bony fish: bone skeletons
  - populate all ocean depths

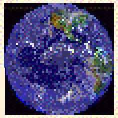


Sharks and Rays:



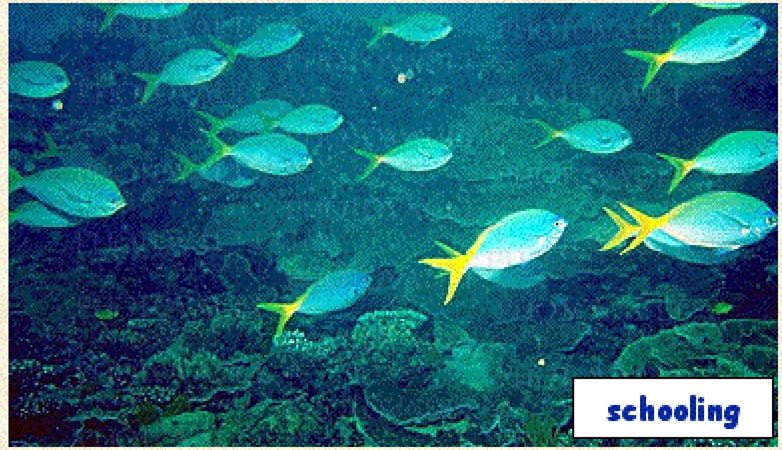


- Cartilaginous Fish
  - 'primative' fish
  - cartilage skeletons
  - plates, denticles, not scales
  - swim constantly
- Sharks
  - acute sense of smell, taste
  - electric fields
  - plankton feeders (basking shark)
  - predators (great white) with serrated teeth
- Rays
  - use electric fields, mostly carnivores feeding on fish, mollusks
  - some plankton feeders (manta ray)



Bony Fish:

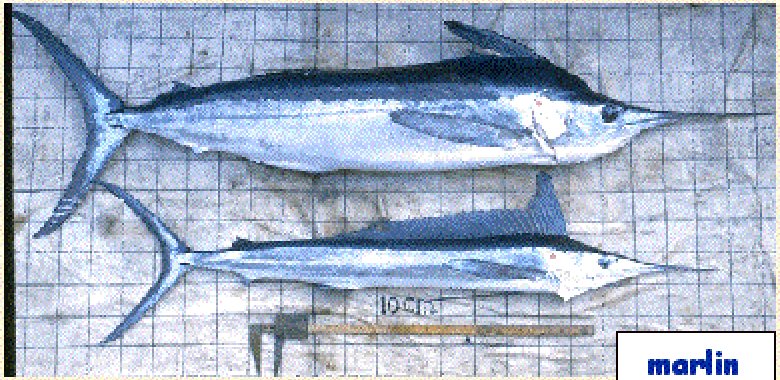
- Characteristics:
  - shapes, colors reflect lifestyle, habitat, feeding strategies, schooling
  - concealment vs. speed: reflected in body shape and coloring
  - most are streamlined predators
  - demersal fish: flatfish living on ocean floor
  - open ocean: tuna, salmon
  - deep-ocean: predators, live in colder waters, may use lures (e.g. angler fish)


schooling


clown fish

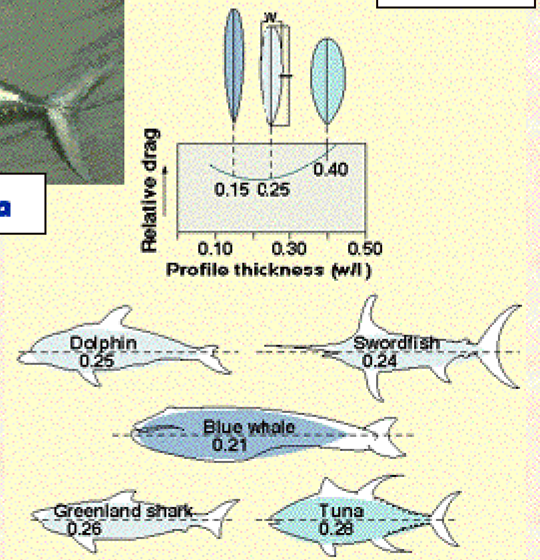
Body Shape:

- Adaptation for Speed
  - swim by body waves
  - fusiform shape to reduce drag
- Demersal Fish
  - flatfish living on ocean floor
  - eyes rotated to same side of body
  - move slowly, often camouflaged

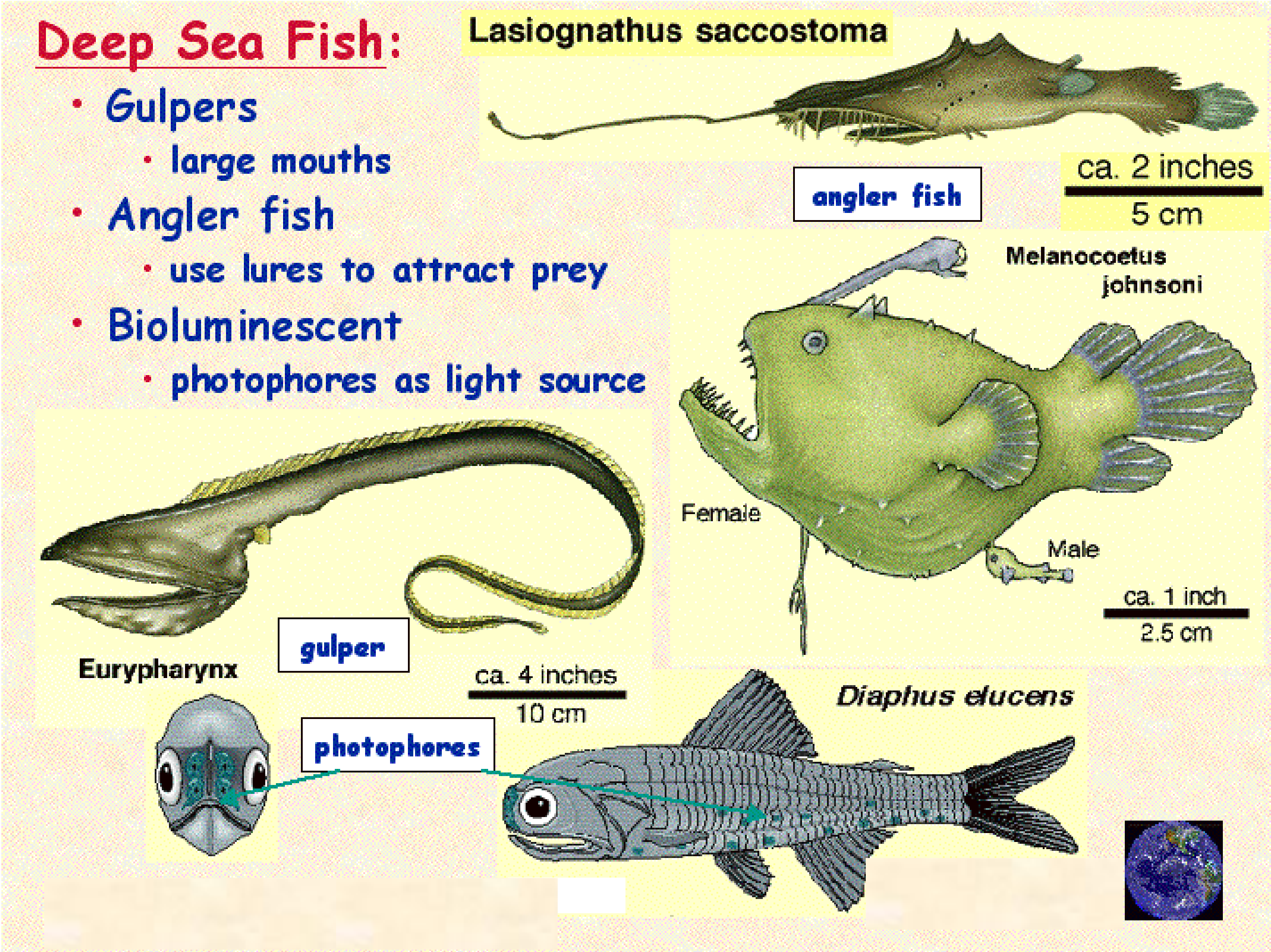


marlin

tuna



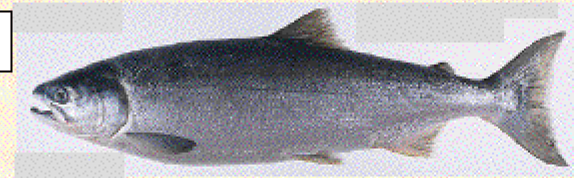
sole


Deep Sea Fish:
• Gulpers
• large mouths
• Angler fish
• use lures to attract prey
• Bioluminescent
• photophores as light source
Lasiognathus saccostoma
ca. 2 inches
5 cm
angler fish
Melanocoetus johnsoni
Female
Male
ca. 1 inch
2.5 cm
Eurypharynx
gulper
ca. 4 inches
10 cm
Diaphus elucens
photophores

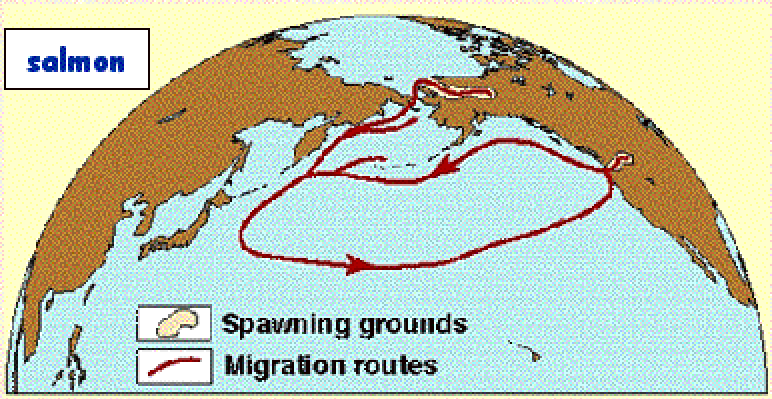
Fish Migration:

- Anadromous: e.g. salmon
  - spawn and grow in freshwater, live in ocean
  - in North Pacific spawn in Alaskan, Washington and B.C. rivers
- Catadromous: e.g. eels
  - spawn in Sargasso Sea, return to fresh waters in Europe, N. America

salmon



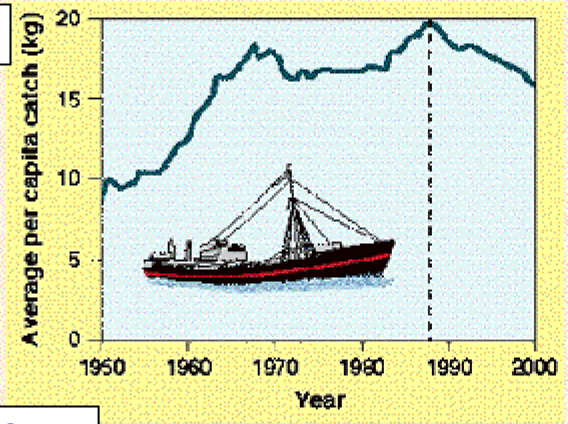
eels



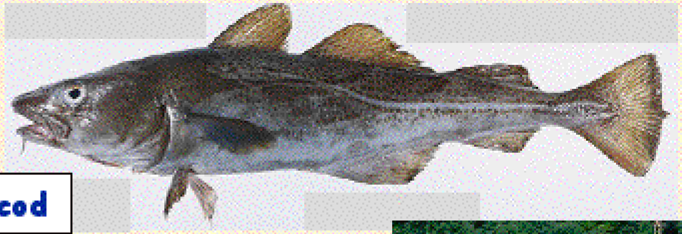
Fishing:

- Herring:
  - sardines, anchovies; for Peruvian fishing affected by El Niño events
- Cod:
  - stocks decimated by overfishing
  - harvests plumetted in 1970's

catch

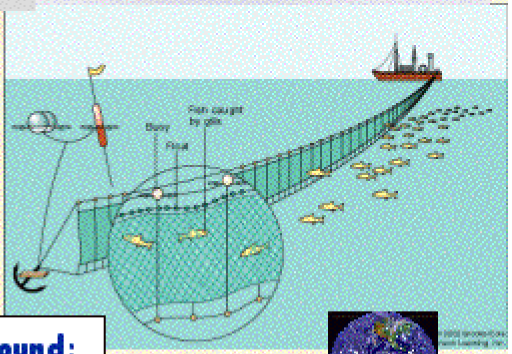


salmon

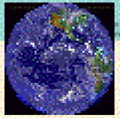


cod

- Salmon:
  - diminishing stocks
  - affected by river pollution?

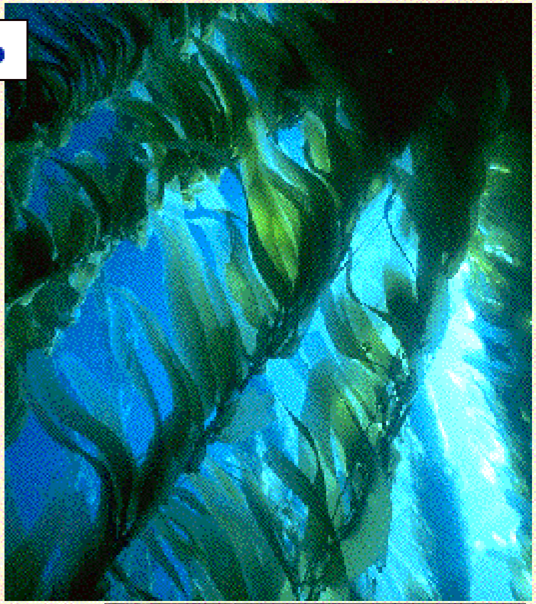


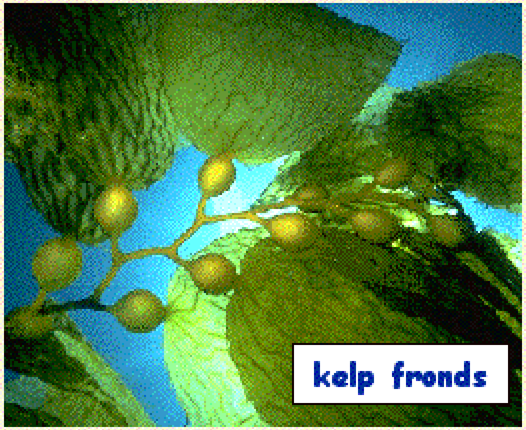
Prince William Sound: salmon fishing

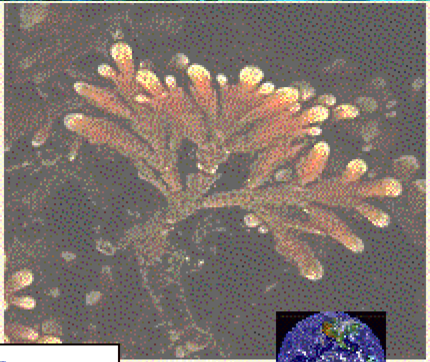


Benthic Algae:

- Plants (seaweeds):
  - red, green and brown algae
  - kelp, large brown benthic alga, with fronds (blades) buoyed by gas-filled bladders
  - photosynthetic, dependent on sunlight, live within photic zone
  - anchored to sea floor by holdfast



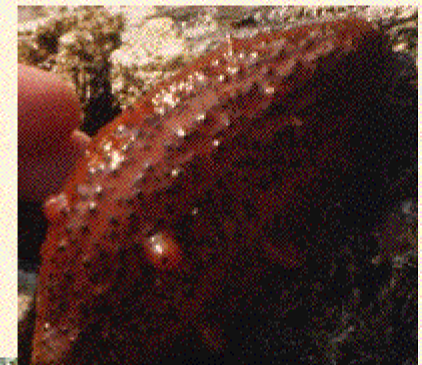




Benthic Animals:

- Two major lifestyles:
  - infauna: buried animals, deposit or filter feeders
  - epifauna: surface animals
  - strategies:
    - attachment: filtering of seawater
    - free movement: predation
    - burrowing: sediment digestion
  - decrease from land

blue clam



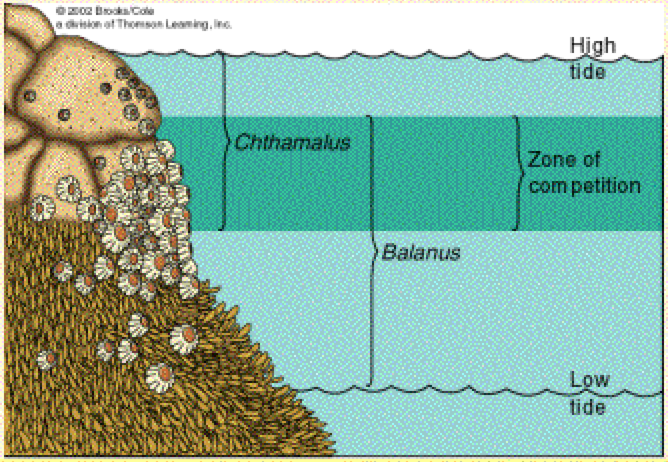
sea cucumber

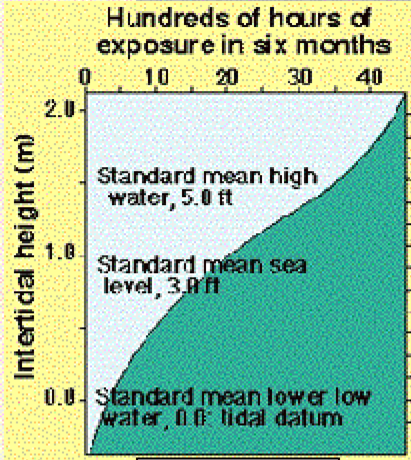
anemone

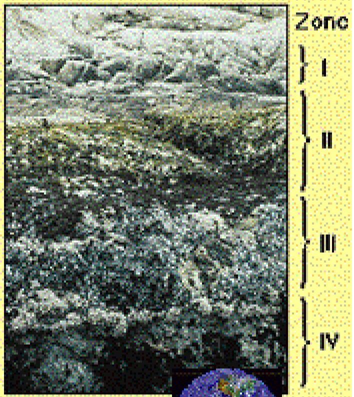
starfish

Intertidal Zone:

- Zonation:
  - dependent on tide levels
  - assemblages of plants and animals
  - competition for living space; shelters
  - benthic algae grazed by animals



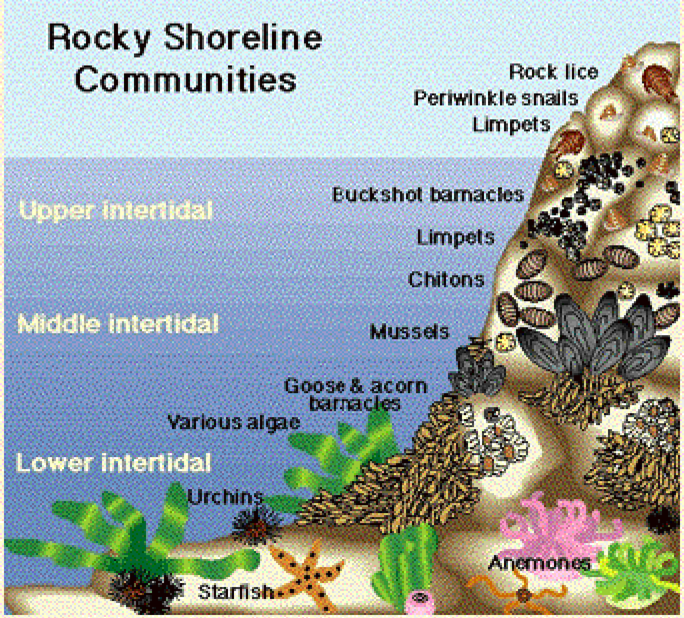




zonation

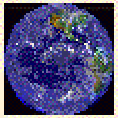
Rocky Shores:

- Major Features:
  - highest levels wetted by spray
  - firm attachment required within littoral zone
  - hierachy dependent on water level



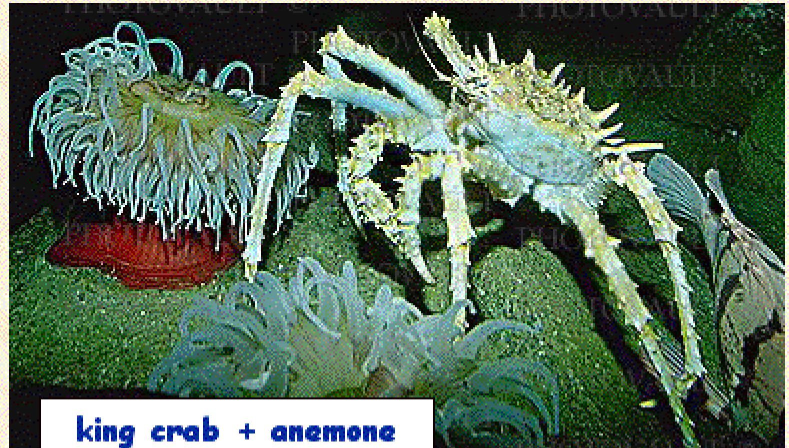
octopus

crab



Rocky Shores:

- Tide pools:
  - specialized organisms adapted to conditions that can change rapidly
  - crabs, starfish, anemones, octopi

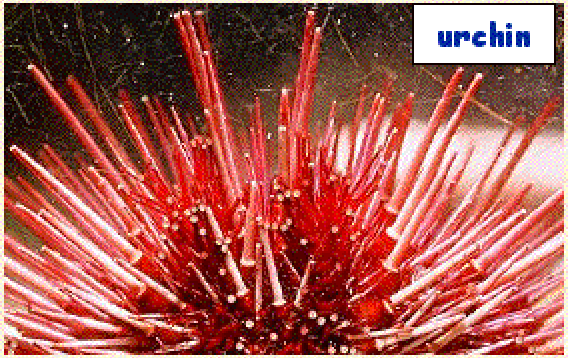

king crab + anemone

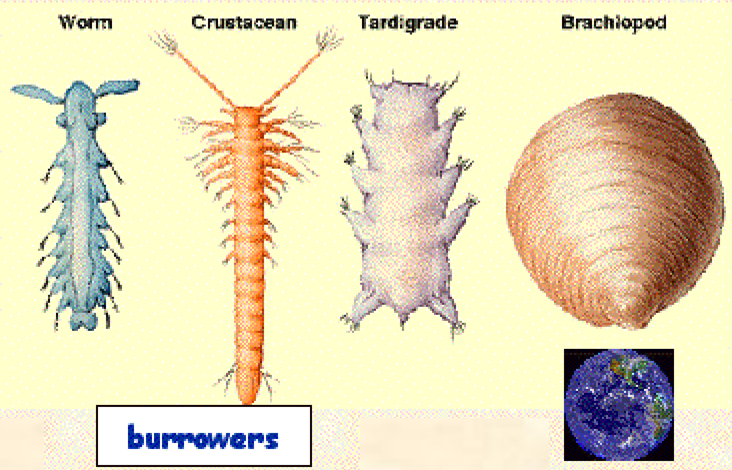

starfish


sponge

Muddy/Sandy Bottom Communities:

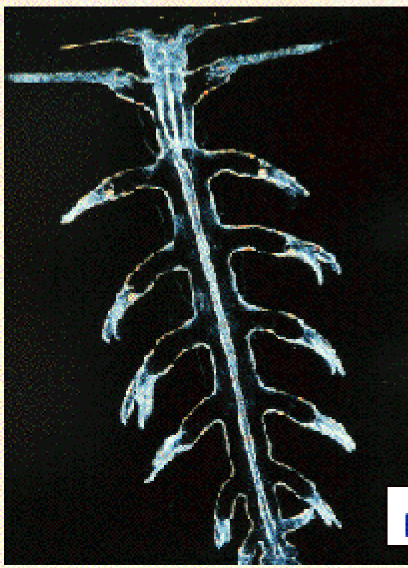
- Inhabited by infauna and occupied by epifauna:
  - suspension feeders in coarse sands
  - ingestions in fine muds
  - burrowers may pump water or ingest sediment
  - bound sediments reduces turbidity and excludes suspension feeders



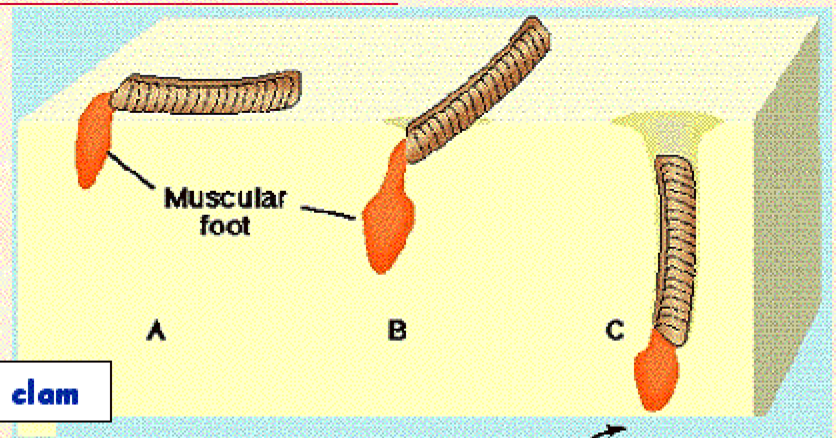


Muddy/Sandy Bottom Communities:

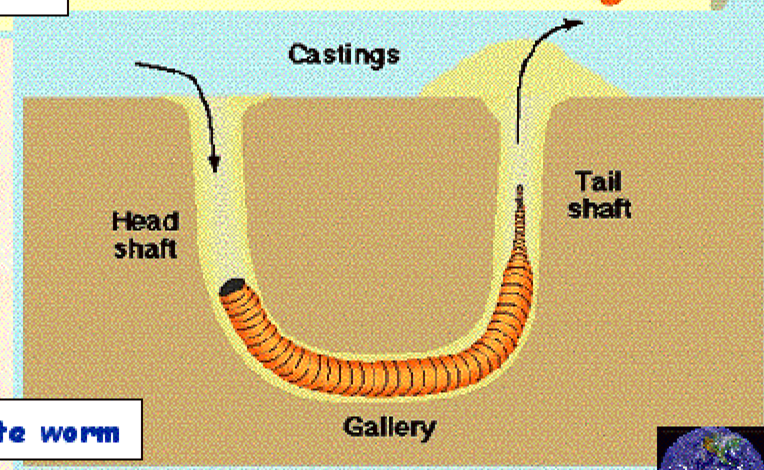
- Infauna:
  - clams: pump and filter water
  - worms: ingest sediment



polychaete worm



clam



Benthos:

- Deep Ocean:
  - predators, brittle stars, crinoids
- Coral Reefs:
  - colonial animals, building calcareous skeletons
  - in waters >18°C
  - support entire community of organisms
  - shaped by wave action and storms

sponges on coral

flower coral

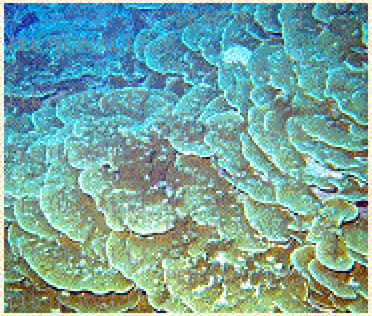
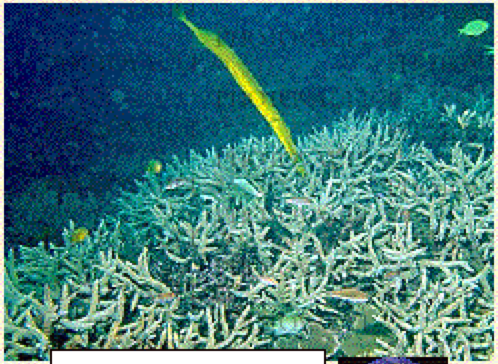


plate coral

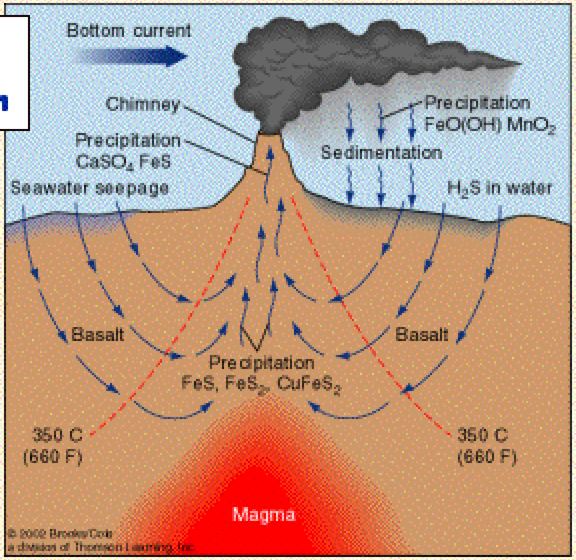


staghorn coral

Vent Communities:

- Dependent on bacterial chemosynthesis:
  - food chain: bacteria, worms, clams, crabs, fish
  - all adapted to vent environment
  - also found at oil/gas seepages

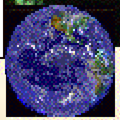
vent system



smokers

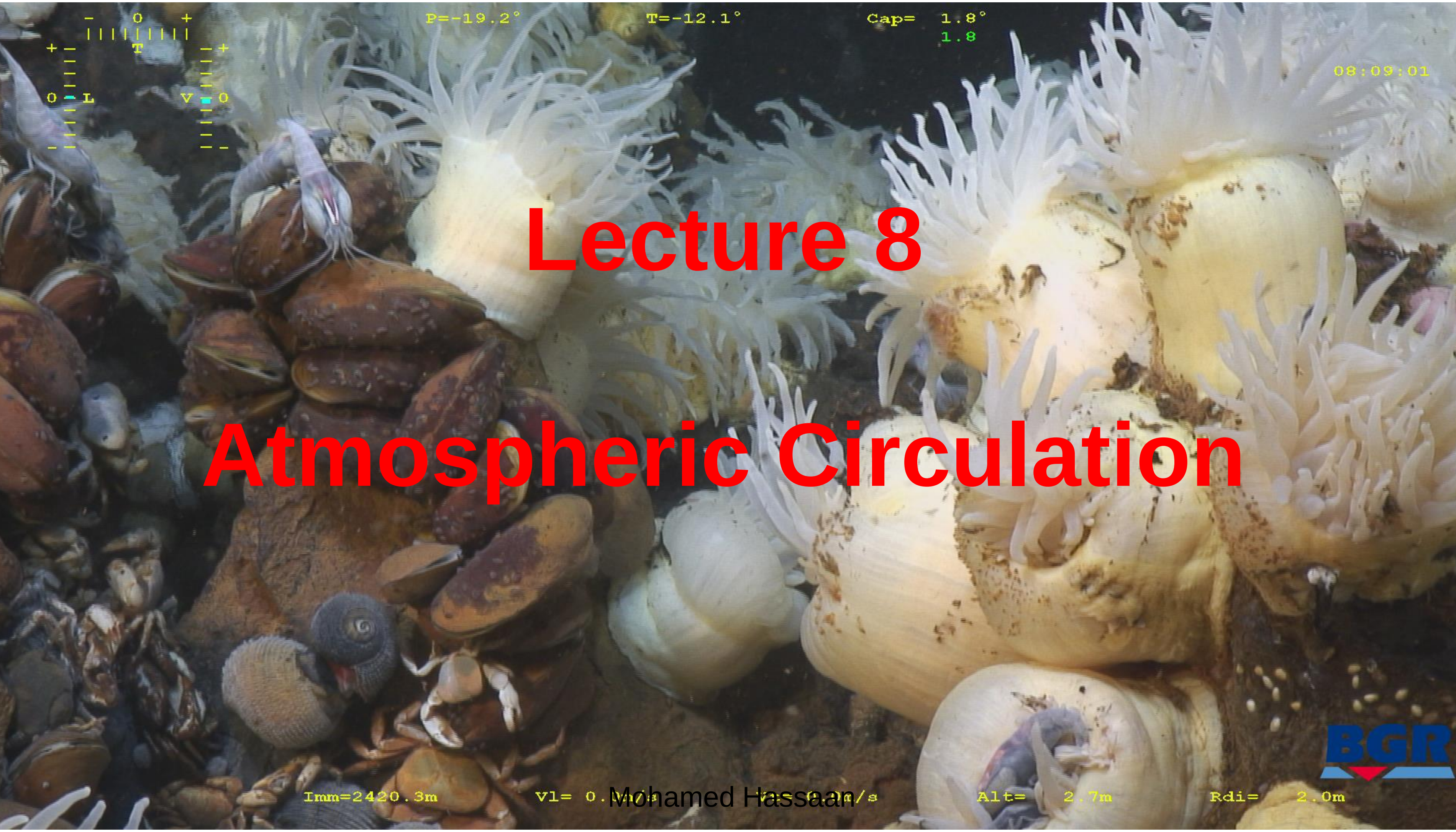
vent worms

worms & clams



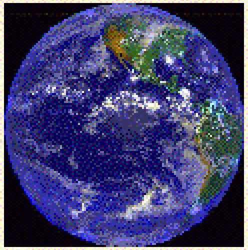
Lecture 8

Atmospheric Circulation



Mohamed Hassaan

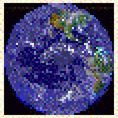
Oceans & Our Global Environment



Atmospheric Circulation

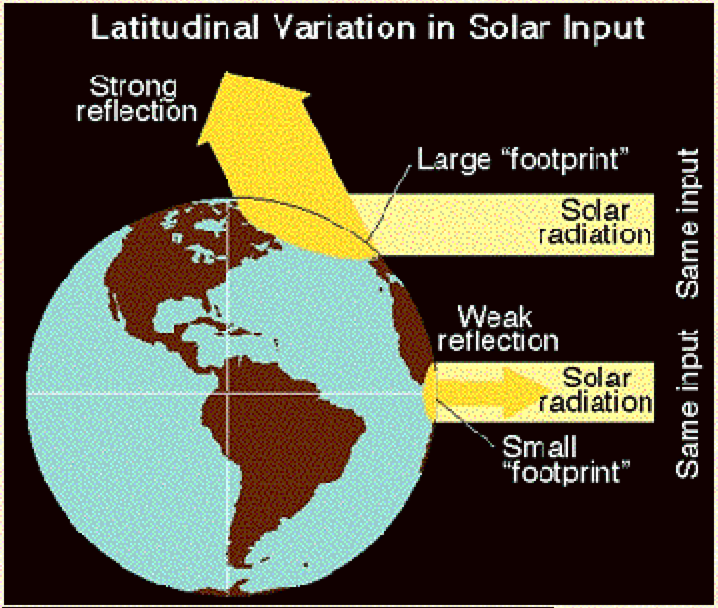
Topics:

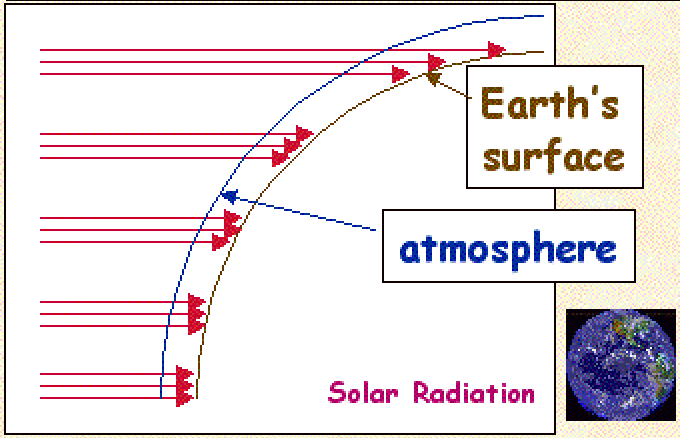
- Heating & Cooling the Earth's Surface
  - solar radiation, heat budget
- The Atmosphere and its Gases
  - structure, composition, pressure
  - changes in CO_2, ozone, sulfur compounds (DMS)
- Atmosphere in Motion
  - winds, rotation, wind bands
  - seasonal changes, monsoons, topography, jet streams
- Hurricanes, El Niño Events



Solar Radiation:

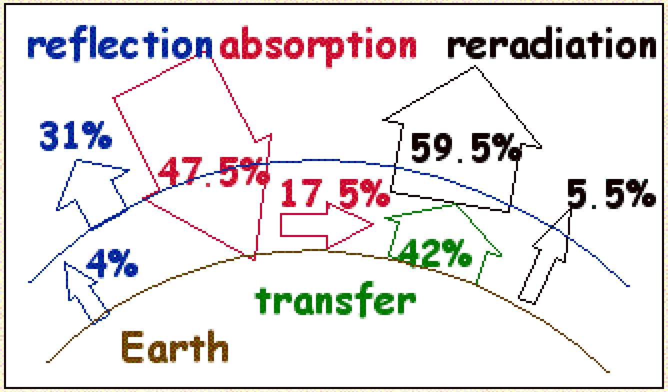
- Varies with latitude
  - equator highest (1.6 cal/cm/min.)
  - decreases with increasing latitude as radiation more oblique
  - absorbed by atmosphere
  - absoption greater at high latitudes
  - reflection (albedo):
    - weak at low latitudes
    - strong at high latitudes (angle of incidence, ice cover)

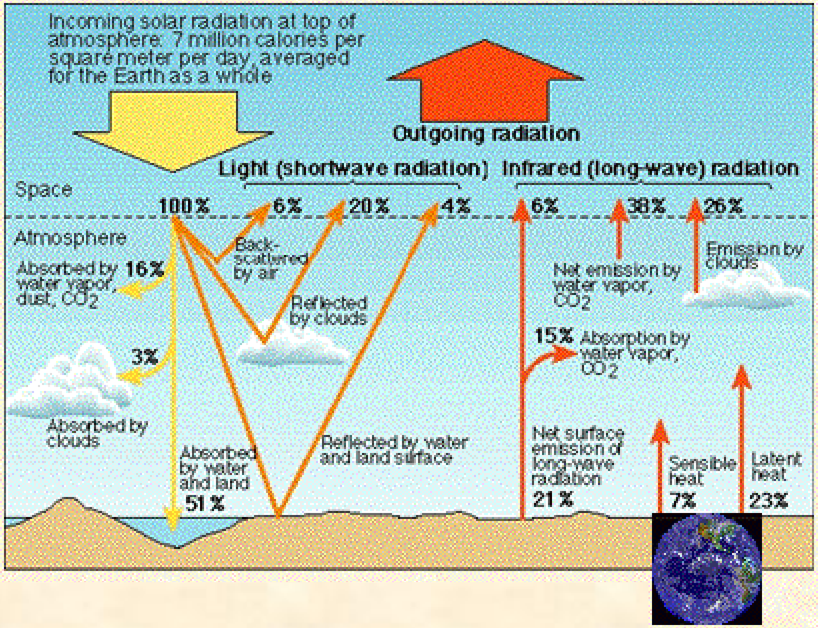




Solar Radiation:

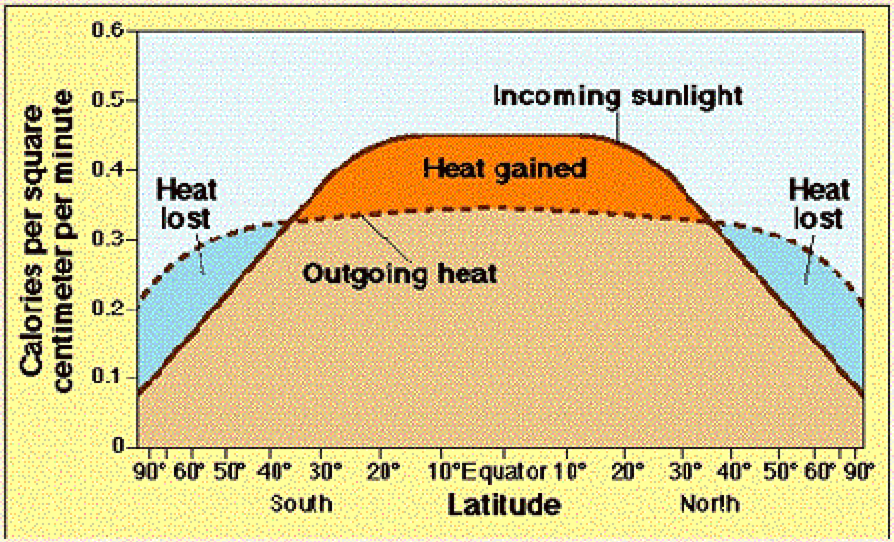
- Heat Budget
  - reflected by atmosphere clouds, gases (31%)
  - reflected by surface (4%)
  - absorbed by atmosphere clouds, gases (17.5%)
  - absorbed by surface land, ocean (47.5%)
  - reradiation by atmosphere (59.5%), by surface (5.5%)
  - transfer from surface to atmosphere (42%), 29.5% by evaporation, 12.5% by conduction

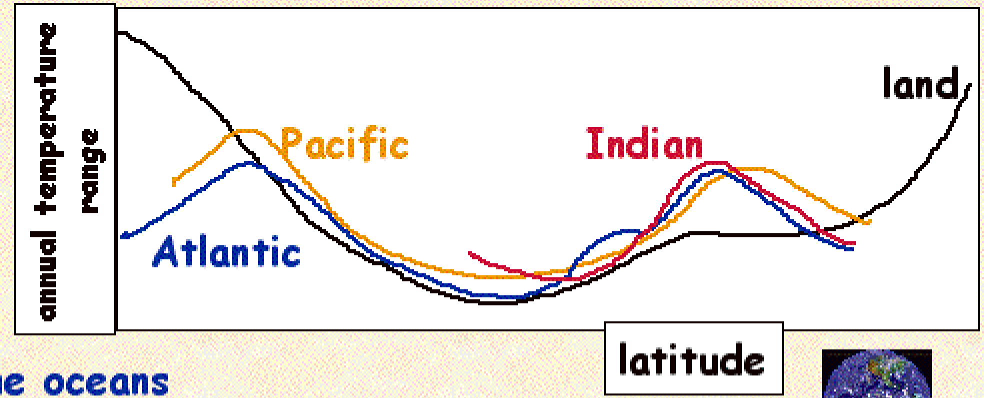


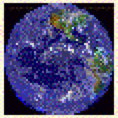


Heat Budget:

- Heat Gain
  - equatorial regions
- Heat Loss
  - polar regions
- Annual Change
  - greatest at mid, high latitudes
- Heat Capacity
  - controlled by oceans
  - land has greater temperature range than the oceans

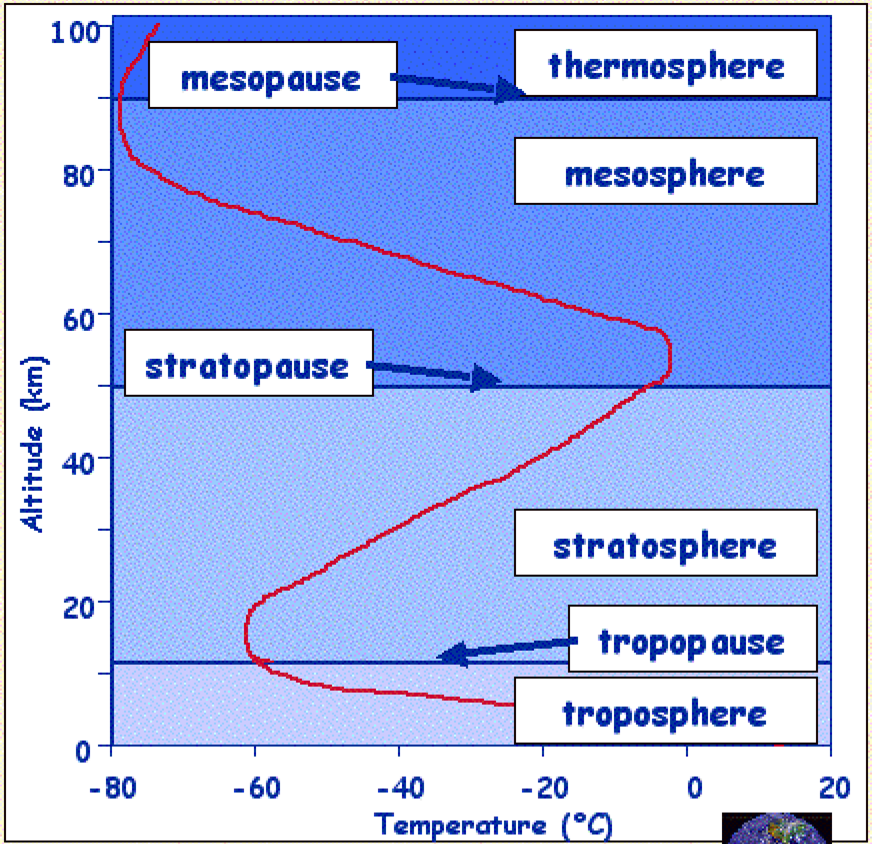


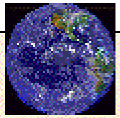




Structure of the Atmosphere

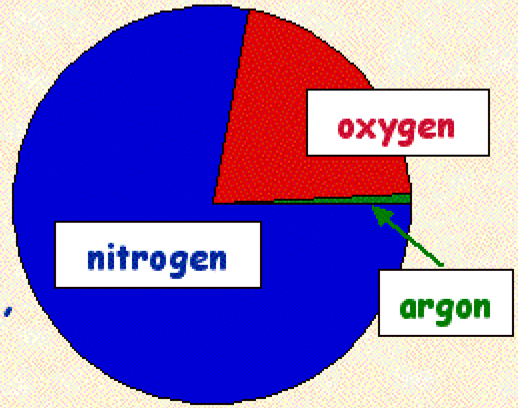
- Series of Layers and Boundaries
  - primarily defined by temperature
- Troposphere (~90%) (clouds)
  - tropopause (jet stream)
- Stratosphere (ozone, jet aircraft)
  - stratopause
- Mesosphere
  - mesopause
- Thermosphere



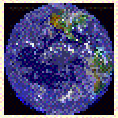


Atmospheric Composition & Pressure:

- Major Gases
  - transparent, odorless, colorless
  - nitrogen (N_2), 78.08%
  - oxygen (O_2), 20.95%
  - argon (Ar) 0.93%
  - carbon dioxide (CO_2), 0.03%
  - neon (Ne), helium (He), kypton (Kr), xenon (Xe), hydrogen (H)

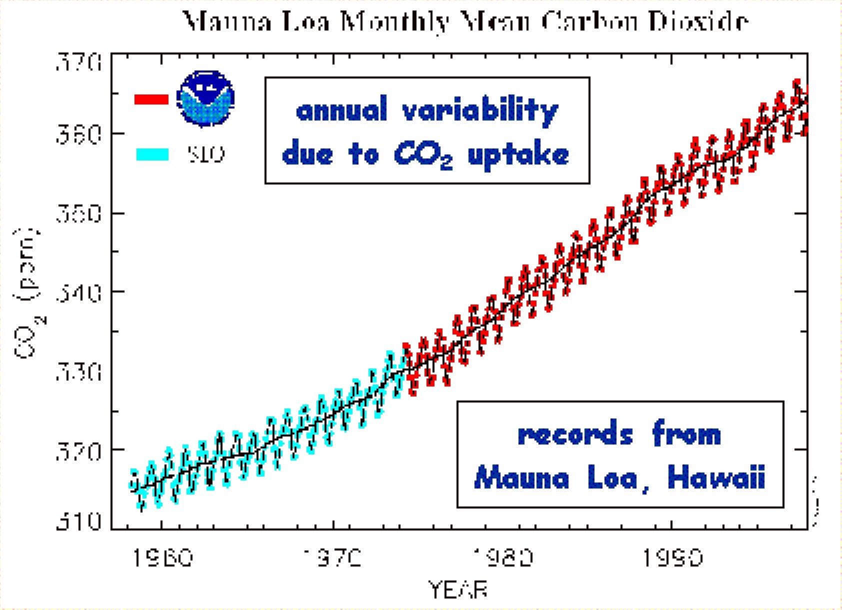


- Density
  - increases when cooled, decreases when warmed
  - increases when water vapor content decreases
- Pressure
  - standard 760mm Hg
  - high pressure > 760mm > low pressure
  - lines of equal pressure: isobars

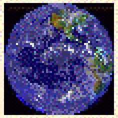


Atmospheric Gases: Changes in CO_2

- Reservoirs
  - ocean (84.9%), terrestrial (13.4%), atmosphere (1.7%)
- Radiation
  - transparent to incoming radiation
  - absorbs outgoing long-wave radiation
  - greenhouse effect

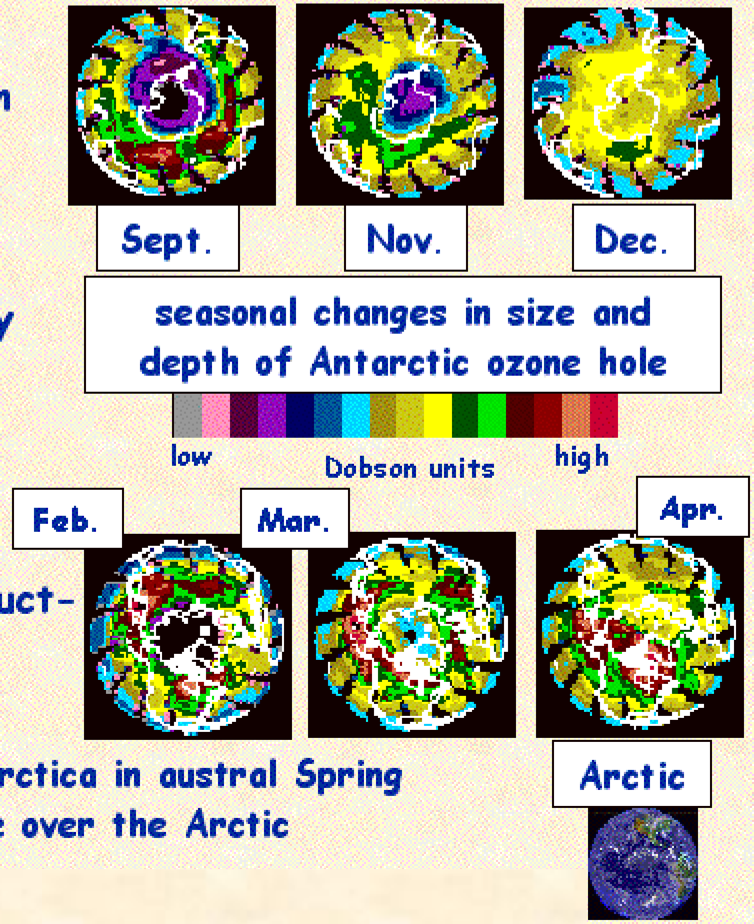


- Temporal Increase
  - 280 to 350 ppm since 1850
  - product of fossil fuel burning
  - global rise of 2-4°C predicted in 100 years



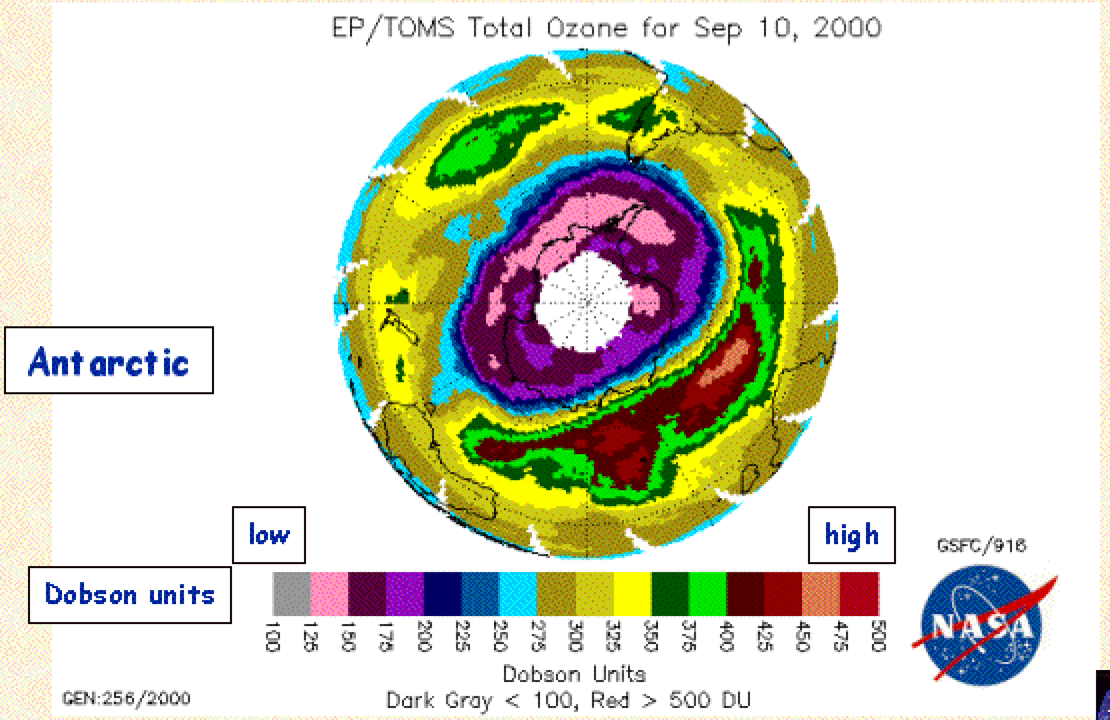
Atmospheric Gases: Ozone Problem:

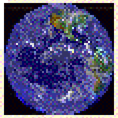
- UV Radiation Shield
  - **ozone absorbs UV radiation**
  - **chlorofluorocarbons from aerosols form chlorine in upper atmosphere**
  - **nitrogen compounds destroy chlorine, but are absent in cold, polar atmospheres**
  - **chlorine catalyzes ozone destruction**
  - **higher UV: less plant production, causes skin cancers**
- Ozone hole
  - **develops seasonally over Antarctica in austral Spring**
  - **similar, but much smaller hole over the Arctic**



Atmospheric Gases: Ozone Problem:

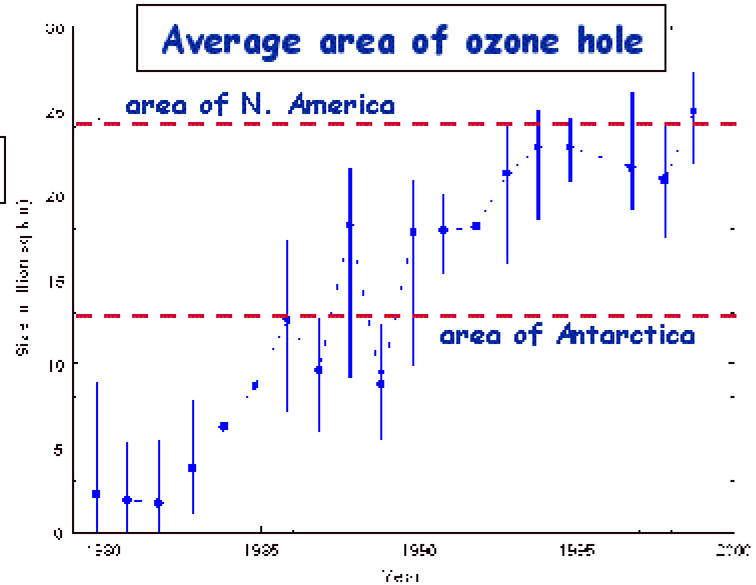
- Largest Antarctic ozone hole recorded **(Sep. 2000)**

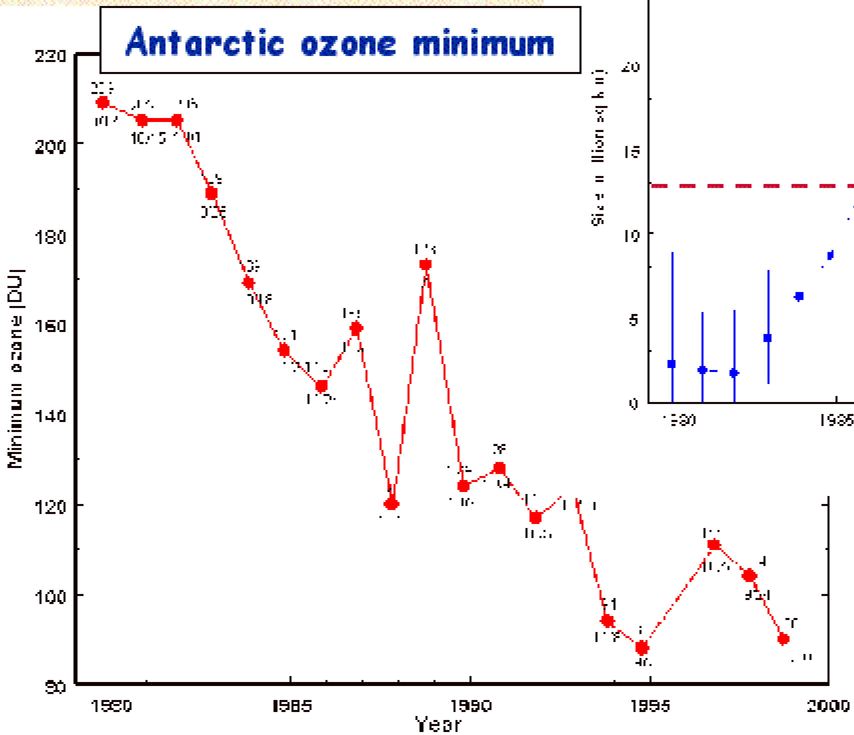




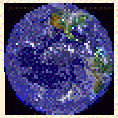
Atmospheric Gases: Antarctic Ozone Hole:

- develops seasonally in austral Spring



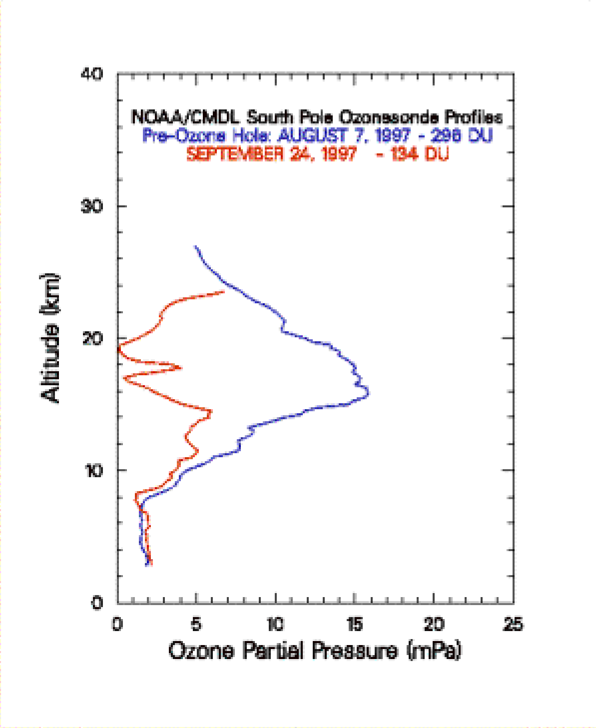


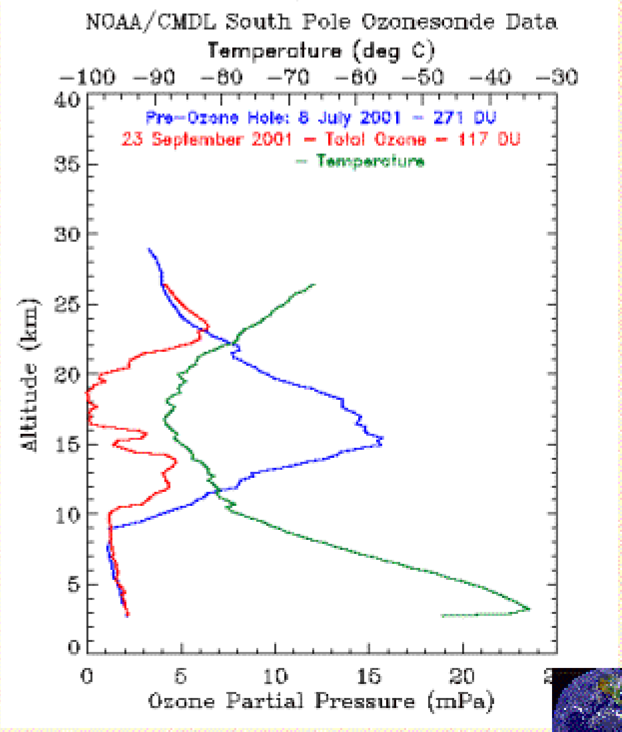
- depth and size of hole varies, has increased over last 20 years

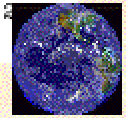


Vertical Profiles of Antarctic Ozone Hole:

- Ozone depletion at 15-20km, annually variable
- Strongest depletion in austral spring

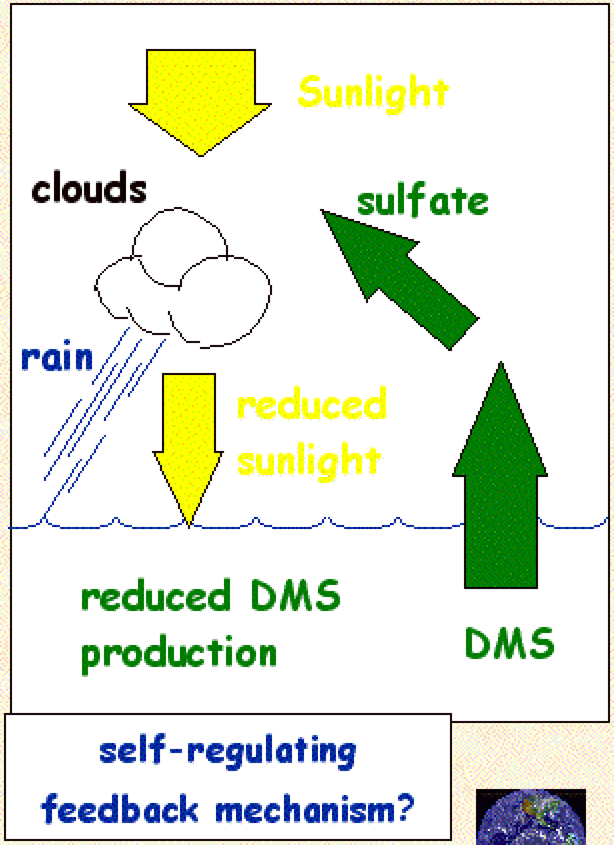


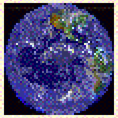




Role of Sulfur Compounds:

- Natural
  - dimethyl sulfide (DMS) produced by oceanic plants
  - forms sulfate and sulfuric acid ("acid rain")
  - role in controlling cloud formation, reducing incident solar radiation and DMS production
  - also, sulfur compounds (SO_2) from volcanoes
- Anthropogenic
  - sulfur compounds from combustion of fossil fuels, especially high sulfur coal

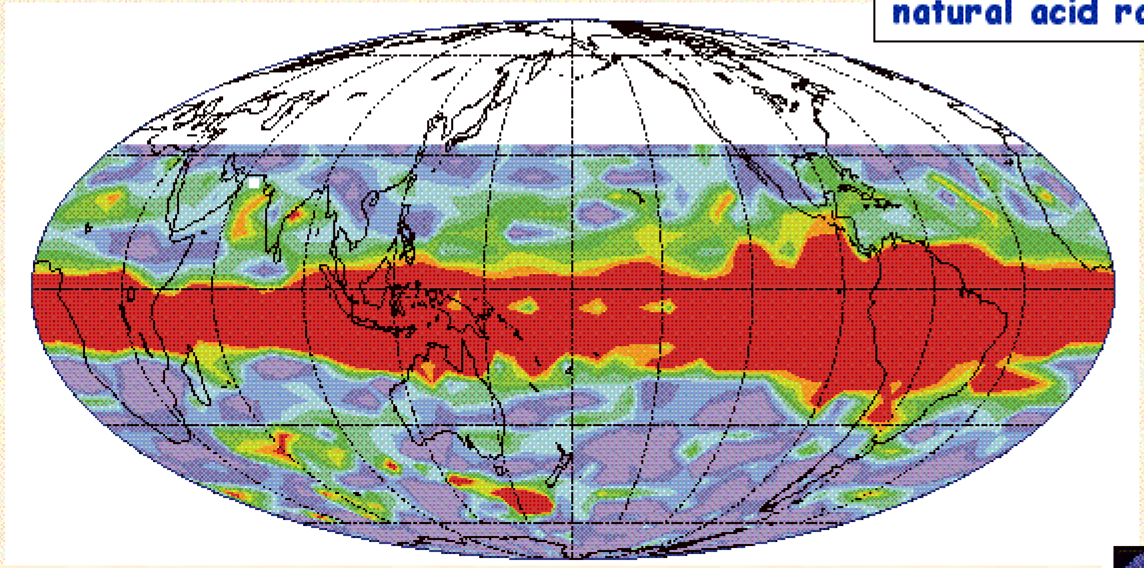


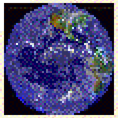


Atmospheric Gases: SO_2 from Mount Pinatubo

- Natural release
  - sulfur compounds (SO_2) from volcanoes
  - plume of SO_2 encircling the Earth at ~5°S
  - effect on global climate?

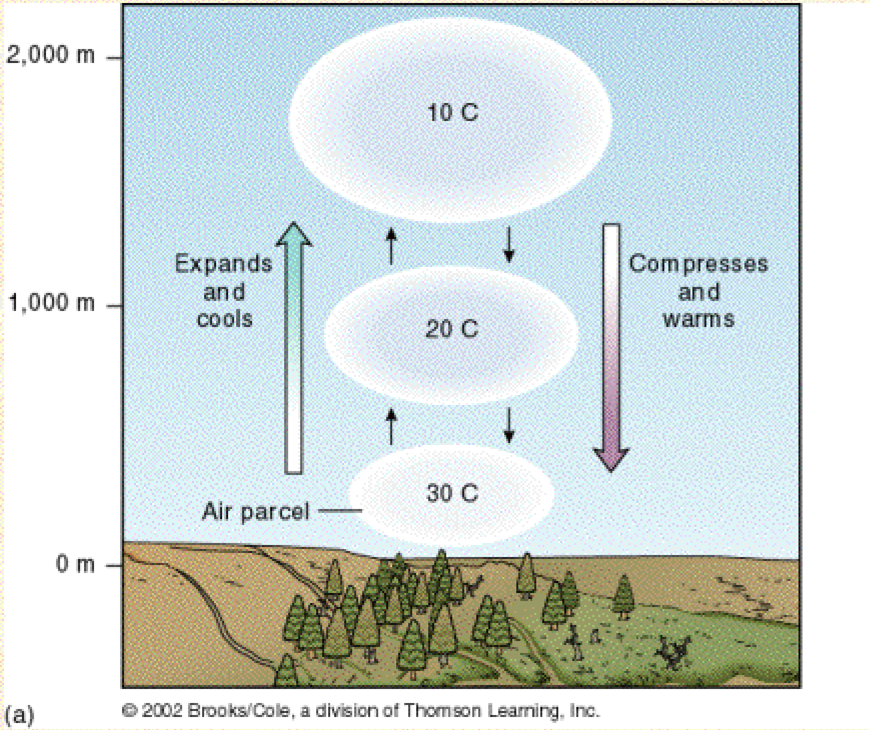
natural acid rain

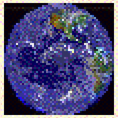




Vertical Movement of Air Masses:

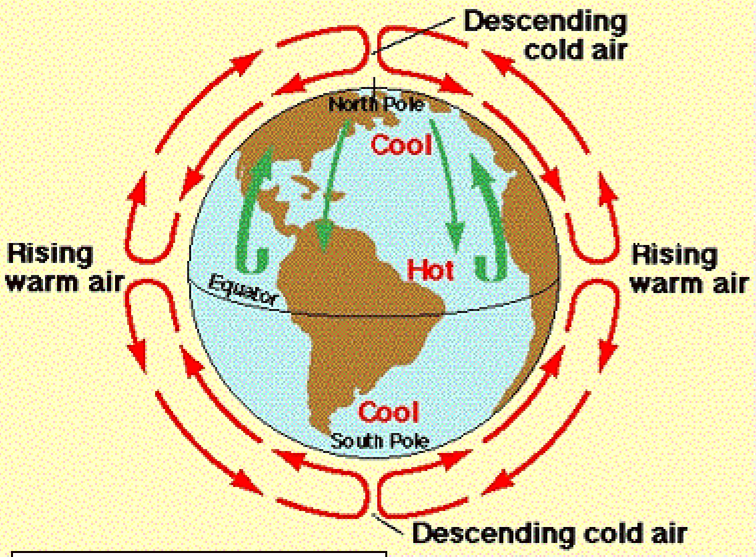
- Warm air
  - Rises, expands and cools
- Cool air
  - Sinks, compresses and warms





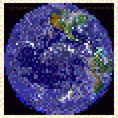
Atmosphere in Motion:

- Without Rotation
  - air warmed and rises at equator
  - air cools and sinks at poles
  - a two-celled system
  - surface winds would blow southward
  - high altitude winds would blow northward



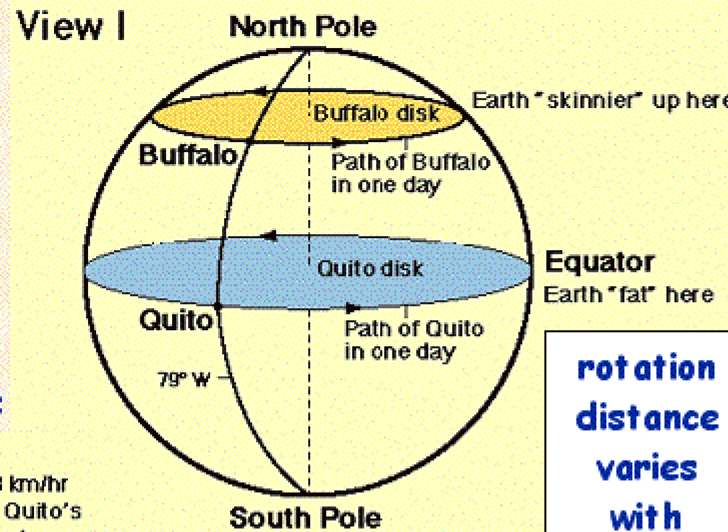
non-rotating Earth

- Rotation of the Earth
  - Earth spins faster at equator (1700 km/h) than at higher latitudes (e.g. 1250 km/h at 45°)
  - rotation of Earth leads to deflection of air masses by the Coriolis effect

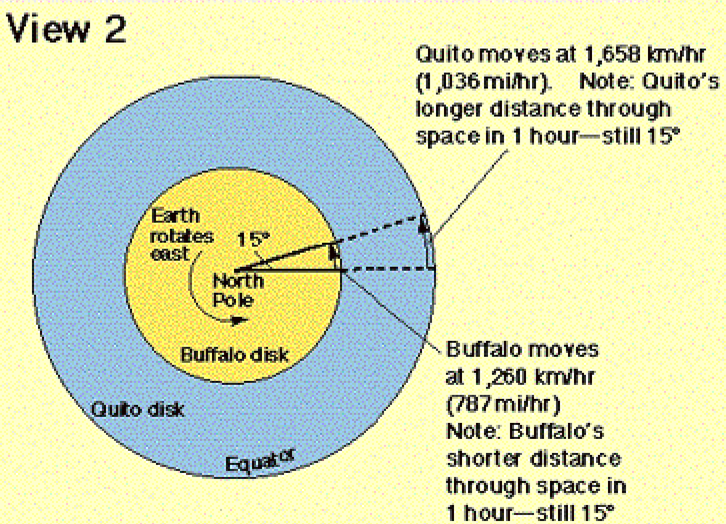


Coriolis Effect:

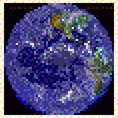
- Compare
  - Quito (Equador): equatorial latitude
  - Buffalo, NY: 43°N, a shorter line of latitude, smaller rotation distance



rotation distance varies with latitude

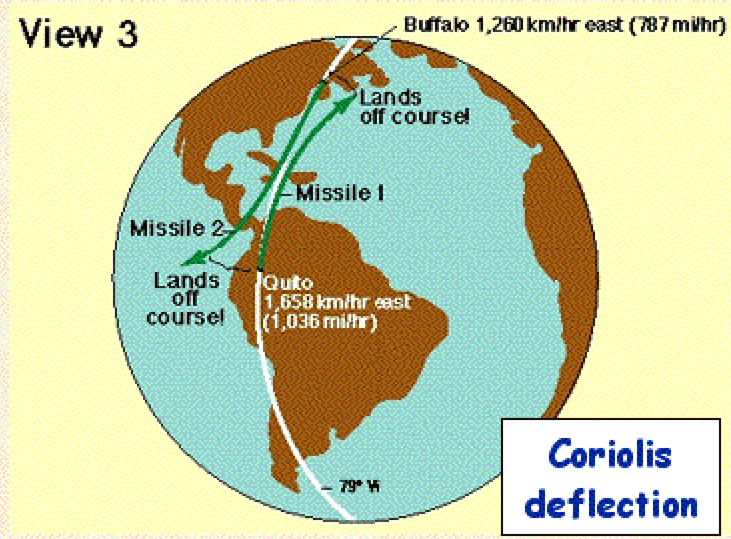


- Rotation Speeds
  - depends on latitude
  - fastest at equator
  - zero at poles
  - Quito: 1,658 km/h
  - Buffalo: 1,260 km/h

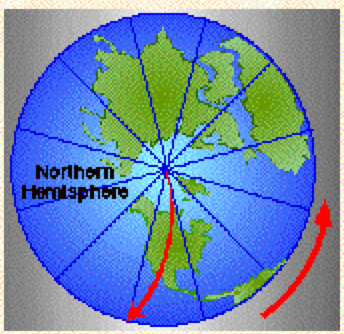


Coriolis Effect:

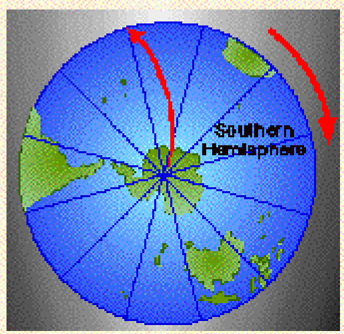
- rotation of Earth deflects objects moving through the air
- deflected to right in northern hemisphere
- deflected to left in southern hemisphere
- no deflection at equator



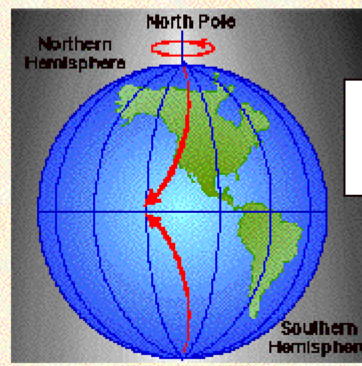
Coriolis deflection



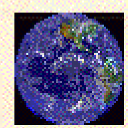
N. hemisphere



S. hemisphere

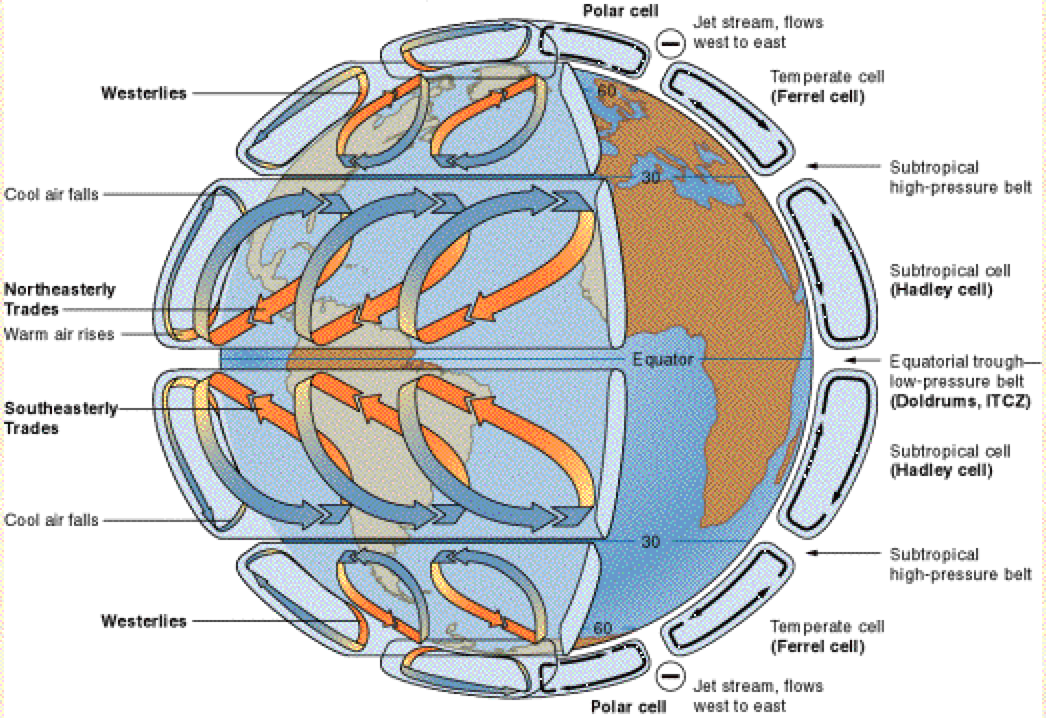


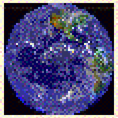
net effect



Atmospheric Circulation: Wind Bands

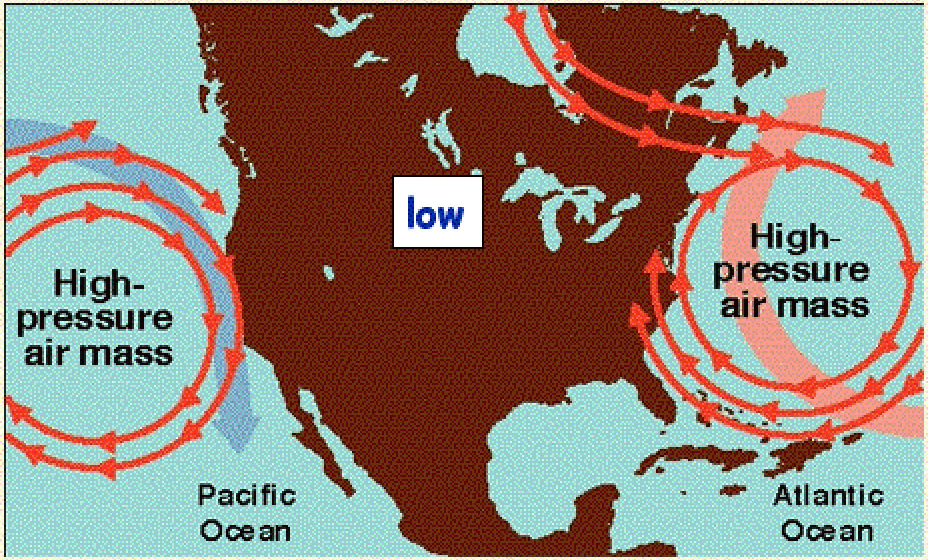
- A six-celled system





Surface Air Pressure over N. America:

- Summer Pressure Regimes
  - land = low, caused by rising air
  - oceans = high, caused by descending air
  - system reverses in Winter



Wind and pressure Systems and Weather

- Variations with latitude

Table 8.2 Major Wind and Pressure Systems and Related Weather

Region	Name	Pressure	Surface Winds	Weather
Equator (0)	Doldrums (ITCZ) (equatorial low)	Low	Light, variable winds	Cloudiness, abundant precipitation in all seasons; breeding ground for hurricanes. Relatively low sea surface salinity because of rainfall (see Figure 17.4)
0 –30 N and S	Trade winds (easterlies)	—	Northeast in Northern Hemisphere, southeast in Southern Hemisphere	Summer wet, winter dry; pathway for tropical disturbances
30 N and S	Horse latitudes (subtropical high)	High	Light, variable winds	Little cloudiness; dry in all seasons. Relatively high sea surface salinity because of evaporation
30 –60 N and S	Prevailing westerlies	—	Southwest in Northern Hemisphere, northwest In Southern Hemisphere	Winter wet, summer dry; pathway for subtropical high and low pressure
60 N and S	Polar front	Low	Variable	Stormy, cloudy weather zone; ample precipitation in all seasons
60 –90 N and S	Polar easterlies	—	Northeast in Northern Hemisphere, southeast in Southern Hemisphere	Cold polar air with very low temperatures
90 N and S	Poles	High	Southerly in Northern Hemisphere, northerly in Southern Hemisphere	Cold, dry air; sparse precipitation in all seasons

Note: Compare to Figure 8.12. (Source: *From Earth in Crisis: An Introduction to Earth Sciences*, 2/e, Thomas L. Burrus, Herbert J. Spiegel, 1980. C .
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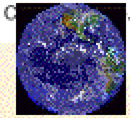
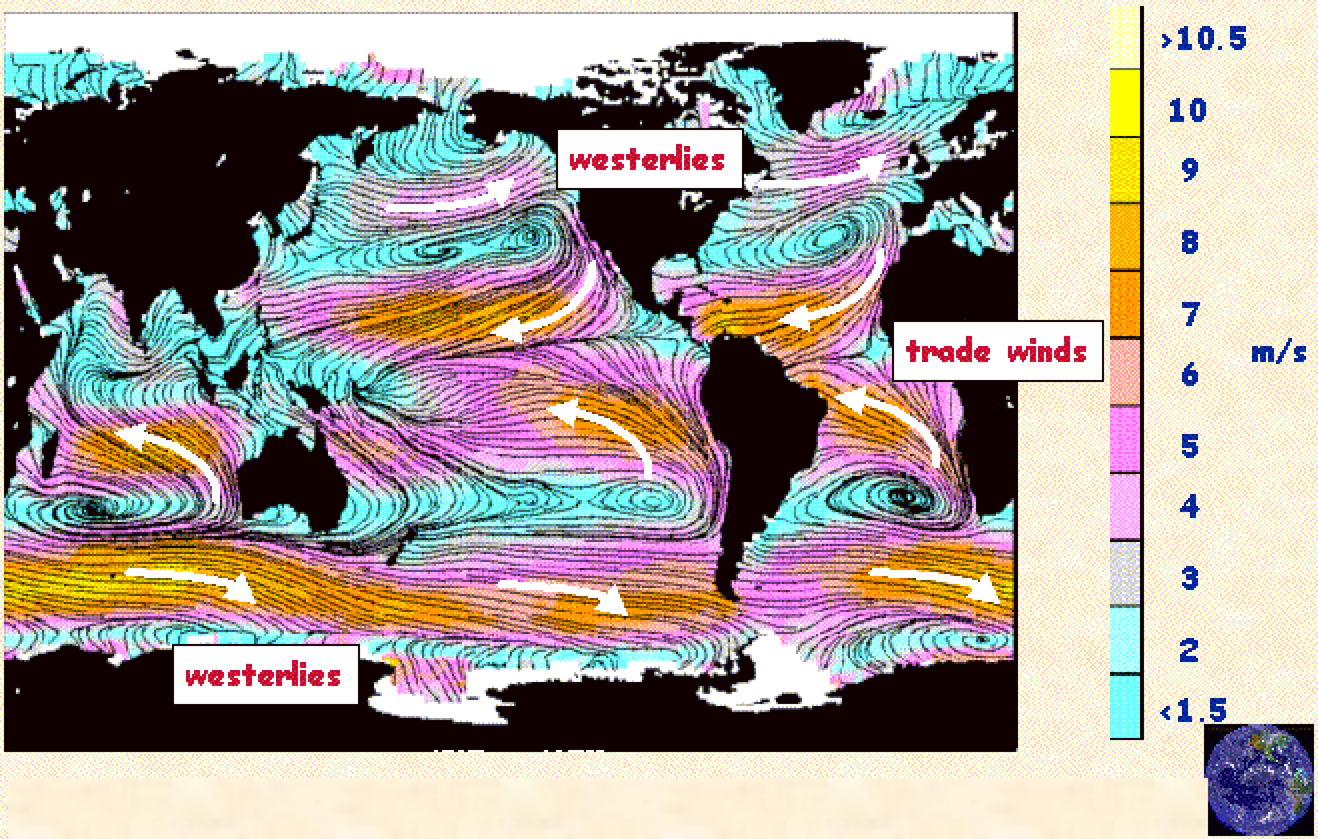
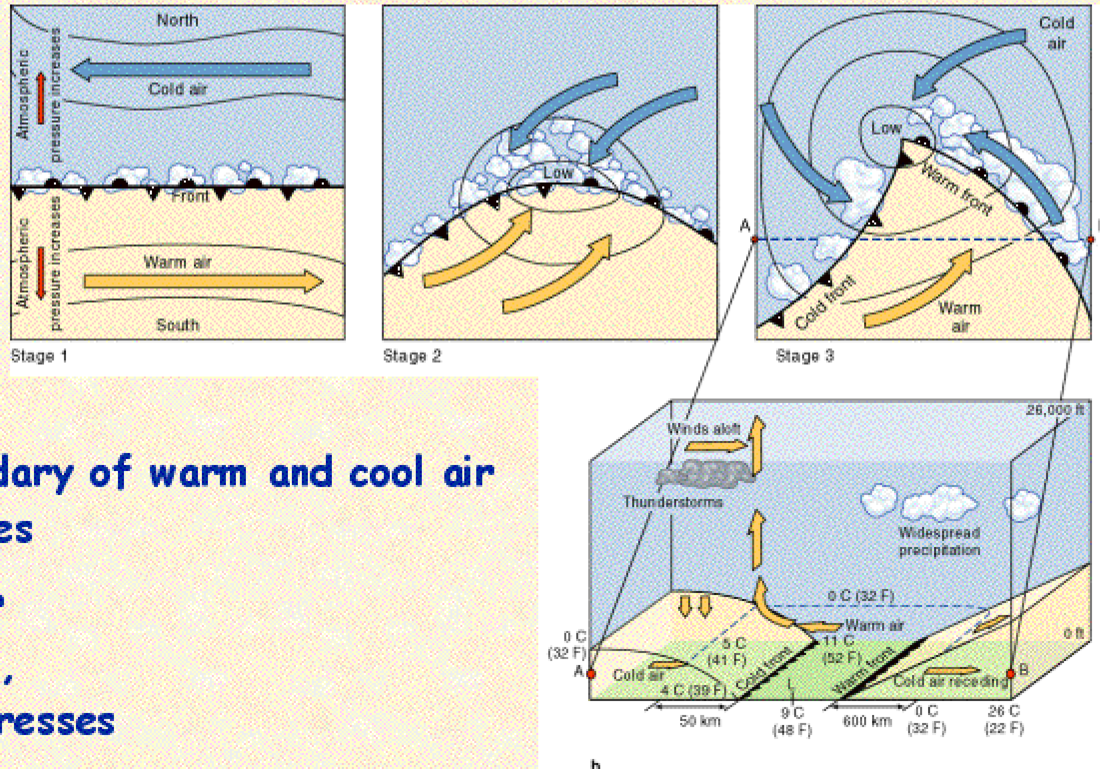


Surface Winds – Annual Average:

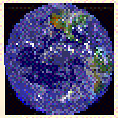
- Satellite measurements of wind intensity and direction



Weather Systems:

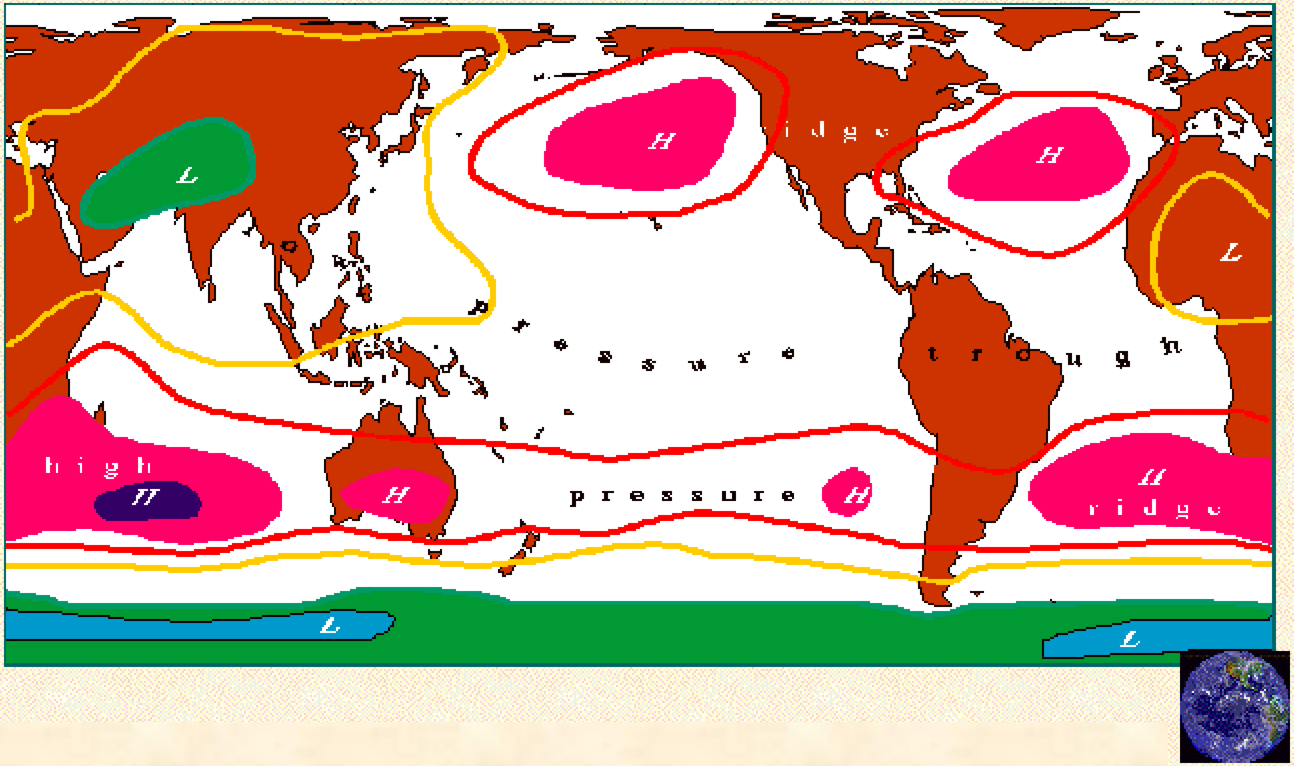


- Fronts
  - Boundary of warm and cool air masses
- Cool air
  - Sinks, compresses and warms



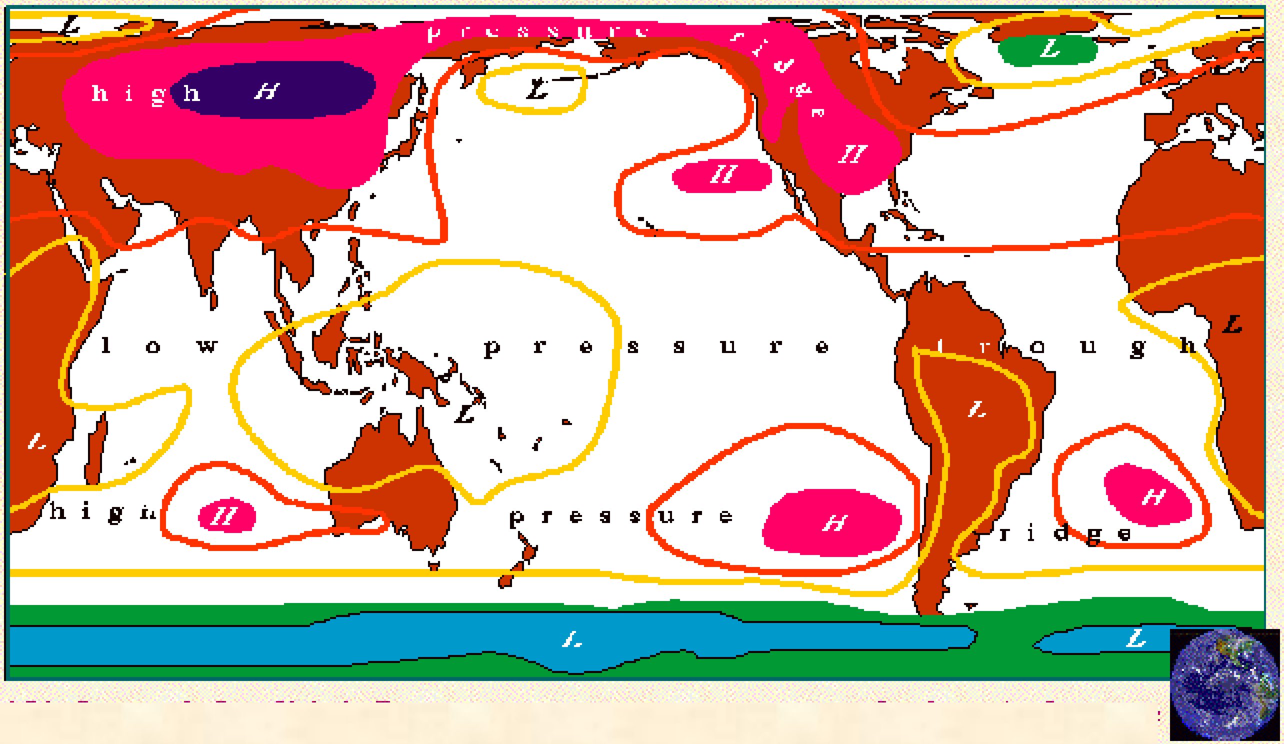
Sea Level Air Pressures in July:

- Northern hemisphere pressure regimes
  - **Asia (land): low; N. Pacific, N. Atlantic (oceans): high**



Sea Level Air Pressures in January:

- Pressure regimes
  - N. hemisphere: land = high; oceans = low
  - S. hemisphere: land = low; oceans = high



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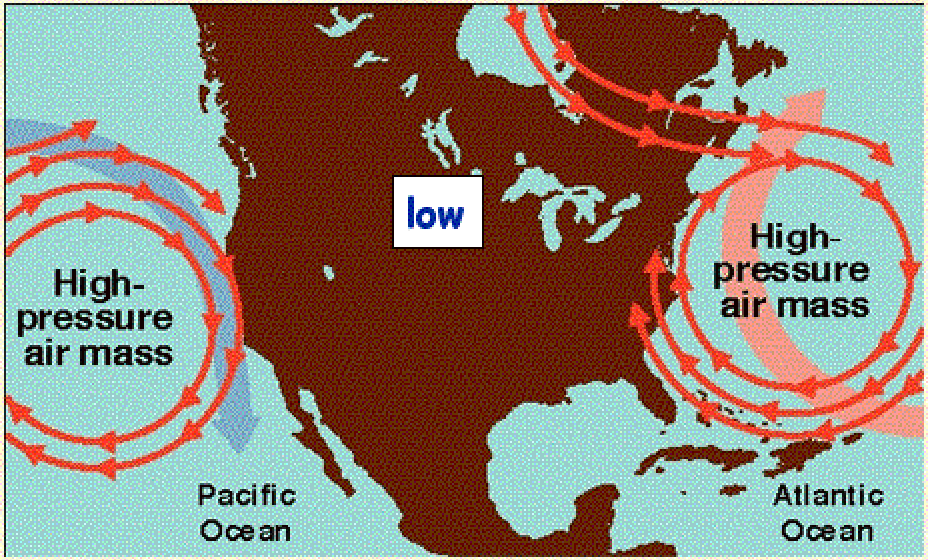
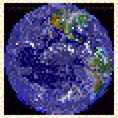
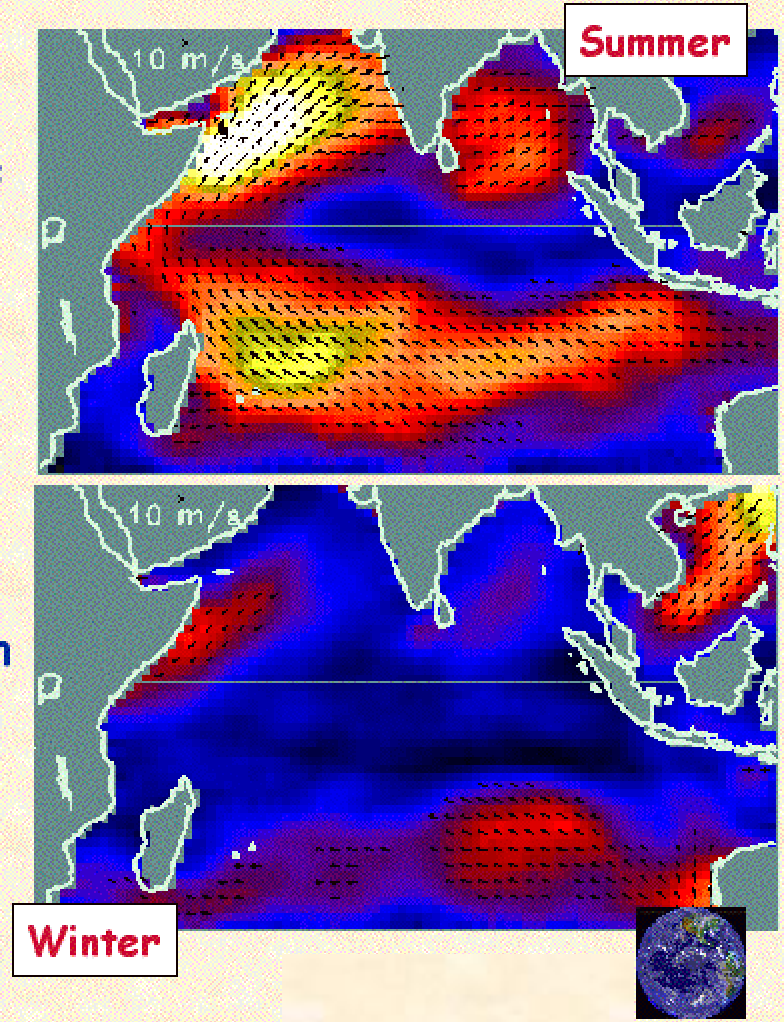




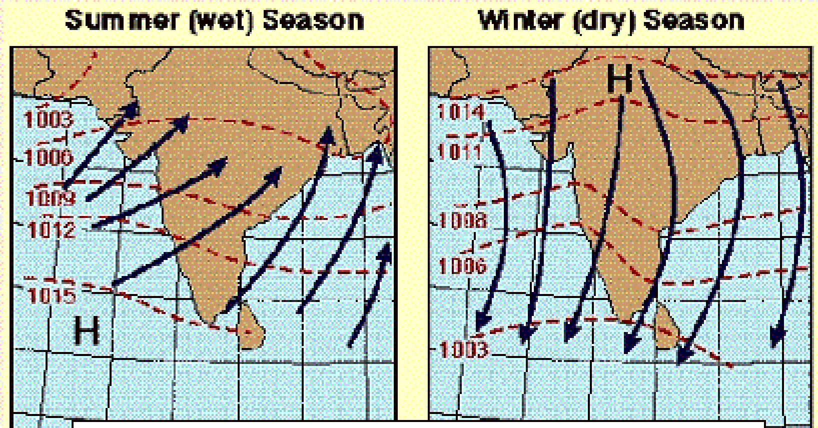
Seasons, Monsoons:

- Seasonal Changes
  - differential heating of ocean and land; result of high heat capacity of water
  - summer: low pressure over land
  - winter: low pressure over ocean
- Indian Ocean Monsoon
  - reversal in winds
  - summer rains from cool moist air drawn from ocean
  - dry winters

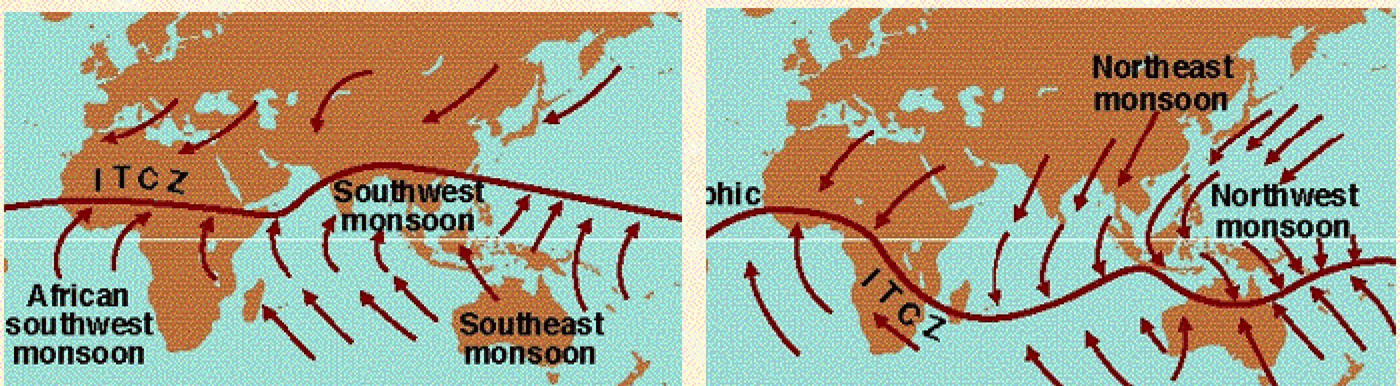


Monsoons:

- Seasonal Changes
  - shift in position of ITCZ and in wind patterns leading to:
  - wet summers (low pressure over land)
  - dry winters (high pressure over land)



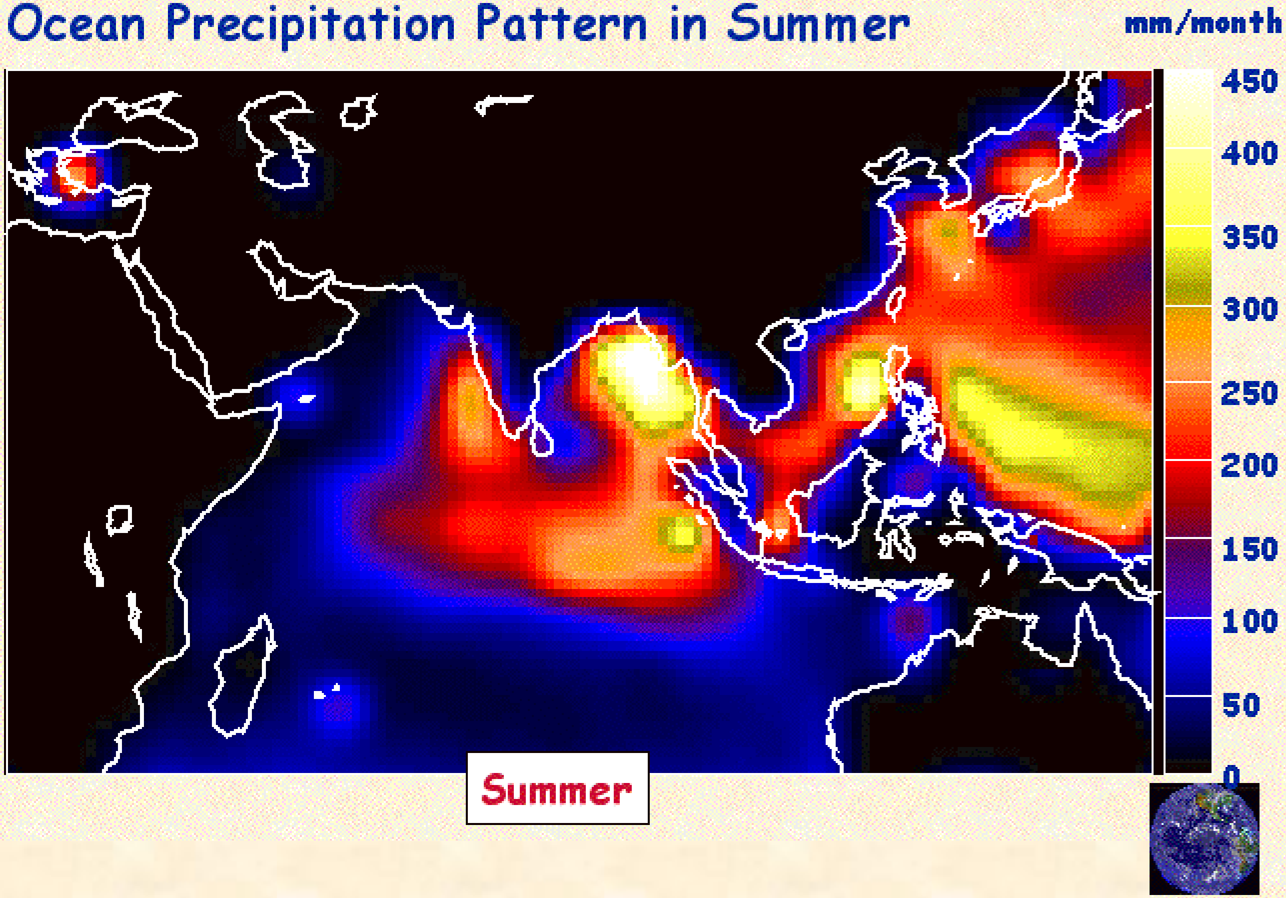
seasonal changes in wind direction



position of ITCZ shifts seasonally, affecting wind patterns

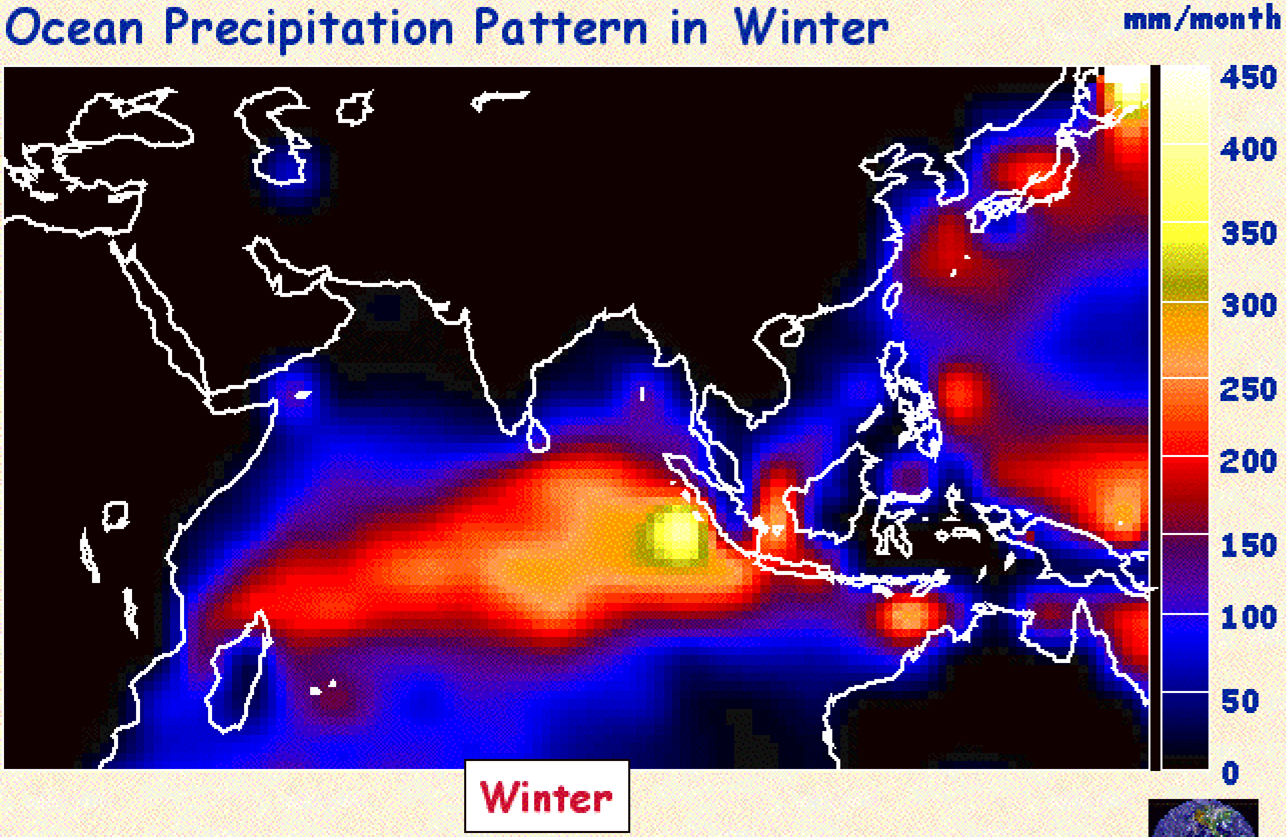
Indian Ocean Monsoon:

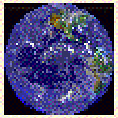
- Ocean Precipitation Pattern in Summer



Indian Ocean Monsoon:

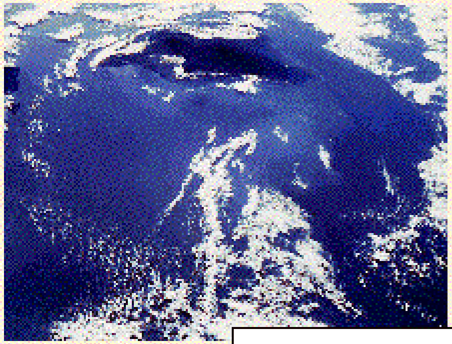
- Ocean Precipitation Pattern in Winter



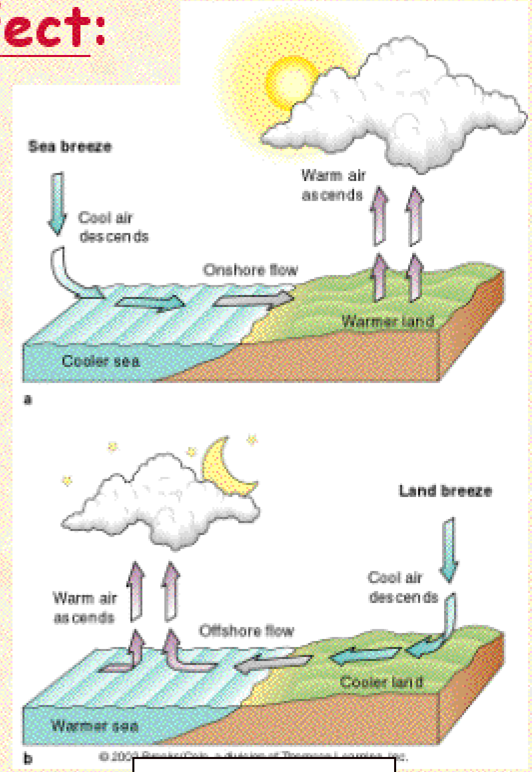


Sea Breezes & Topographic Effect:

- Sea Breezes
  - day: rising air over warm land draws breeze off cool ocean
  - night: rising air over warm ocean draws breeze off cool land
- Topographic Effect
  - moist air rising over mountains leads to rainfall on windward side of continent or island
  - dry (cloud-less) air on leeward side



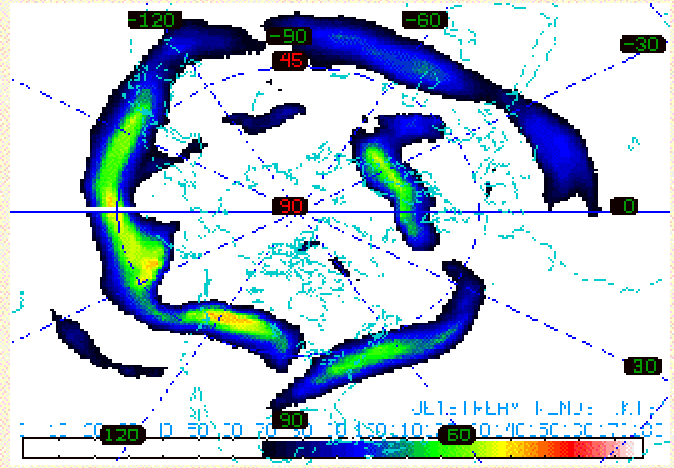
island cloud wake

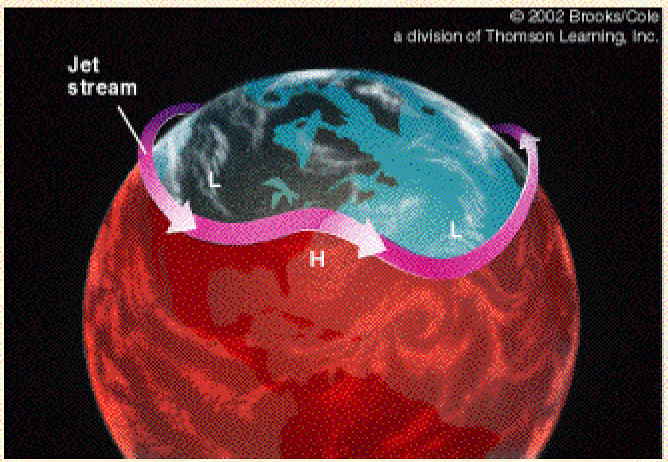


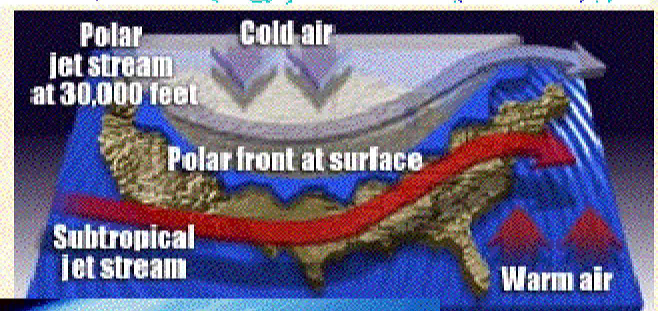
sea breezes

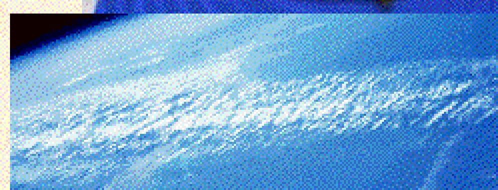
Jet Streams:

- High speed winds of upper troposphere
  - Westerlies in two zones
    - ~60° Polar
    - ~30° subtropical
  - non-continuous; oscillate, especially in winter

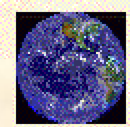






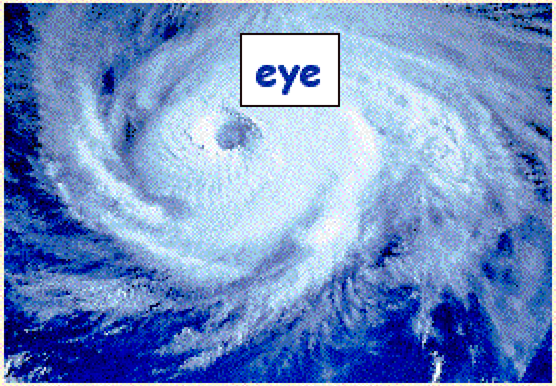


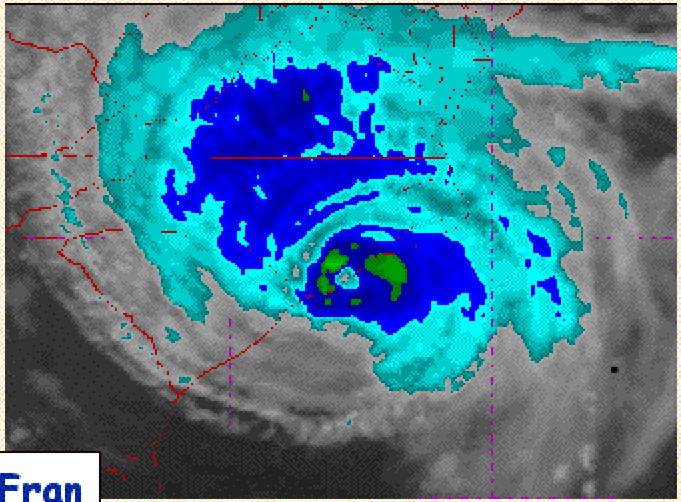
cirrus clouds

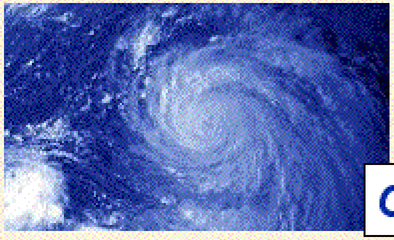


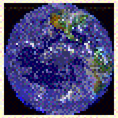
Hurricanes:

- Typhoons in Pacific
- Characteristics of Formation
  - require waters >27°C, typically at 10-20° latitude
  - convergence of rotating winds (counterclockwise)
  - intense low pressure cells
  - move westwards
  - dissipate over land or cold water
  - form seasonally



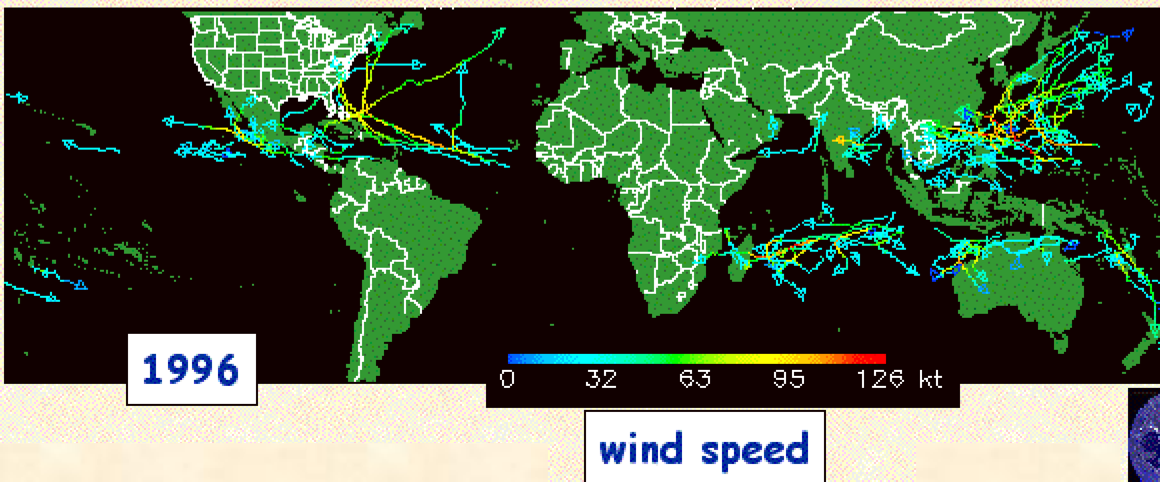


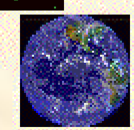




Global Hurricanes and Typhoons:

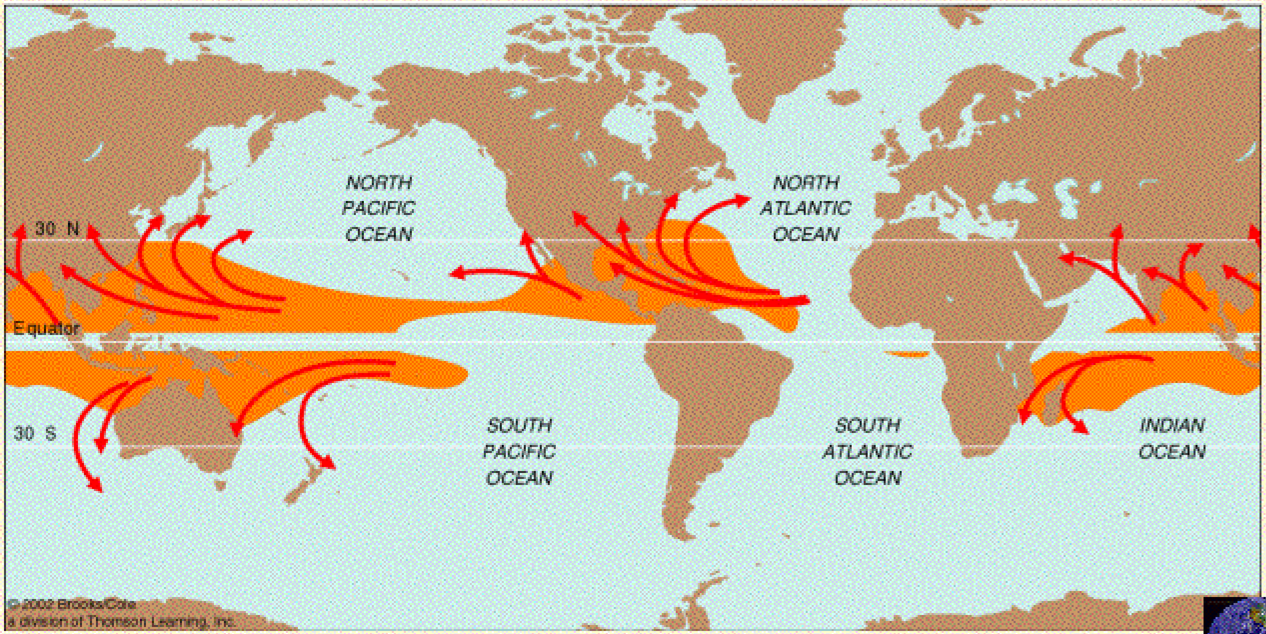
- Variations in hurricanes
  - first develop as tropical depressions (low pressure systems), build to tropical storms, then hurricanes
  - oceanic region (latitude of origin and dissipation)
  - strength (pressure, wind speed, persistence)
  - direction of travel
  - temporal occurrence (seasonal phenomena)

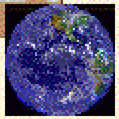




Global Hurricanes and Typhoons:

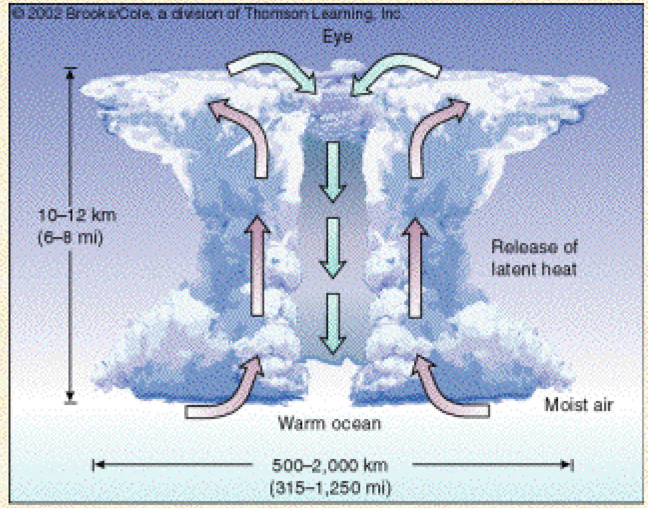
- Global occurrence
  - Limited to specific regions, do not form in equatorial regions



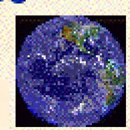


Hurricanes:

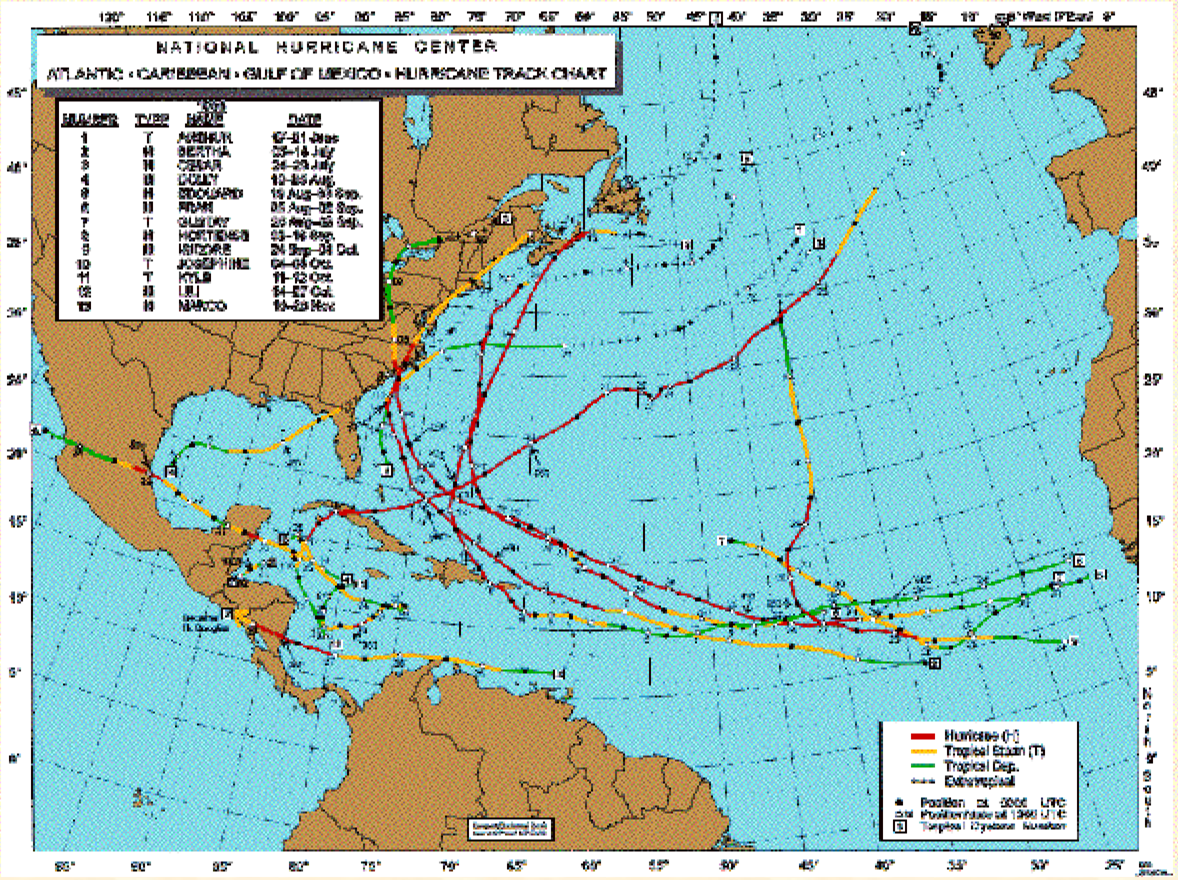
- Characterized by pressure and wind speed
- Categories: Saffir-Simpson scale
- Separates tropical depressions, tropical storms and hurricanes
- Seven Categories:

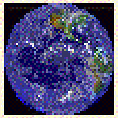


Type	Category	Pressure (mb)	Wind Speed (mph)	Surge (ft)
Depression	TD	-	< 39	-
Tropical Storm	TS	-	39 - 73	-
Hurricane	1	> 980	74 - 95	4 - 5
Hurricane	2	965 - 980	96 - 110	6 - 8
Hurricane	3	945 - 965	111 - 130	9 - 12
Hurricane	4	920 - 945	131 - 155	13 - 18
Hurricane	5	< 920	> 155	> 18



1996 Atlantic Hurricanes:

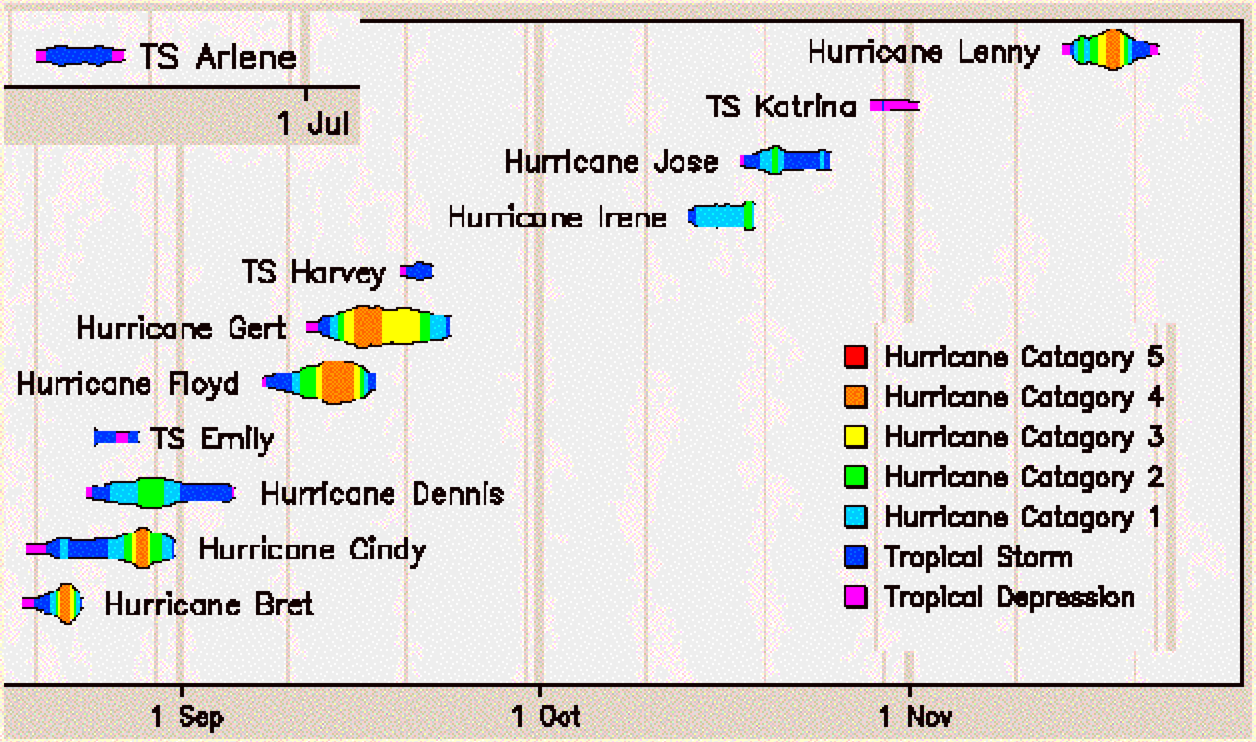


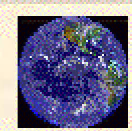


1997 East Pacific Hurricanes:

- Hurricane tracks in the East Pacific Ocean

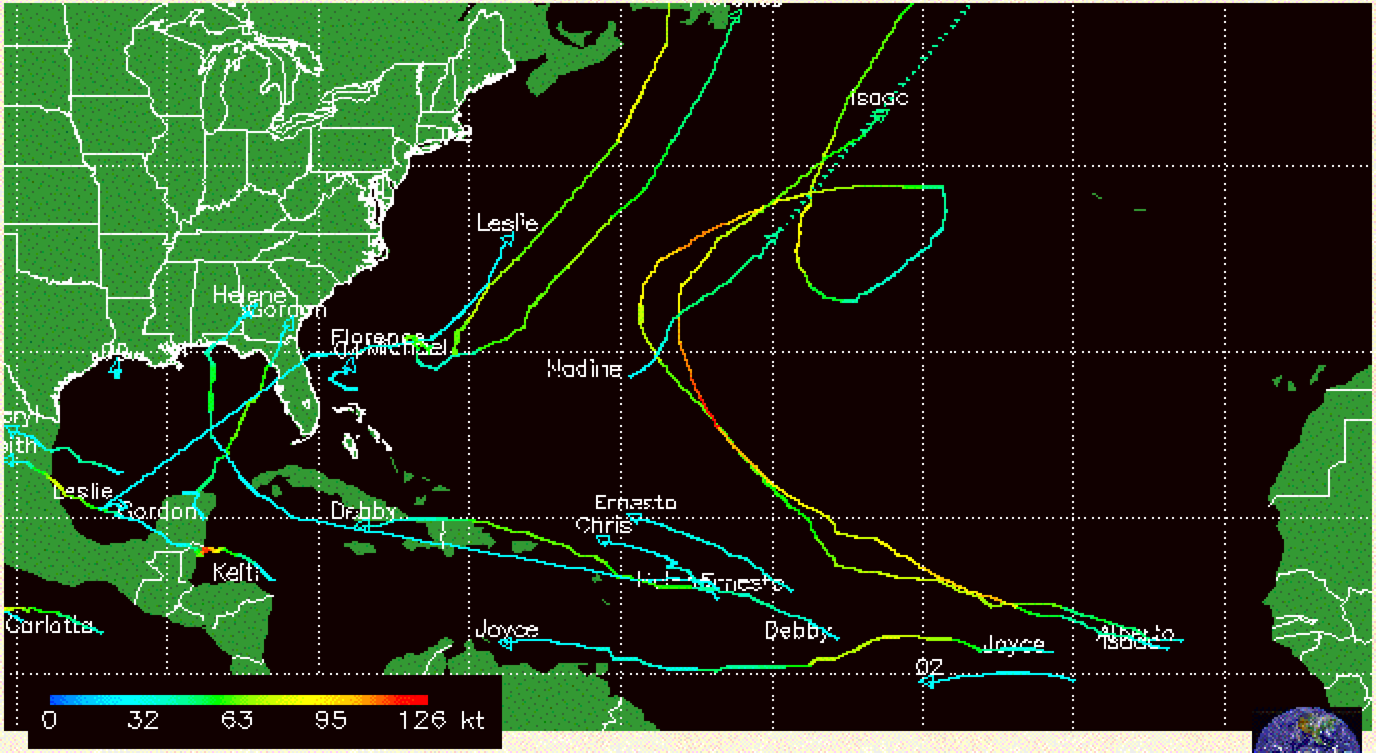
1999 Atlantic Hurricane Season:

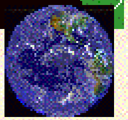




2000 Atlantic Hurricane Season:

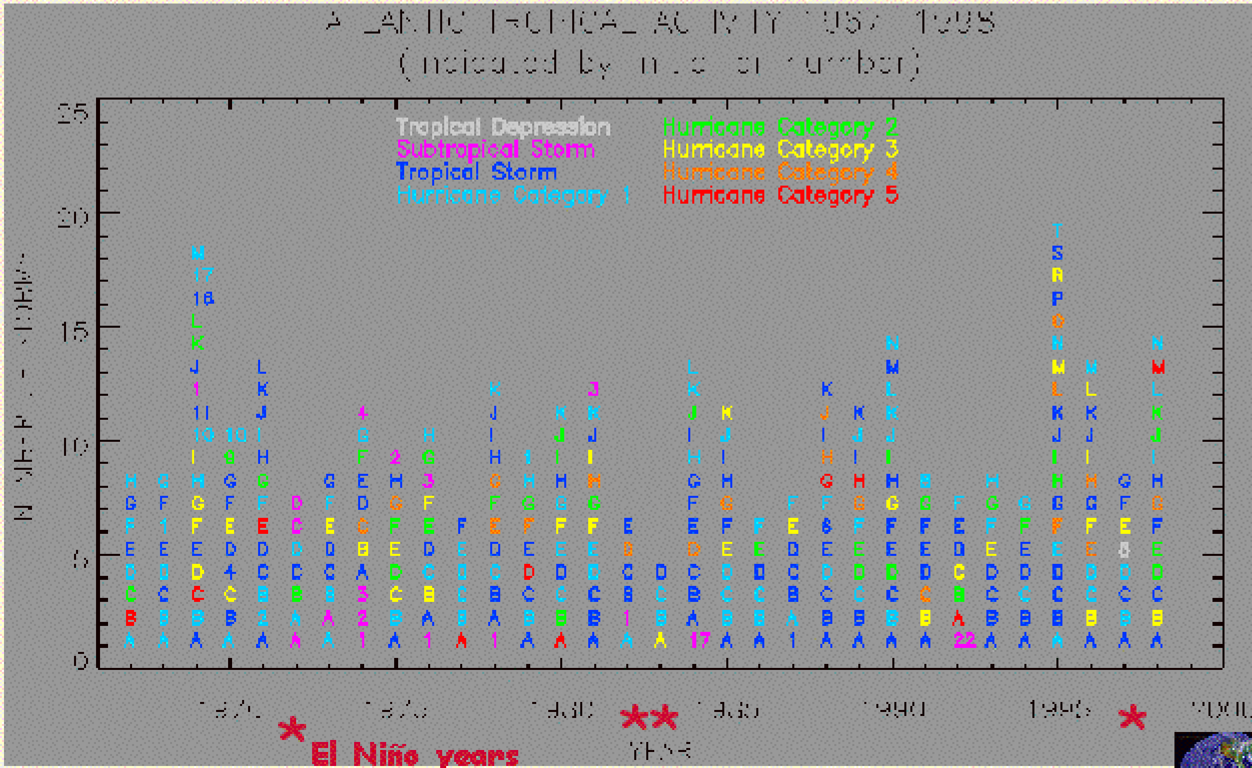
- Hurricane tracks in the Atlantic Ocean

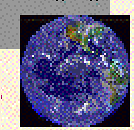




Hurricane Frequency:

- Varies from year-to-year

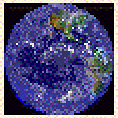




Storm Surges:

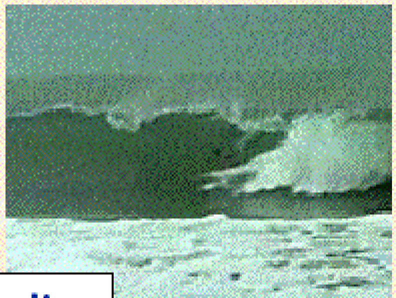
- Elevated Seas
  - caused by storms, e.g. hurricanes, typhoons, cyclones
  - flood coastal areas
  - typical sequence: slight fall in sealevel, then builds to surge as storm passes

storm surge



Hurricane Devastation:

- Coastal Flooding from Storm Surge



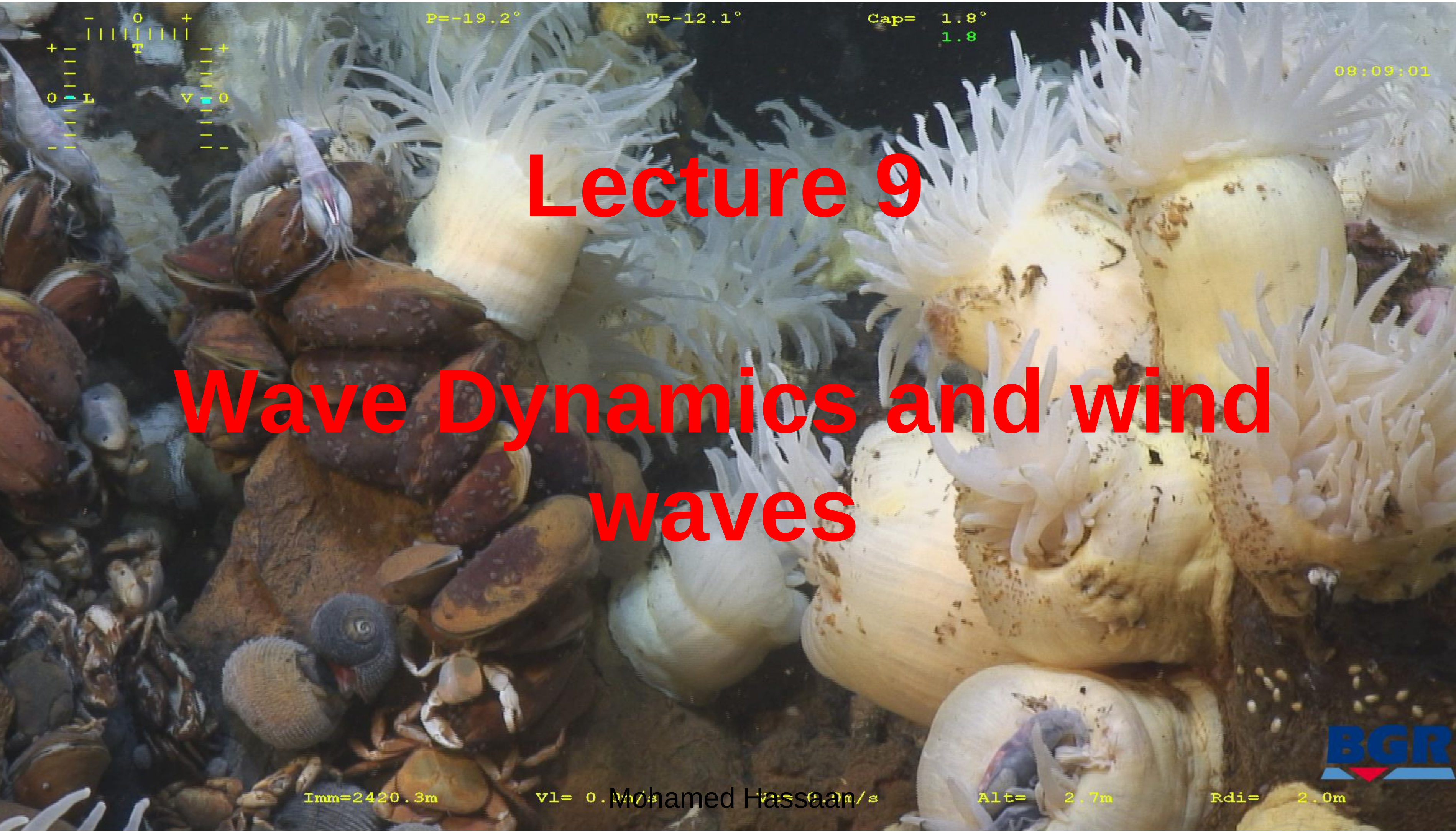
Pauline

- Inland: wind damage

Andrew

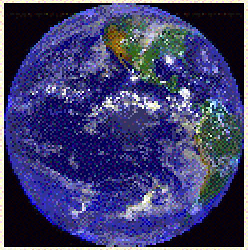
Lecture 9

Wave Dynamics and wind waves



Oceans & Our Global Environment

Wave Dynamics & Wind Waves



Topics:

- Wave Formation, Anatomy, Motion and Speed
- Deep-Water Waves
  - storm centers, dispersion, group speed, wave interaction
- Wave Height
  - episodic waves, wave energy and steepness
- Shallow-Water Waves and the Surf Zone
  - refraction, reflection, diffraction, breakers, transport

Wave Formation:

- Requires generating force
  - like ripples created by stone thrown in a pond; alternating disturbance & recovery; size of ripples depends on force (size, speed of stone)

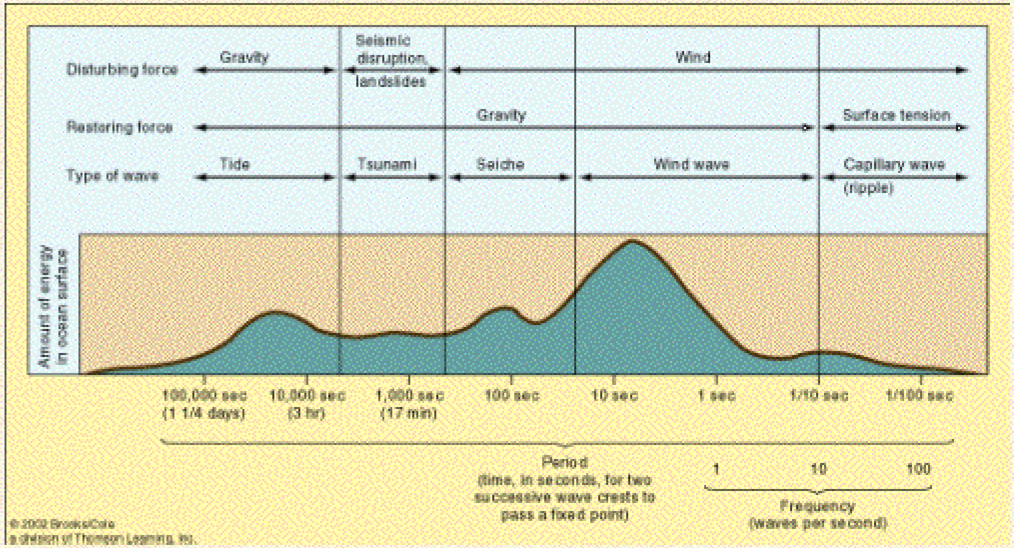
Table 10.1 Wavelengths and Disturbing Forces of Important Ocean Waves

Wave Type	Typical Wavelength	Disturbing Force
Wind wave	60–150 m (200–500 ft)	Wind over ocean
Seiche	Large, variable; a function of basin size	Change in atmospheric pressure, storm surge, tsunami
Seismic sea wave (tsunami)	200 km (125 mi)	Faulting of seafloor, volcanic eruption, landslide
Tide	½ circumference of Earth	Gravitational attraction, rotation of Earth

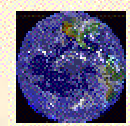
- Natural disturbing forces
  - winds, storms, earthquakes, gravity create ripples, or capillary waves
- Restoring forces
  - surface tension (small waves); gravity (larger waves); Coriolis effect

Wave Formation:

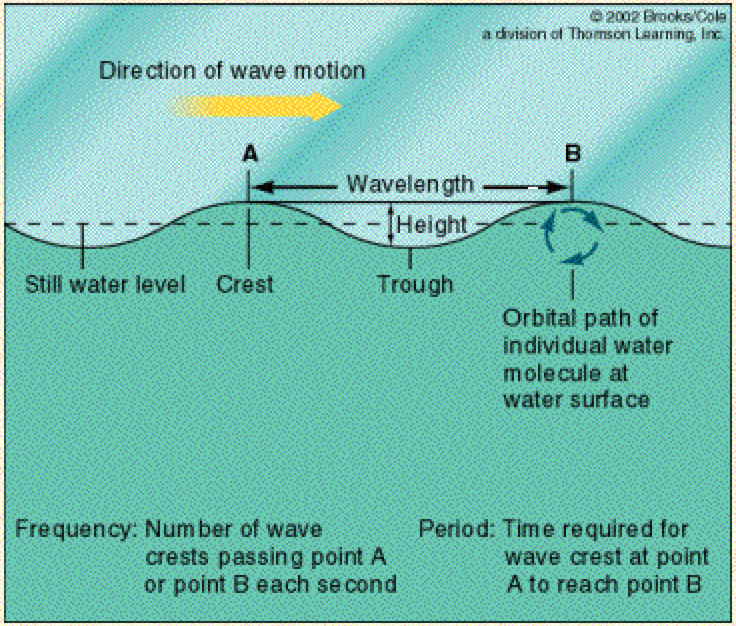
- Wave Types
  - tides, tsunami, seiches, wind waves, capillary ripples
  - defined by period, vary in energy



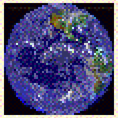
- Disturbing Forces
  - generate waves: gravity (Sun, Moon), wind, earthquakes
- Restoring Forces
  - Coriolis effect, gravity, surface tension



Wave Characteristics:

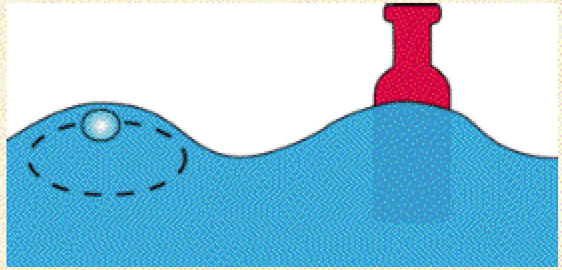


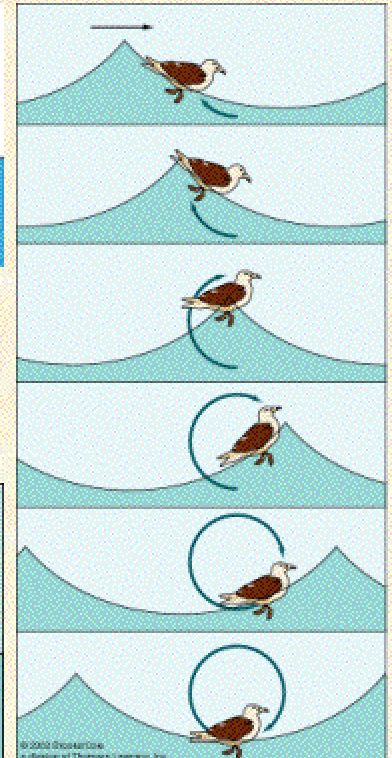
- High and low point of Progressive Waves
  - crest and trough
- Dimensions
  - height (H): altitude difference between trough and crest
  - amplitude (H/2): half height
  - wavelength (L): distance between successive crests
  - period (T): time interval between wave crests
  - frequency: number of waves passing a fixed point in unit time
- Motion and Speed
  - water parcels move in circular orbits

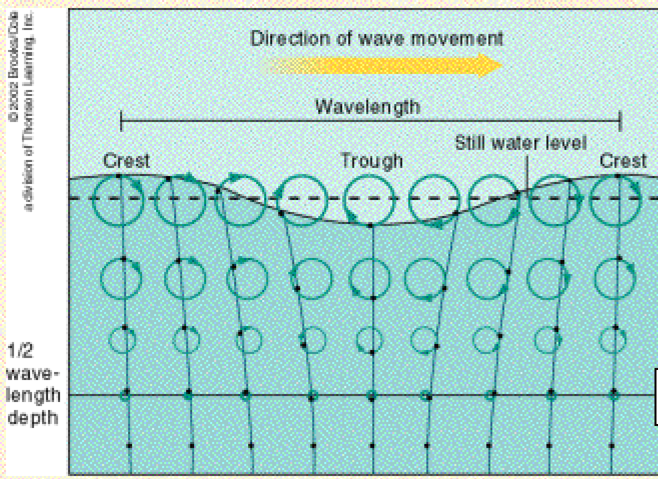


Wave Motion:

- Motion of Parcels
  - circular orbits with slight forward displacement
  - orbit size decreases with depth:
  - at surface equivalent to wave height
  - zero at wave base



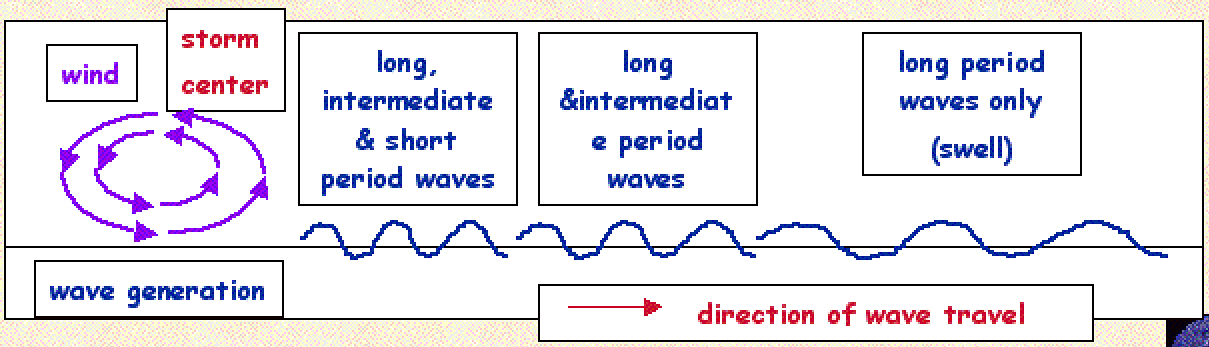


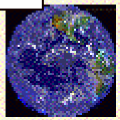


wave base

Deep-Water Waves:

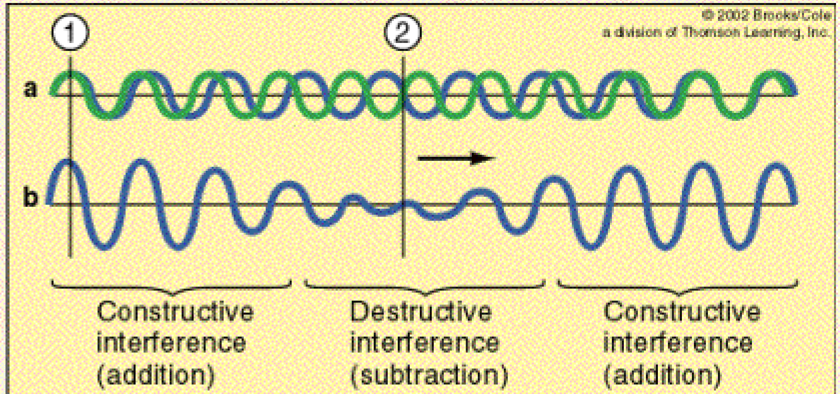
- Length and speed related
  - $L = gT^2/2\pi$, or $L = 1.56T^2$ m/sec^2, $C = 1.56T$
- Storm Centers
  - progressive waves formed by persistent winds
  - waves move away from storm centers, build "sea"
- Dispersion
  - waves with long L and T travel faster, sorts waves
  - storm centers in Pacific at 40-50°S create swell off Alaska

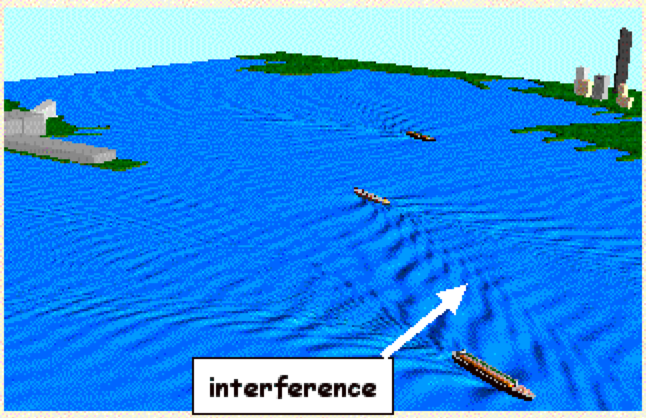


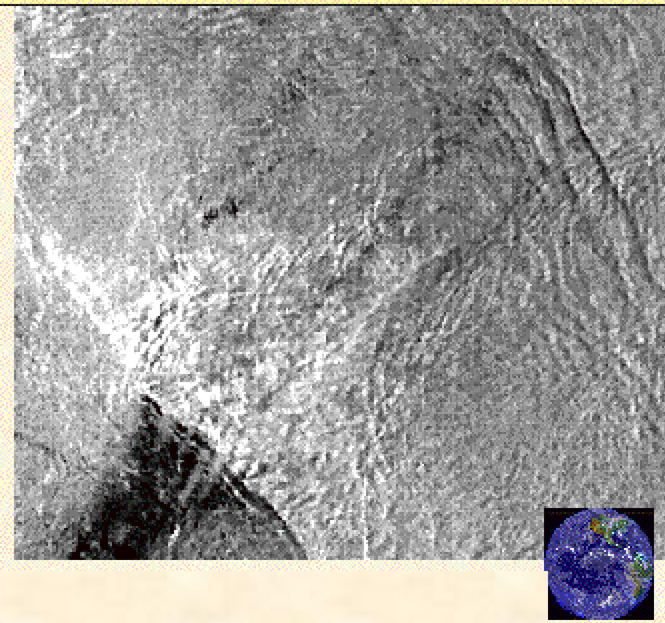


Wave Interaction:

- Wave combination
  - waves intersection
  - may reinforce one another (construc -tive interference)
  - or cancel one another (destructive interference)

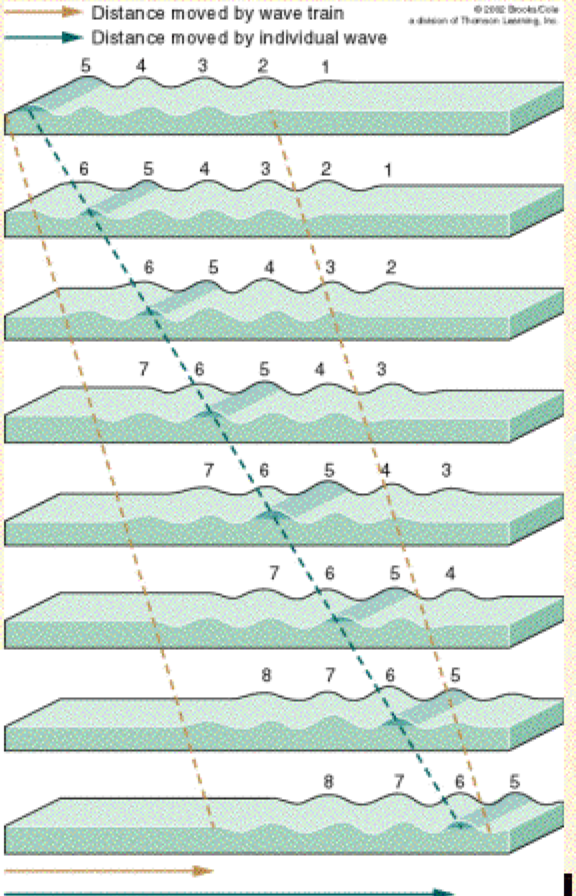


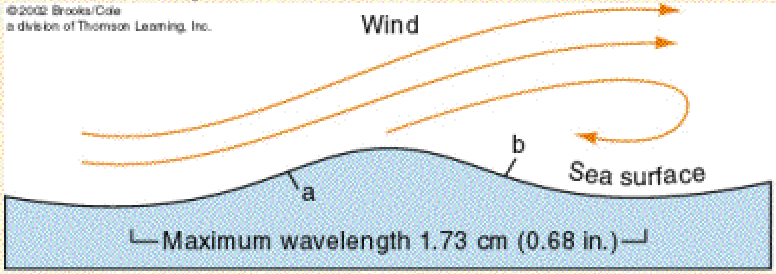




Deep-Water Waves: Wave Trains

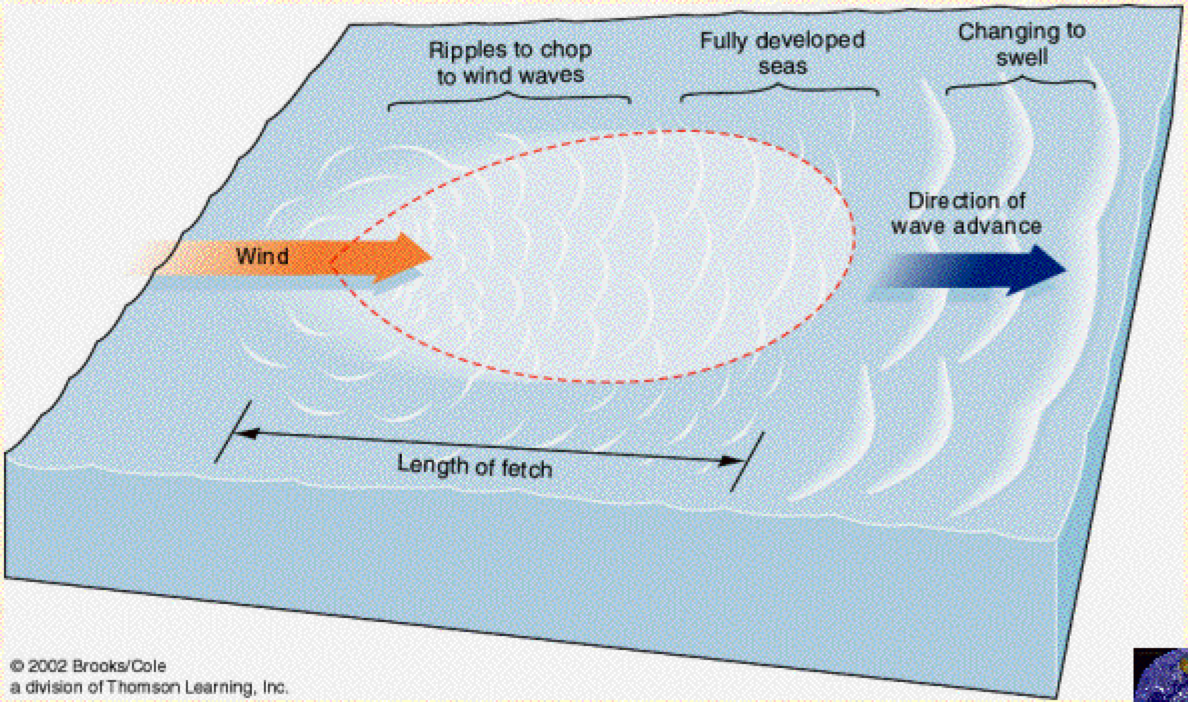
- Wave Groups
  - group moves at half speed of individual waves (V = C/2)
  - successive loss of leading wave as new wave forms to rear
- Wind-Driven Waves
  - dependence on wind strength





Wave Height:

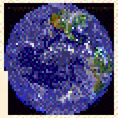
- Progressive development of waves
  - winds acting over a fetch of ocean (distance), build waves from ripples to waves to "fully developed sea" to swell



Wave Height:

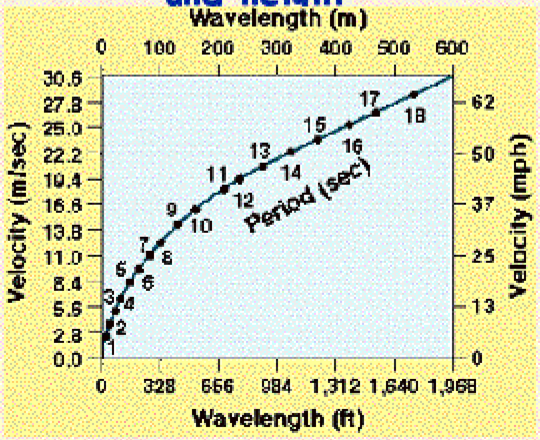
- Three Factors determine
  - speed of wind, duration of wind, fetch of ocean (distance across ocean), lead to "fully developed sea"
  - determines wave size (height, wavelength, period)
  - largest reports: Atlantic (to 11m), Pacific (up to 34m)

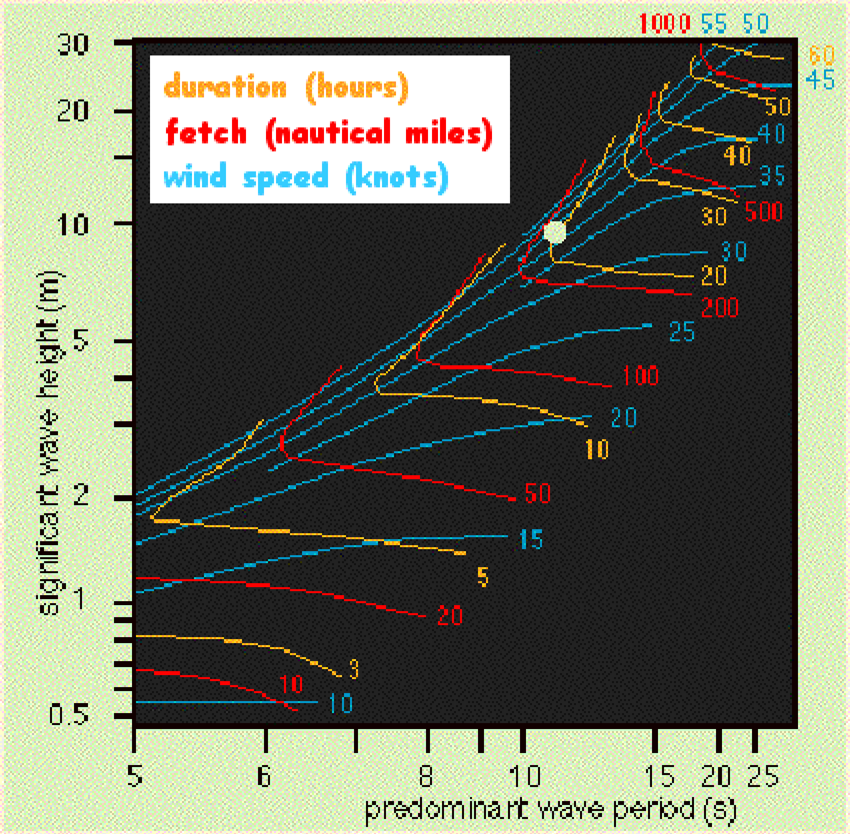
Wind Conditions			Wave Size		
Wind Speed	Fetch	Wind duration	Average Height	Average Wavelength	Average Period
19 km/hr (12 mi/hr)	19 km (12 mi)	2 hr	0.27 m (0.9 ft)	8.5 m (28 ft)	3.0 sec
37 km/hr (23 mi/hr)	139 km (86 mi)	10 hr	1.5 m (4.9 ft)	33.8 m (111 ft)	5.7 sec
56 km/hr (35 mi/hr)	518 km (322 mi)	23 hr	4.1 m (13.6 ft)	76.5 m (251 ft)	8.6 sec
74 km/hr (58 mi/hr)	1,313 km (816 mi)	42 hr	8.5 m (27.9 ft)	136 m (446 ft)	11.4 sec
96 km/hr (58 mi/hr)	2,627 km (1,633 mi)	69 hr	14.8m (48.7 ft)	212.2 m (696 ft)	14.3 sec



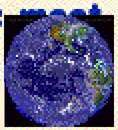
Wave Height:

- Limiting Factors
  - wind speed, duration and fetch
  - influence speed and height



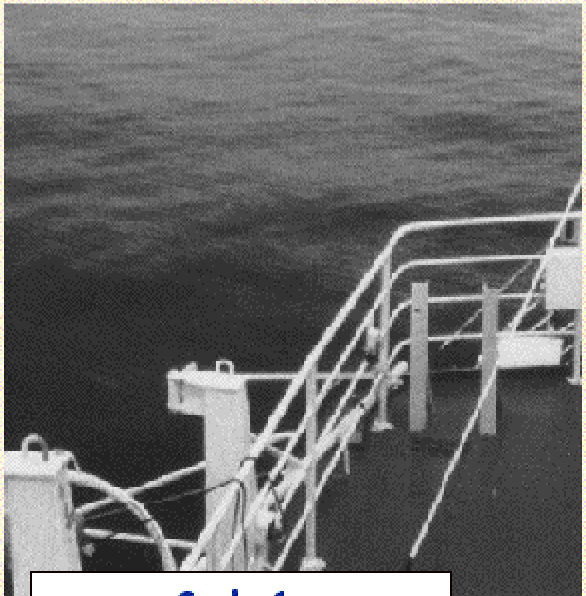


- Episodic Waves
  - formed when large waves combine, especially where currents meet (e.g. Agulhas current)



Wind Scales:

- Beaufort (0-12), Sea State Code (0-9)

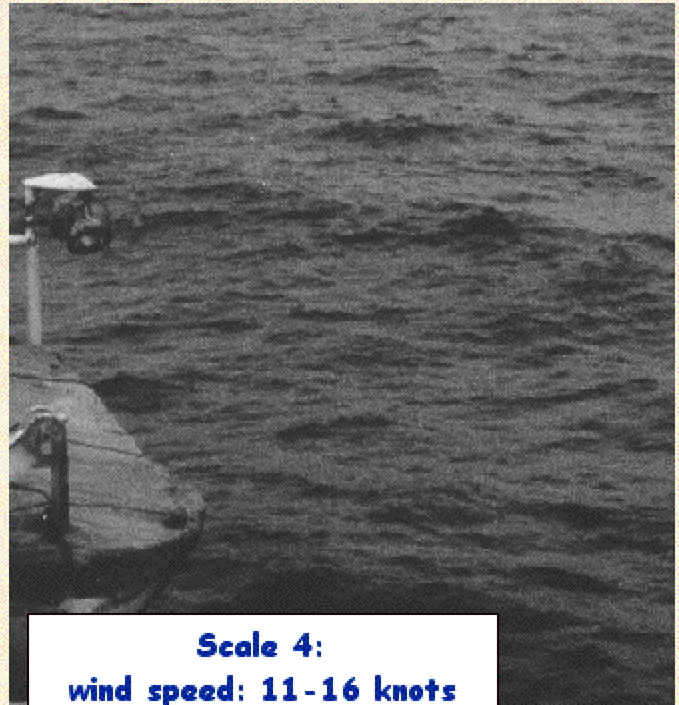


Scale 1:
wind speed: 1-3 knots
wave height: 10cm
ripples

Scale 2:
wind speed: 4-6 knots
wave height: 20-30 cm
wavelets

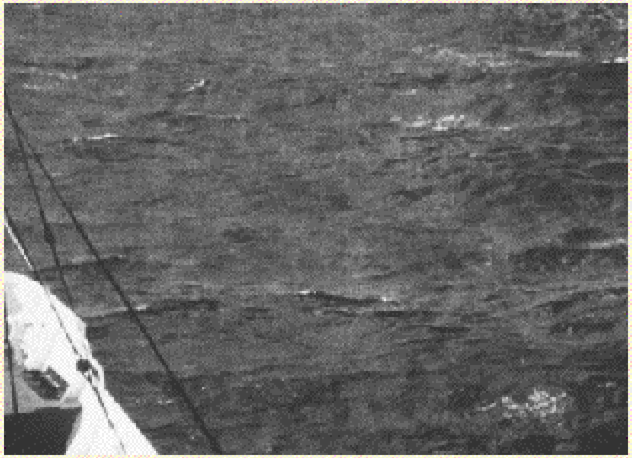
Wind Scales:

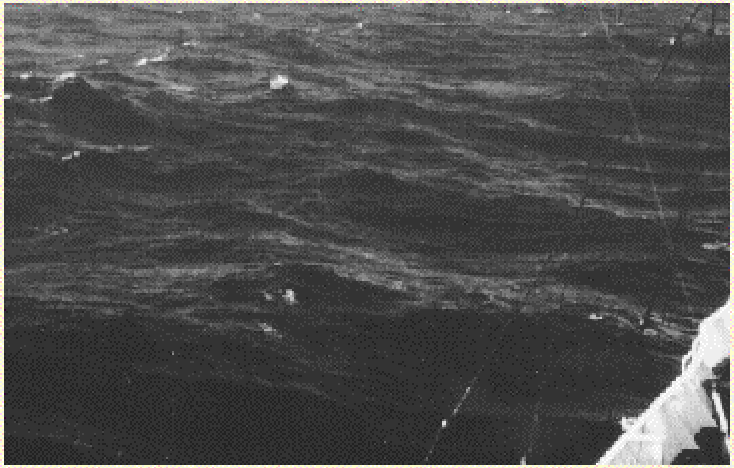
Scale 3:
wind speed: 7-10 knots
wave height: 60-100cm
large wavelets



Scale 4:
wind speed: 11-16 knots
wave height: 1-1.5m
small waves

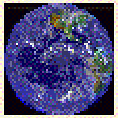
Wind Scales:

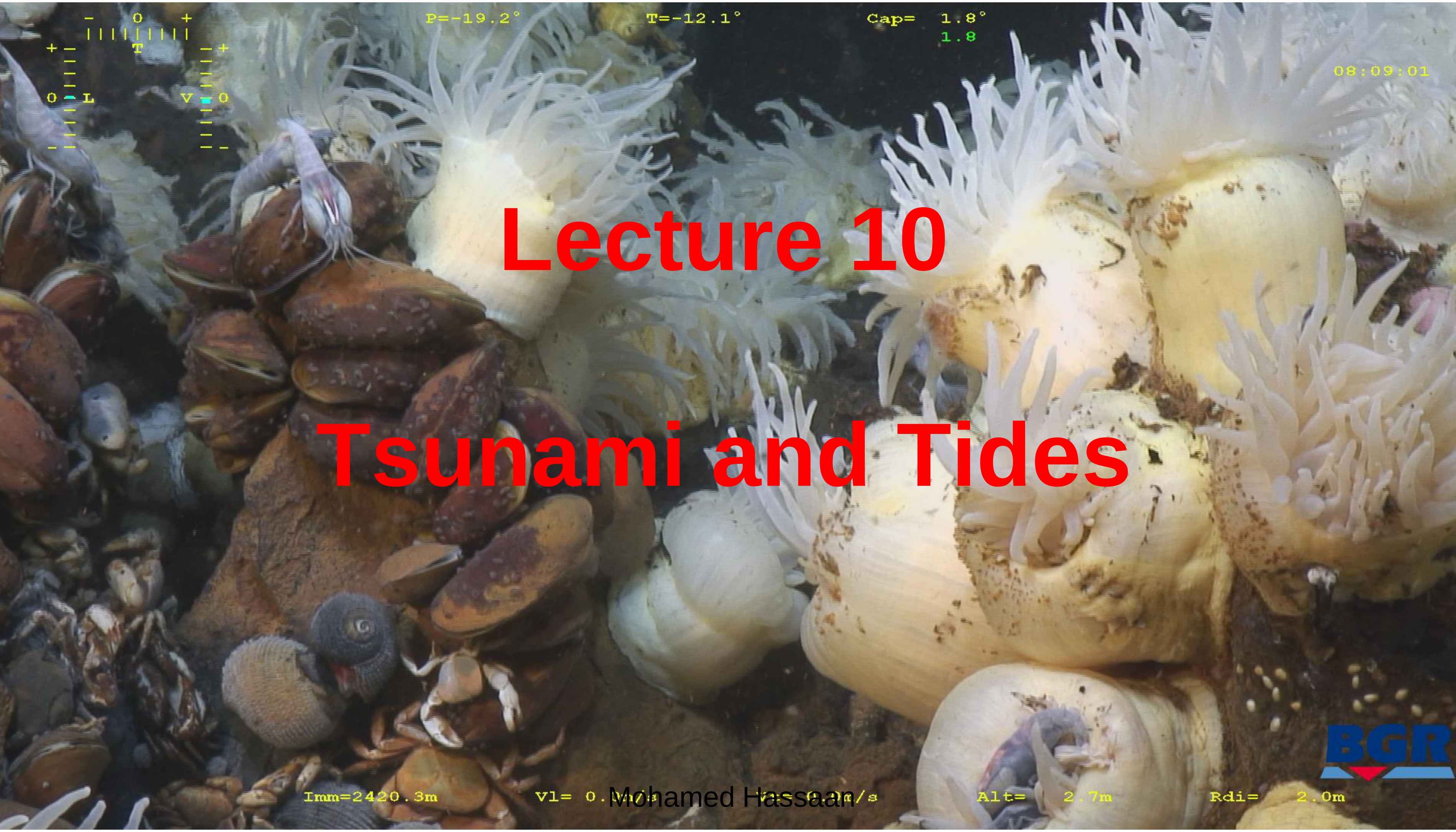




Scale 5:
wind speed: 17-21 knots
wave height: 2-2.5m
moderate waves

Scale 6:
wind speed: 22-27 knots
wave height: 3-4m
moderate waves





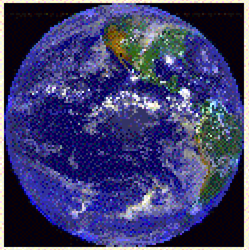
Lecture 10

Tsunami and Tides

Mohamed Hassaan

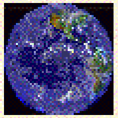
Oceans & Our Global Environment

Seiches, Tsunami and Tides



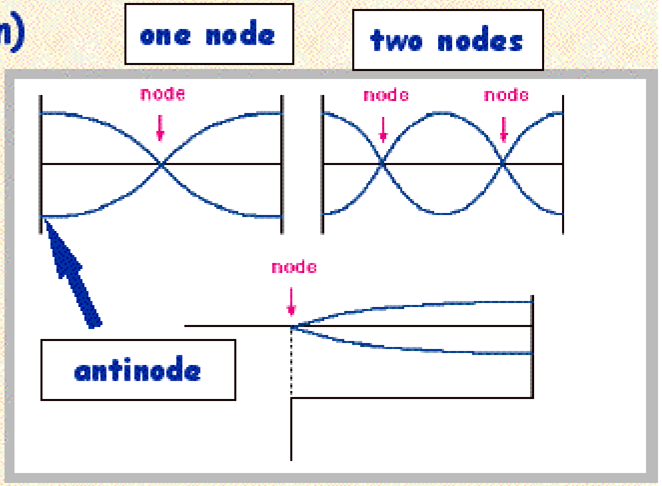
Topics:

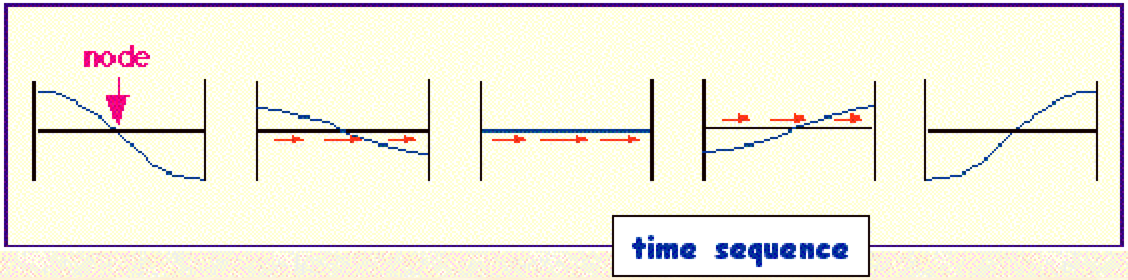
- Seiches and Tsunami
- Tide Patterns and Levels, Tidal Currents
  - diurnal, semidiurnal, semidiurnal mixed
- Equilibrium Tidal Theory, Dynamic Theory of Tides
  - forces, Moon tide, tidal day, tide wave, Sun tide
  - spring & neap tides, declinational tides, elliptical orbits
- Dynamic Theory of Tides
  - progressive tide, standing wave tides
  - tide waves in narrow basins, tidal bores
- Predicting Tides and Tidal Currents

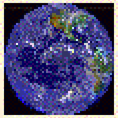


Standing Waves (Seiches):

- Contrast with Progressive Waves
  - stationary line or point node (n)
  - maximum change at antinodes
  - period: time interval between successive antinodes at a given point
  - oscillation (water pendulum)
  - occurs in basins, lakes
  - sloshing motion

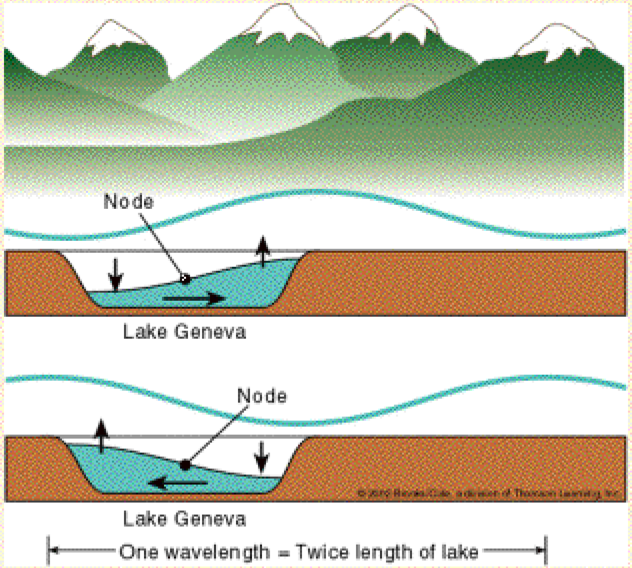


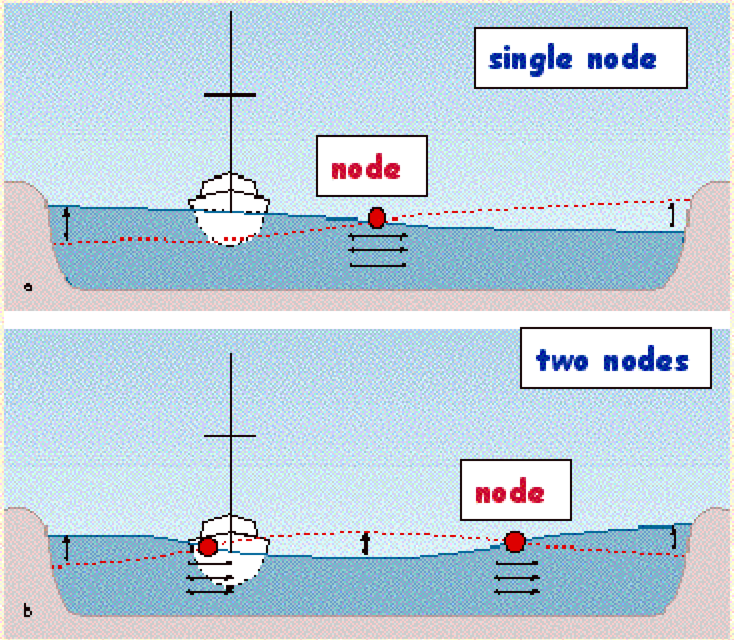




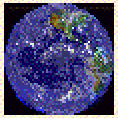
Standing Waves (Seiches):

- Waves that oscillate
- Enclosed Basins
  - one node or two nodes
  - point(s) of no movement



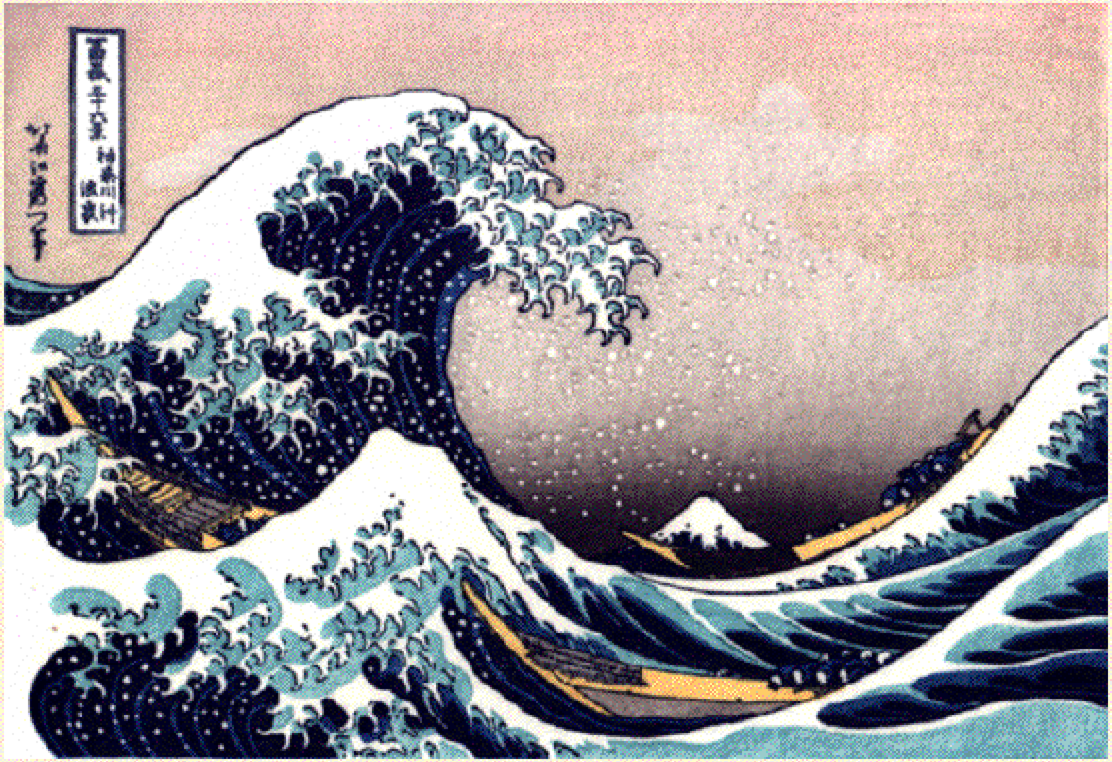


- nodes depend on natural period of basin (e.g. Lake Geneva)

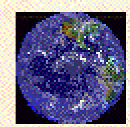


Tsunami:

- Seismic sea waves created by earthquakes

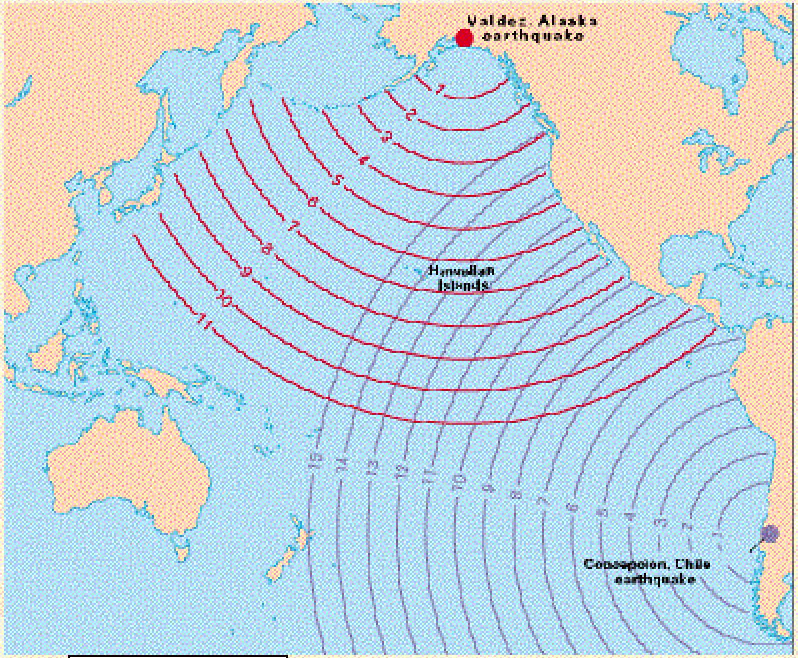


津波

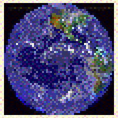


Tsunami:

- Tsunami Characteristics
  - entire water column set in motion
  - long periods
    - T = 10-20 minutes
  - long wavelengths
    - L = 100-200 km
  - fast speed (limited by ocean depth)
    - C = 200 m/s
  - deep wave base
  - create huge breakers on landfall
  - Tsunami warming system in Pacific

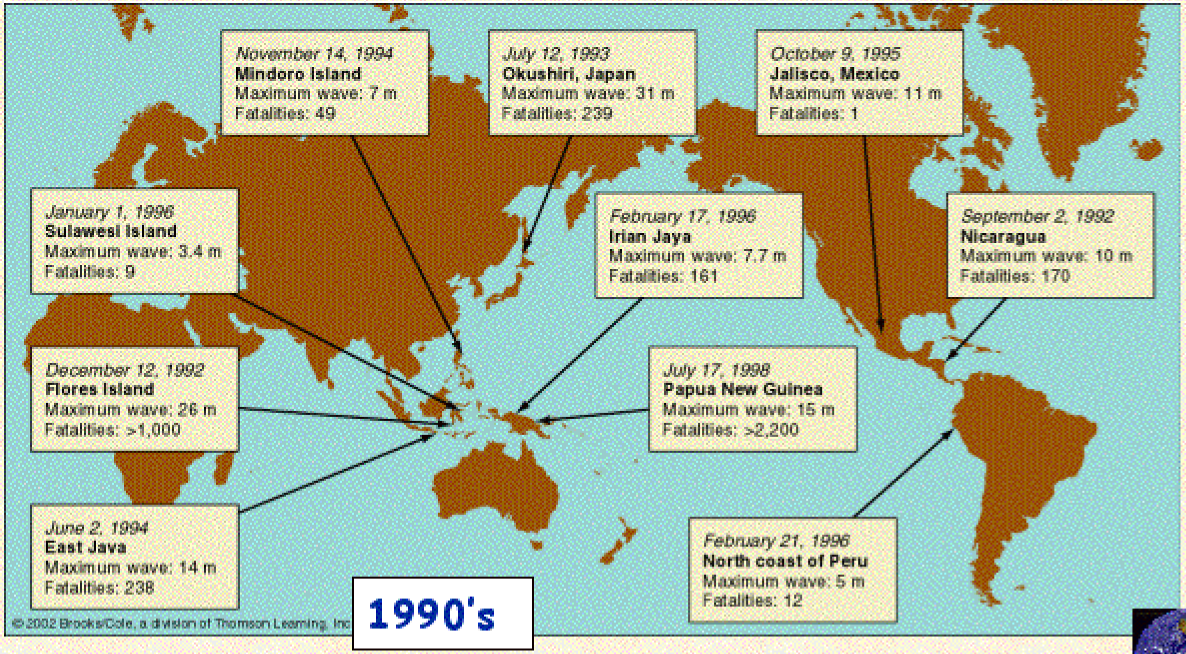


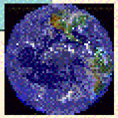
travel times



Historical Tsunami in the Pacific:

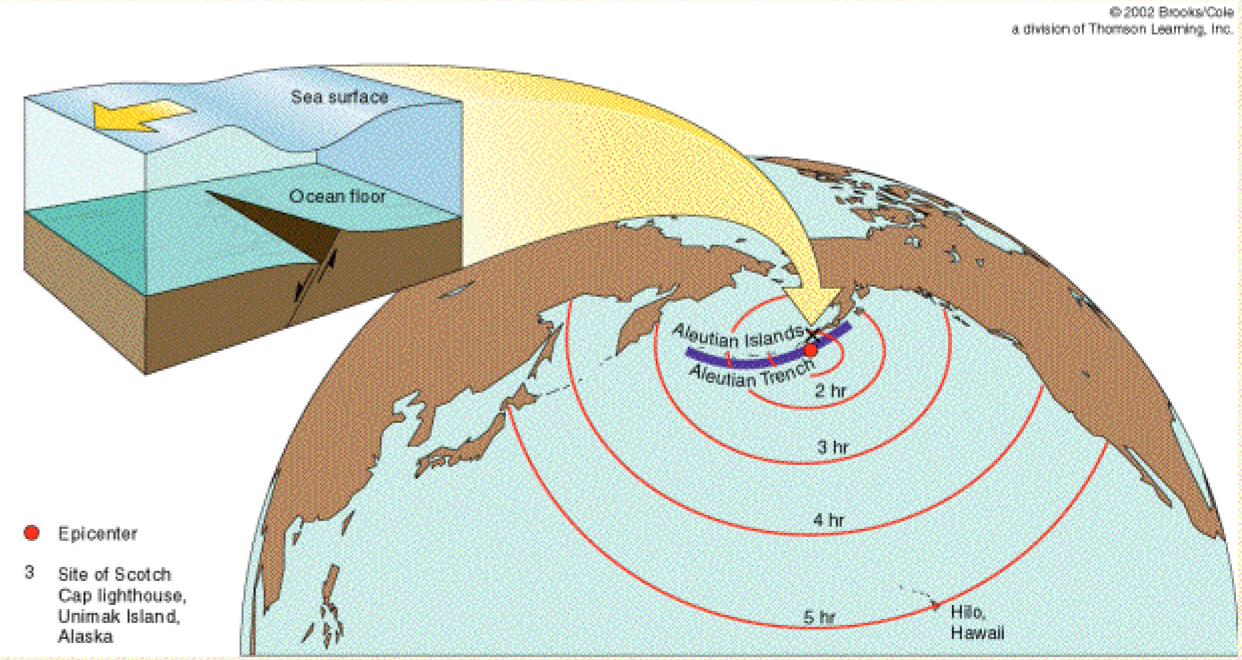
- Records History and 1990's
  - 1946 Aleutian (Hawaii); 1957 Aleutian (Hawaii); 1960 Chile (Chile, Hawaii); 1964 Prince William Sound (Alaska).

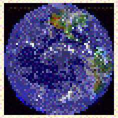




Historical Tsunami in the Pacific:

- Earthquakes in Aleutians create tsunami in Hawaii

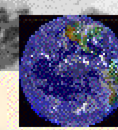




Tsunami:

- Tsunami Effects
  - surge (wall) of high water, then retreat
  - potentially devastating force

Hilo, Hawaii, April 1, 1946



Tsunami:

- Effects
  - buildings flattened
  - vessels transported inland
  - zones of complete and partial destruction
  - debris strewn into piles by advancing waters
  - may be preceded by water drop

Kodiak, Alaska

1964

Sea level falls

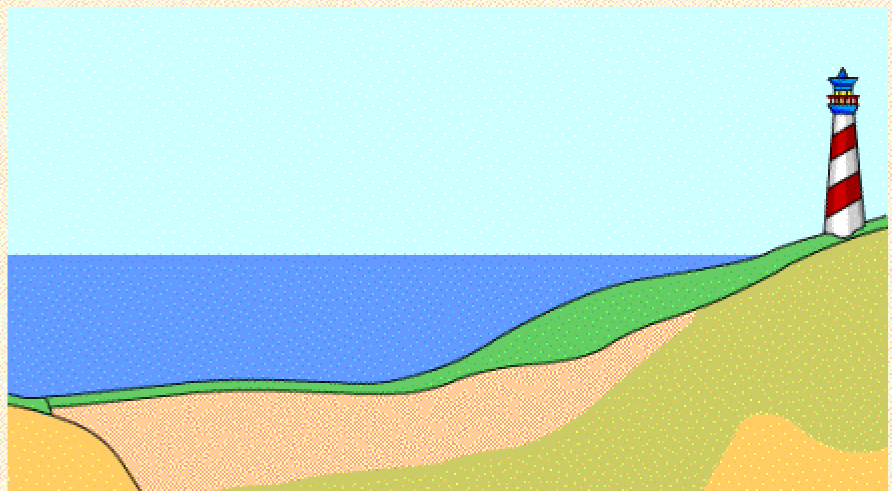
Tsunami:

- Laie Point, Oahu, Hawaii
  - March 9, 1957
  - surge of water engulfing beach house

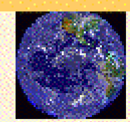
Chilean Earthquake, 1960:

Chilean coast

Hilo, Hawaii



simulation



Okushiri Island, Hokkaido, July 12 1993:

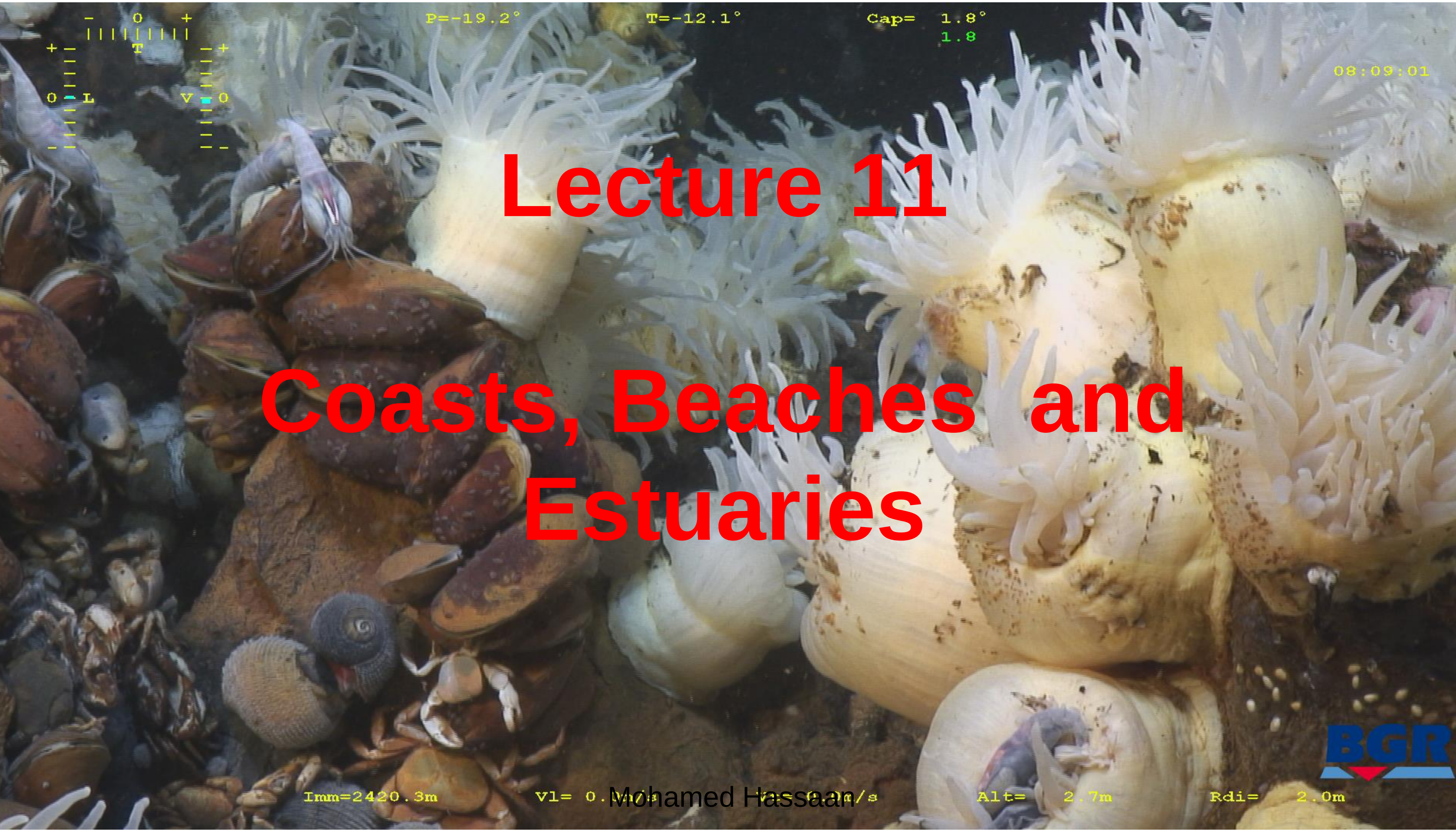
Lighthouse destroyed, areas of complete & partial devastation

75m vessel dumped 75m inland, debris left on shoreward side as wave retreated

Okushiri Island, Hokkaido, July 12 1993:

Vessel and vehicles destroyed

High water mark on side of house



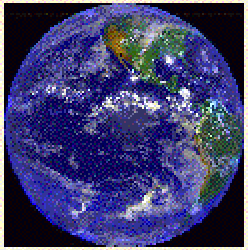
Lecture 11

Coasts, Beaches and Estuaries

Mohamed Hassaan

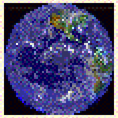
Oceans & Our Global Environment

Coasts, Beaches and Estuaries



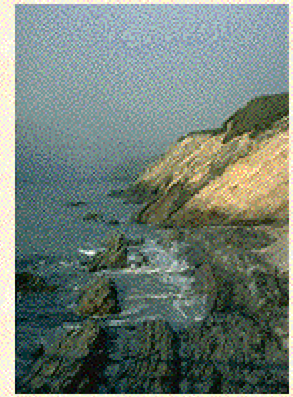
Topics:

- Major Coastal Zones: Coasts, Shores, Beaches
- Types of Coasts
  - primary (land-dominated), secondary (ocean-dominated)
- Beaches and Beach Dynamics
  - shapes, structures, sizes, composition, color of materials
  - processes: longshore transport, coastal circulation
- Estuaries
  - salt wedge, well-mixed, partially-mixed, fjords
  - circulation patterns, evaporation

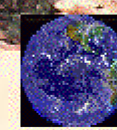


Types of Coasts:

- Landform Features governed by Coastal Processes
  - geomorphology, modified by sea-level changes
  - affected by rivers, currents, storms, ice, organisms (e.g. corals)
  - dominated by either *Land* or *Ocean* processes
- Primary Coasts: Land-dominated
  - erosion by water, wind, ice, sea-level
  - sediments deposited by rivers, winds, glaciers
  - formed by volcanic activity, or earth movements



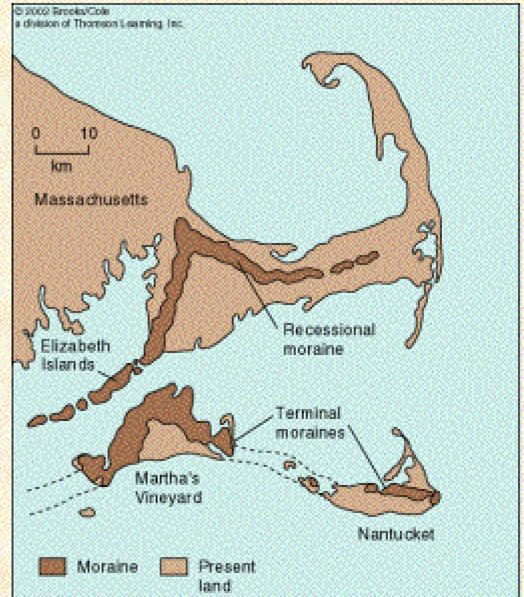
- Secondary Coasts: Ocean-dominated
  - erosion by waves, currents, seawater
  - sediments deposited by waves, tides, currents, storms
  - deposits formed or altered by marine plants and animals



Primary Coasts:

- U-shaped valleys carved by glaciers: fjords
  - shallow sill at mouths, formed as morraine when glacier retreated
- V-shaped valleys formed from drowned rivers
  - created by sea-level rise

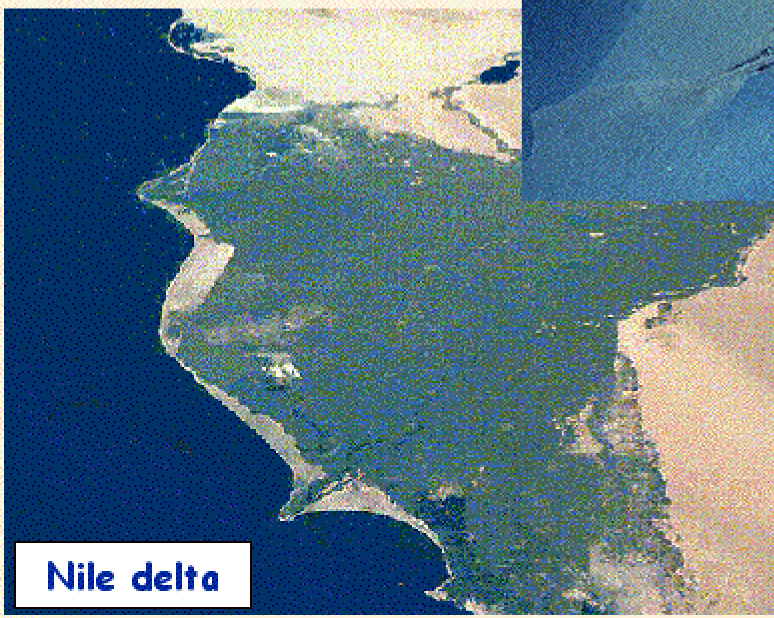
glacial valley



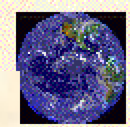
fjord

Primary Coasts:

- Deltas
  - sediment deposits at mouths of large rivers



- sediments accumulations tend to thicken with time and progress (prograde) seaward
- course of deltas changes periodically



Primary Coasts:

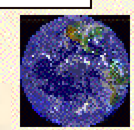
- Dune Coasts
  - wind-modified coasts formed by sand migration
- Lava Coasts
  - produced by volcanic deposits
- Tectonic Coasts
  - shaped by tectonic activity

dune coast, OR

dunes, CA

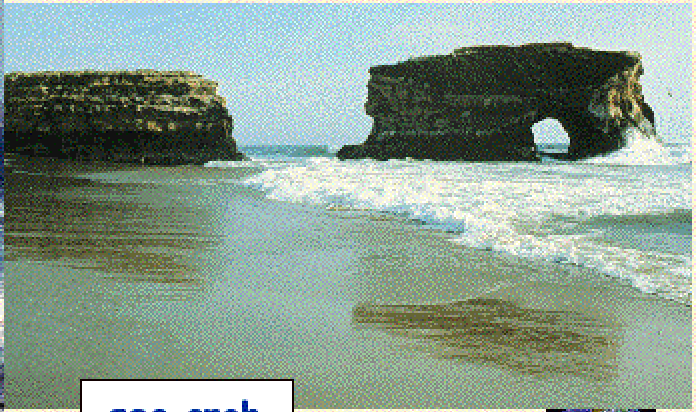
lava coast, HI

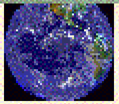
tectonic coast, CA



Secondary Coasts:

- Cliffs, Pinnacles and Sea Stacks
  - shaped by waves
  - eroded materials form bars, barrier islands, sand spits





Secondary Coasts:

- Cliffs, Coasts
  - shaped by waves
  - depends on rock types, especially weaknesses

Monterey, CA

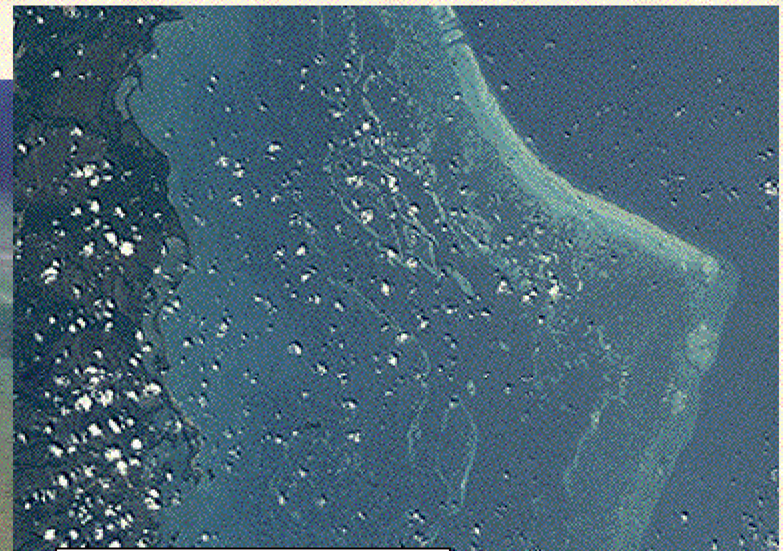
Maine

Secondary Coasts:

- Reef Coasts:
  biological influences
  - biological influences of plants and animals
  - progressive growth

Bora Bora

coral atoll, Australia



barrier reef, Belize

Secondary Coasts:

- Mangroves and salt marshes
  - plants retaining sediments, periodic tidal flooding
  - plants that tolerate saline conditions

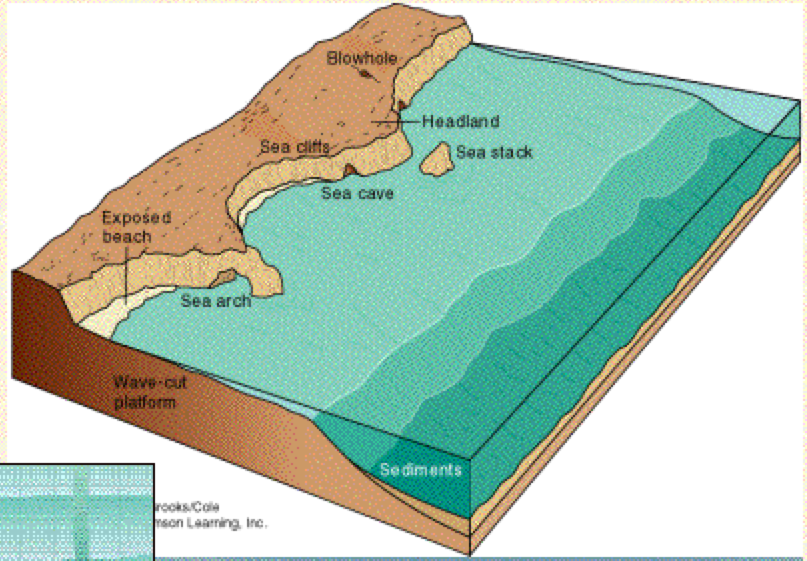
mangroves

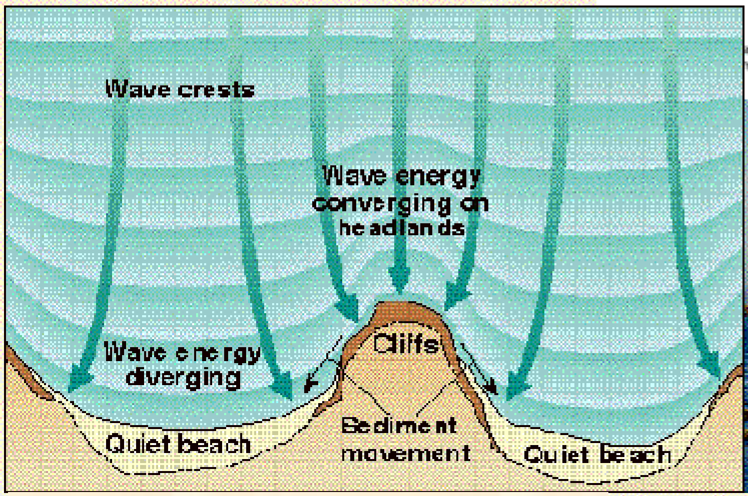
mangroves

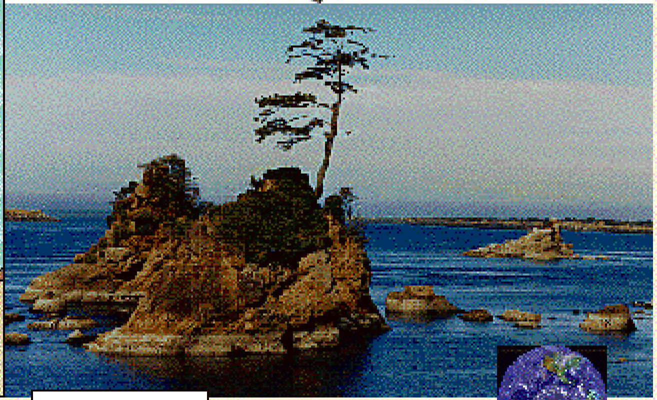
wetlands, marshes

Secondary Coasts:

- Shaped by ocean processes:
  - wave action and energy distribution
  - balance of erosion and deposition



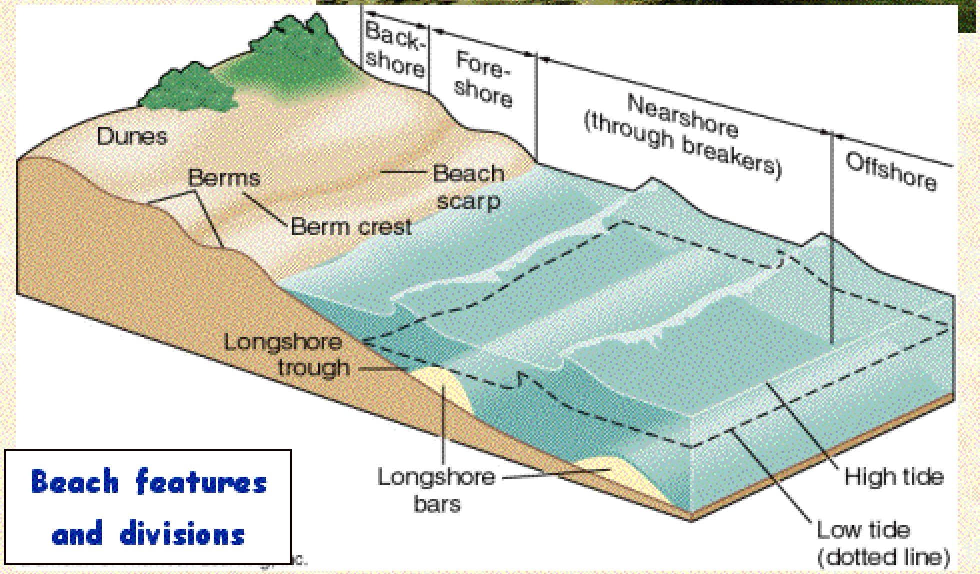




Oregon

Beach Characteristics:

- Division of shoreline related to tides:
  - offshore, foreshore, backshore
  - features tend to parallel coastline
- Features:
  - longshore bars & troughs
  - summer & winter berms (high tide crests)



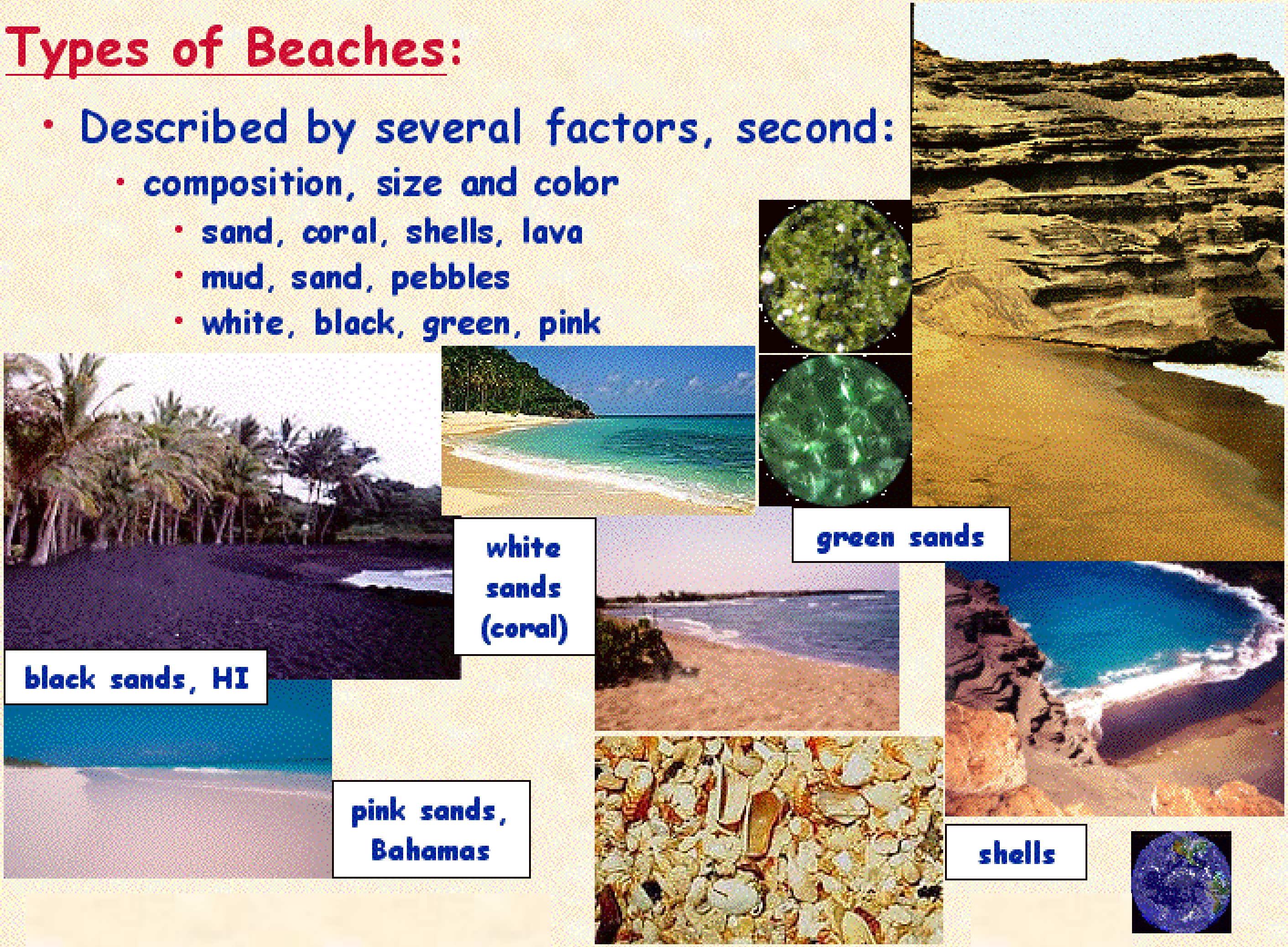
Beach features and divisions

Types of Beaches:

- Described by several factors, first:
  - shape and structure
    - wide/narrow
    - steep/flat
    - long/discontinuous

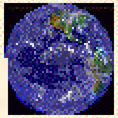
Types of Beaches:

- Described by several factors, second:
  - composition, size and color
    - sand, coral, shells, lava
    - mud, sand, pebbles
    - white, black, green, pink



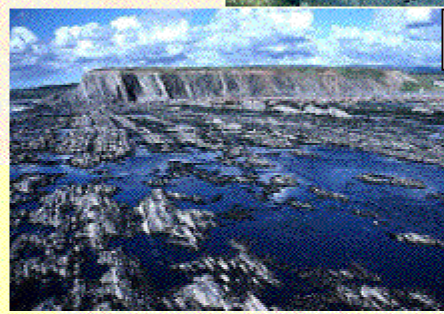
Types of Beaches:

- Processes and forces determine:
  - composition and size of beach materials
    - create lag deposits, armored beach

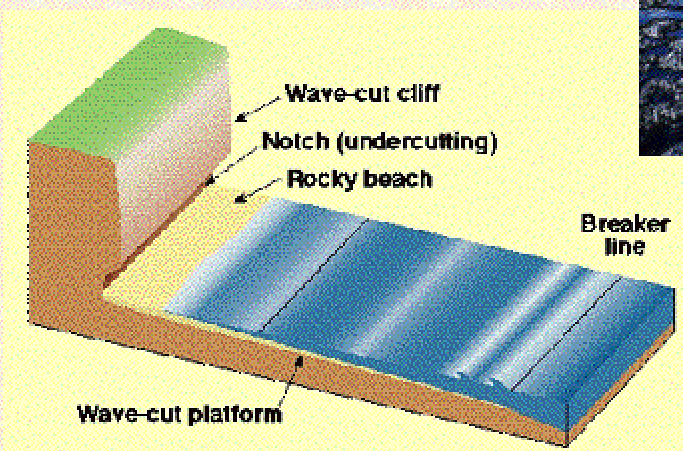


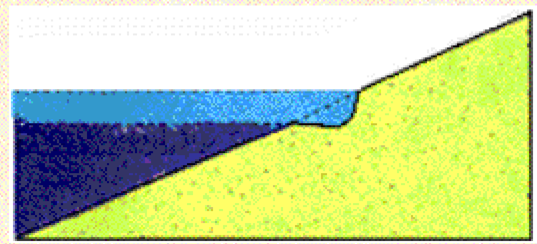
Wave-Cut Cliffs & Platforms:

- Product of wave-action:
  - may undercut cliffs
  - creates terraces or platforms
  - depends on rock strata
  - progressive erosion

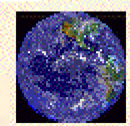


wave-cut platforms



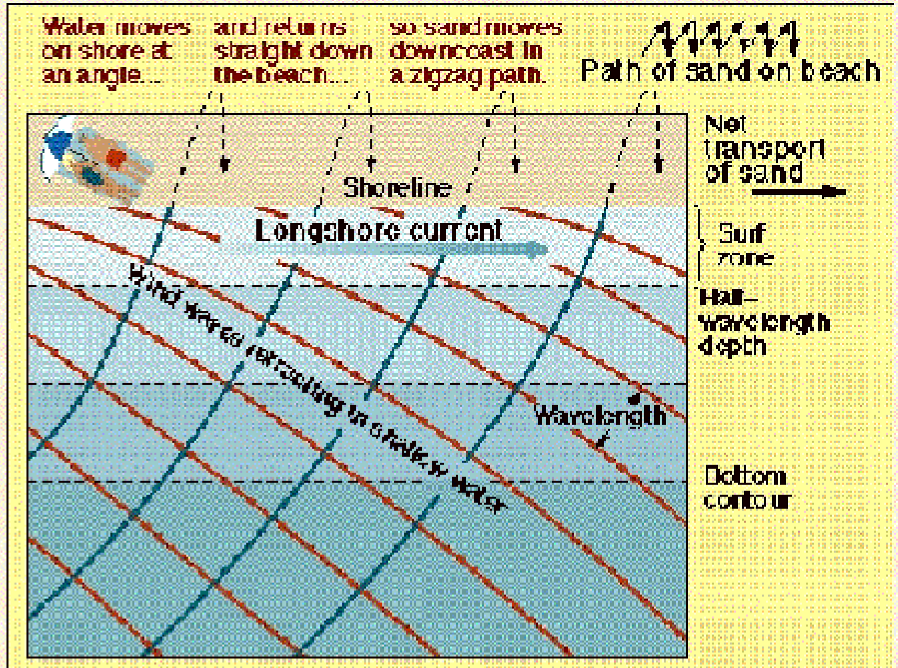


sequence of formation

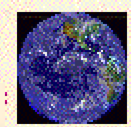


Beach Dynamics:

- Dynamic equilibrium between depositional and erosional processes
- Water motion:
  - onshore current creates surf zone where waves break
  - longshore currents parallel to shoreline moves sediment in zigzag path along shore
  - transport direction determined by waves

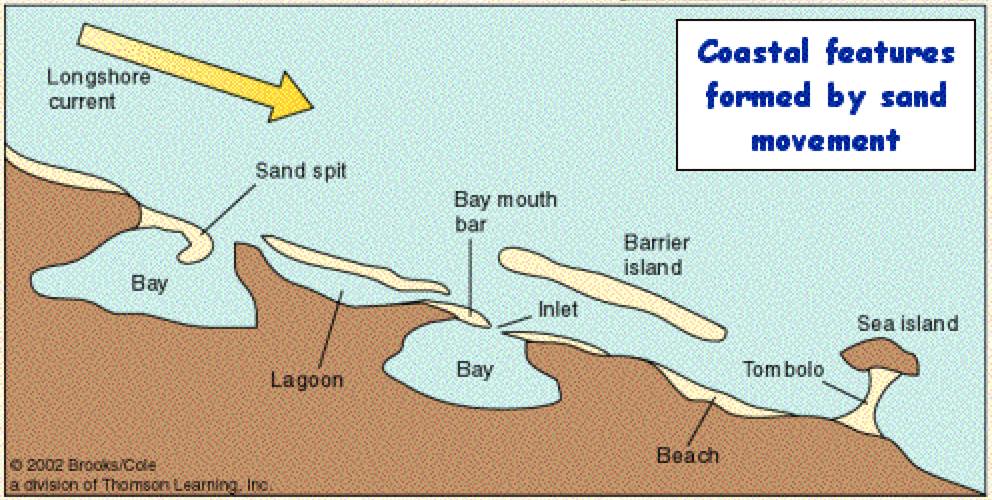


wave-dominated shoreline processes

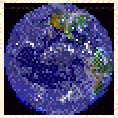


Longshore Transport:

- Movement of sand driven by longshore current
- Shapes features of coastline

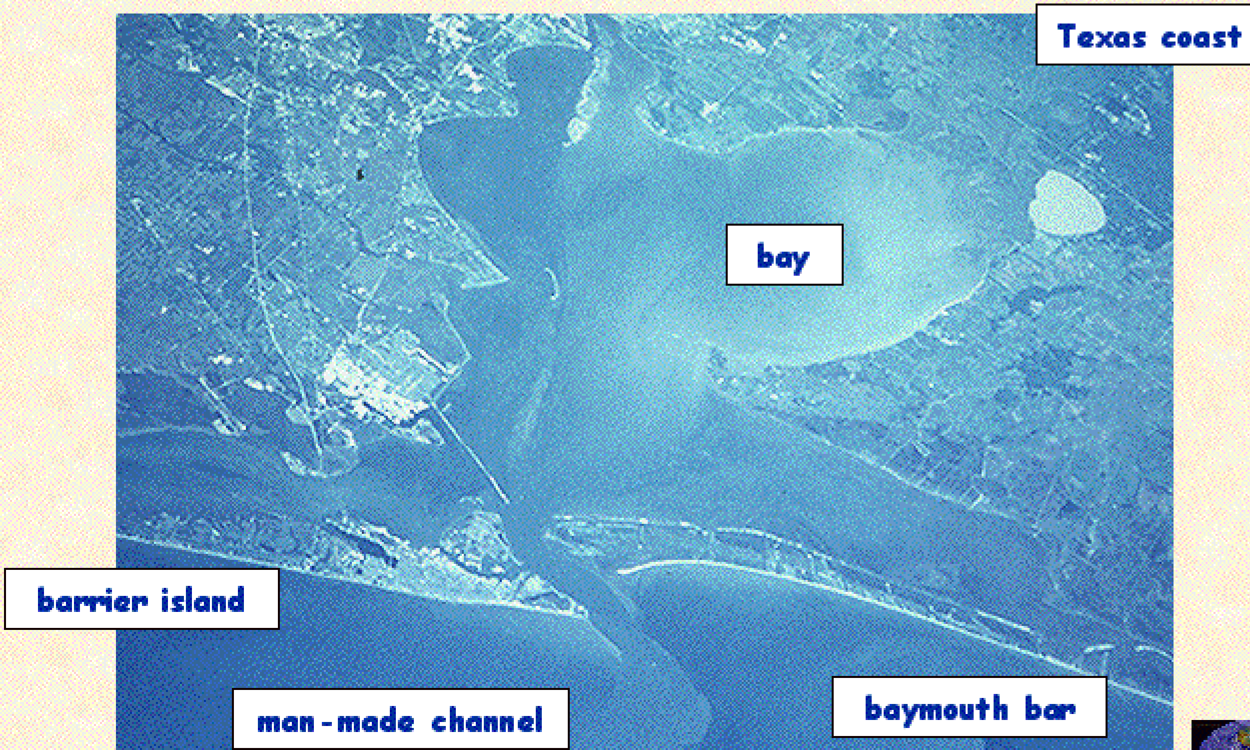


- sand spits across bays, bars, barrier islands, lagoons, tombolos



Barrier Islands and Bays:

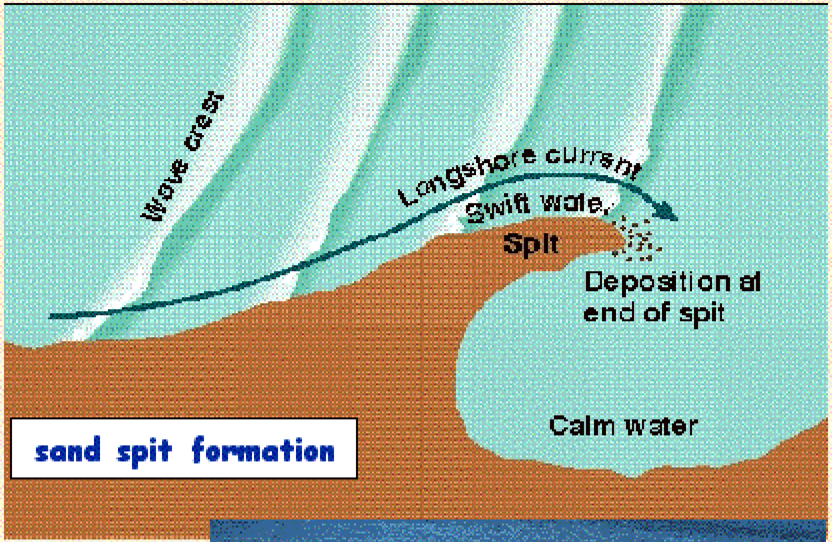
- Created by longshore movement of sand



Sand Spit Formation:

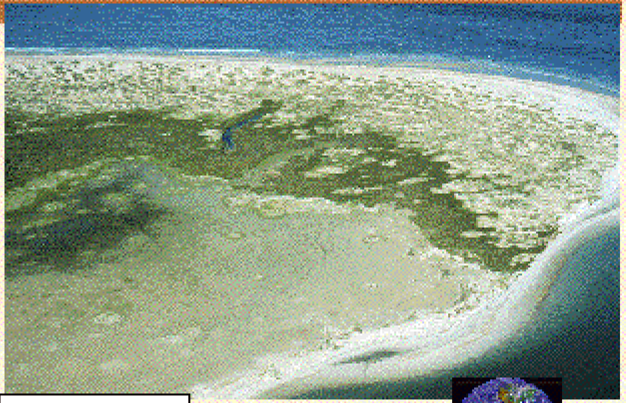
- Sand Movement:
  - created by longshore current and sand movement

sand spit

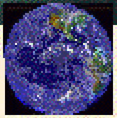


sand spit formation

- sand deposited in calmer waters
- spits gradually grow and migrate as sand accumulates

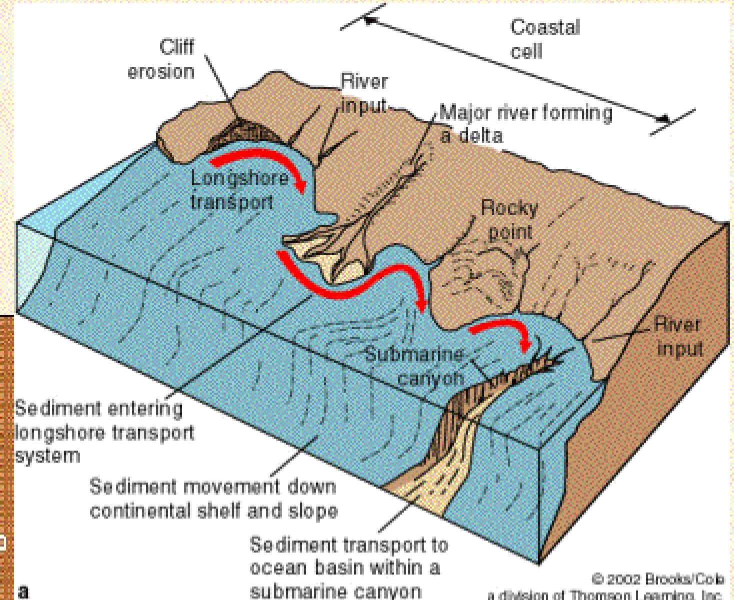


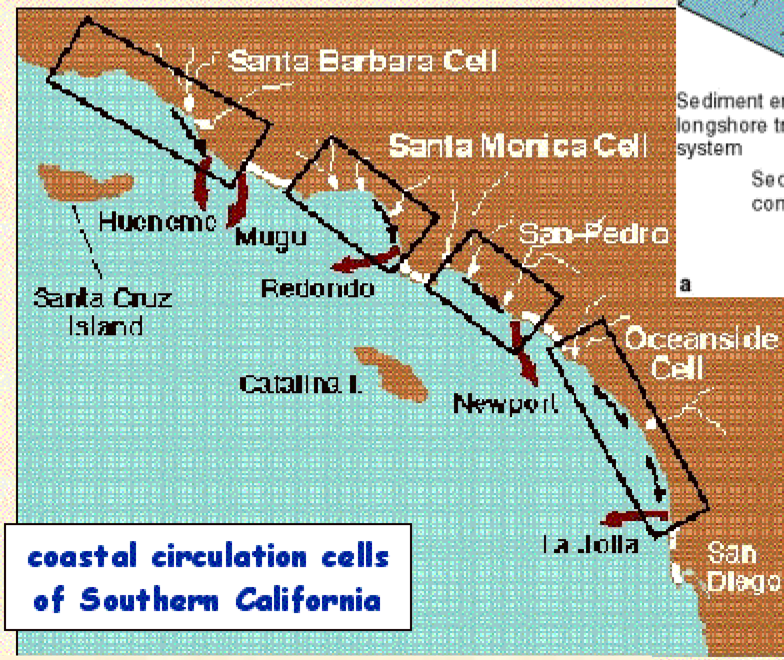
sand spit



Coastal Sediment Circulation Cells:

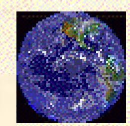
- Division of coast based on sediment budgets:





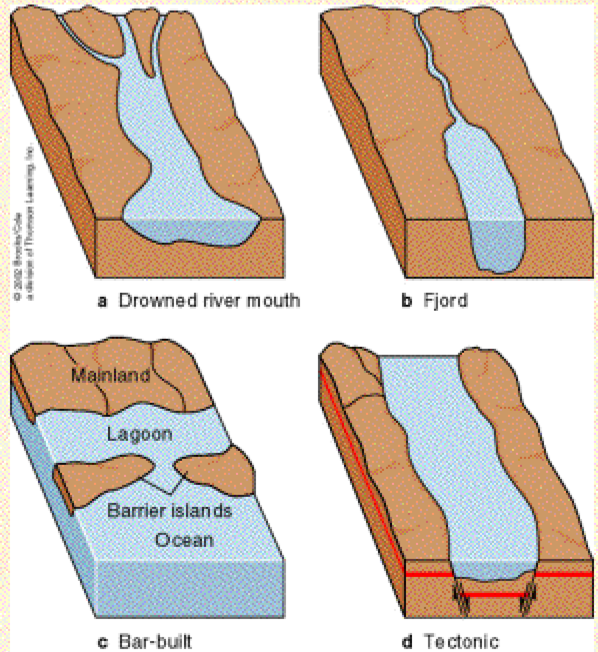
coastal circulation cells of Southern California

- each cell begins and ends at rocky headlands
- sand moved by longshore transport
- sand transported offshore into submarine canyon



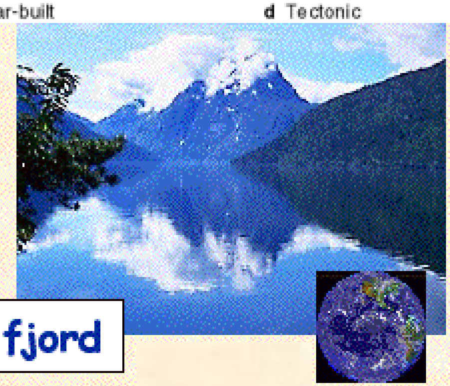
Estuaries:

- Mixing zones of dense sea-water, less dense freshwater
  - semi-enclosed embayments created in various ways:
    - flooded river valleys (e.g. Chesapeake Bay)
    - coastal plain estuaries (e.g. Cape Hatteras)



Cape Hatteras

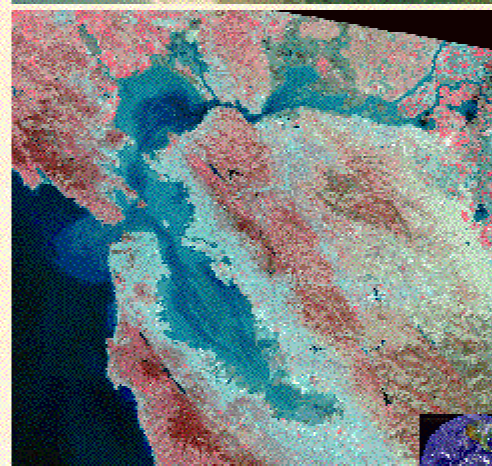
- fjords, flooded glacial valleys (e.g. in Norway)
- tectonic estuaries (e.g. San Francisco Bay)



fjord

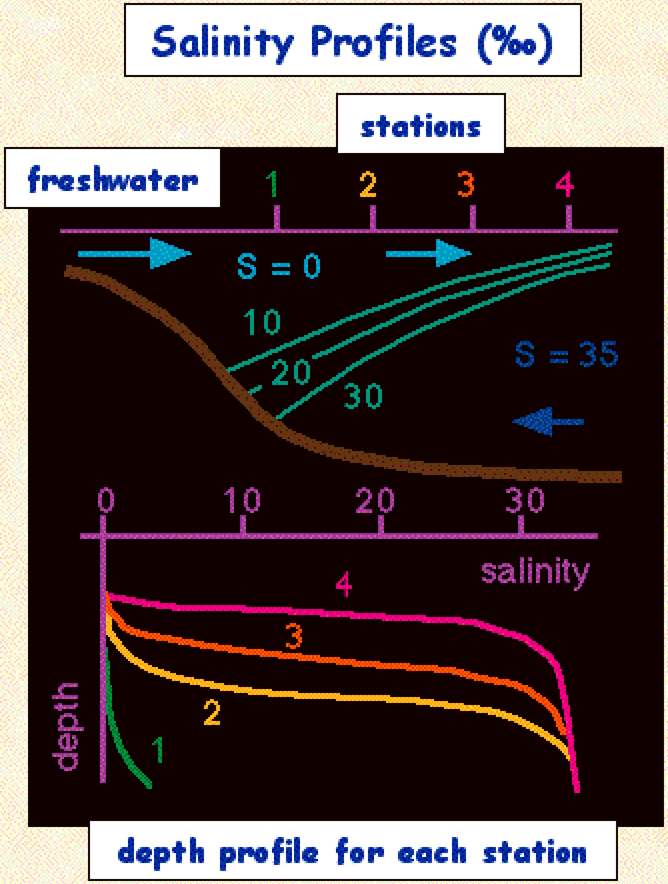
Estuaries:

- Mixing zones of dense seawater and less dense freshwater
  - described by mode of formation or by circulation features
  - 4 principal types of circulation:
    - salt-wedge
    - well-mixed
    - partially-mixed
    - fjords
  - mixing depends on:
    - strength of tides
    - volume of freshwater influx (river flow)
    - topography



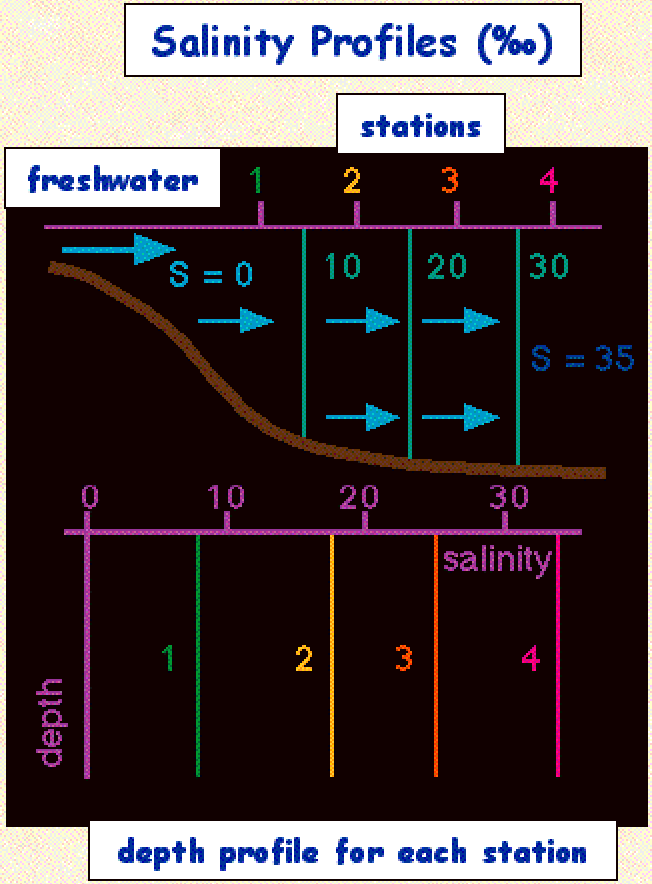
Salt-Wedge Estuary:

- River Flow:
  - large; strong surface flow of freshwater
- Tidal Range:
  - low; small surface flux of seawater
- Result:
  - stratification: water is salty at depth
  - lower layer of salt water is entrained by freshwater
  - gradual mixing occurs
  - surface water salinities only increase toward ocean



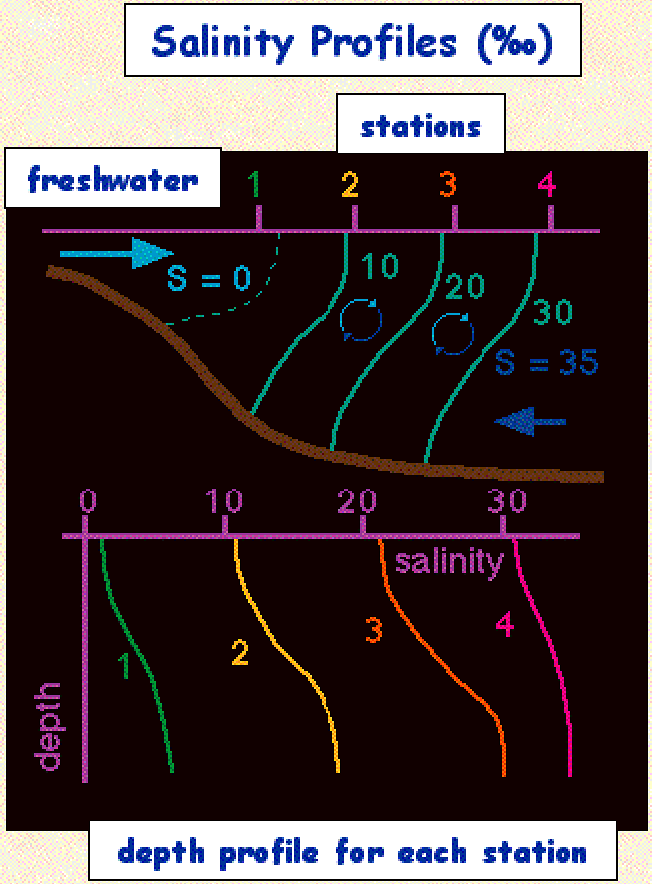
Well-Mixed Estuary:

- River Flow:
  - low; weak surface flow of freshwater
- Tidal Range:
  - high; strong mixing of seawater and freshwater
- Result:
  - little depth stratification
  - turbulent mixing
  - surface water salinity progressively increases seaward



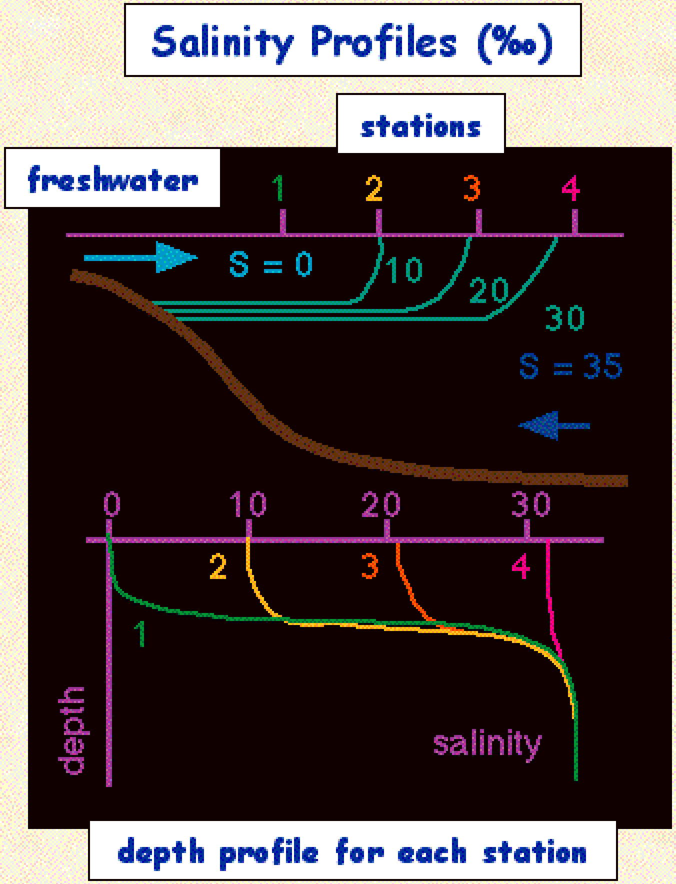
Partially-Mixed Estuary:

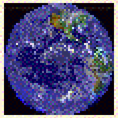
- River Flow:
  - moderate; surface flow of freshwater
- Tidal Range:
  - moderate; gradual mixing of seawater and freshwater
- Result:
  - some stratification
  - strong net seaward flow of freshwater
  - surface water salinity gradually increases seaward



Fjord-Type Estuary:

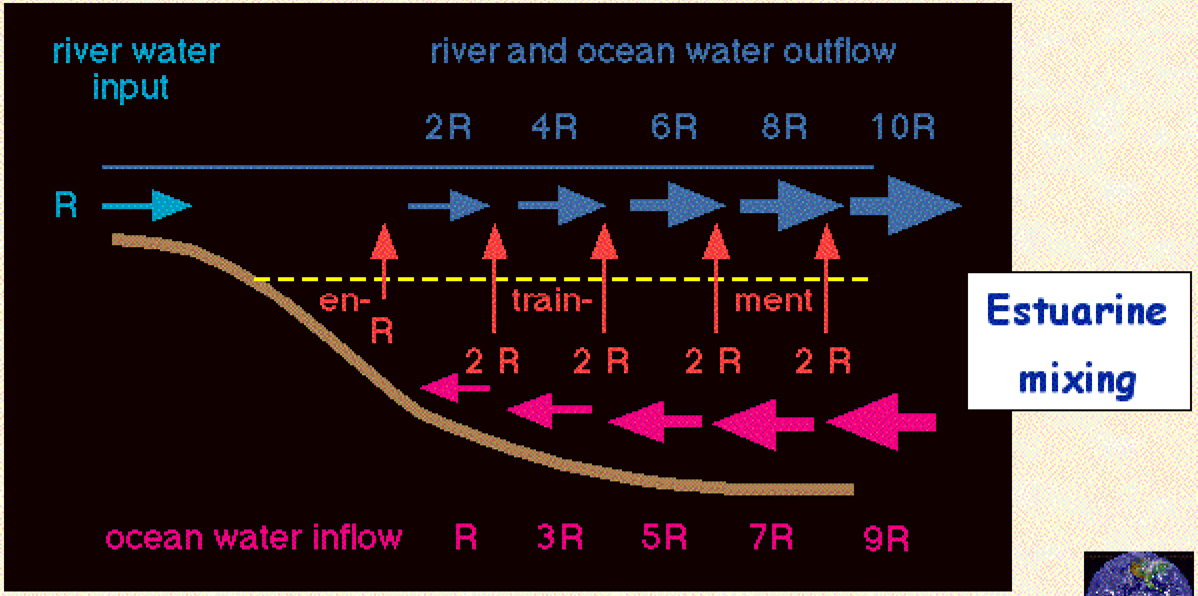
- Ocean Connection:
  - may be restricted by shallow sill (glacial moraine)
- River Flow:
  - moderate; surface flow of freshwater
- Tidal Range:
  - little tidal mixing of seawater and freshwater
- Result:
  - strong stratification, little mixing below surface
  - surface water salinity gradually increases
  - little influx of seawater

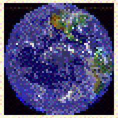


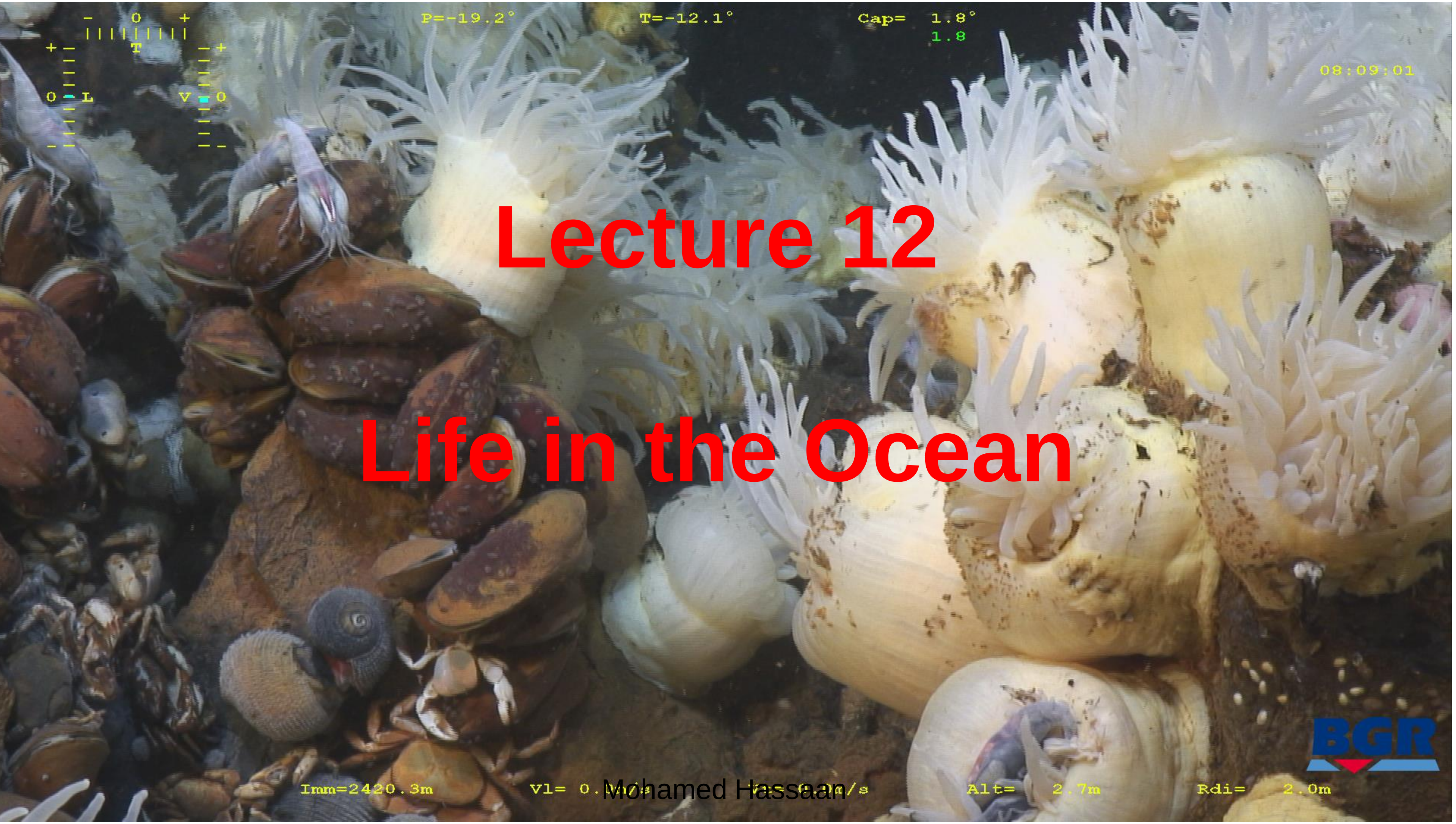


Estuarine Circulation:

- Described by water and salt budgets:
  - mixing upward of 2 units of seawater reduces inflow and decreases outflow by 2 units
  - salinity gradually increases seaward







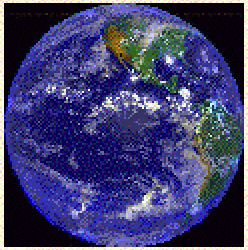
Lecture 12

Life in the Ocean

Mohamed Hassaan

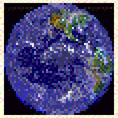
Oceans & Our Global Environment

Life in the Ocean



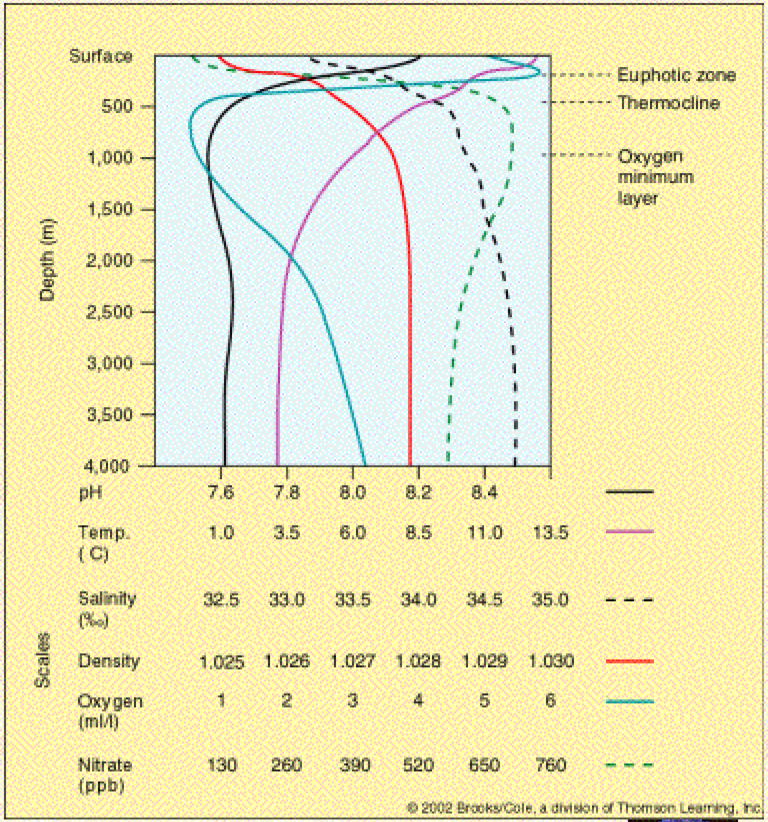
Topics:

- Physical Requirements for Marine Life
  - buoyancy, flotation, osmosis
  - temperature, pressure, gases, nutrients
  - light, color, bioluminescence
  - barriers and boundaries, bottom types, circulation
- Environmental Zones, Classification of Organisms
  - habitat: neritic, pelagic, benthic
  - lifestyle: plankton, nekton, benthos



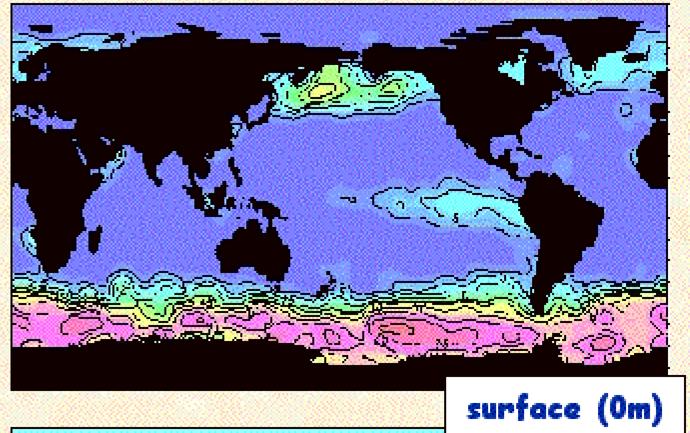
Physical Requirements for Marine Life:

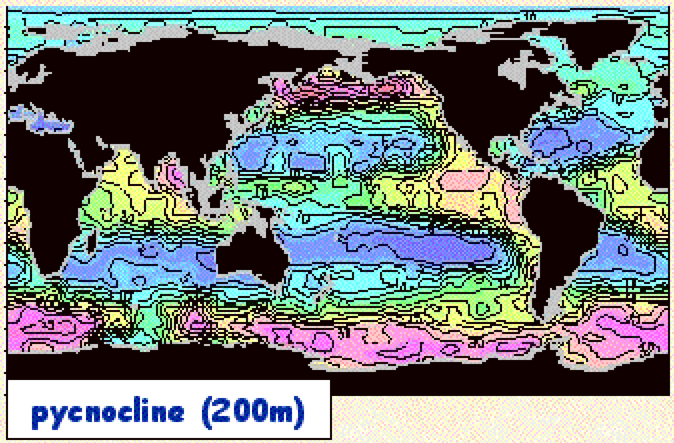
- Physical Environment:
  - changes with depth
- Gases:
  - CO_2 required for photosynthesis
  - O_2 required for respiration
  - organisms may be restricted if O_2 changes rapidly
  - absence of O_2 favors anaerobic organisms (bacteria)

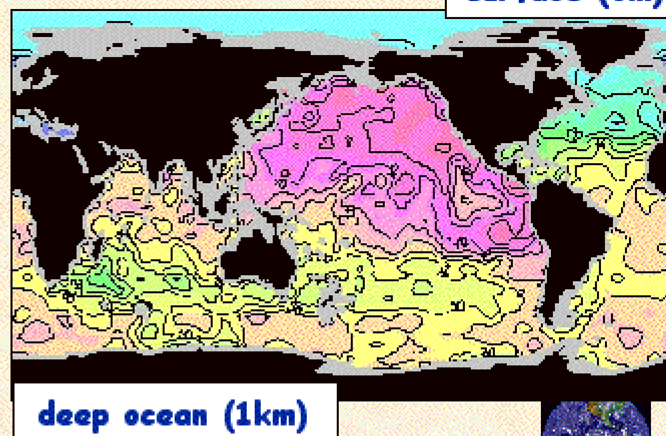


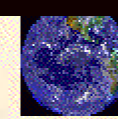
Physical Requirements for Marine Life: Nitrate

- Spatial and Depth Variation in Nitrate
  - increasing concentrations: purple to blue to green to yellow to pink
  - abundant in deep ocean waters, upwelling regions



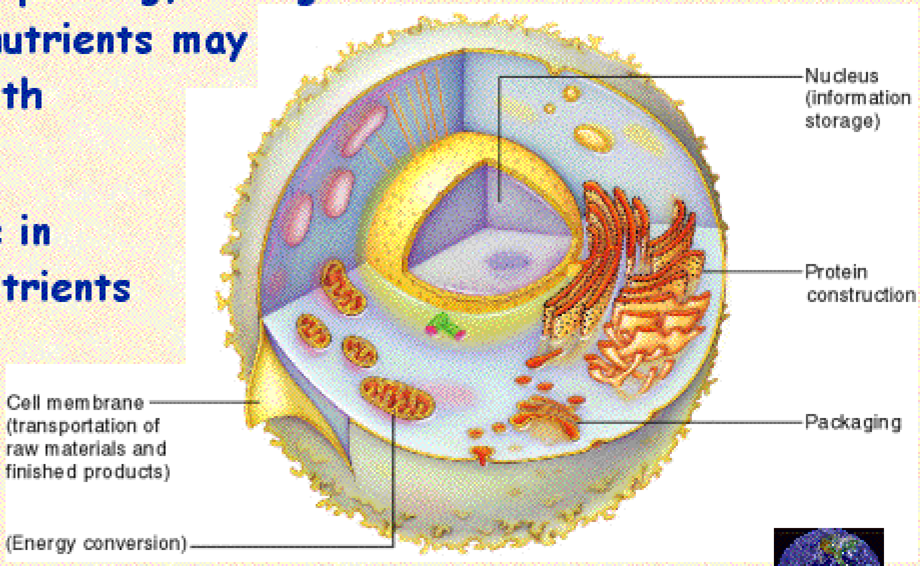


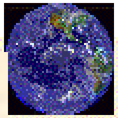




Physical Requirements for Marine Life:

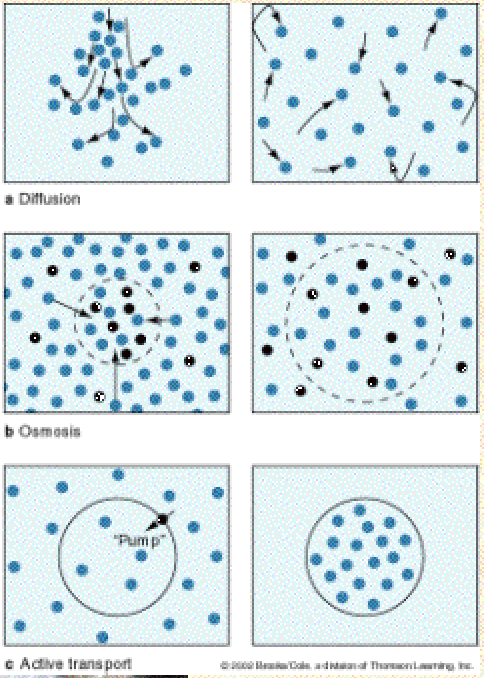
- Nutrients:
  - essential for plant growth: N as NO_3^-, P as PO_4^{3-}
  - depleted in surface waters, recycled by decomposition, non-conservative constituents of seawater
  - replenished by upwelling, mixing
  - availability of nutrients may limit plant growth
- Cell:
  - membrane: role in transport of nutrients

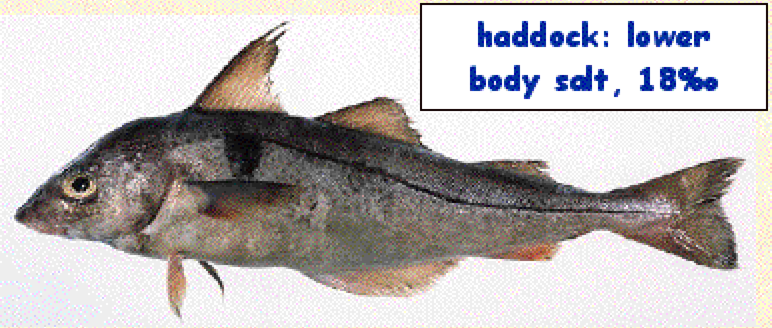




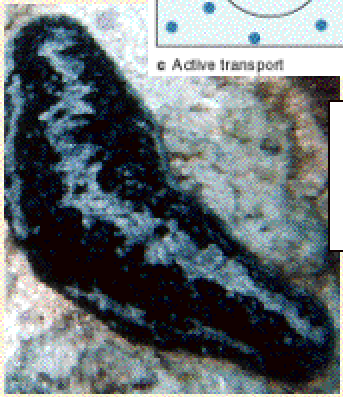
Physical Requirements of Marine Life:

- Osmotic Pressure:
  - internal vs. external salinity
  - nutrients (not salt) in
  - waste products out
  - membrane excludes salt (e.g. fish)
  - or salinity tolerant (e.g. sea cucumber)

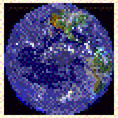




haddock: lower body salt, 18‰

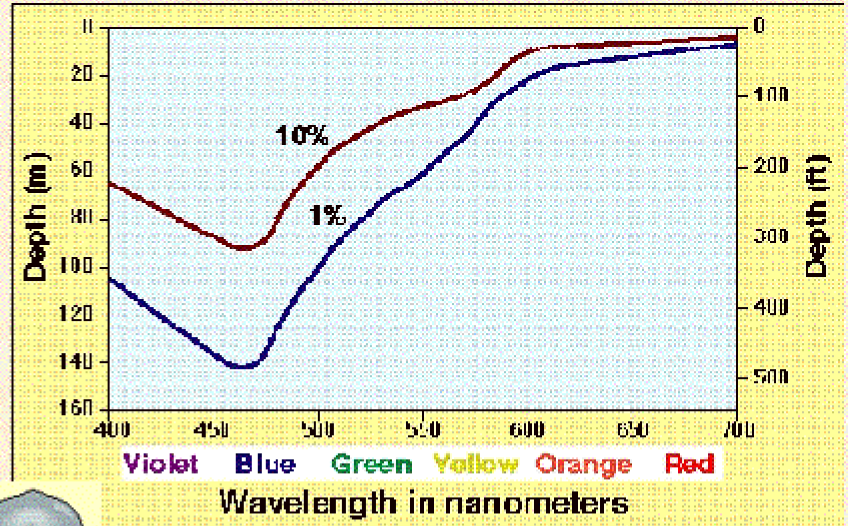


sea cucumber internal salinity = 35‰

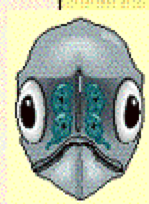


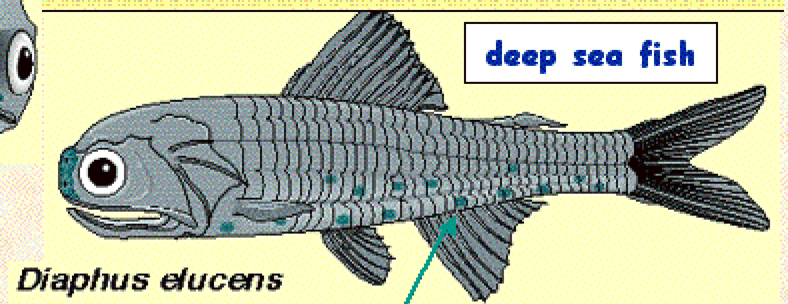
Physical Requirements for Marine Life:

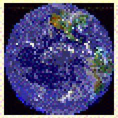
- Light:
  - sunlight penetrates photic zone
  - depth dependent on suspended particles, angle of sunlight and wavelength
  - aphotic zone below; no photosynthesis



- Bioluminescence:
  - interaction of luciferin and enzyme luciferase
  - organisms with light-producing organs: photophores

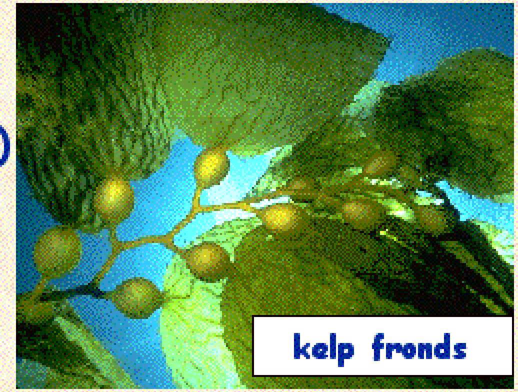


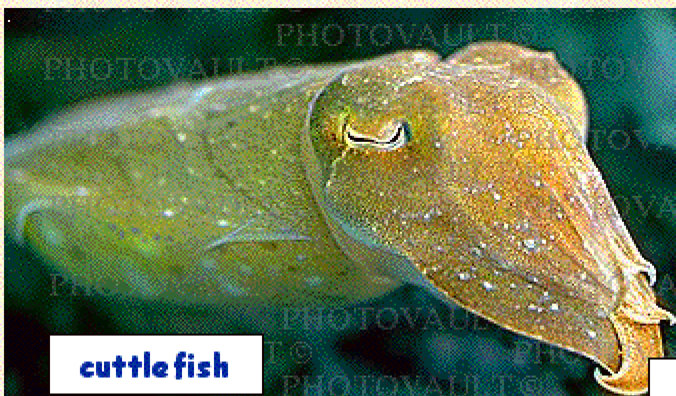


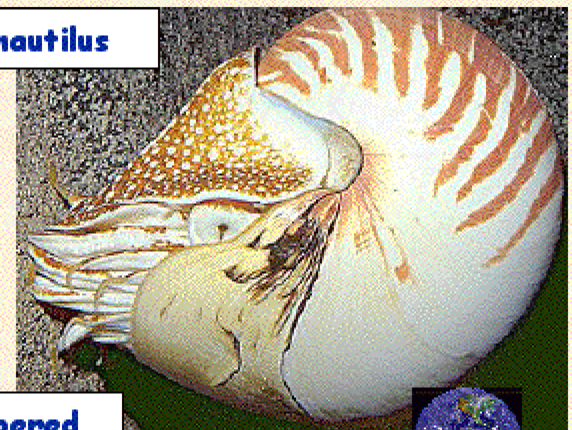


Physical Requirements for Marine Life:

- Buoyancy:
  - relationship to seawater density
  - gases for flotation (fronds, bladders)
  - fish: swim bladders (O_2, CO_2, N_2), or constant swimming (sharks, rays)
  - shells with gas-filled chambers
  - fats, blubber (e.g. cetaceans, seals)
  - air sacs (e.g. seabirds)





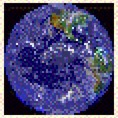


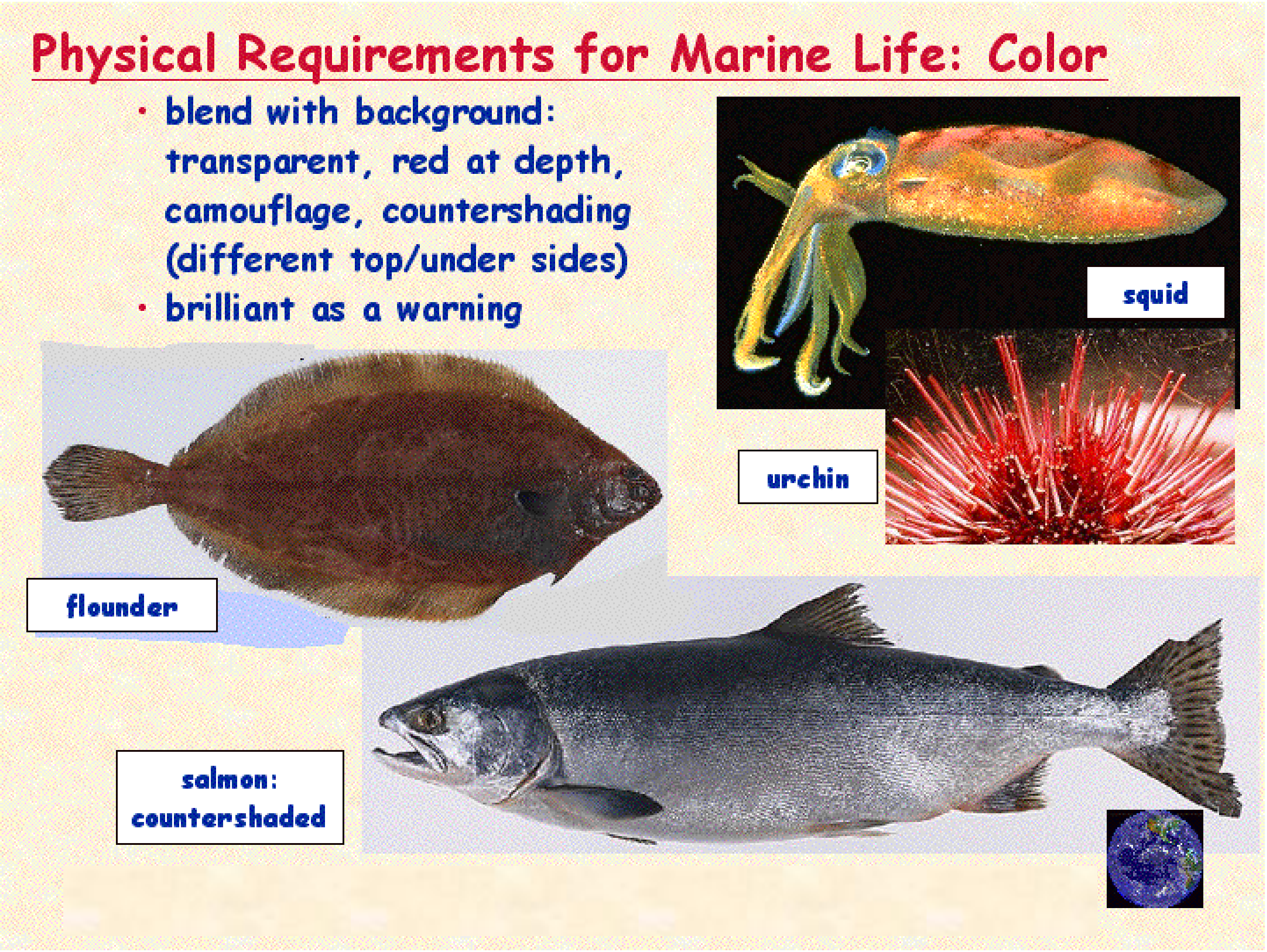
Physical Requirements for Marine Life:

- Temperature:
  - ectotherms (cold-blooded), live at environmental temperatures, tend to grow slowly, live longer
  - endotherms (warm-blooded)
- Pressure:
  - no adaptation needed if no gas-filled cavities
  - change in blood physiology required for air-breathing mammals: high O_2 contents, tolerance to high CO_2

ectotherm: sea turtle

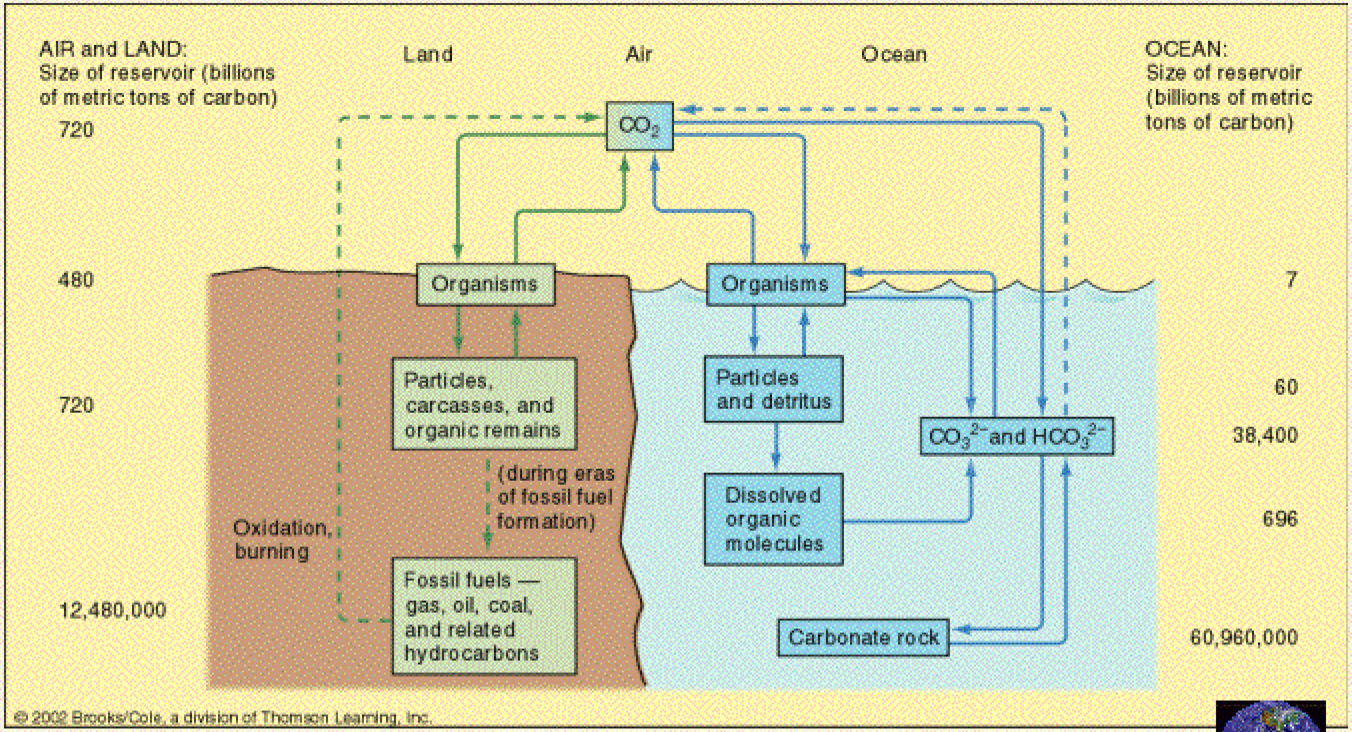
endotherm: killer whale

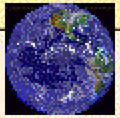



Physical Requirements for Marine Life: Color
• blend with background: transparent, red at depth, camouflage, countershading (different top/under sides)
• brilliant as a warning
squid
urchin
flounder
salmon: countershaded

Global Biogeochemical Cycling and the Ocean:

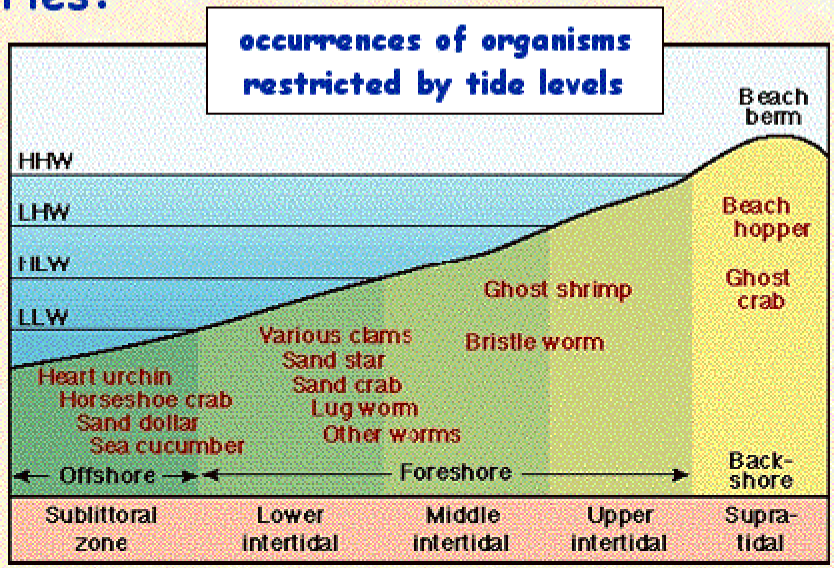
- **Carbon Cycle:**
  - **Terrestrial and marine systems**



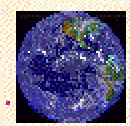


Physical Requirements for Marine Life:

- Circulation:
  - vertical/horizontal movement of organisms governed by
    - currents, buoyancy, swimming ability
- Barriers and Boundaries:
  - restricted by:
    - water properties (temperature, salinity)
    - tolerance
    - water flow
  - topography (connectivity)

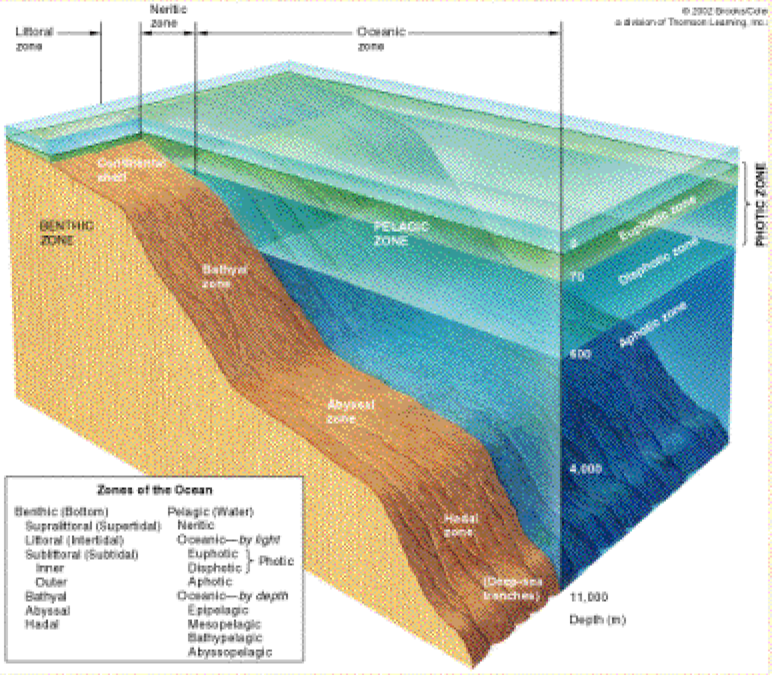


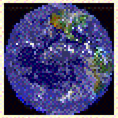
- Bottom Types:
  - substrate influences organisms, especially bottom-dwellers
    - mud vs. sand vs. gravel vs. rock



Environmental Zones:

- Ocean Life:
  - concentrated at sea surface & ocean floor
- Habitats:
  - neritic (coastal)
  - pelagic (open ocean)
  - benthic (sea floor)
- Oceanic Depth Zones:
  - 0-200m: epipelagic, 0.2-1km: mesopelagic
  - 1-4km: bathypelagic, >4km: abyssopelagic
- Sea Floor Depth Zones:
  - supralittoral (splash), littoral (intertidal), sublittoral (subtidal), shelf, 0.2-4km: bathyal; 4-6km: abyssal; >6km: hadal



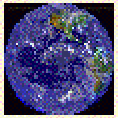


Classification of Marine Organisms:

- Taxonomic Classification
  - hierarchial arrangement from kingdom to species

Taxonomic level	Human example
Kingdom	Animalia
Phylum/Division	Vertebrata
Class	Mammalia
Order	Primates
Suborder	Anthropoidea
Superfamily	Hominoidea
Family	Hominidae
Genus	Homo
Species	sapiens

- Classification by Habitat
- Plankton:
  - drifting organisms
  - carried by currents
  - plants, bacteria, zooplankton (animals)
- Nekton:
  - swimming organisms, move independent of currents
  - fish, squid, marine mammals & reptiles
- Benthos:
  - attached to sea floor (physically held, or dependent)
  - plants (in shallow waters) and animals

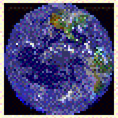


Classification of Organisms:

- **Genetic Approach**
  - **relationships based on genetic phylogeny**

Table 13.2 Classification of Organisms into Six Kingdoms

Group	Kingdom	Characteristics	Examples
Prokaryotes: Single-celled organisms lacking a nucleus and other internal structural subdivisions; feed by absorption, photosynthesis, chemosynthesis.	Bacteria	Single chromosome, asexual reproduction, extreme metabolic diversity, no nucleus or cytoskeleton.	Bacteria, cyanobacteria ("blue-green algae").
	Archaea	Superficially similar to bacteria, but with many different genes capable of producing different kinds of enzymes; often live in extreme environments.	*Methanococcus*, *Pyrolobus*, "extremophiles."
Eukaryotes: Single- or multicelled organisms possessing a nucleus and other internal structural subdivisions; feed by absorption, photosynthesis, or ingestion of particles.	Protista	Usually unicellular, sexual or asexual reproduction, great genetic diversity.	Diatoms and dino agellates, radiolarians and foraminifera, single- and multicellular marine algae (seaweeds).
	Fungi	Usually multicellular, sexual or asexual reproduction; release enzymes that break down organic material for absorption.	Molds, mushrooms, symbionts within lichens.
	Plantae	Multicellular photosynthetic autotrophs, sexual or asexual reproduction.	Mosses, ferns, flowering plants.
	Animalia	Multicellular heterotrophs, sexual or asexual reproduction.	Invertebrates, vertebrates.



Atolls:

- Sequence of formation
    - island with fringing reef
    - barrier reef & lagoon
    - atoll reef
    - submerged

Tahiti

fringing reef

barrier reef and lagoon

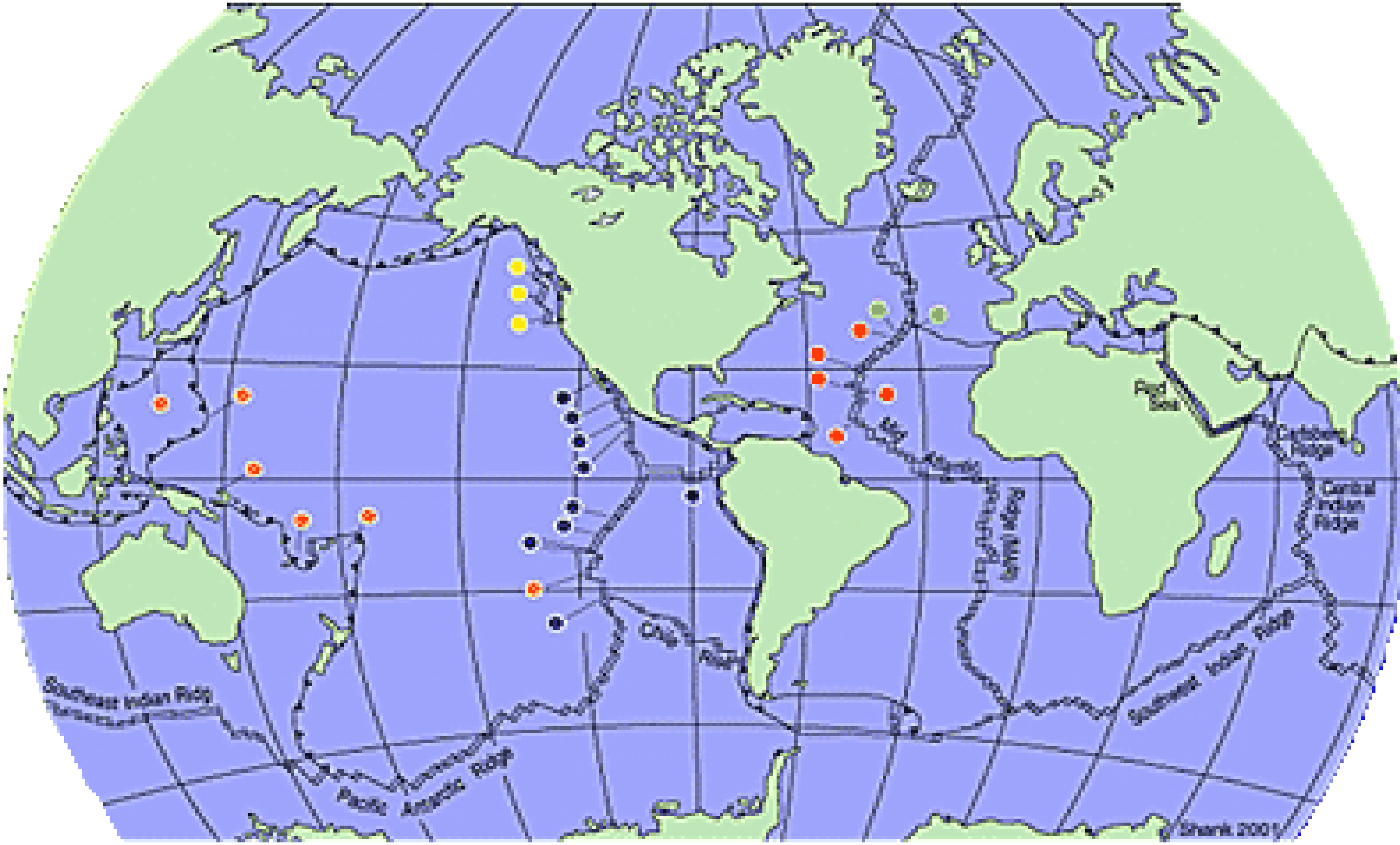
atoll reefs

Lecture 13

HYDROTHERMAL VENTS

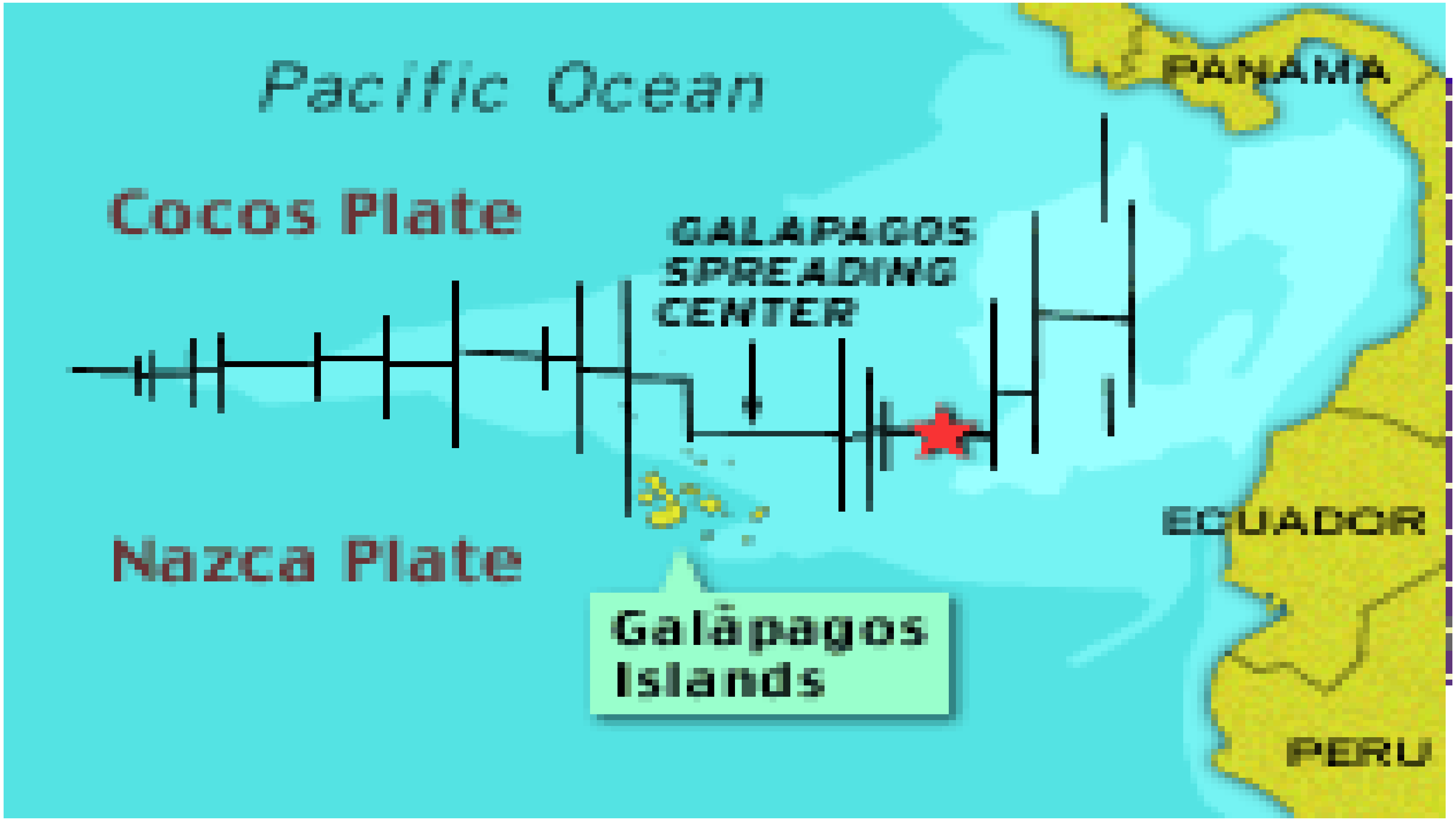
Mohamed Hassaan

Where are vents located?



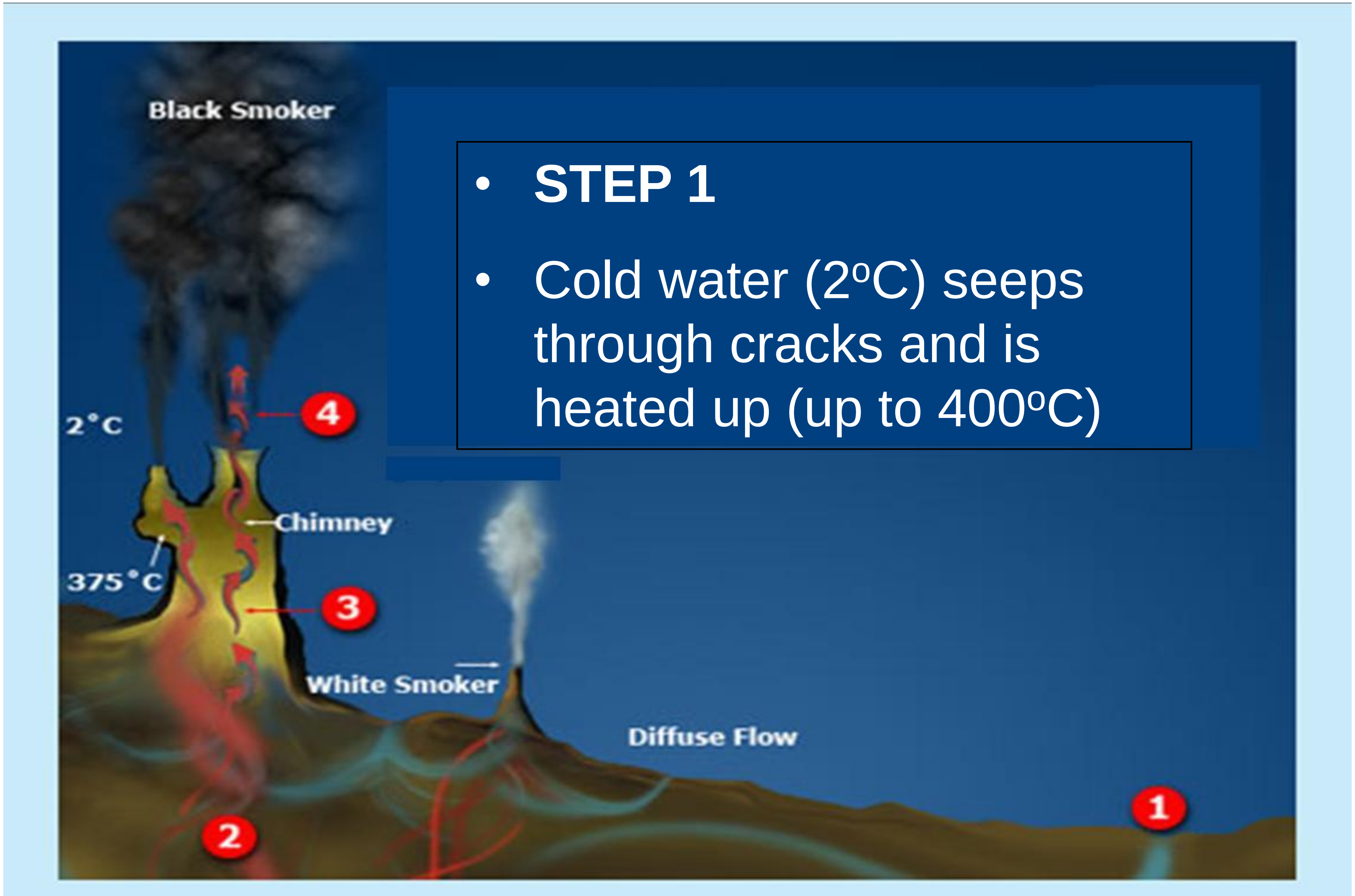
Where magma is close to the surface – Mid Ocean Ridges.

1977 1st vent found by Alvin



Alvin

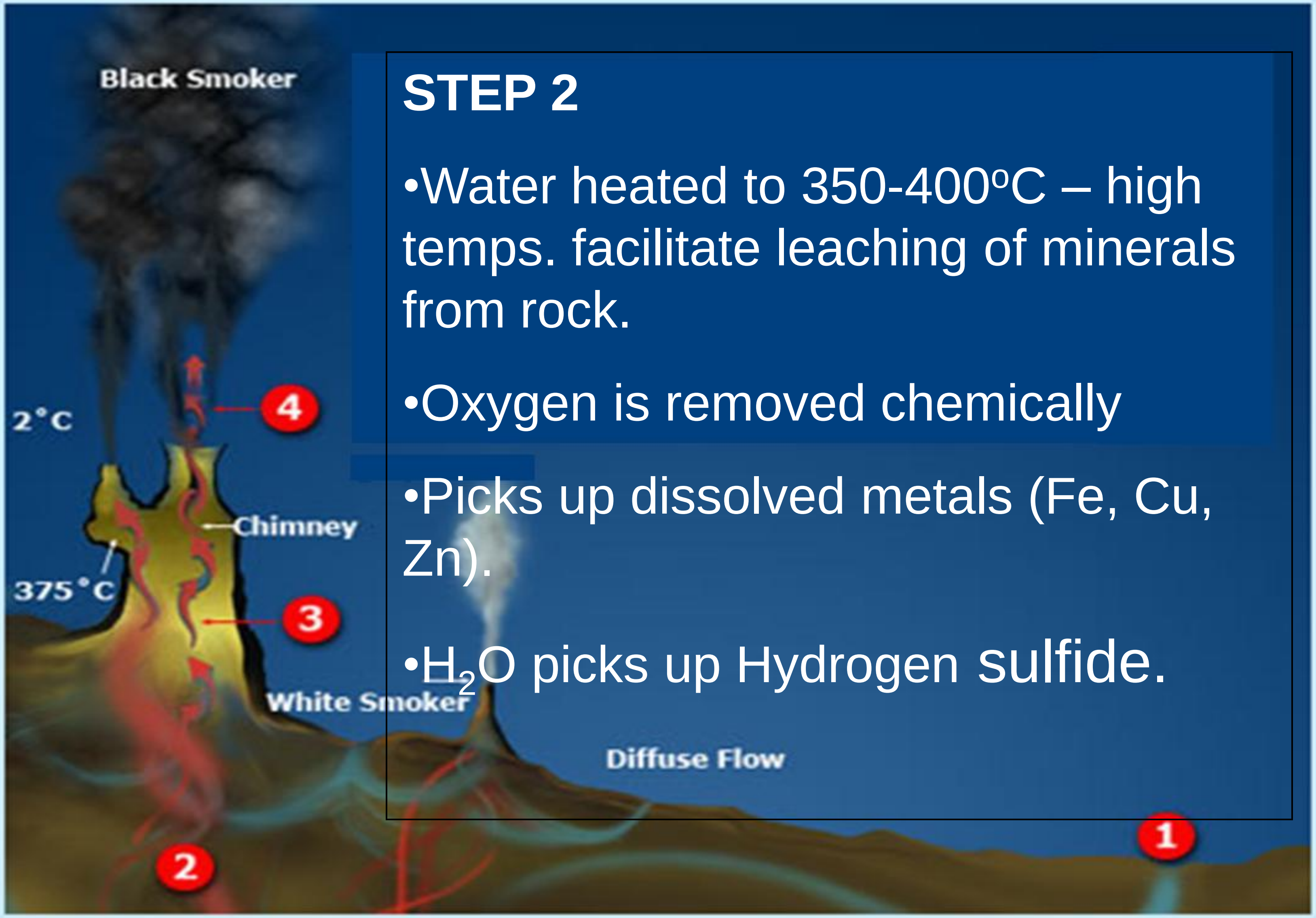
Steps of vents creation



- **STEP 1**
- Cold water (2ºC) seeps through cracks and is heated up (up to 400ºC)

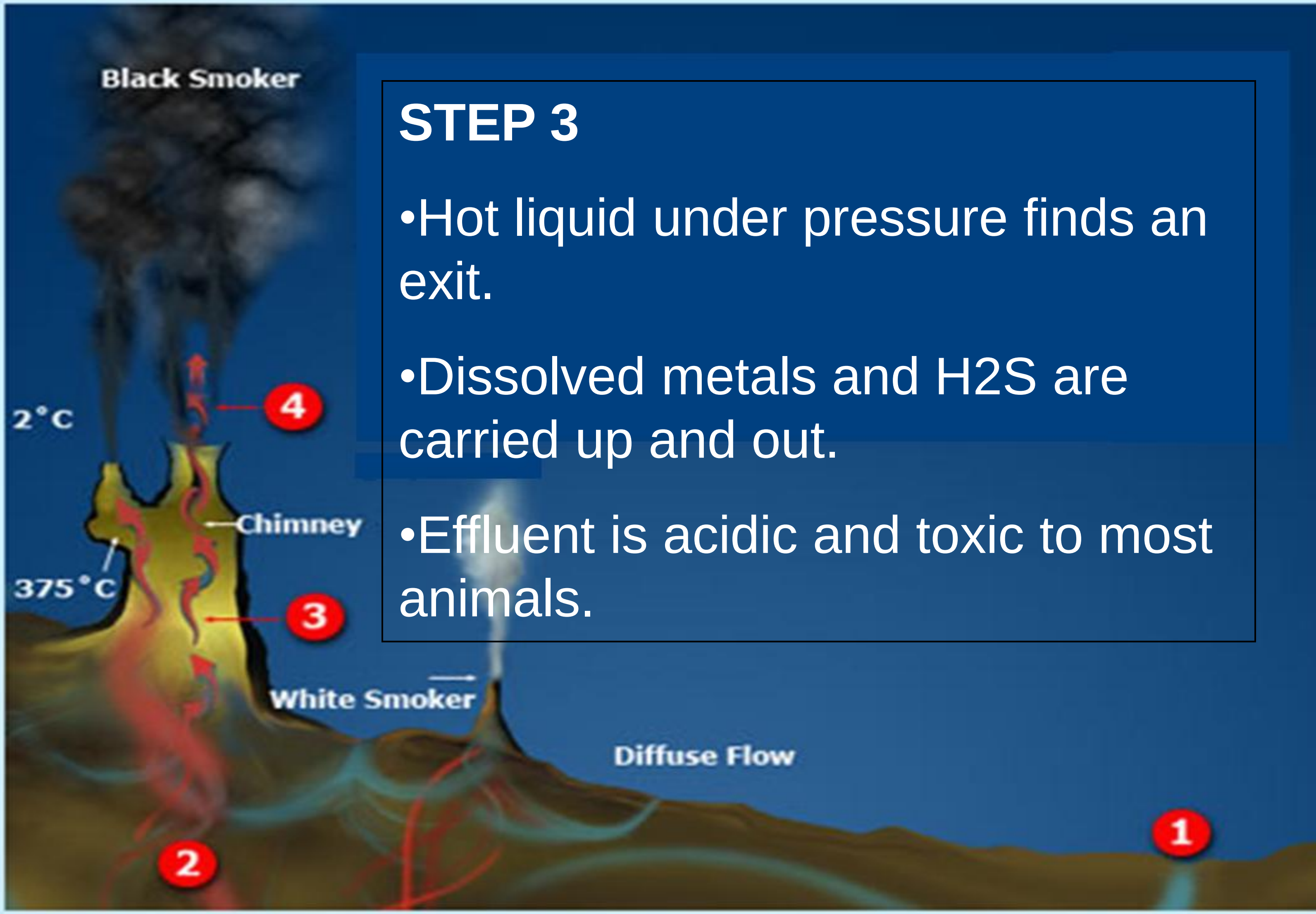
STEP 2

- Water heated to 350-400ºC – high temps. facilitate leaching of minerals from rock.
- Oxygen is removed chemically
- Picks up dissolved metals (Fe, Cu, Zn).
- H_2O picks up Hydrogen sulfide.



STEP 3

- Hot liquid under pressure finds an exit.
- Dissolved metals and H2S are carried up and out.
- Effluent is acidic and toxic to most animals.



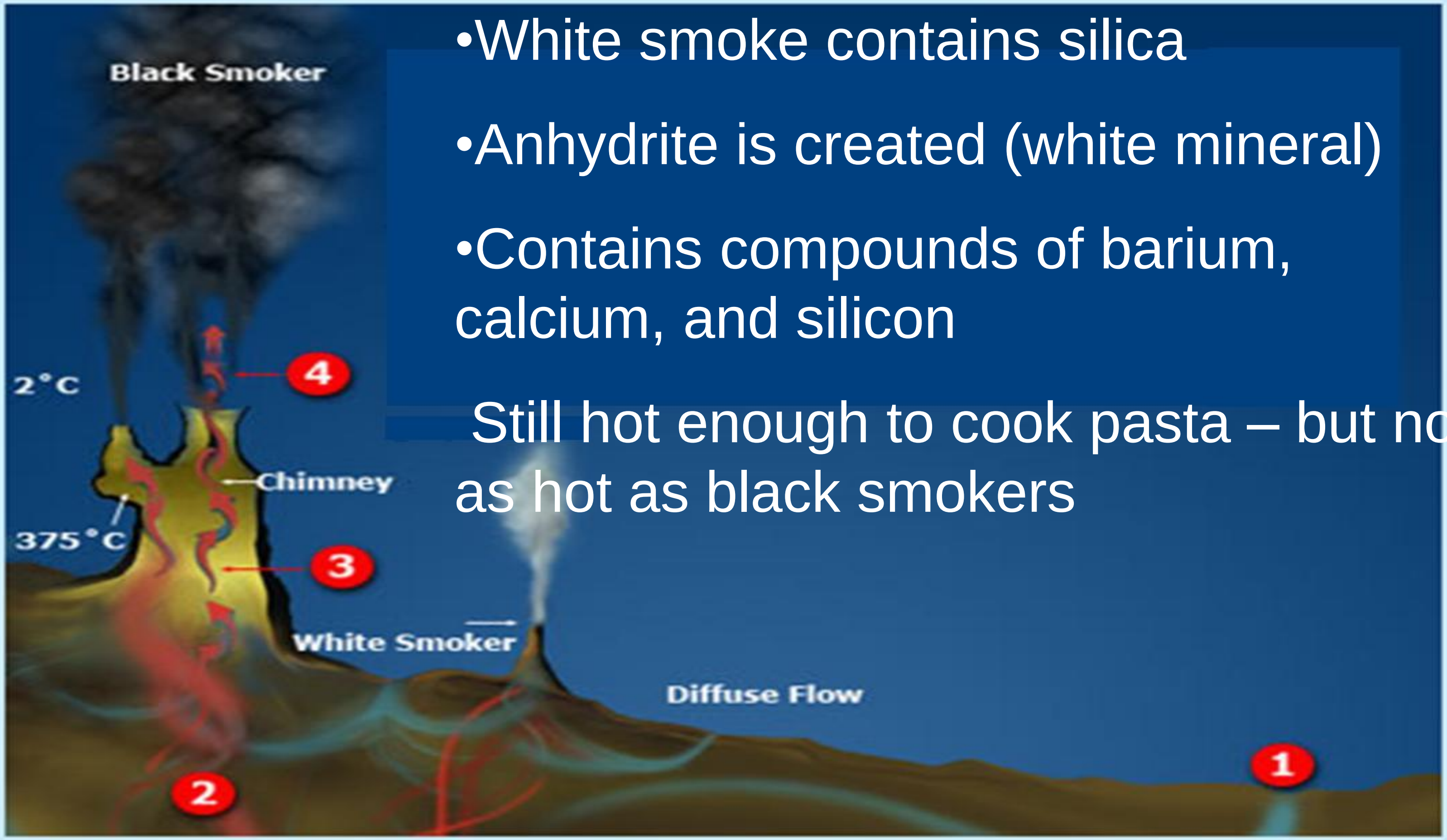
Types of Hydrothermal Vents

- Black smokers
- White smokers
- Sometimes clear smokers

Black Smoker

- Hottest of all Vents. They spew mostly iron and sulfide, which combine to form iron monosulfide. This compound gives the smoker its black color.

White Smokers



- White smoke contains silica
- Anhydrite is created (white mineral)
- Contains compounds of barium, calcium, and silicon

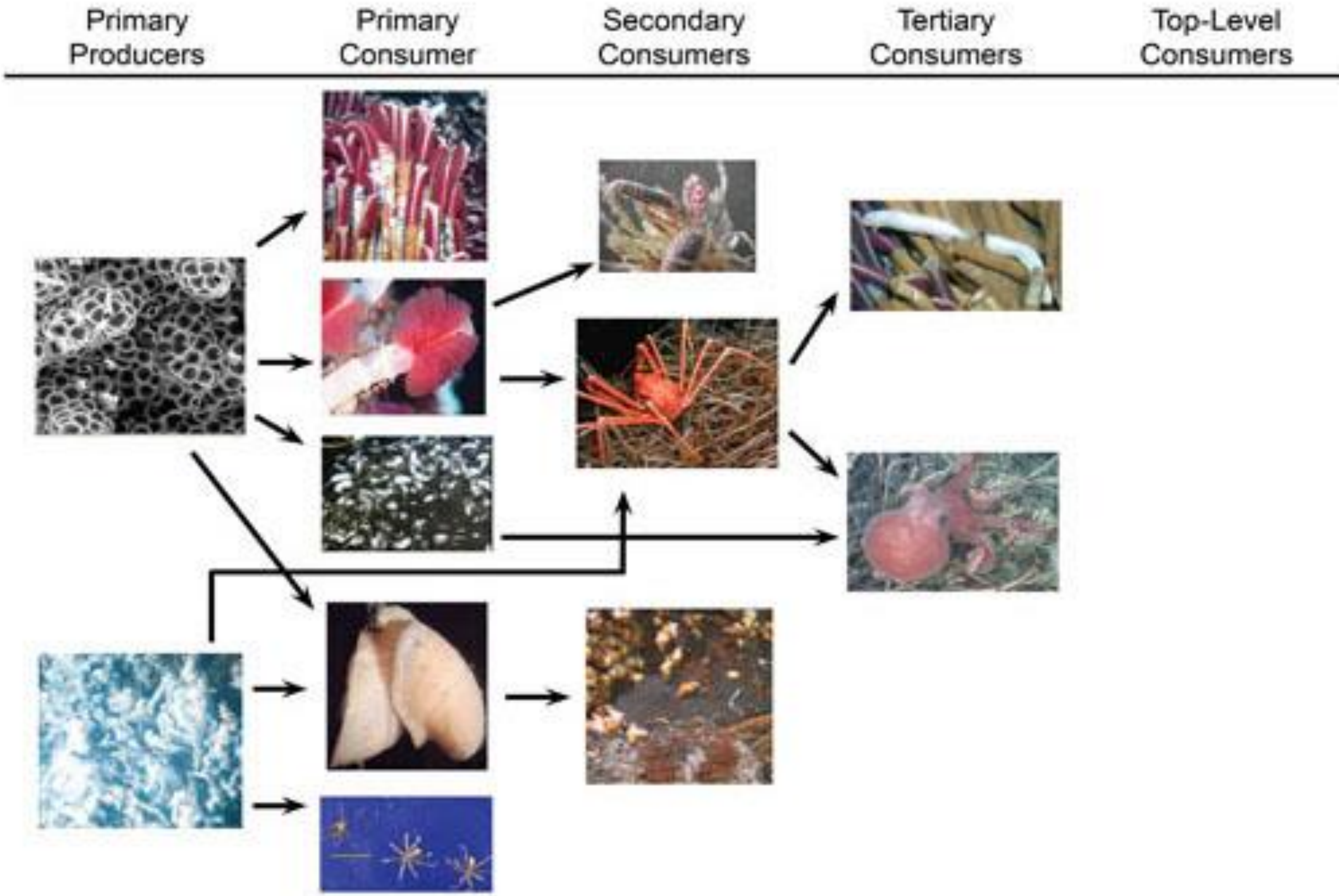
Still hot enough to cook pasta – but not as hot as black smokers

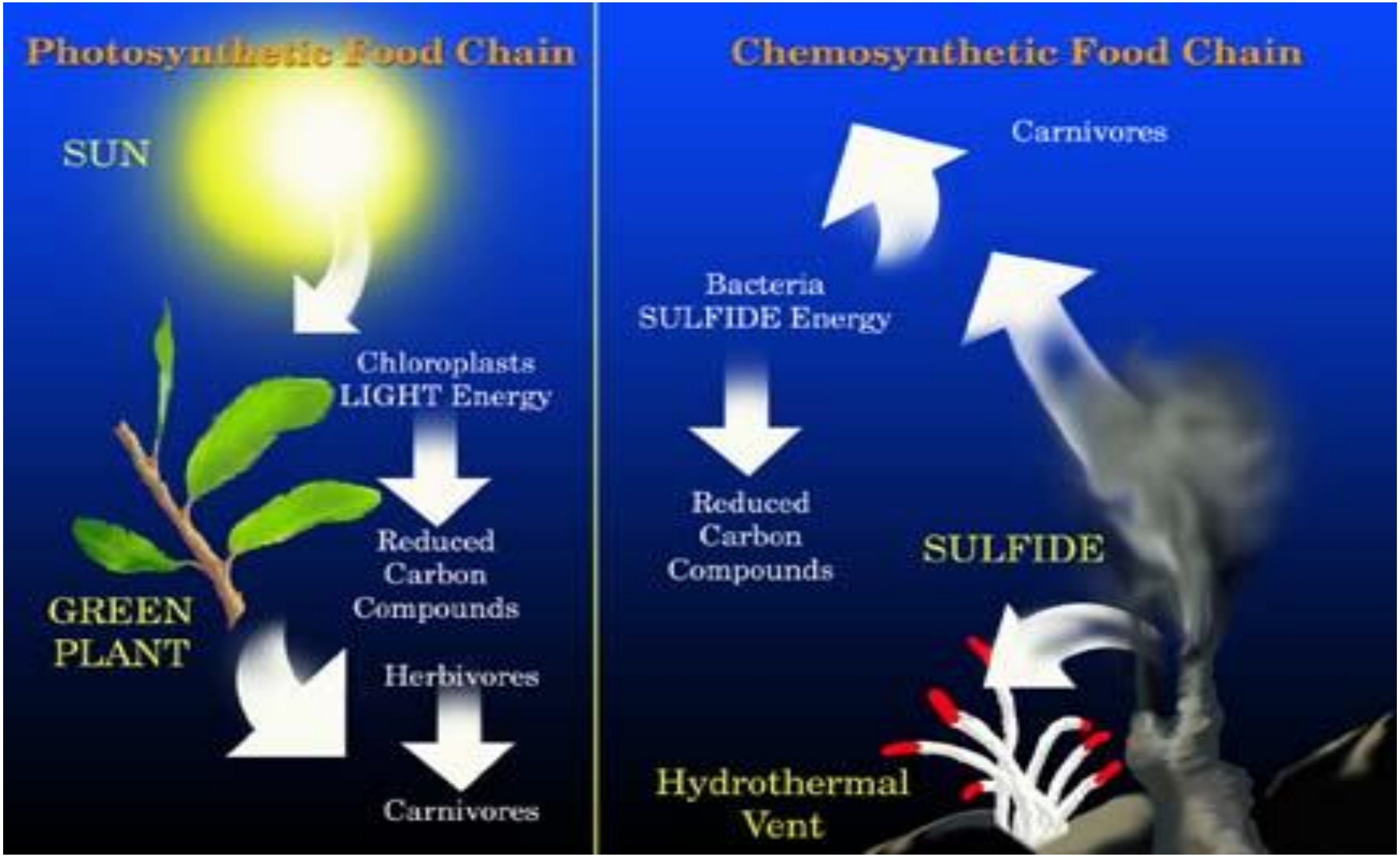
HYDROTHERMAL VENT COMMUNITIES

HYDROTHERMAL VENT COMMUNITIES

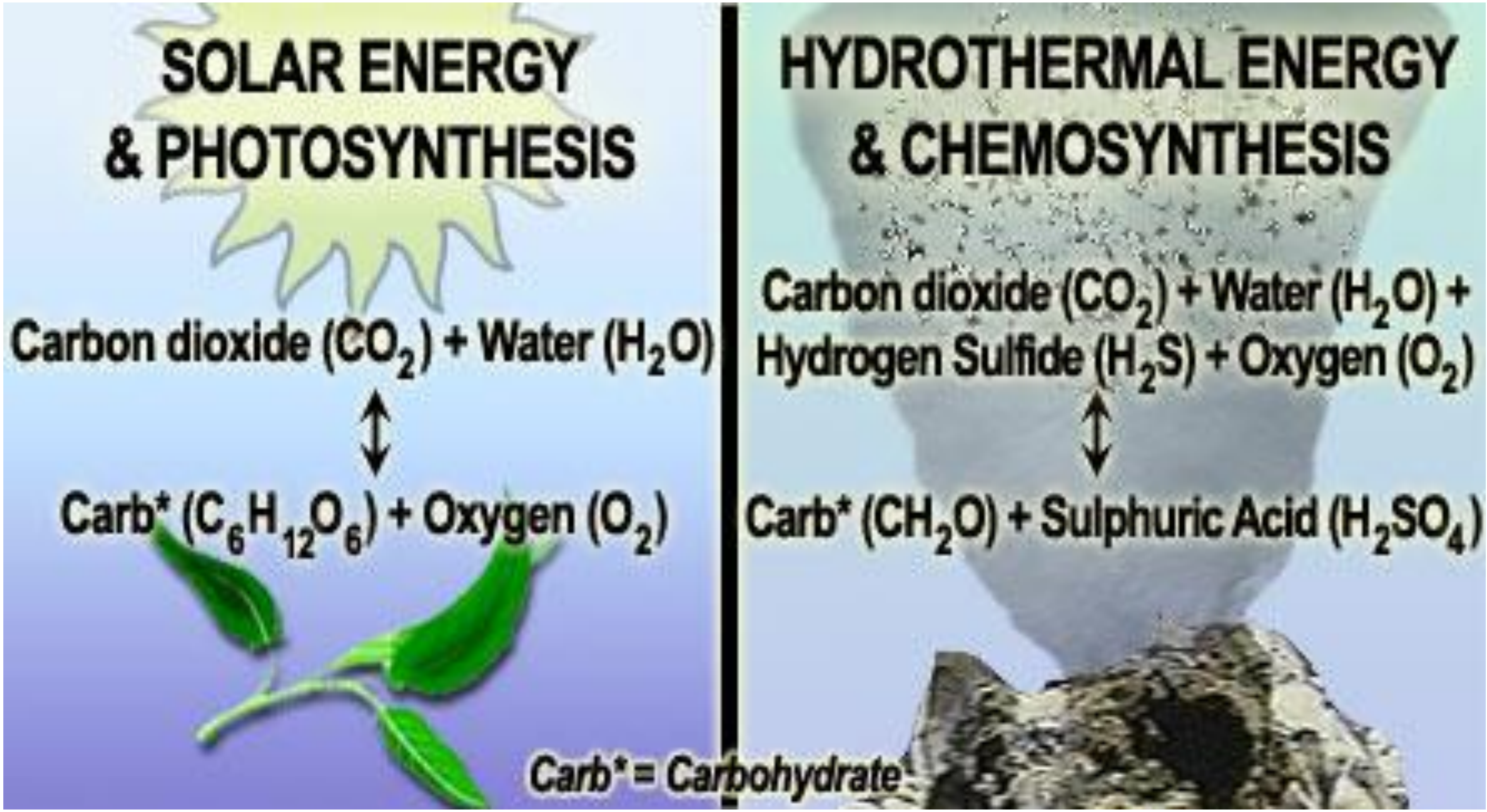
With no sunlight, what is the base of the food web?

CHEMOSYNTHESIS


Primary Producers
Primary Consumer
Secondary Consumers
Tertiary Consumers
Top-Level Consumers


Photosynthetic Food Chain
SUN
Chloroplasts
LIGHT Energy
Reduced
Carbon
Compounds
GREEN
PLANT
Herbivores
Carnivores
Chemosynthetic Food Chain
Carnivores
Bacteria
SULFIDE Energy
Reduced
Carbon
Compounds
SULFIDE
Hydrothermal
Vent

chemosynthesis significant goal is carbohydrate creation.



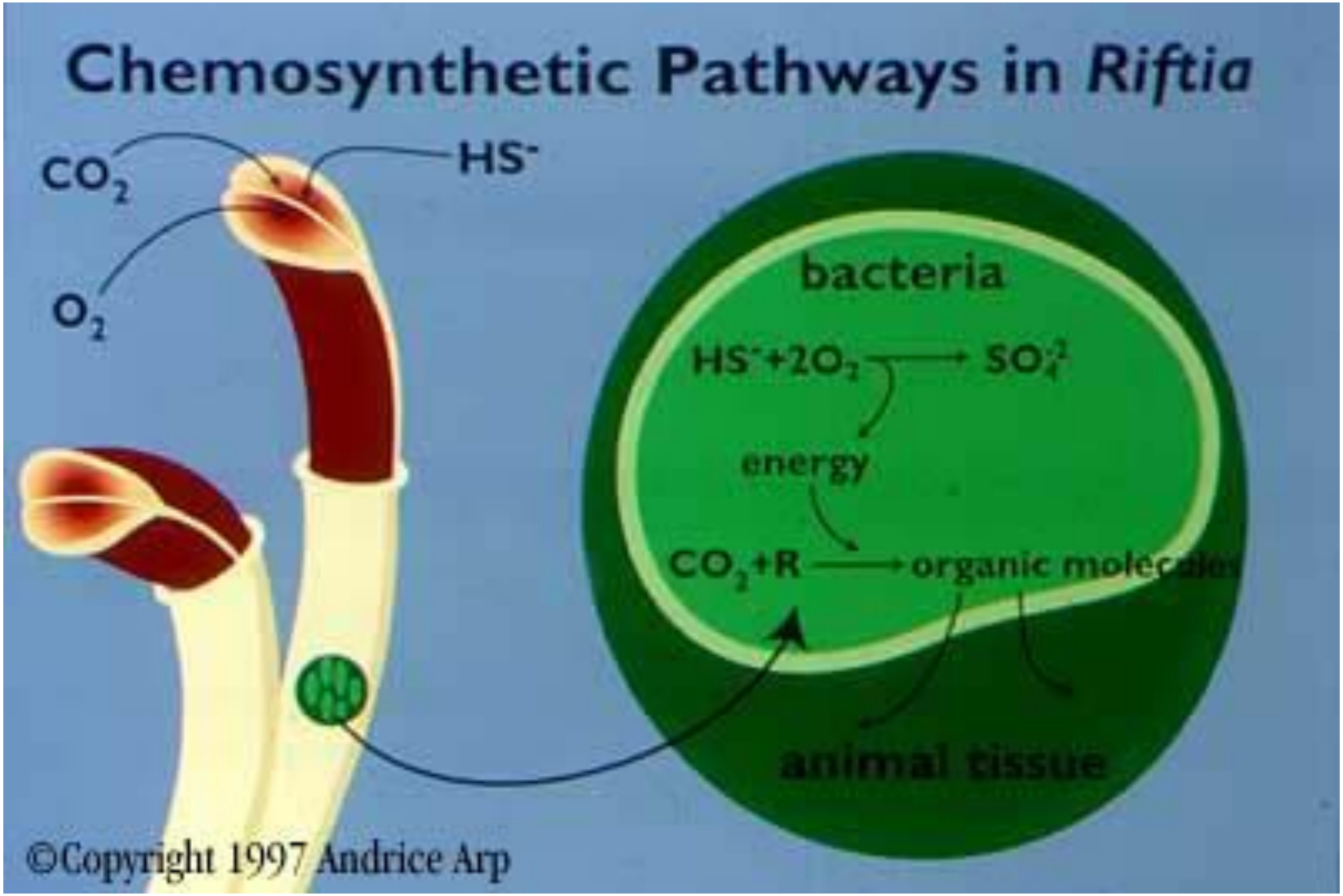
Reasons of studying hydrothermal vents

- They contain unique organisms that have biological and pharmaceutical importance.
- May be the origin of life on our planet
- Vents heavily influence chemical composition of sea water adding sulfides, chloride ion, magnesium, etc.
- Can change weather & climate of planet

Vent Worms

- *Riftia pachyptila*
- Up to 2 meters long and 10 cm in diameter
- tubes are made of chitin
- Tubeworms do not eat! NO mouth or stomach!
- gill-like red plumes absorb hydrogen sulfide from the hot water and oxygen from the cold water


With no
mouth or
stomach
, HOW
DO
THEY
GET
FOOD?


Chemosynthetic Pathways in Riftia
CO2
HS-
O2
bacteria
HS-+2O2 → SO4-2
energy
CO2+R → organic molecules
animal tissue
©Copyright 1997 Andrice Arp

Symbiotic Bacteria

- **Symbiotic bacteria live inside the tubeworms**
- **Produce sugars for worm.**
- **Tubeworms, clams and mussels use some of these sugars as food.**
- **Bacteria get hydrogen sulfide and oxygen from the worm.**
- **Bacteria convert toxic chemicals released by the vents into food and energy**

Zoarcid Fish

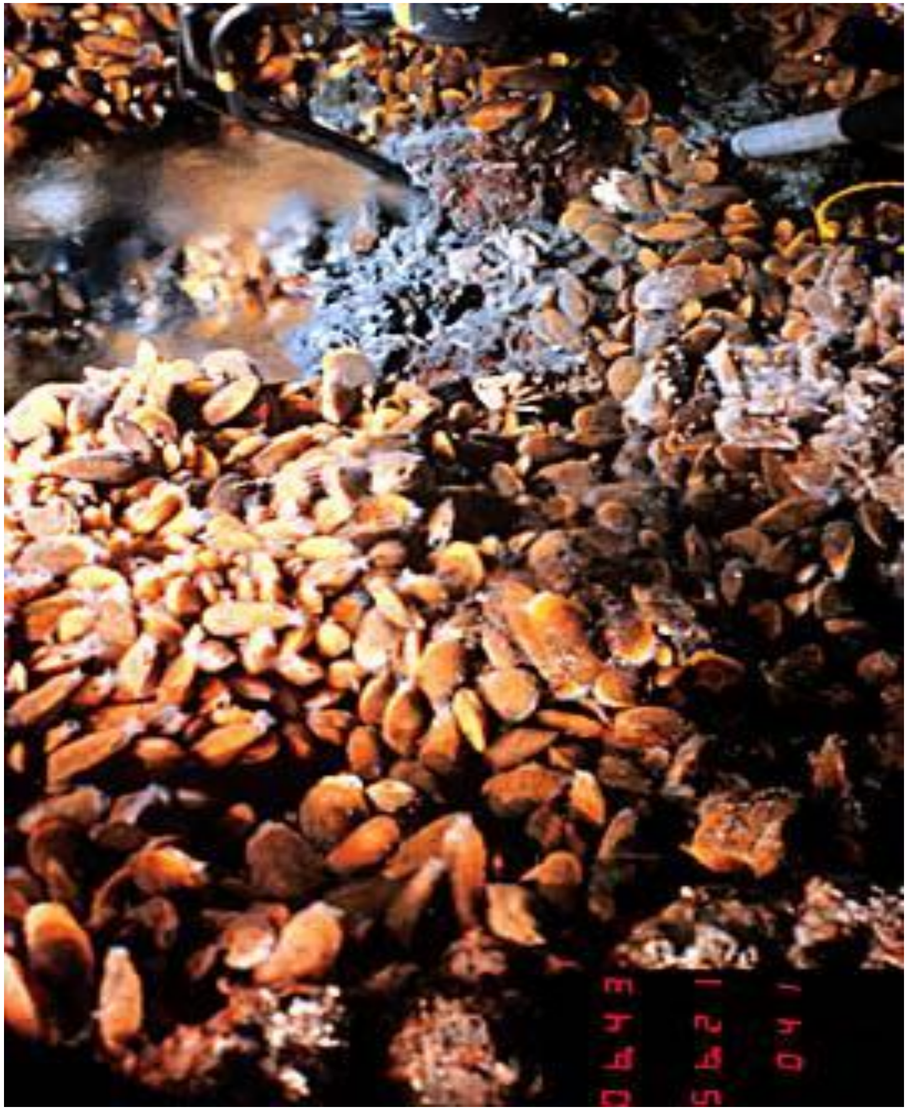
- 2 foot long white fish
- Top predators around vents
- Eat everything from tubeworms to shrimp
- Slow and lethargic

Octopus

- several species
- typically one meter long
- heads are about the size of an orange
- top predators
- eat crabs, clams, and mussels

Mussels

- first to colonize
- Filter feeders & symbiotic microbes
- Crabs and shrimp feast on mussels.

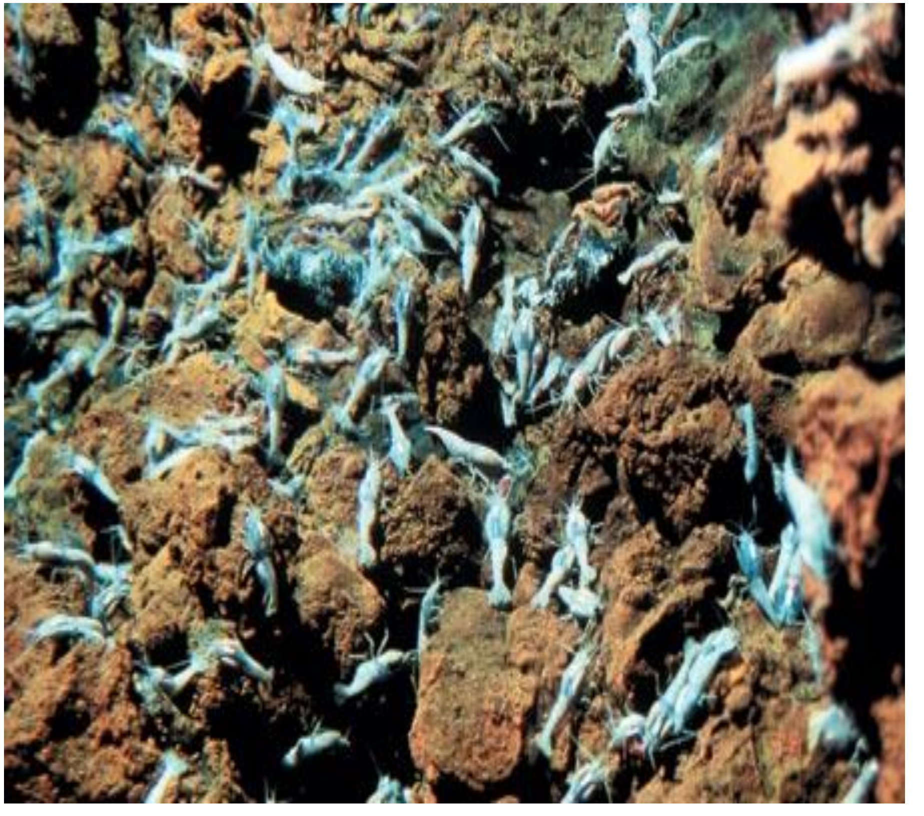


Giant Clams

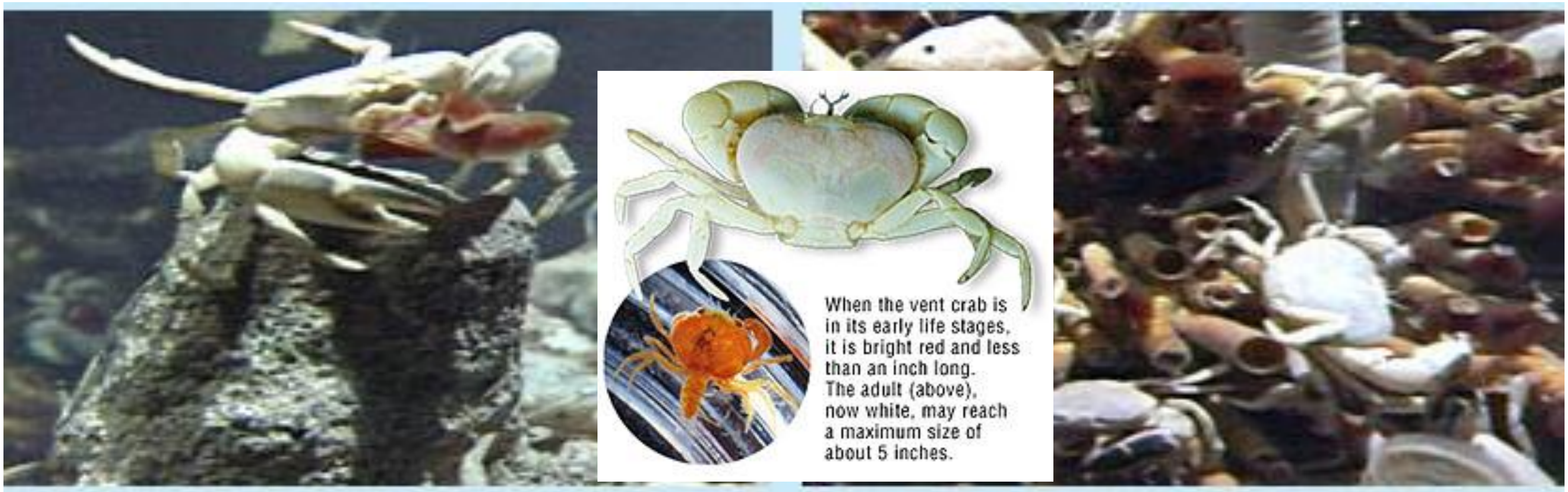
- symbiotic bacteria
- Despite their thick shells, clams are eaten by crabs and octopi

Vent Shrimp

- Many species of shrimp
- live around clumps of tube worms and mussels
- shrimp eat mussels and microbes that grow on the chimney and their bodies
- Crabs, anemones, and zoarcid fish eat shrimp



Crabs



Galatheid crab, or squat lobster (Atlantic Ocean)

- All oceans but increase in numbers at vents
- Scavengers (eat bacteria and dead animals)

Brachyuran crabs (Pacific Ocean)

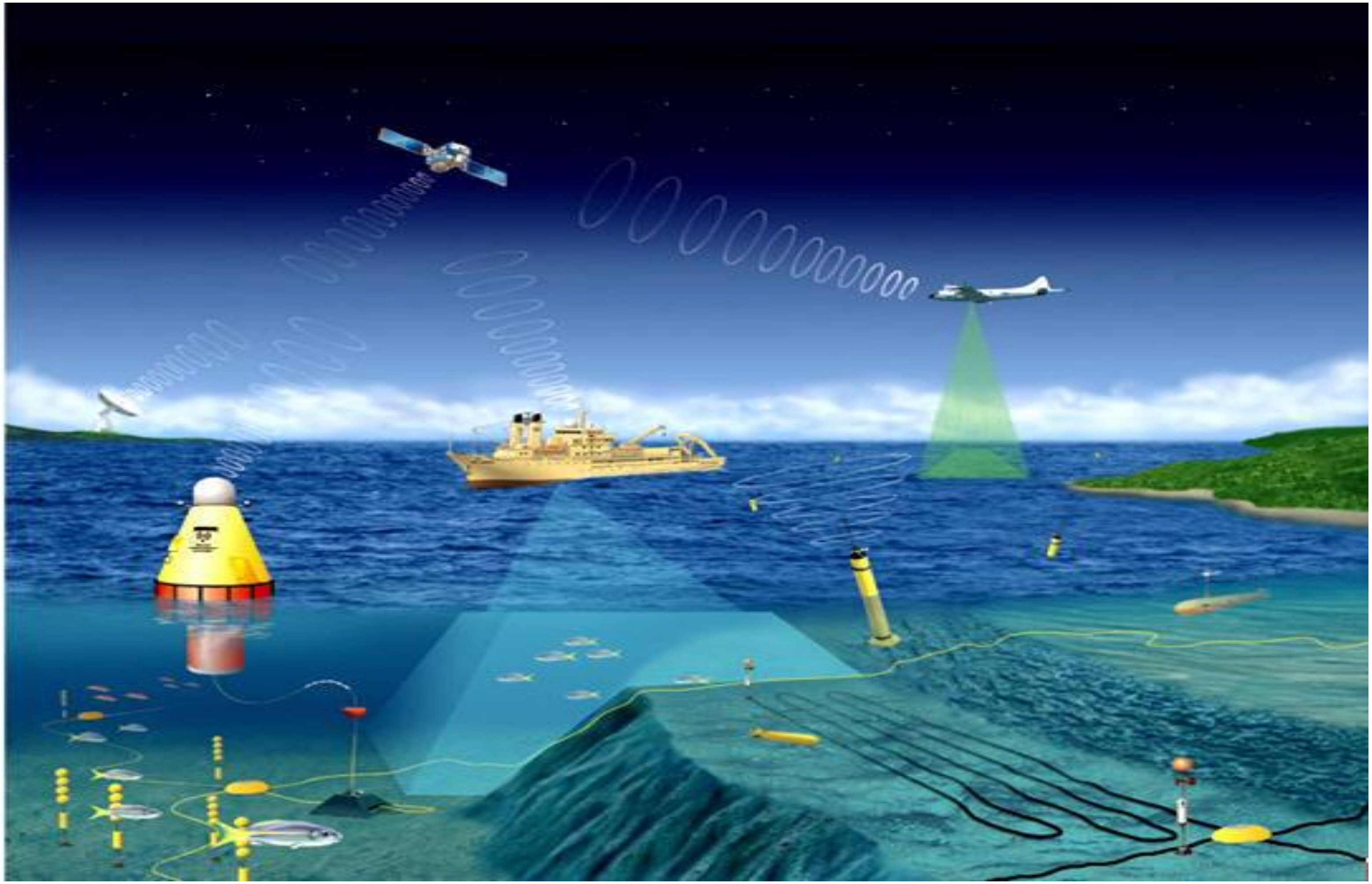
- round white crabs
- fierce predators (eat bacteria, shrimp, mussels, clams, tubeworms, and even each other)

Lecture 14

ROV and Underwater technologies

Mohamed Hassaan

Ocean Observing Systems



Why do we Observe the Oceans?

Can improve:

- The efficiency and safety of marine operations
- National and homeland security
- Predictions of natural hazards and their effects
- Predictions of climate change
- Public health
- Protection and restoration of healthy ecosystems
- The sustainability of living resources
- Emergency management
- Search and Rescue
- Oil spill response
- Fishing and vacation/beach nowcasting
- Commercial shipping
- Better weather/storm prediction

Historical Underwater Vehicles

From Britannica online

FNRS-2

First bathyscaphe; built by Auguste Piccard (Belgium) from 1945-1948.

Trieste

Built 1953.

1960 - Reaches the deepest point of the *Marianas Trench*, known as the *Challenger Deep*, which is the deepest point in the ocean, down 35,810 ft.

ABCs of Underwater Technology

Deep

Submergence

Vehicle

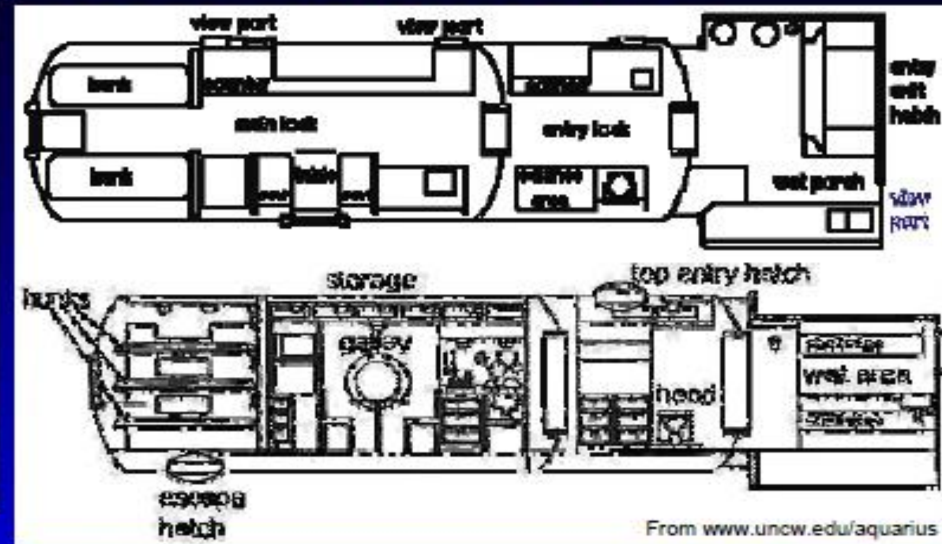
From www.nicholas.duke.edu

Alvin

From http://www.dkimages.com

From www.frc.ri.cmu.edu

Aquarius Underwater Habitat

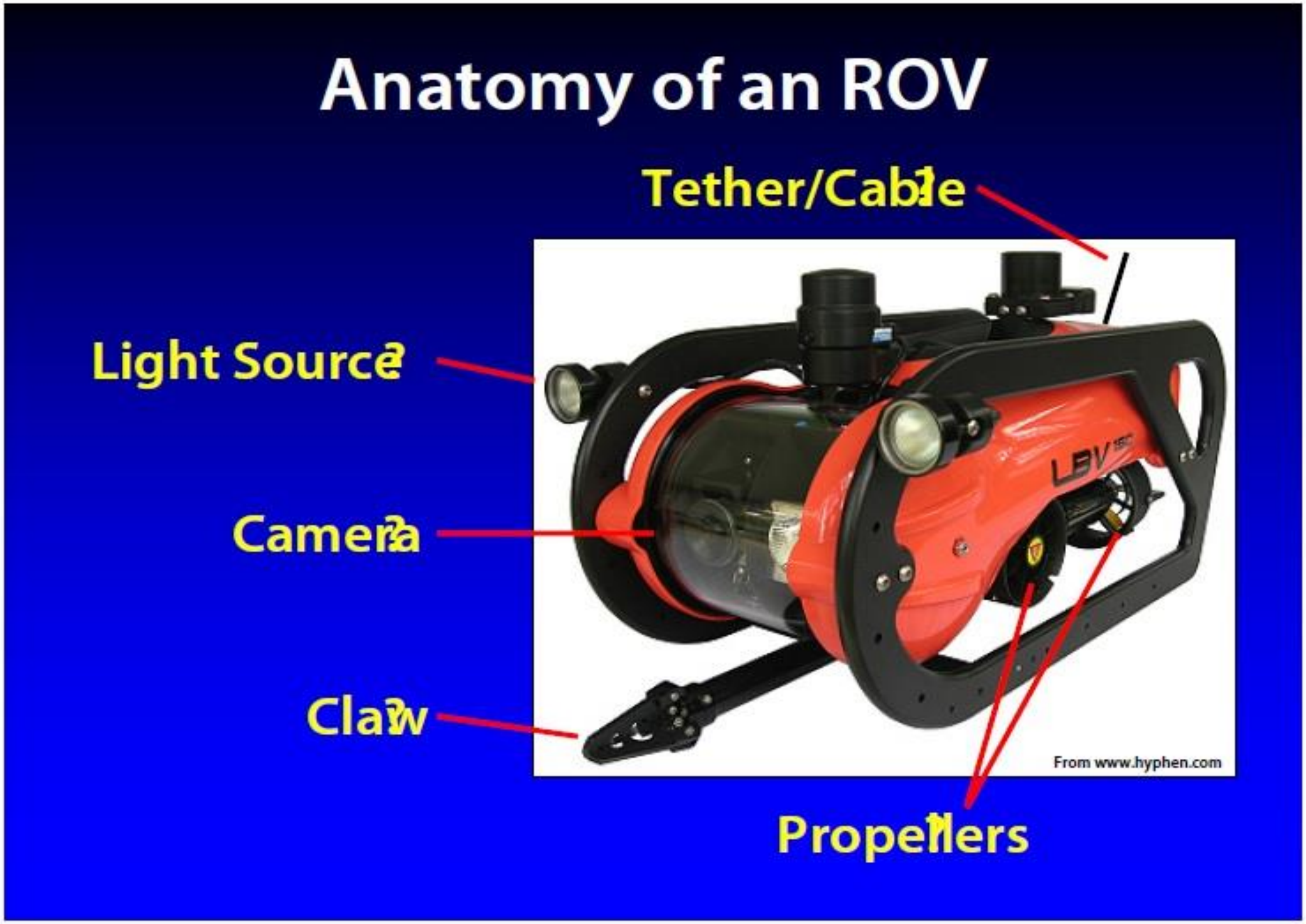


Underwater Sampling

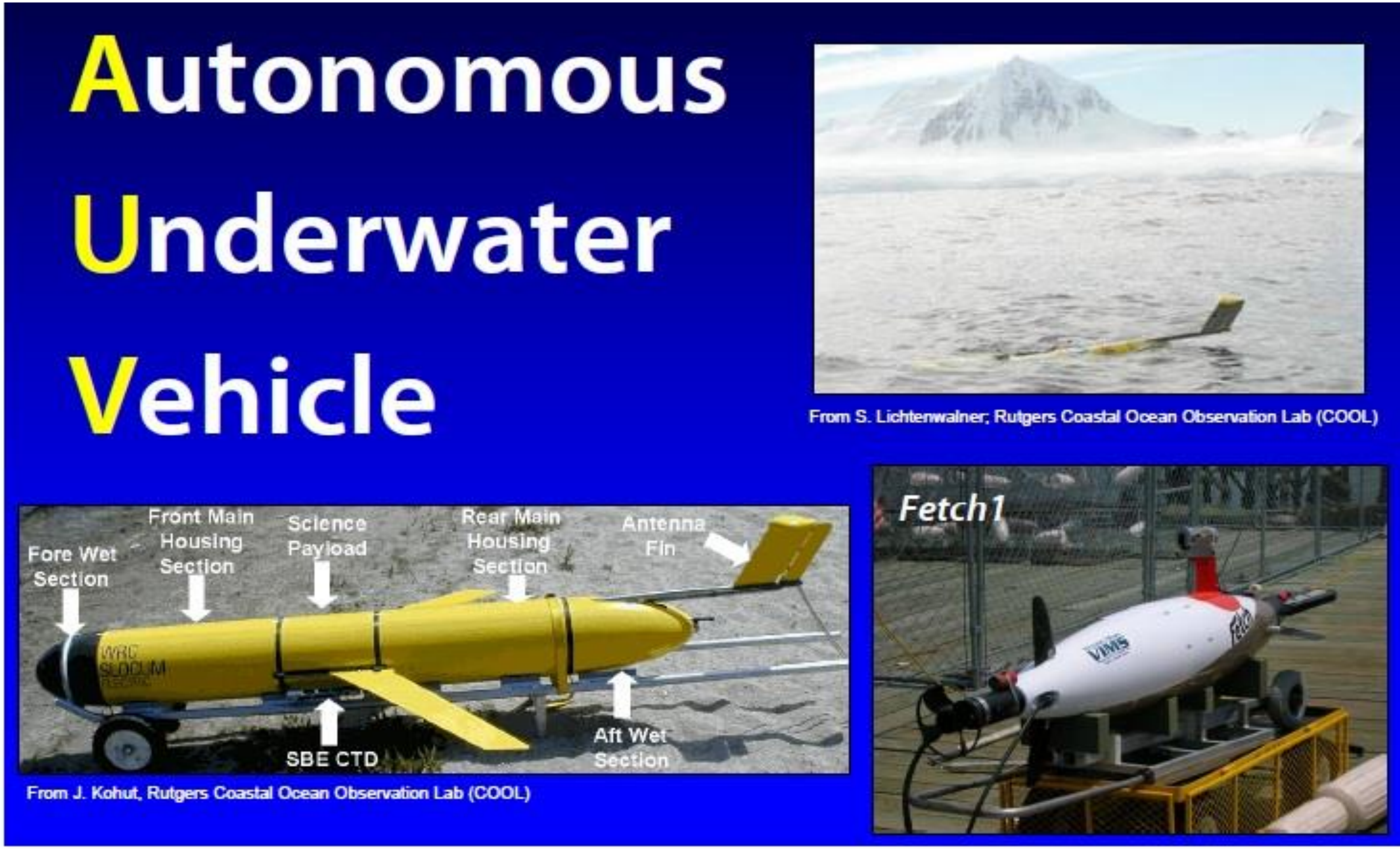
ROV


Remotely
Operated
Vehicle
From http://oceanexplorer.noaa.gov
ARGO
From www.whoi.edu
Sea Perch

ROV (Victor 6000)


Anatomy of an ROV
Tether/Cable
Light Source
Camera
Claw
Propellers
From www.hyphen.com

AUV


Autonomous
Underwater
Vehicle
From S. Lichtenwalner; Rutgers Coastal Ocean Observation Lab (COOL)
Front Main Housing Section
Science Payload
Rear Main Housing Section
Antenna Fin
Fore Wet Section
SBE CTD
Aft Wet Section
From J. Kohut, Rutgers Coastal Ocean Observation Lab (COOL)
Fetch1

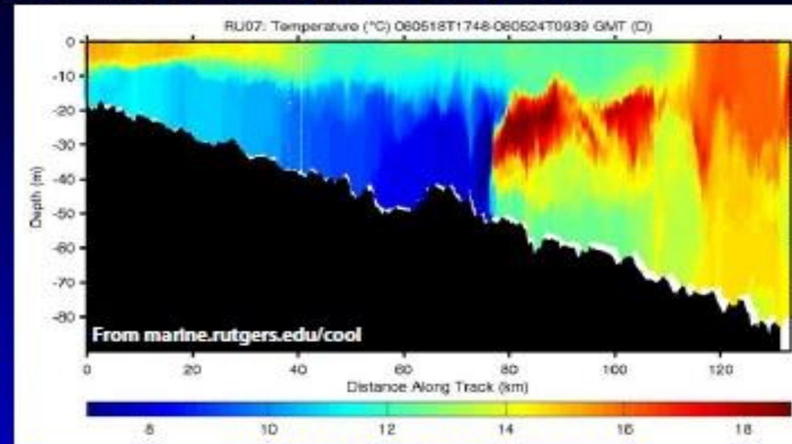
REMUS


REMUS – Remote Environmental Monitoring Units
From WHOI
HYDROID
REMUS
From ONR
GPS / Iridium
CTD Sensor
Inertial Navigation System
Video Camera
Acoustic Imaging System
Single or Dual Frequency Side Scan Sonar
ADCP / DVL
Acoustic Modem
Ultra Short Baseline Navigation
Optical Sensors
From Hydroid

UUV


Unmanned
Underwater
Vehicle
Talisman
From http://warisboring.com
From http://www.southcom.mil
http://www.navy.mil/navydata/cno/n87/usw/issue_26/uuv.html

Why do we use ROVs/AUVs?



Hydrothermal Vent Research/Discovery

Water Quality Research

Oil Rig Inspection

Shipwreck Discovery/ Investigation/Research

Dock/Dam Inspection

All the best

For further information:-

mhss95@mail.com