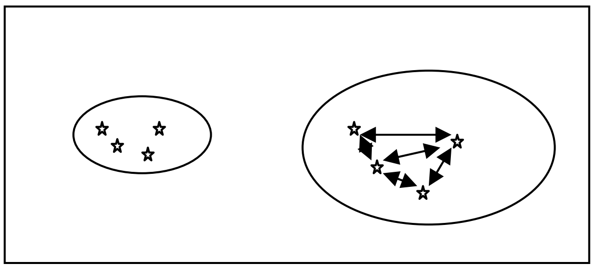
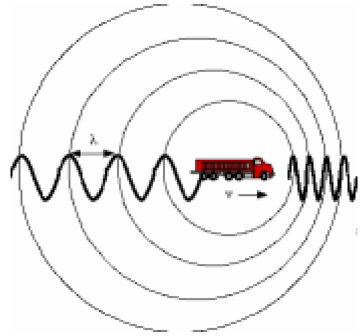
Creation of the universe

• The Big Bang theory (coined in the late 1940s by Fred Hoyle)

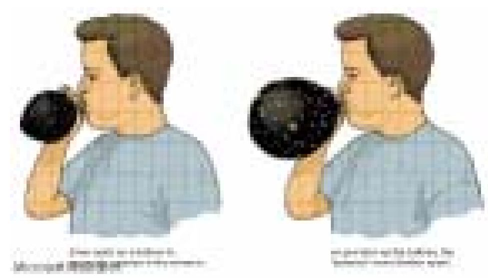
Observation: the universe is expanding, most stars red shifted.





Doppler Effect

(balloon model = space expanding)



Big Bang Time Line

- Big Bang = **creation** of ALL *matter (H, He), space & time*
- Began as a "singularity" ~13.7 billion years ago
  Point with no size, ∞ density
- Nothing known before Planck time (10^{-43} sec)
  - o Before this laws of physics don't apply
- Temp = 10^{32}K
- Universe expands, cools, condenses
  - o 10^{-12} sec – protons & neutrons form at
  - o 10^{-2} sec – electrons form at
  - o ~ 3 minutes – ***H & He*** nuclei (10^{9} K)
  - o 300,000 years – Full atoms (w/ electrons)
    - ▪ Becomes transparent to light
    - ▪ Cosmic Microwave Bkgrnd (2.7K) COBE satellite
  - o 10^{9} years (T=20K) galaxies begin to form, then stars & planets

:. Universe is NOT infinite
- What we can see is limited by speed of light and age of universe
- There is no “outside” or edge
  (analog: earth’s surface has no edges but finite)

<u>Big Questions</u>

- What caused it? Where did it come from?
- Why is it inhomogeneous?
- Is the Universe open or closed or “flat”?
    - Open = Will expand forever (heat death) or
    - Closed = Will slow, contract, collapse (Big Crunch)
    - Flat = expansion = gravity, will slow, stop and stay
- Analogy – throw a base ball
    - Open = flies into space (> escape velocity)
    - Closed = fall back to earth (< escape velocity)
    - Flat = go into orbit (= escape velocity)

Early matter *(H, He)* condensed into stars & galaxies.

Stars “burn” by **fusion** (H -> He ... Fe) [657 million tons/sec]

- Have finite life times, use up “fuel” (sun will last ~ 5 by more)
    - if small (white dwarf) may explode as nova & collapse
    - if large (> 8 solar masses) explode as supernovas
    (fission: only way to create elements heavier then Fe)
    “We are stardust...”
    - Nebula = cloud of gas and dust

- Solar system is 2nd or 3rd generation system

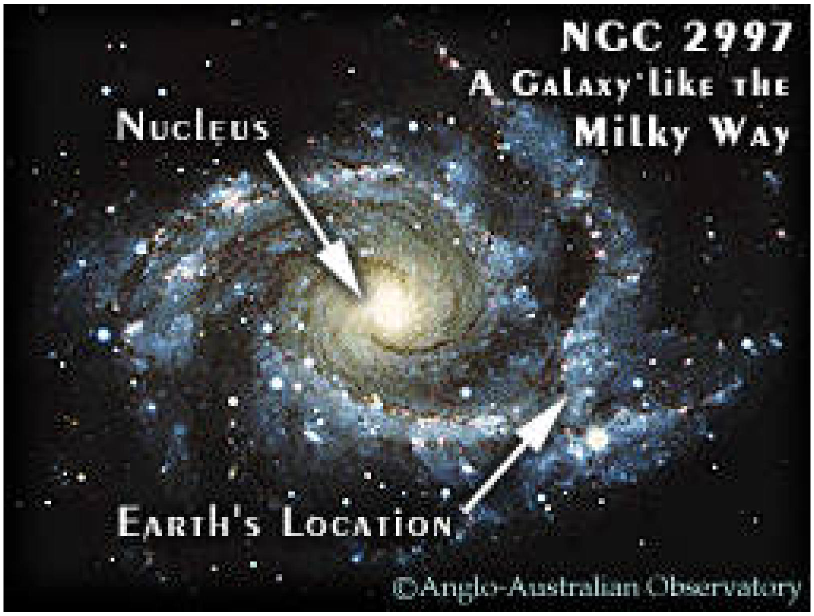
- Formed by dust and gas from:
    - original big bang
    - exploded starts (novas)

The Scale of the Universe

Universe contains ~$20 * 10^9$ galaxies

"Local Group" = 3 large + 37 dwarf (elliptical) galaxies within $5x10^6$ ly

Our galaxy is the "Milky Way"
- ~100 billion stars
- 100,000 ly across ($9*10^{16}$ km) (1 ly = $3*10^5$ km/sec)
- rotates once in 230 million years (1 mill. km/hr)



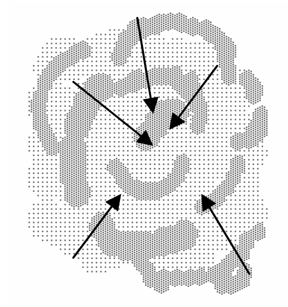
Scientific Notation

Scientific notation is a convenient way to write large or small numbers and do calculations with them. It also quickly conveys two properties of a measurement that are useful to scientists—significant figures and order of magnitude.

Examples

- An electron's mass is about **0.00000 00000 00000 00000 00000 00000 91093 826** kg. In scientific notation, this is written **$9.1093826 \times 10^{-31}$ kg.**
- The Earth's mass is about **5,973,600,000,000,000,000,000,000** kg. In scientific notation, this is written **5.9736×10^{24} kg**.

Creation of the solar system - The Nebular Hypothesis
(Kant & LaPlace ~1798)

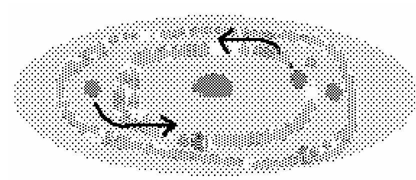


1) dust and gas condense by gravitational attraction, possibly driven by nearby novas.

2) cloud (nebula) continues to collapse due to gravity

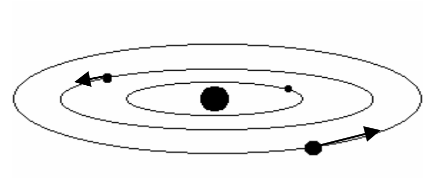
3) cloud begins to spin

(conservation of *angular momentum*)



4) cloud flattens into disk, segregates into rings (like a pizza crust),

- all orbit/revolve in same direction
- all lie on **ecliptic plane**



5) rings condense into planets

6) sun reaches critical mass and fusion begins (99.9% of mass)

7) excess gas and dust "blown out" by solar wind

This model explains why:

- All planets and satellites (moons) orbit ccw (viewed from the north)
- All planets revolve ccw (viewed from the north) [except Venus which has "tipped" over on it's axis]

Gravity = an intrinsic property of all matter that causes mutual attraction between objects with mass.

The force of gravity (F) depends on the mass of the objects (m_1 & m_2) considered and their distance (r).

$$F = G\frac{m_1 m_2}{r^2}$$

F is the magnitude of the gravitational force between the two point masses
G is the gravitational constant
m_1 is the mass of the first point mass
m_2 is the mass of the second point mass
r is the distance between the two point masses

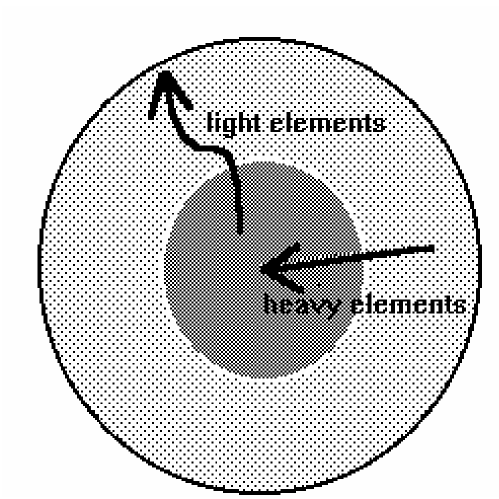
The constant G is approximately equal to 6.67×10^{-11} N m^2 kg^{-2}.

Formation of Earth (~4.6 billion years ago)

1) Earth forms by **accretion** (condensation) like a snowball
   a. Craters have been erased by erosion and tectonics
   b. Can still be seen on Moon, Mercury, etc.

2) After ~100 million years Earth heats up to melting due to:
   a) impact energy
   b) gravitational compression
   c) **radioactive decay** (U, Th, K) (keeps earth hot)
   Lord Kelvin incorrectly estimated age of earth at 20-40 million years when radioactive decay was not taken into account

3) Earth **differentiates (= density layers)** (examples: oil & vinegar dressing)



- Heavy Fe & Ni to core
- Intermediate "mafic" minerals to mantle
- Light silicates to crust
- Lightest gases to atmosphere & seas (outgassing)

<u>Outgassing ("Big Burp")</u>- H_2, CO_2, H_2O, N_2, CO, HCl

(current rate at volcanic vents ~1/4 needed :. must have been greater)

- Light gases escaped to space (H, He)

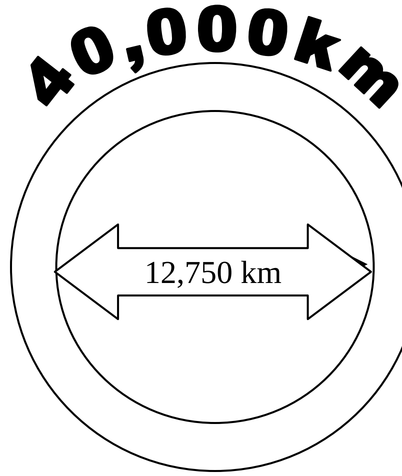
- Reactive gases combined to make compounds (O)

- Water (H_2O) condensed into oceans (with Na and Cl, :. always salty)
  (comet hypothesis says water came from comets - doubtful)

- Original atmosphere was N_2, CO_2

- Plant life (algae) later consumes CO_2 and produces O_2 (~3-3.5bya)
  (i.e. current atm. was "polluted" by plants)

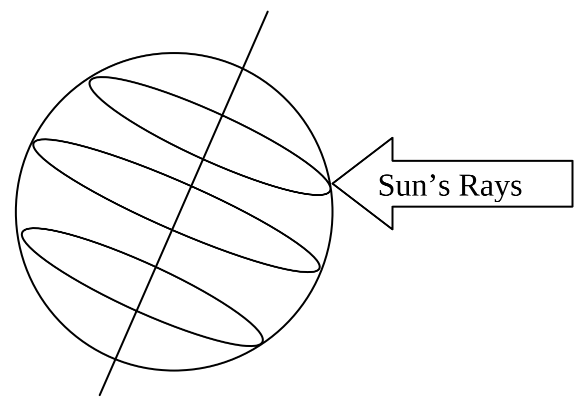
Intro to the Earth



Vital Statistics

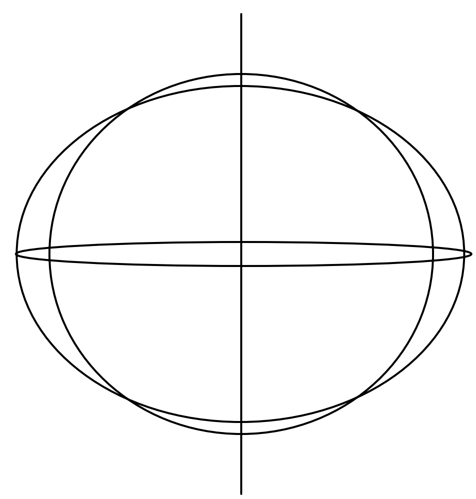
- Size →
- Density = 5.5 g/cm^3
- Mass = $5.976x10^{24}$ kg
- Age 4.6 $*10^9$ yr (Ga)

Motion



- Rotational velocity
    - 1037mph at equator
    - 860 mph at our latitude
- Orbital velocity = 66,700 mph
- Galactic orbital vel. = ~10x that

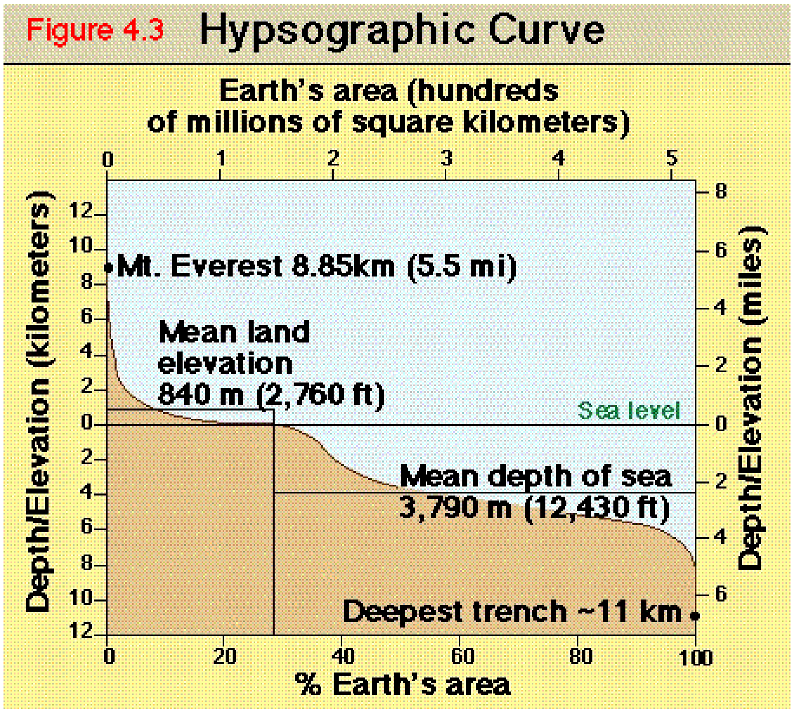
Axis Tilted 23.5° - causes seasons



- Equatorial Bulge
    - Oblate by ~21km
    - 0.3%
    - Pizza dough analogy
    - :. Earth is elastic

Surface Features

- 71% ocean
- ~3% ice

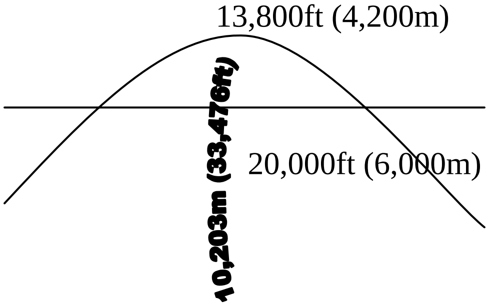


Everest climbed
1953 Hillary & Norgay

Challenger Deep
Mariannas Trench
1960 "Trieste"
Walsh & Piccard

Lowest point on land
- Dead Sea: -1,291ft (-393m) [Jordan & Israel]
- Death Valley: -282ft

Tallest Mountain
- Mauna Kea



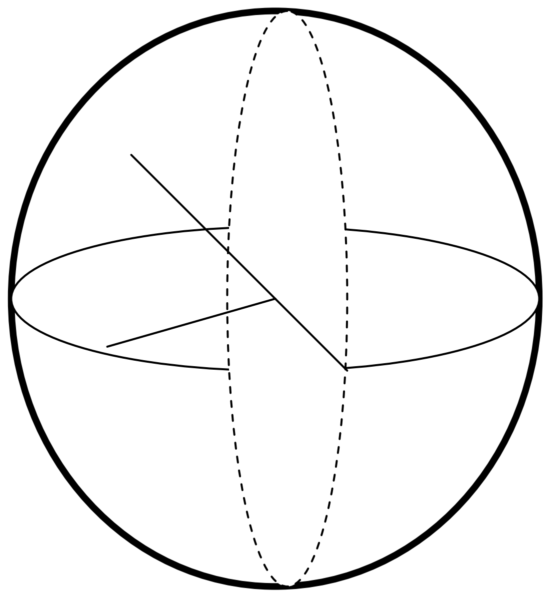
Point farthest from earth's center
- Chimborazo, Ecuador
- 20,700 ft (6,310 m) + 21,000km oblateness

Latitude & longitude

All coordinate systems need:

1. A starting place (origin)
2. Units

Most reasonable way to locate on a sphere is to use angles.
All circles have 360°



Prime Meridian passes thru Royal Naval Obs. In Greenwich, Eng. Est. 1884

Latitude = angular distance N & S from equator, from 0° – 90°

- All lines of latitude are small circles except the equator.
- Also called "parallels"

Longitude = angular distance E & W from Prime Meridian, from 0° - 180°

- All lines of longitude are Great Circles
- Also called "meridians"

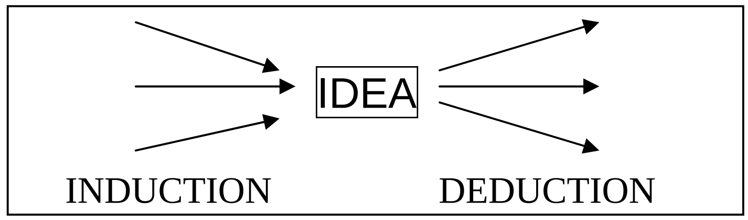
1° = 68.7 statue miles (110km)
Degrees of longitude get smaller near poles (depend on latitude)

1° = 60 nautical miles :. 1' (minute) = 1 nautical mile
[:. 1 nautical mile = 1.15 statue miles or 1.85 km]

SCIENCE ≡ systematic process of learning about the natural (physical) world

From Latin *scientia* = "to know" (as in "sentient" being)

Reason from the specific to the general ("induction") then back to specifics ("deduction")



Very powerful but limited.

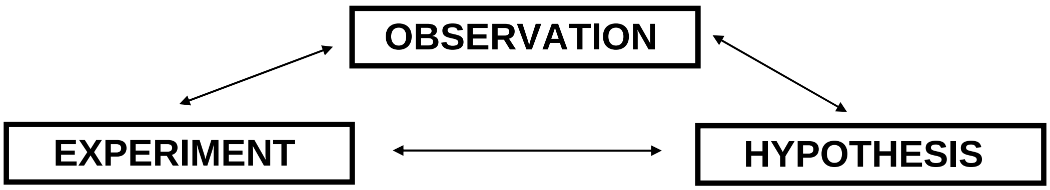
Science attempts to discover **general rules** of how the universe works but cannot advance question of why. (metaphysics=after physics)

Because science deals with only physical world it can lead to mistake of Naturalism (materialism) = belief that matter & energy are **all** there is.

Can't prove God scientifically because science denies the "supernatural" *a priori* . (supernatural = "outside nature")

Science only useful for material universe (matter & energy) Not for morals, ethics, religion.

Scientific method: (simple version)
(Observation + hypothesis = empiricism)



1) Observations
- quantitative (exp. “83°“ not “its hot” = qualitative)
- free from bias or interpretation (Black sheep story)

2) Hypothesis
- explains the observations
- consistent with all knowledge (i.e. reasonable)
- not unnecessarily complex (Ocham’s razor)
- predicts $\therefore$ is testable

3) Experiment
- unambiguously tests the hypothesis
- repeatable
- experiment doesn’t affect outcome
-

Science cannot <u>prove</u> an idea absolutely, can only <u>disprove</u>.

1) Hypothesis:
- put forward without proof
- tentative, subject to revision or rejection

2) Theory: (most scientific knowledge is here)
- survived repeated testing
- useful, widely accepted

3) Law:
- quantitative, mathematical (physics)
- very fundamental “rule” of nature

MODEL ≡ idea or construct that exhibits some of the behavior of the real thing

Examples:

- map, globe, computer program, equation, wind tunnel

Model is less then the real thing ∴ falls short in prediction

---

Articles of faith of science (accepted without proof :. faith)

1) There is a reality external to us (not illusion or created by us) [ontology = theory of being]

2) Reality is as we perceive it (senses reveal real world) [epistemology = theory of knowing] ("The Matrix")

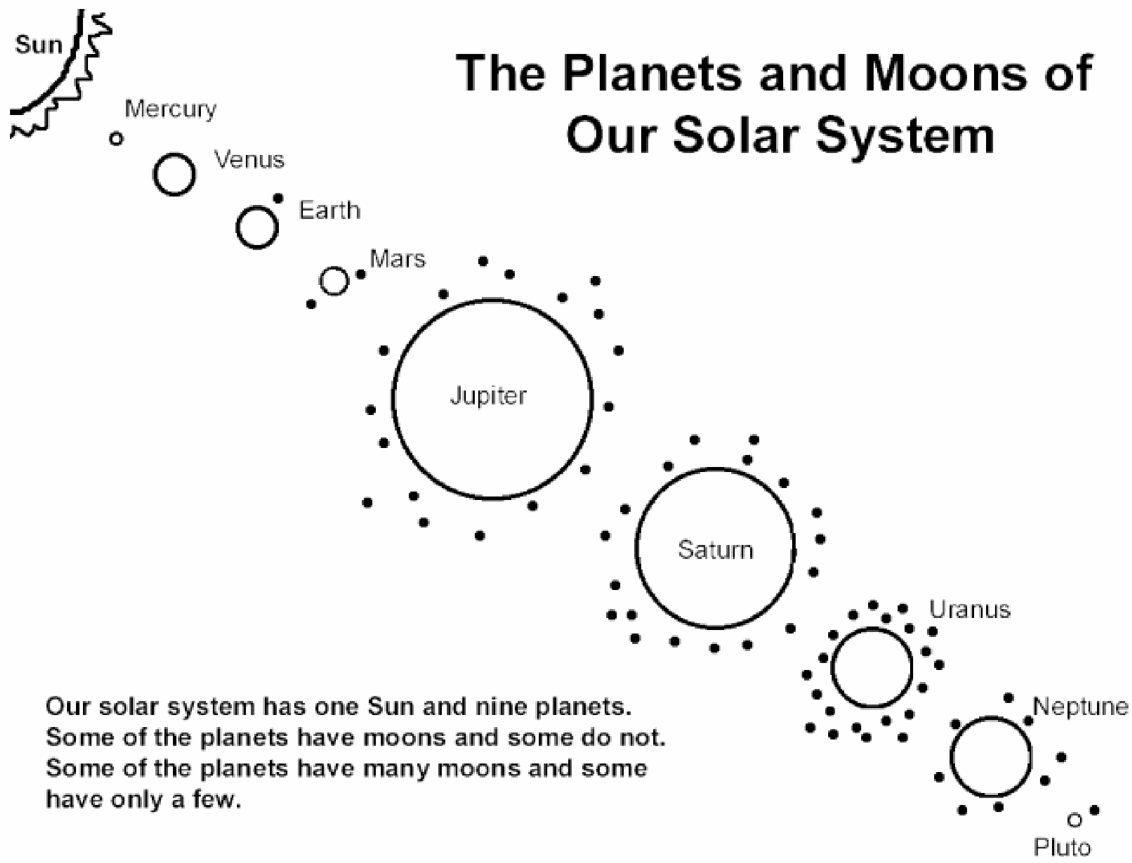
3) Reality is consistent in space and time (rules don't change)

4) Reality is understandable by us ("God may be subtle but he is no malicious." – A. Einstein).

Solar System

	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto
diameter (Earth=1)	0.382	0.949	1	0.532	11.209	9.44	4.007	3.883	0.180
diameter (km)	4,878	12,104	12,756	6,787	142,800	120,000	51,118	49,528	2,300
mass (Earth=1)	0.055	0.815	1	0.107	318	95	15	17	0.002
mean distance from Sun (AU)	0.39	0.72	1	1.52	5.20	9.54	19.18	30.06	39.44
orbital period (years)	0.24	0.62	1	1.88	11.86	29.46	84.01	164.8	247.7
orbital eccentricity	0.2056	0.0068	0.0167	0.0934	0.0483	0.0560	0.0461	0.0097	0.2482
mean orbital velocity (km/sec)	47.89	35.03	29.79	24.13	13.06	9.64	6.81	5.43	4.74
rotation period(days)	58.65	-243*	1	1.03	0.41	0.44	-0.72*	0.72	-6.38*
inclination of axis (degrees)	0.0	177.4	23.45	23.98	3.08	26.73	97.92	28.8	122
mean surface temp (C)	-180 to 430	465	-89 to 58	-82 to 0	-150	-170	-200	-210	-220
gravity at equator (Earth=1)	0.38	0.9	1	0.38	2.64	0.93	0.89	1.12	0.06
escape velocity (km/sec)	4.25	10.36	11.18	5.02	59.54	35.49	21.29	23.71	1.27
mean density	5.43	5.25	5.52	3.93	1.33	0.71	1.24	1.67	2.03
atmospheric composition	none	CO_2	N_2+O_2	CO_2	H_2+He	H_2+He	H_2+He	H_2+He	CH_4
number of moons	0	0	1	2	60	31	27	13	1
rings?	no	no	no	no	yes	yes	yes	yes	no

* Negative values = retrograde rotation



1 AU = 150,000,000 km (93,000,000 mi)

The <u>Kuiper</u> Belt [Trans-Neptunian objects] (discovered 1992)

- disk-shaped region past the orbit of Neptune
- Much bigger than asteroid belt
- extending roughly from 30 to 50 AU from the Sun containing
- many small icy bodies (~35,000 > 100km) like:
    - Pluto?
    - Quaoar >1000 km, 40 AU (discovered 2002)
- source of the short-period comets

Oort Cloud (theorized 1950's)

- Possible source of long period (200 My) comets
- Not directly visible
- Comet orbits suggest they originate from about 50,000 AU

Extra-solar planets

- Only big ones detectable (stellar wobble)
- ~ 150 known
- ~ 3% of those checked have one

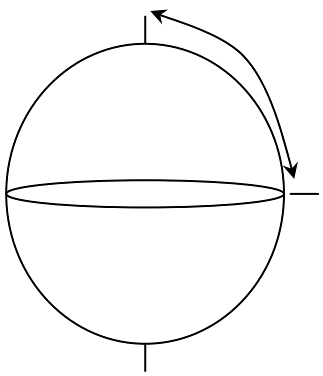
Units of Measure

Systemé International D'Unites -- International System of Units (SI)

1799 – Paris Academy of Sciences

1. Any rational system of weights & measures needs:
   a. A starting point
   b. An increment
   c. Must be reproducible

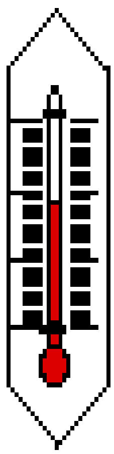
2. Length – area – volume => METER



   a. Based on one ten-millionth part of the quadrant of the earth on meridian between Dunkirk and Barcelona.
   b. = 10,000,000 m (or 10,000km)
   c. Kept as a polished platinum bar
   d. As of 1983 "The length of path traveled by light in a vacuum during the time interval of 1/299,792,458 of a second"

3. Mass => gram

   a. Mass of one cm^3 of pure water at 4°C



4. Temperature => degrees Celsius (Fahrenheit makes no sense)

   a. Anders Celsius (1701-1744) devised scale with 0 at boiling and 100 at freezing – SI reversed it

   b. 0°C = triple-point (freezing) of water (at 1atm), 100°C = boiling point

   c. Actual SI temperature is in "kelvins"
      no thermal motion at 0°K = -273.15°C

5. Prefixes

Prefix	value	symbol	example	etymology
Yotta	10^24	Y	Yottajoule	from otto, eight italian
Zetta	10^21	Z	Zettamole	from sette, seven italian
Exa	10^18	E	Exaweber	from hex, six in Greek
Peta	10^15	P	PetaHertz	from pente, five in Greek
Tera	10^12	T	Teracandela	teras, monster in Greek
Giga	10^9	G	Gigawatt	gigas, giant in Greek
Mega	10^6	M	Megakelvin	megas, huge in Greek
kilo	10^3	k	kilovolt	khilioi, thousand in Greek
hecto	10^2	h	hectoradian	hekaton, hundred in Greek
Deca/Deka	10	D	Dekapascal	deka, ten in Greek
deci	10^-1	d	decisievert	decimus, tenth in Latin
centi	10^-2	c	centimetre	centum, hundred in Latin
milli	10^-3	m	milliampere	mille, thousand in Latin
micro	10^-6	mu	microohm	mikros, small in Greek
nano	10^-9	n	nanosecond	nanos, dwarf in Greek
pico	10^-12	p	picofarad	pico, little bit in Spanish
femto	10^-15	f	femtonewton	femten, 15 in Danish or Norwegian
atto	10^-18	a	attogram	atten, 18 in Danish or Norwegian
zepto	10^-21	z	zeptohenri	from sept, seven Greek
yocto	10^-24	y	yoctolitre	from okto, eight Greek

Plate Tectonics – historic approach

"Continental Drift"

Alfred Wegener (1980-1930) meteorologist

1915 published "The Origin of Continents and Oceans"
Eng. Trans. 1924

Idea: continents "drifted" apart from ancient supercontinent **Pangaea** (=*all lands*) 200 million years ago

Evidence

1) Fit of Atlantic coast lines, noted since reliable maps were made.

2) Distribution of ice sheets (paleoclimate ~300 my)
   a) would be huge in southern hemisphere but not north
   b) direction of glacial striations

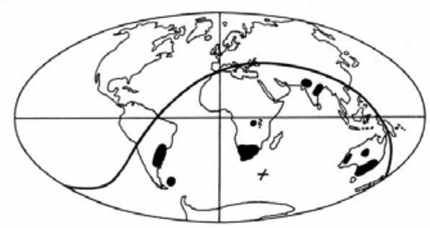
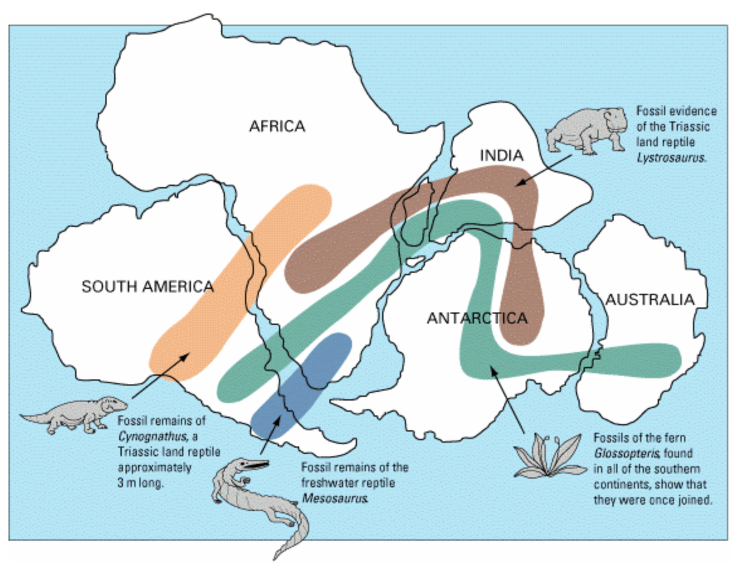


Fig. 34. Traces of the Permo-Carboniferous inland glaciation on present-day continents. The cross indicates the position of the South Pole most suitable for the explanation; the broad curve is the associated equator.

3) Fossils
   a) Mesosaurus (fresh water), Lystrosaurus, Glossopteris, etc.



* Couldn't swim across ocean

* ecosystems are different on each continent now

* tropical life in Antarctica?

4) Geologic structures
5) Locations of quakes around Pacific rim

Objections:

1) Too radical
2) No driving force
3) Granitic continents can't "plow" through basaltic seafloor

Arthur Holms – mantle convection

New evidence from the WWII technology

Echo sounding
1) German ship *Meteor* 1920's
2) Mid-ocean ridge system

Harry Hess
1) Princeton geol. Professor & Naval Captain in WWII.
2) Collected echo-sounding records in Pacific
3) Why oceans weren't filled by sediments? (too young)
4) 1962 proposed mobile seafloor ("seafloor spreading" from Dietz)

Global Seismic Network -- Nuclear Test detection
1) Showed shallow events at mid-Ocean ridges
2) Deep quakes around Pacific

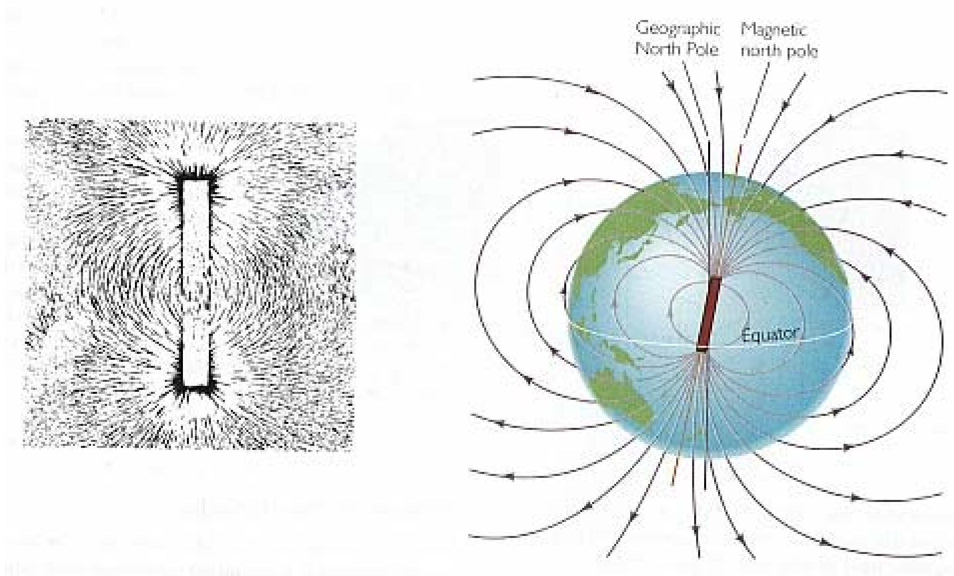
Radiometric dating of ocean basalts

Magnetometers

Paleomagnetism

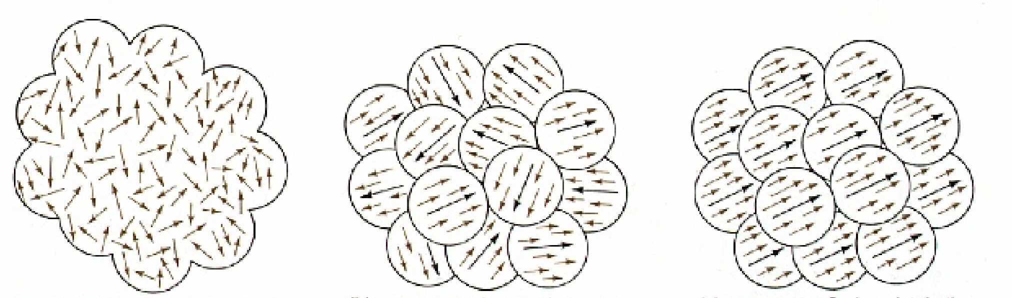
1) Earth has a magnetic field

a) Probably caused by rotation of solid Inner Core in liquid Outer Core (both mostly Fe) ("Magneto effect")



2) *Remanent magnetization* (*thermoremanent)*-- Many rocks have magnetic minerals that align with the earth's magnetic field as they cool past the Curie point (580° C)

3) Rocks retain "memory" of magnetic field when they cool.

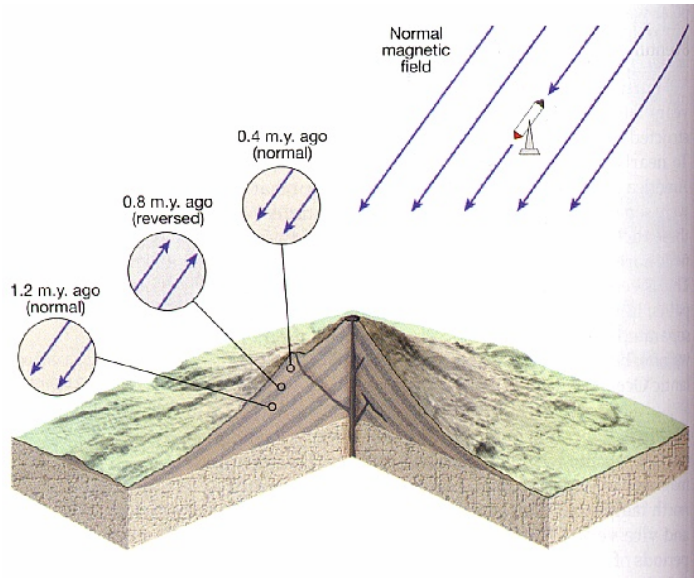


(a) Above the Curie point, atoms take random directions

(b) Below the Curie point, atoms become parallel within domains

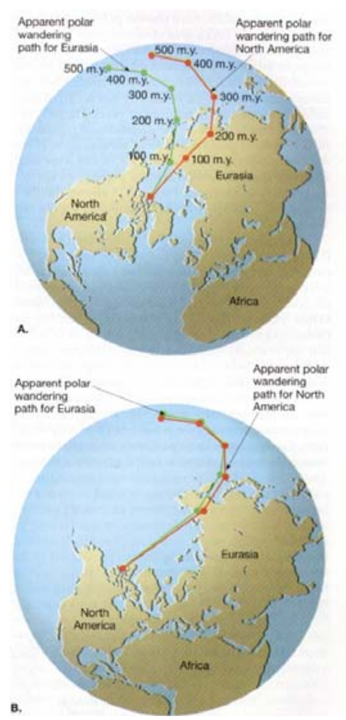
(c) Below the Curie point, in the presence of an external magnetic field, domains line up

4) Polar Reversals - Different aged rocks show that the polarity of the magnetic pole has reversed many times in the past.



Frequency of flips: ten thousand to tens of millions
Last polarity reversal was 690,000 years ago

5)
6) Polar wandering curves



a) Earth's magnetic pole moves over time. Path is called a "polar wander curve"

b) Different continents show different curves

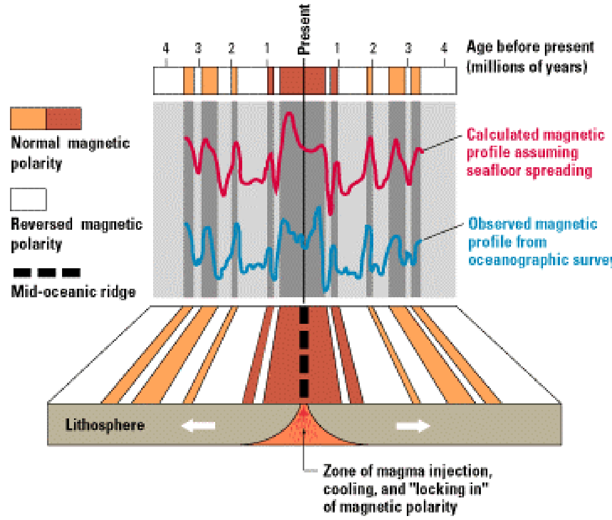
further proof continents have moved

(back to plate tectonics…)

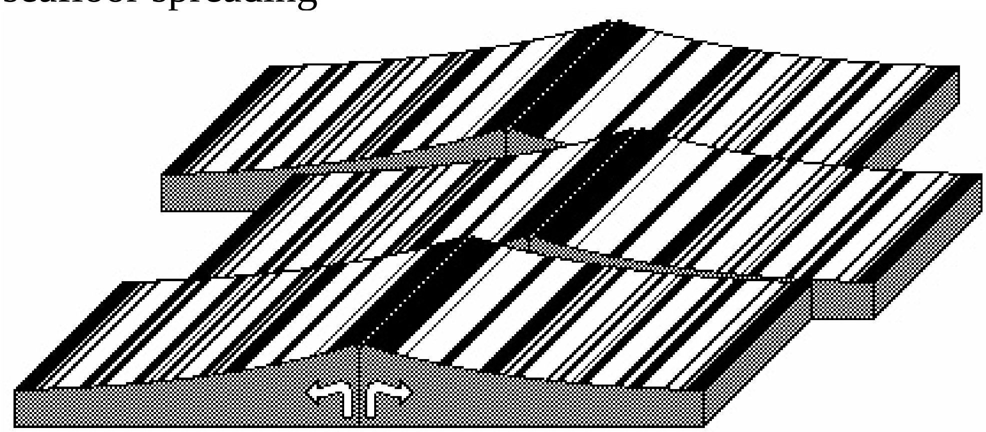
Magnetization of the sea floor (detected with magnetometers)

1) Sea floor basalt magnetometer readings

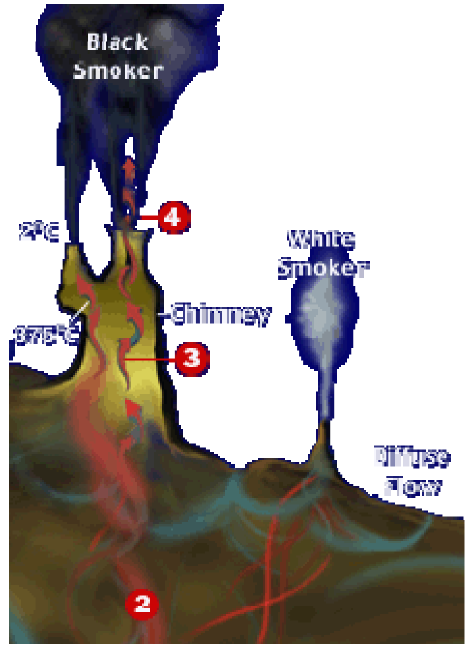
2) magnetic stripes
   a) parallel to mid-ocean ridges
   b) symmetrical



3) *Vine & Matthews – 1963* (Cambridge University) explained by seafloor spreading



Hydrothermal Vents
(geothermal vents)



First discovered in 1977 off of S. America

Found on ridges and hotspots

Like hot springs, geysers on land

Avg. depth ~2,000m

Water temp up to 400°C (750°F) 4x boiling – under high pressure

"Black smokers" – hotter, iron monosulfide dissolved causes color (Pb, Zn, Co, Cu, Ag)

"White smokers" – cooler, barium, calcium, and silicon

May have profound affect on ocean chemistry and heat budget (34% of ocean heat?)

Chimneys grow (precipitate) up to 9m (30 ft) high in 18 months

Reach heights of ~50m

Collapse to form "sulfide mounds"

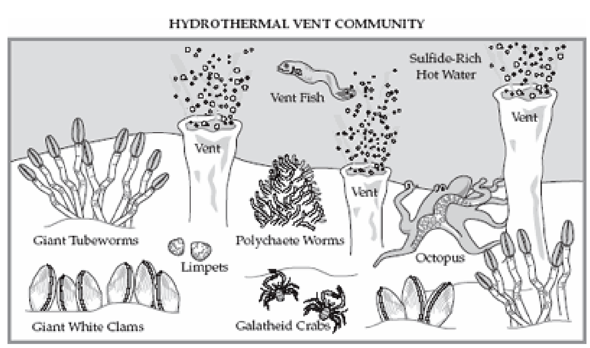
<u>Vent Communities</u> (> 300 new species)

Support rich ecosystems – only one NOT dependent on sun light!
("Whale falls" carcass – but whale ate krill, that ate plankton, that used sunlight)

They do need O_2 which gets into the ocean as a byproduct of photosynthesis.

Chemosynthetic bacteria at base of food chain

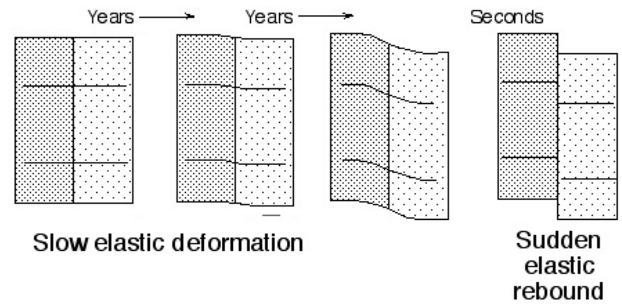
- Symbiotic Giant red tube worms (no digestive system, read blooded)
  1.5m long, 2cm thick, live > 200 years
- gigantic clams (~30cm)
- mussels
- crabs
- shrimp
- deep-water skates



Earthquakes

Elastic Rebound Theory (foam model)

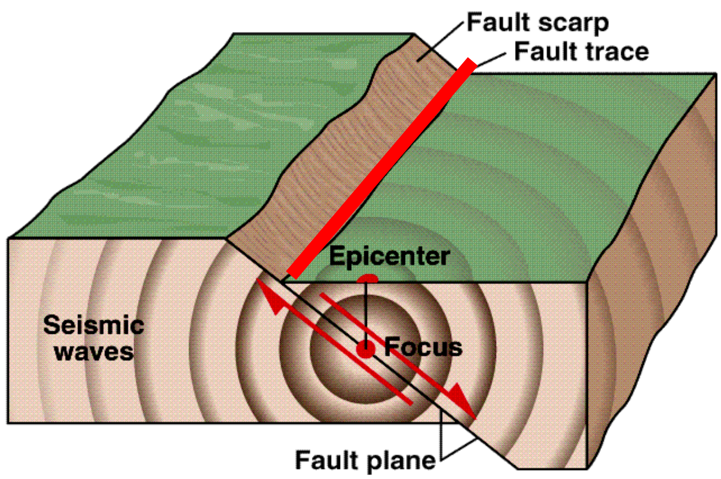
- 1906 San Francisco EQ
    - H.F. Reid & G.K. Gilbert
- Rocks are elastic
    - store energy over year
    - release it in seconds
    - slip on a fault
    - “Stick-slip”



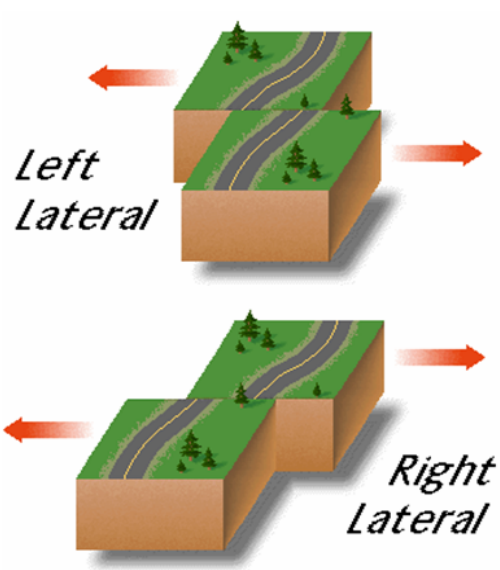
Anatomy of a fault

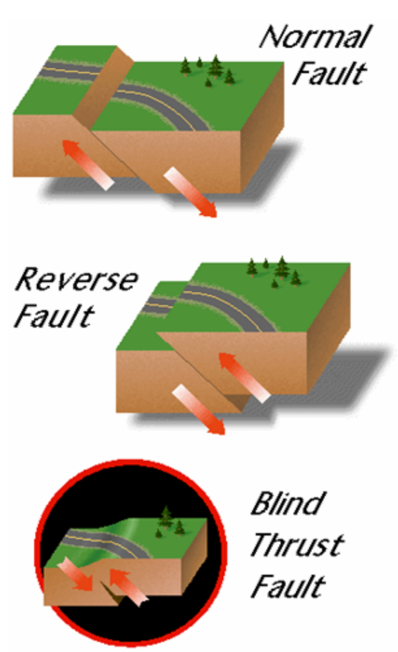
Vocabulary:

- Epicenter
- Focus (hypocenter)
- Fault trace
- Fault zone
- Fault plane
- Scarp
- Strike
- Dip

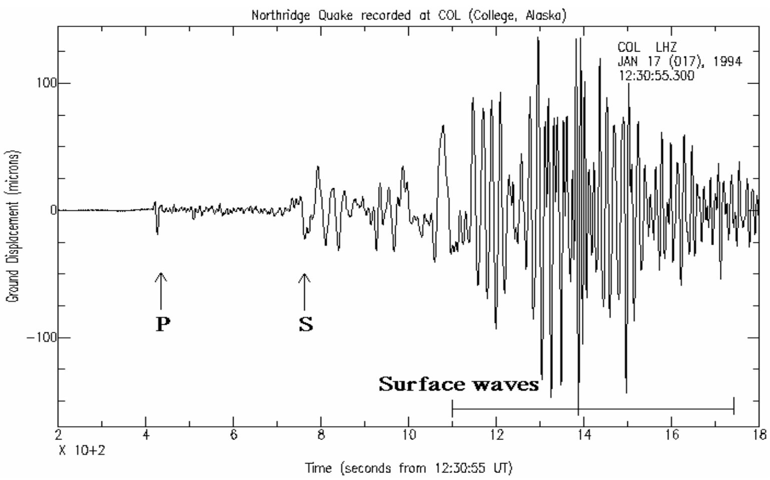


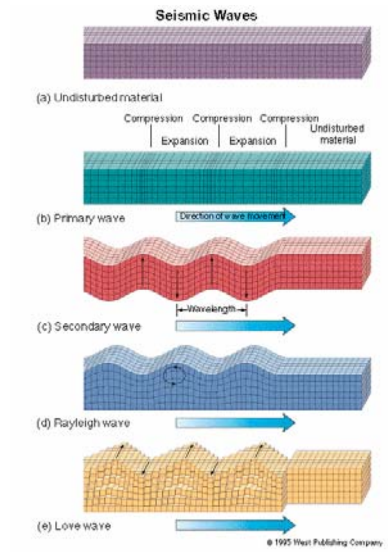
Types of fault motion:



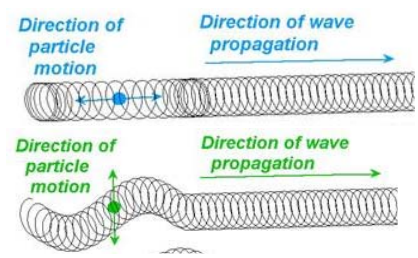


Seismic Waves



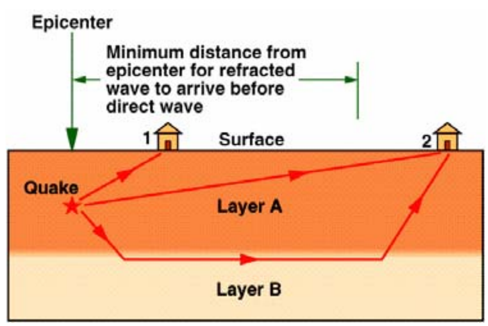


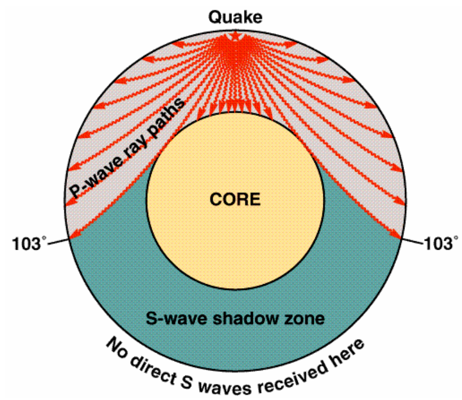
P-Wave	S-Wave	Surface Wave
Interior	Interior	Surface only
compression "**P**ush"	Shear "**S**hake"	shimmy & roll
particle parallel	Particle **S**ideways	complex
"**P**hast"	**S**low	Slowest
small amp	large amp	large amp
Pass thru liquids	**S**top in liquids	Don't pass

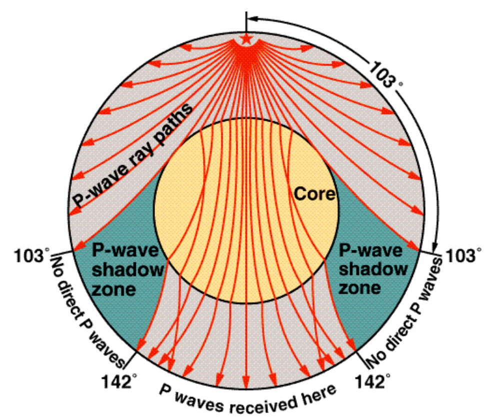


Used to image earth's interior

- **Wave speed generally increases with depth**
- **:. Fastest path is a curve**







Magnitude & Intensity

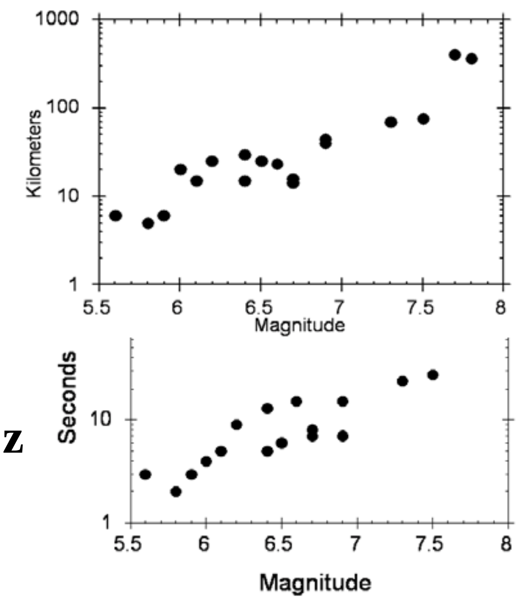
- **Magnitude scales (Richter 1935)**
  - **Not 0-10, logarithmic**
  - **M_L = log(amp) * dist. correction**
  - **Moment (energy in dyne – cm)
    = shear mod * fault area * disp.**
  - **Mw = Mo calibrated to M_L**

Magnitude, Amp and Energy

Magnitude Change	Amp. Change	Energy Change
1.0	10.0 times	~32 times
0.5	3.2 times	~ 5.5 times
0.3	2.0 times	~ 3 times
0.1	1.3 times	~ 1.4 times

- **Modified Mercalli Intensity Scale**
  - **Shaking intensity:
    magnitude + distance + local site magnification**

- **As the Magnitude increases so does the :**
  - **Fault length (area)**
  - **Slip (displacement, offset)**
  - **Event duration**



Example:

Chile 1960, May 22, 19:11:14 z

Largest quake ever
Largest quake possible?

- Mw = 9.5
- Mo = 2.5 X 10^{30} dyn·cm
- Duration = 7 min.
- Slip = ~25m
- Fault length = 1,600km (1,000mi)
- 2,000 killed, 3,000 injured, 2,000,000 homeless
- $550 million damage in southern Chile
- Tsunami caused
  - 61 deaths, $75 million damage in Hawaii
  - 138 deaths and $50 million damage in Japan
  - 32 dead and missing in the Philippines
- $500,000 damage to the west coast of the United States.

Earthquake effects

~1,300,000 fatalities in past 100 yrs

- Fault rupture (Alquist-Priolo Special Study Zones)
- Shaking – structures kill people
    - Construction matters!
    - Unreinforced masonry the worst (URMs)
    - 3rd world construction: Bam, Kobe
- Fires – San Francisco
- Landslides
- Floods – Van Norman (almost)
- Liquefaction – saturated, fine sands
- Tsunamis

Earthquake Myths

- California will fall into the ocean
- Earthquake weather
- Predictions: animals, psychics, scientists
- Number of earthquakes worldwide is increasing
- They always happen in the morning
- Faults swallow things
- My building is on rollers...
- There are "jolting" earthquakes and "rolling" earthquakes
- Aftershocks are different from mainshocks
- Small quakes "relieve the stress", make big one less likely
    - Scale is logarithmic (x10)
    - 8 = 32x7 = 1000x6 = 32,000x5 = 10^6x4 = 32x10^6 x 3
- Get in a doorway

Global Earthquakes

Frequency of Occurrence of Earthquakes (10x 13's)

Descriptor	Magnitude	Average Annually
Great	8 and higher	1 [1]
Major	7 - 7.9	17 [2]
Strong	6 - 6.9	134 [2]
Moderate	5 - 5.9	1319 [2]
Light	4 - 4.9	13,000 (estimated)
Minor	3 - 3.9	130,000 (estimated)
Very Minor	2 - 2.9	1,300,000 (estimated)

Atoms and Atomic Structure

1) Atoms

   a) **Atom** = smallest unit of an element
      i) 1 drop of water contains 1 million million billion atoms ($1x10^{21}$)

   b) **Element** = substance that cannot be decomposed into another substance by chemical or physical means.
      i) **Example:** burning, breaking

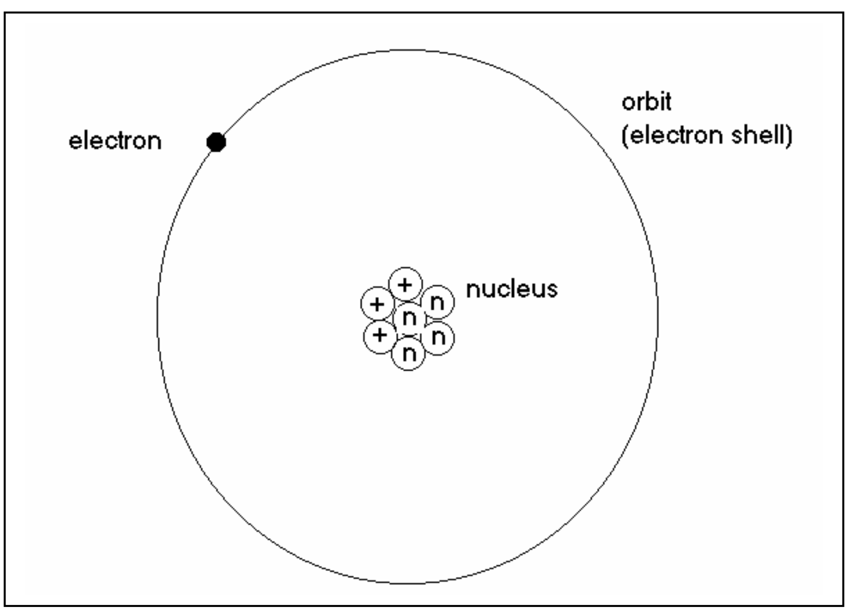
2) 109 elements --- 92 naturally occurring

3) 1 or 2 letter "atomic symbols" arranged in <u>periodic table</u>
   a) Some obvious: **O, H, Si, Al**
   b) Some not obvious: **Fe** (iron, L. *ferrum*), **Pb** (lead, L. *plumbum*), **Ag** (silver, Gk. Argyros [Argentina]), **Au** (gold, L. *aurum*)

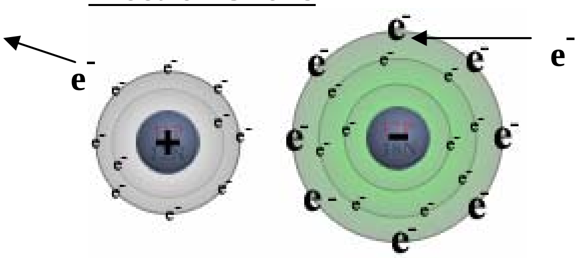
Atomic Structure

1) Bohr Model
   a) Three sub-atomic particles:

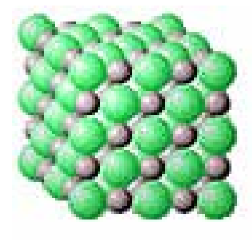
Particle	**Charge**
Proton	+
Electron	-
Neutron	-none-



Electron Shells



$^{1}Na^{+}$ $^{17}Cl^{-}$



Chemical Bonds

1) **Ionic** – electrostatic attraction between ions *(dating)*
   "Electron transfer"

2) **Covalent** – sharing of "valence" electrons (*marriage*)

   a) Strong bonds: many mineral, including diamonds

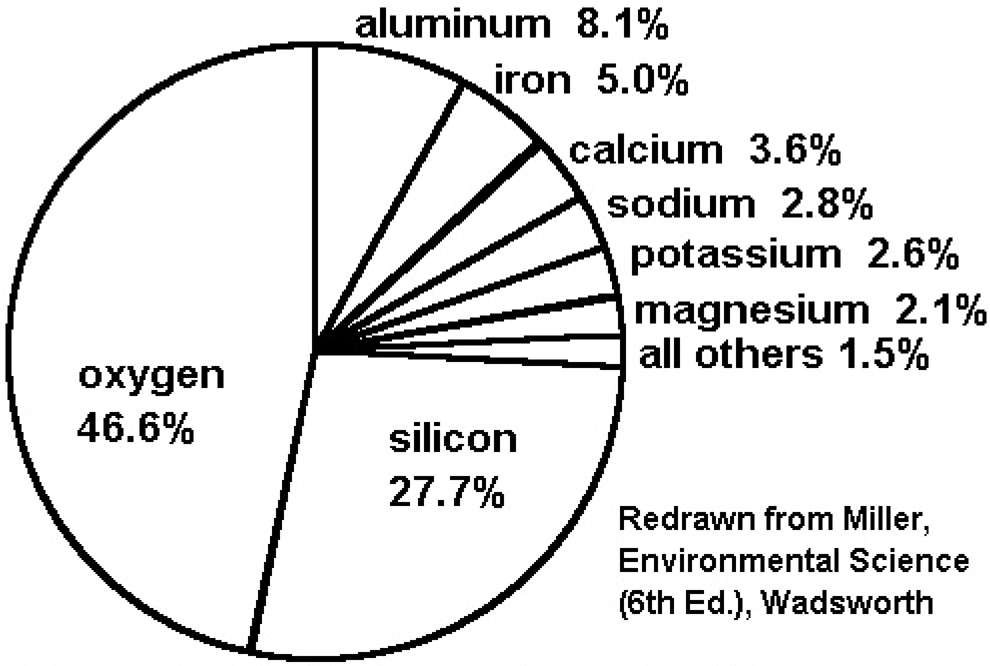
These next two we will not worry about

3) **Metallic** (rare) – too many orbital vacancies to fill, (*commune*)
   nuclei packed tight in a "sea" of electrons

   a) Good conductor of heat and electricity
   b) Malleable (hammer out flat) mallet=hammer
   c) Opaque

4) **Van der Waals** (rare) – polarized molecules attracted to one another

8 Elements make up 98.5% of the earth by weight



% by weight of elements in Earth's crust

Mineral = a naturally occurring, inorganic solid with a definite chemical composition and orderly internal atomic arrangement.

Mineral Groups

Silicates: Most common rock-forming minerals are silicates. A combination of oxygen and silica that form silicon-oxygen tetrahedron (SiO_4)

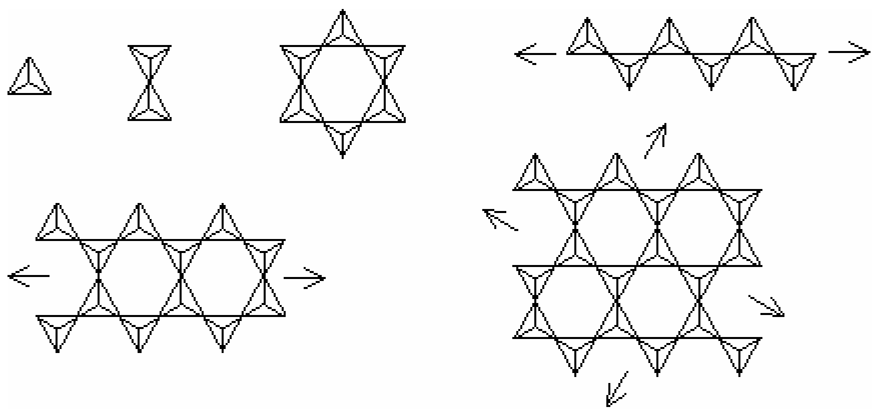
Independent tetrahedra — olivine

Single chain — pyroxenes

Double chain — amphiboles

Sheet silicates — micas

Framework silicates — quartz and feldspar



Carbonates : have CO_3 polyatomic ion – calcite $CaCO_3$ and dolomite

Oxides : oxygen – corundum, hematite and magnetite (ice!)

Sulfides: S_2 – galena and chalcocite

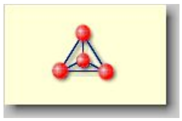
Sulfates : SO_4 – gypsum, barite

Native elements: gold, silver, copper, diamond

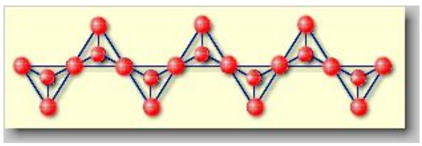
Phosphates: PO_4 – apatite

Halides: "salts" – halite, fluorite

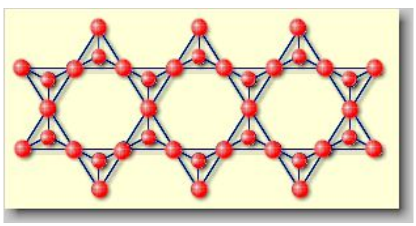
Silicate Structures



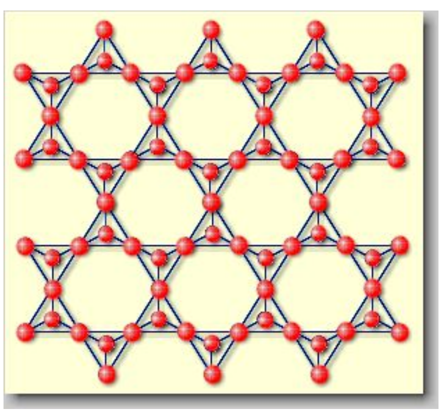
Isolated tetrahedron $[SiO_4]^{-4}$ The isolated $[SiO_4]^{4-}$-tetrahedra exist as independent units which are linked together by cations like Fe^{2+}, Mg^{2+} or Zr^{4+}. Examples are olivine $(Fe,Mg)_2[SiO_4]$, zircon $Zr[SiO_4]$, also the minerals of the garnet group like almandine $Fe^{2+}{}_3Al_2[SiO_4]$.



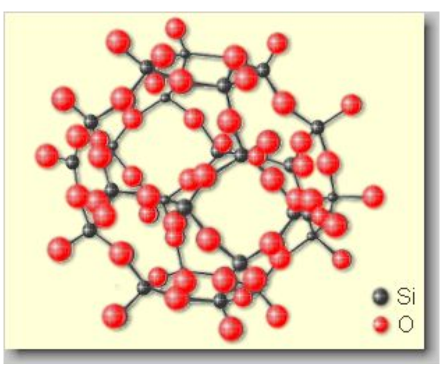
SingleChain silicates: silica tetrahedra are linked at corners to form continuous chains. They may be represented by a composition of $[SiO_3]^{2-}$. An example is diopside $CaMg[Si_2O_6]$, in which the "endless" chains are held together by Ca^{2+}- and Mg^{2+}-ions.



Double chain silicates: Two single silicate chains are linked by the corners forming double chains yielding $[Si_4O_{11}]^{6-}$ -ions. An example is glaucophane $Na_2Mg_3Al_2[(OH,F)|Si_4O_{11}]_2$.



Sheet silicates: are formed when silicate chains are linked at the corners to form continuous sheets with the chemical formula $[Si_2O_5]^{2-}$. Examples are the mica group, pyrophyllite $Al_2(OH)_2[Si_4O_{10}]$ or talc $Mg_3(OH)_2[Si_4O_{10}]$.

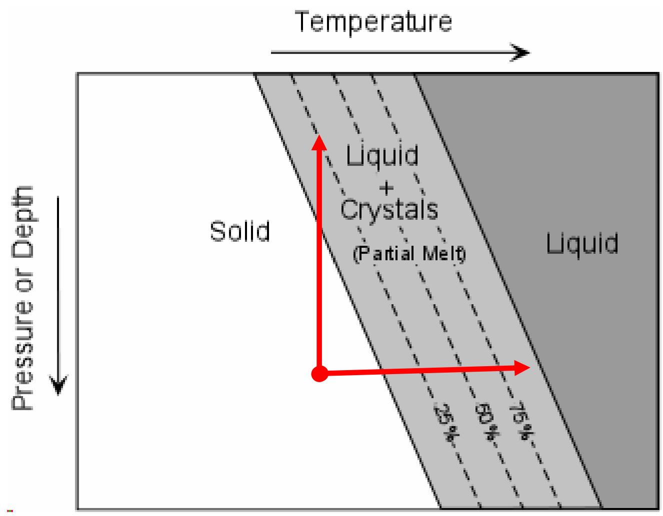


Framework silicates: are formed by silicate tetrahedra which are linked together with four neighboring tetrahedra in a three-dimensional framework in such a way, that the tetrahedra share one oxygen atom. This yield a ratio of (Si,Al):O=1:2, where silicon may be replaced by aluminum. Examples include the feldspars like orthoclase $K[AlSi_3O_8]$ as well as zeolites like natrolite $Na_2[Al_2Si_3O_{10}]\cdot 2H_2O$.

Igneous Rocks

1) **Igneous** – crystallized (cooled) from a magma (like "ignite").

2) Melt (magma) ≡ mixture of melted minerals



   a) Different minerals melt at different temps.
      (800°C - 1300°C)

   b) ∴ Can get partial melting

   c) Melting temp.
      - increases with pressure
      - decreases with water

3) Three main compositions of magma

   a) Basaltic – from partial melting in the mantle (spreading centers)
      Mafic ~50% SiO_2

   b) Andesitic – partial melting with water present (subduction zones)
      Intermediate ~60% SiO_2

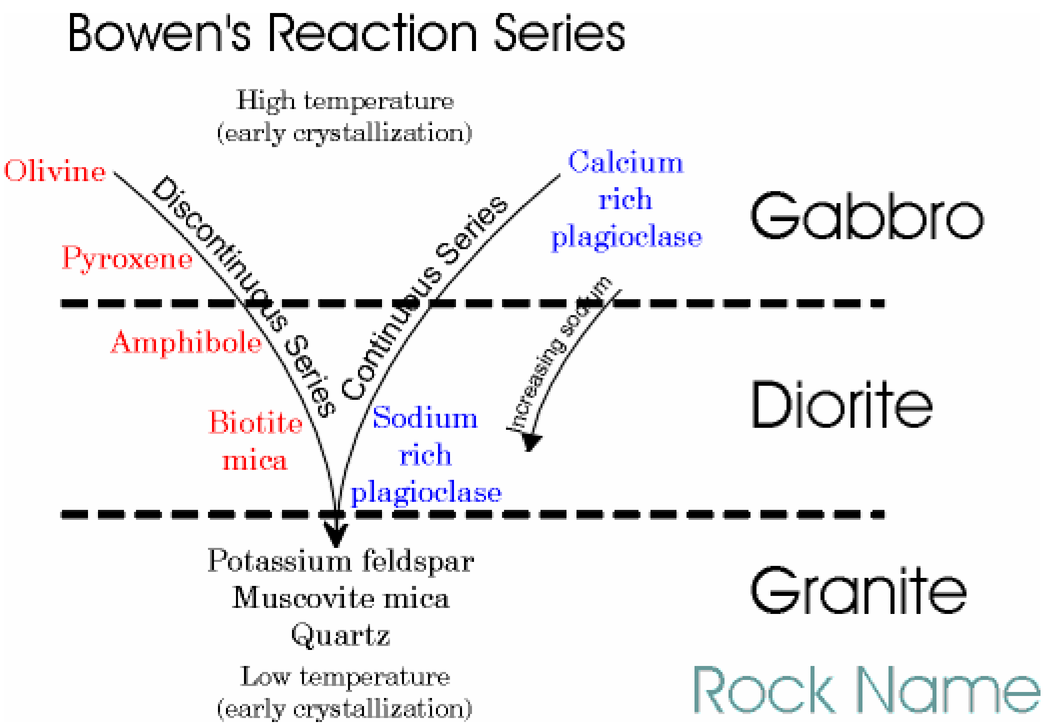
   c) Rhyolitic – melting of the continental crust w/ water present
      Silicic (felsic) ~75% SiO_2

   All contain water vapor & CO_2 (<3%)

Sequence of Crystallization

1) Minerals melt (and xlize) at different temps
   ∴ in a particular ORDER as the rock heats or cools

2) Describes in Bowen's Reaction Series (Norman L. Bowen ~1925)



   a. Shows order of crystallization as melt cools

   b. Mafic → intermediate → felsic (silicic) minerals

   c. Generally dark colored → lighter colored

   d. Continuous series (feldspars) – early xlized minerals remove atoms from the melt so composition of melt changes as cooling continues. **Zoned xls**

   e. Discontinuous series (mafic minerals) – as melt cools first xlized minerals become unstable and react with the melt to form a new minerals… Olivine → pyroxene
   :. Olivine rarely found with other minerals

3) Magmatic differentiation – Melt of one composition can produce rocks of different compositions (depending on cooling history and fractionation)

    a. unless **<u>fractionation</u>** occurs – separation of xls by:
        i. gravity differentiation – settling or floating of xls
        ii. flow segregation – remaining melt flows away leaving xls behind.

4) As minerals Xlize they intergrow

    a. Earliest growing xl larger & better formed

    b. Longer to cool = larger xls

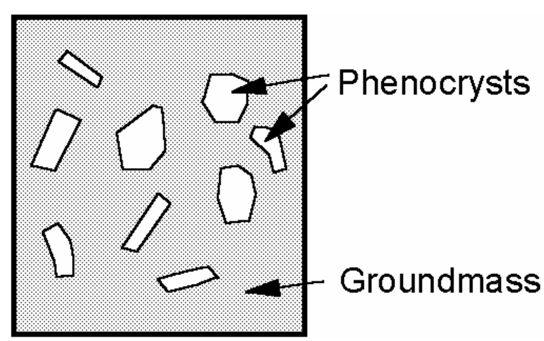
5) ∴ Can interpret "Cooling history"

    a. Very fast = glass

    b. Fast = small xls (aphanitic)

    c. Slow = lg. Xls (phaneritic)

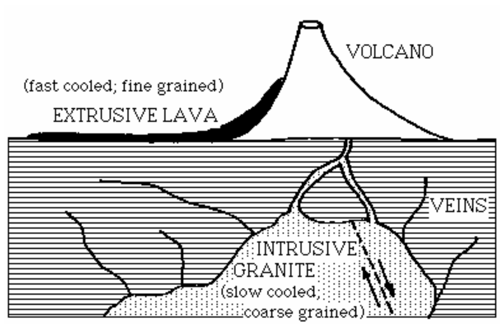
    d. Slow at first then fast = both small & lg xls (porphyritic) Phenocrysts



6) Generally

    a. Aphanitic = extrusive

    b. Phaneritic = intrusive



Identification of Igneous Rocks

1) Identified by <u>texture</u> & <u>composition</u>

   a) <u>Texture</u> -- tells you about cooling history, depth of burial, etc.

      i) **Phaneritic** – xls visible to the naked eye (Gk *phanero* = visible)
         (1) indicates slower cooling, deeper burial – time for xls to grow
         (2) intrusive (plutonic)

      ii) **Aphanitic** – xls invisible to eye but visible in microscope
         (1) indicates rapid cooling, shallow burial or at surface
         (2) extrusive (volcanic)

      iii) **Glass** – no xls (technically a very viscous liquid or "mineraloid")

      iv) **Pyroclastic** (fire – chunks) heat welded tephra (lapilli to "ash")

      v) **Seriate –** xls of all sizes

      vi) **Porphyritic** – (Gk = *purple*) larger xls (phenocrysts) in an aphanitic matrix. Indicates two phases of cooling: first phase xls form then lava erupts "freezing" the rest.

      vii) **Pegmatitic** – Huge xls (>2cm) late-stage, v. slow cooling

   b) <u>Composition</u>

      i) Range from
         (1) **felsic** (***fel***dspar & ***si***lica) [O, Si, Al, K, Na] to
         (2) **mafic** (***ma***gnesium & "***fe***rrium" (Latin for Fe)) [Fe, Ma, Ca]

      ii) Feldspars range from K → Na → Ca
         (k-spar → orthoclase → plagioclase)

Igneous Rock Chart (see Lab 4, pgs. 10 & 11)

Texture

Aphanitic	rhyolite	dacite	andesite	basalt	*komatiite (rare)*
Phaneritic	granite	granodiorite	diorite	gabbro	peridotite
	quartz K-spar some mafic	quartz Na feldspar more mafic	little quartz Na-Ca feldspar more mafic	Ca feldspar pyroxene olivine	olivine Ca feldspar

2.65 g/cm3 <----------------------------------- denser ------------------------------> 3.3g/cm3

-------------------------------more mafic (darker) --------------------------------→

600 C <------------------------------- higher xtlization temp ---------------------------------- 1300 C

←---------------------------------- More viscous ←--

Plagioclase Series

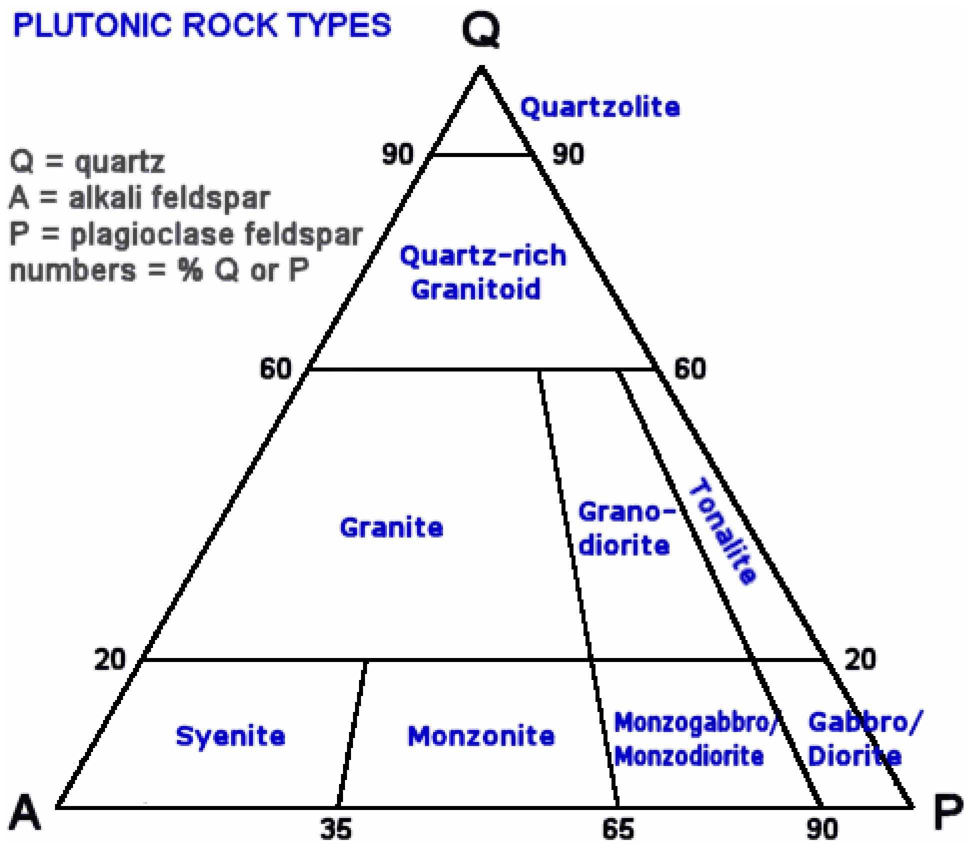
(Na,Ca)$Al_{1-2}Si_{3-2}O_8$

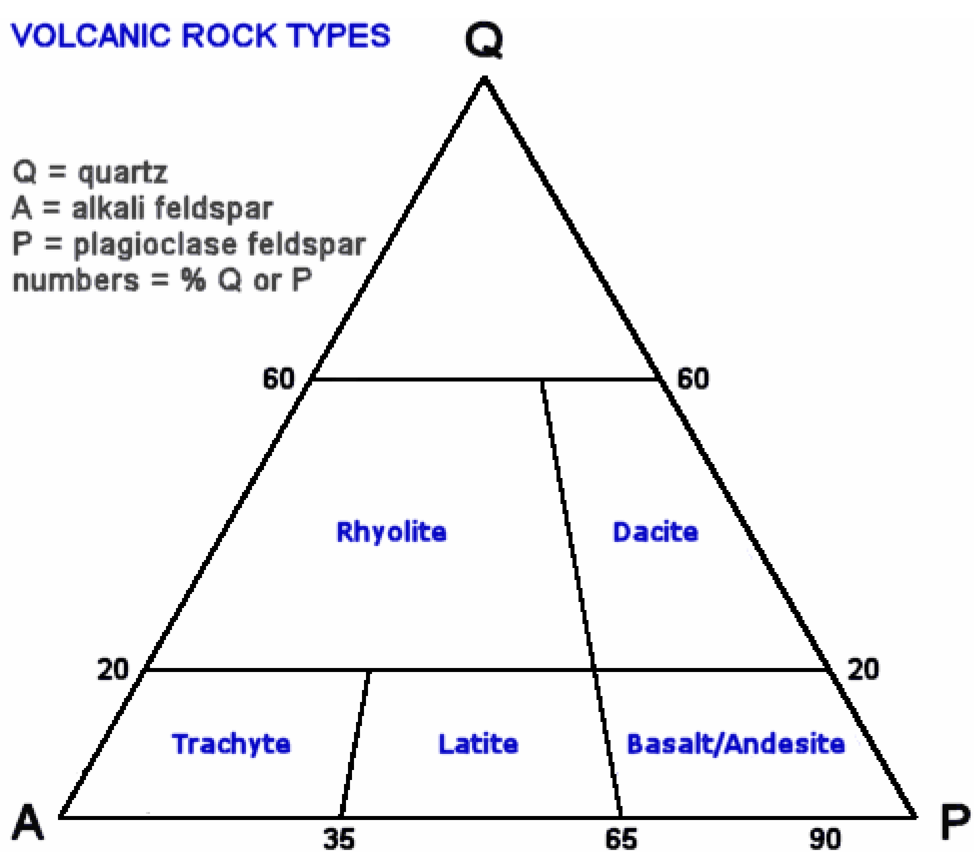
Variations in the amount of sodium and calcium; and aluminum and silicon, form different minerals in this series:

	Amount of sodium and calcium	*Percentage of Albite* (**Ab**) *and Anorthite* (**An**)
Albite	(**Na** $_{100\%}$, **Ca** $_{0\%}$) **Al Si** $_3$ **O** $_8$	90-100% **Ab** ; 0-10% **An**
Oligoclase	(**Na** $_{90\%}$, **Ca** $_{10\%}$) **Al** $_{1-2}$ **Si** $_{3-2}$ **O** $_8$	70-90% **Ab** ; 10-30% **An**
Andesine	(**Na** $_{70\%}$, **Ca** $_{30\%}$) **Al** $_{1-2}$ **Si** $_{3-2}$ **O** $_8$	50-70% **Ab** ; 30-50% **An**
Labradorite	(**Na** $_{30\%}$, **Ca** $_{70\%}$) **Al** $_{1-2}$ **Si** $_{3-2}$ **O** $_8$	30-50% **Ab** ; 70-50% **An**
Bytownite	(**Na** $_{10\%}$, **Ca** $_{90\%}$) **Al** $_{1-2}$ **Si** $_{3-2}$ **O** $_8$	10-30% **Ab** ; 70-90% **An**
Anorthite	(**Na** $_{0\%}$, **Ca** $_{100\%}$) **Al** $_2$ **Si** $_2$ **O** $_8$	0-10% **Ab** ; 90-100% **An**

Actual formula of end members are:

Albite	**Na Al Si** $_3$ **O** $_8$
Anorthite	**Ca Al** $_2$ **Si** $_2$ **O** $_8$





From: geology.about.com

Plutonism & Volcanism

Setting – Where volcanism (igneous activity) happens

1) Spreading centers -- basalt

2) Subduction zones – more silicic because down-going slap carries water to upper mantle, lowers melting point of surrounding rock and partial melting of lower temp. rx occurs.

    a) Diorite/andesite (e.g. Andes Mtns.)
    b) Granite/rhyolite

3) Hotspots

4) Extensional areas (e.g. continental rifting)

Intrusive (plutonic) structures (intrusions)

Usually intrude at > 8km depth

How intrusion works (the space problem):

1) Wedging – forces way through cracks and faults

2) Stoping – break off and consume country rock
    - Xenoliths (foreign rx) are evidence

3) Melting – melts country rock

<u>Two general categories:</u>

Concordant structures – parallel to the layers of the "country" rock

Discordant structures – cross-cut the layers of the "country" rock

All are “**plutons**”

Concordant

- Sill – tabular (sheet-like)
- Laccolith
- Loppolith

Discordant

- Dike -- tabular (sheet-like) cm’s to 100’s m across: radiating : ring
- Stock (< 100 km^2)
- Batholith (> 100 km^2) coalesced plutons over long time period
  (Ex. Sierra Nevada built over 20 my)

Volcanic Settings

~600 <u>active</u> volcanoes (many more under ocean)

~ 70% are in "ring of fire" – subduction zones

Types of volcanoes

1) Shield volcanoes

   a. Wide and low (< 5° slope) (Kiluea > 30,000 ft!)
   b. Basaltic
      i. Aa – rough blocky surface texture.
         More viscous because gas is gone
      ii. Pahoehoe – ropy, wrinkled surface texture
   c. Ex. Hawaii

2) Cinder cone

   a. Pyroclastic cone – pile of tephra (ash + lapilli)
   b. basaltic
   c. Ex. Red Hill

3) Composite (stratovolcano)

   a. Alternating layers of tephra and lava
   b. Classic cone-shape, steep sided
   c. Ex. Rainier, Shasta

4) Fissure eruption

   a. Large scale outpouring of basalt
   b. Ex. Columbia Plateau, Snake River Plain, Deccan Traps

Volcanic Hazards

1. **Volcanic Earthquakes**
   a. *Tectonic* – stress due to inflation/deflation of magma chamber
   b. *Long-period* – injection of magma into cracks
   c. Uplift, tilt, and earthquake activity are important precursors to eruption

2. **Directed Blast**
   a. Mt. St. Helens (1980) lateral blast
      i. Trees snapped 30 km away, truck overturned 26 km away
      ii. Devastated ~600 km^2

3. **Ash & Tephra**
   a. Ash fall
      i. Bishop tuff -- ~730,000 yr ago, 140mi^3 of material
         1. from Long Valley Caldera
         2. as far away a Kansas
         3. 200m thick
         4. 2,200 km^2
   b. Hazard to intake of aircraft
   c. Climate change
      i. El Chichon, Mexico – April 1982
         1. caused cooling of ~1°C for about 1 yr.
         2. Caused(?)El Niño conditions

4. **Pyroclastic flows**
   a. Cold flows (avalanches & landslides)
      i. Lahars (Indo. "mud flow") water (snow melt) & tephra
         1. 1985, Nevado del Ruiz, Armero, Columbia buried w/ ~23,000 killed
   b. Hot flows
      i. **nuée ardent** (Fr. "glowing cloud") gas & tephra
         1. up to 400 km/hr , 100 km distance
         2. example went up and over a 700 m high ridge
         3. 1902 near Mount Pelee in the town of St. Pierre, Martinique, 30,00 killed
   c. produces "welded tuff" deposit 100's m thick

5. **Lava Flows**
    a. Pahoehoe destroyed 180 homes at Kalapana 1990
    b. Attempts to divert flows – limited success in Iceland, Italy, HI, etc.
        i. 1936 -- Bombing flows from Mauna Loa to protect Hilo Dropped 20, 600-pound bombs
        ii. Lead by Lt. Col. George Patton
        iii. Flow may have stopped naturally

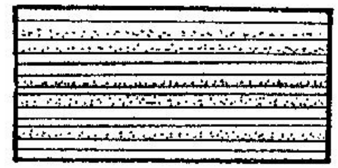
6. **Volcanic Gases**
    a. Killed the residents of Pompeii when Vesuvius erupted in 79A.D.
    b. CO_2 killing trees at Horseshoe Lake, Mammoth Lakes
    c. Kau Desert, HI – acid rain

7. **Tsunamis**
    a. Krakatoa (1883 – Sunda strait)
        i. 35m runnup
        ii. ~35,000 killed

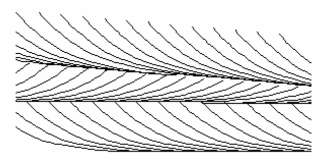
Sedimentary Structures

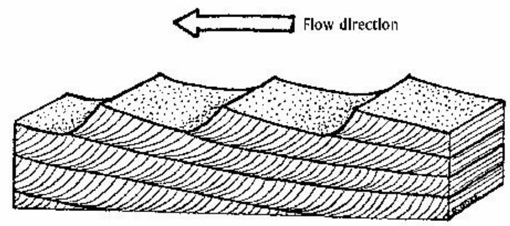
Clastic (Mechanical) Deposition

Layers (bedding, stratification) – sed. tends to be layed down in flat layers (planar bedding)



Crossbedding – dunes or beaches, beds NOT layed down in flat layers



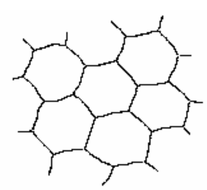


Channel fills (cut & fill) – stream channels cut and fill as river meanders in flood plane.

Ripple marks – ripples caused by currents in shallow water

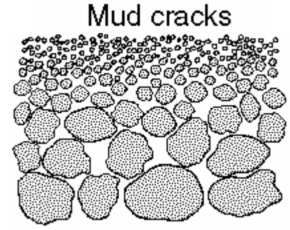
Ripple marks

Mudcracks – contraction of mud (silt & clay) in dry lake or mud flats



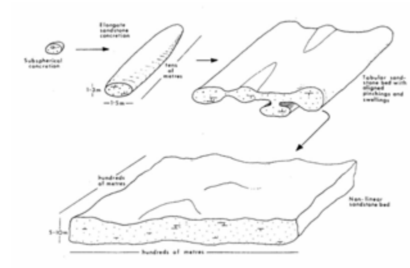
Mud cracks

Graded Bedding – ordered settling of poorly sorted sed. from a turbidity flow (water saturated avalanche of sed)



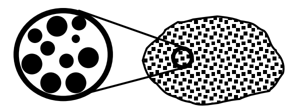
Graded Bedding

Chemical Deposition



Concretions – preferred precipitation around a fossil or mineral grain

Oolites — are small (1/4 - 2mm), concentrically layered, spherical grains composed of primary carbonate materials. Form where gentle wave action in warm waters allow carbonate precipitation on all sides of a grain of sand or shell fragment.



Evaporites — drying lake, sea, embayments.
PPT products change as water becomes more saturated with salts.

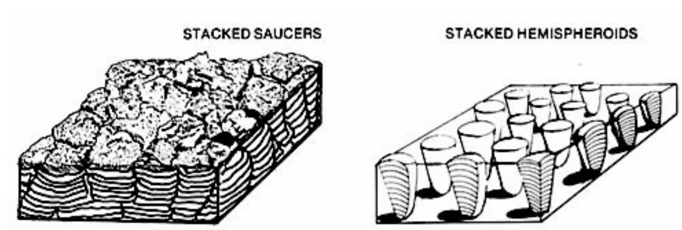
K & Mg salts
Salt
Sulphates (gypsum)
Carbonate

Biogenic

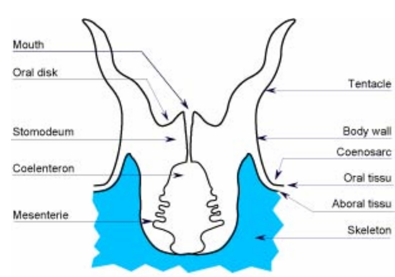
Limestone –

a) precipitation in carbonate rich shallow marine environment (perhaps aided by organisms) Removes CO_2 from the atmosphere (carbon sink).
b) Accumulation of $CaCO_3$ shells
   a. plankton – **chalk**
   b. Mussels, clams, oysters, and corals, etc. – **coquina**

Stromatolites are finely laminated algal accumulations (>10cm in diameter) that result when Cyanobacteria or blue-green algae grow upwards trapping carbonate mud into thin layers.



Reefs – massive to bedded forms built during carbonate deposition by coral polyps that precipitate calcium carbonate.



Sedimentary Rocks

1) Sediment ≡ material that has been <u>deposited</u> in layers at the Earth's surface by:
   a) mechanical transport by gravity, water, wind or ice (detrital or clastic)
   b) chemical precipitation from solution (chemical)
   c) biological production by organisms (biochemical)

2) 7% of crust by volume but 75% of surface area

3) Sed. material is derived from **weathering** (aka erosion "wx")
   ≡ mechanical or chemical breakdown of rocks at the Earth's surface

   a) **Mechanical wx** = physical disintegration of rx
      i) Thermal shattering (exp. Moon)
      ii) Frost wedging
      iii) Abrasion (rubbing)

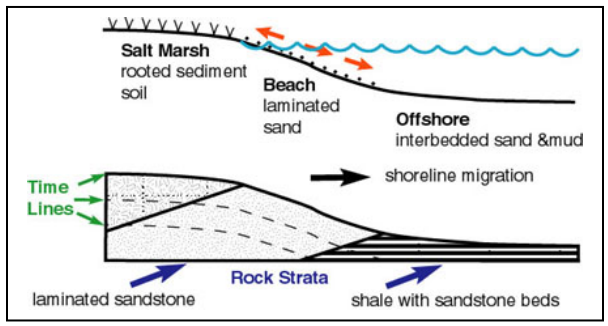
   b) **Chemical wx** = dissolving of ions in the rx

   c) **Transport** (gravity energy) causes sediment grains (clasts) to become generally:
      i) smaller
      ii) more rounded (sphericity)
      iii) better sorted
      iv) more homogeneous ("soft" minerals are lost, "resistant" minerals remain)
         (1) mafic & feldspars → silt & clay
         (2) quartz → sand

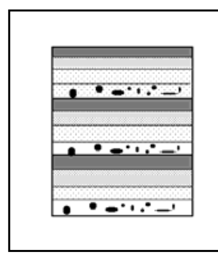
4) Deposition ≡ settling or precipitation of sed. material
   a) Rock texture & structure tell you about depositional environment (aka "**facies**")
      i) Agent
         (a) water – rivers, creeks, sheetwash, ocean currents, waves
         (b) ice – glacial till, moraine, v. poor sorting
         (c) wind – dunes: v. good sorting

      ii) Energy (high – moderate – low)
         (a) High – waves, river
         (b) Low – lagoon, deep ocean

   b) Rule of superposition of facies ≡ facies you find vertically adjacent in the stratigraphic column you find aside-by-side at the surface. Facies migration.



Facies examples:
      i) river – conglomerates, sandstones, channel fills
      ii) beaches -- mature qtz, feldspar-rich sands -- some cross bedding
      iii) continental slope – turbidites (graded bedding)
      iv) sand dune – cross bedded sandstone ("*Aeolian*")
      v) deep marine -- lithograph limestone (micrite)
      vi) evaporates – ppt. dry lake or sea



5) Lithification (diagenesis) == conversion of sed. to rock by:

   a) compaction – weight of overlying sed.
      decreases void space (can initially be 60%)

   b) cementation – ppt. in pore space
      i) calcium carbonate (calcite) $CaCO_3$
      ii) silica (quartz) SiO_2
      iii) iron oxide (limonite) Fe_2O_3

   c) recrystalization – under pressure grains
      re-xlize at points of contact

Classification of Sedimentary Rocks

(see CHART in Lab #6 page 4)

Sedimentary rock ID based on:

1) Depositional type
   a. clastic – settling of material
   b. chemical (crystalline) – ppt. of material

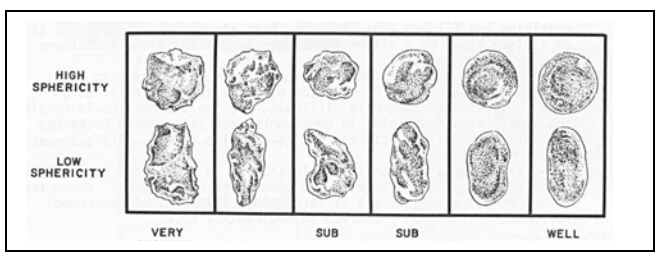
2) Mineral content (composition)

3) Texture
   a. particle size – Wentworth Scale (see Lab #6)

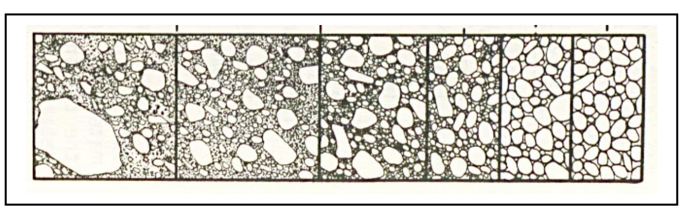
Phi Units*	Size	Wentworth Size Class	Sediment/Rock Name
-8	256 mm	Boulders	Sediment: GRAVEL Rock RUDITES: (conglomerates, breccias)
-6	64 mm	Cobbles	
-2	4 mm	Pebbles	
-1	2 mm	Granules	
0	1 mm	Very Coarse Sand	Sediment: SAND Rocks: SANDSTONES (arenites, wackes)
1	1/2 mm	Coarse Sand	
2	1/4 mm	Medium Sand	
3	1/8 mm	Fine Sand	
4	1/16 mm	Very Fine Sand	
8	1/256 mm	Silt	Sediment: MUD Rocks: LUTITES (mudrocks)
		Clay	

* Udden-Wentworth Scale

   b. rounding



   c. sorting



Common Sedimentary rock types (see CHART in Lab #6 page 4)

1) Clastic ("chunks")

- conglomerate – rounded pebbles + matrix
- breccia – angular pebbles + matrix
- quartz arenite (sandstone) – well sorted, quartz sand
- arkose – angular sand, >25% feldspar
- greywacke – arkose w/ >20% clay ("dirty sandstone")
- siltstone – silt (gritty)
- claystone – clay (not gritty)
- shale – laminated claystone

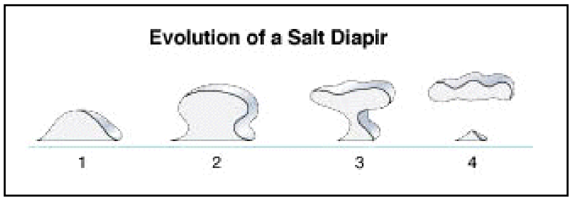
2) Biochemical (crystalline texture – ppt.)

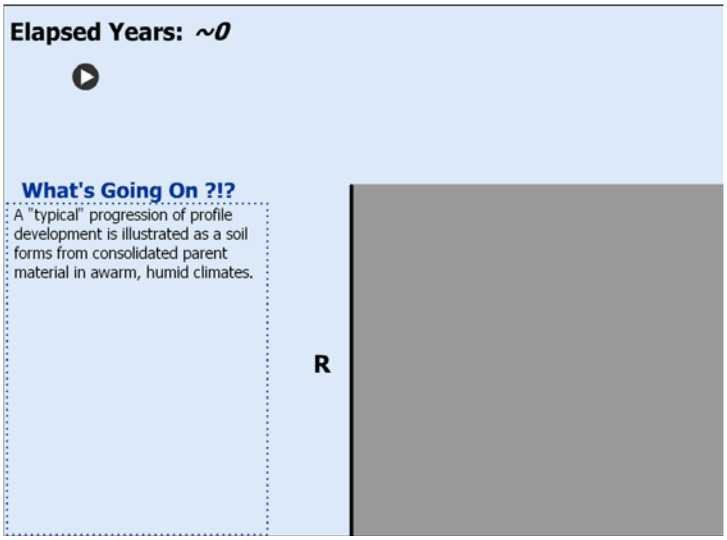
- carbonates [$CaCO_3$] – limestone (will fizz in dilute HCl)
  Types:
  - lithographic (micrite) – fine grained
  - crystalline – coarser grained
  - oolitic – tiny spheres (oolites)
  - coquina – fossiliferous

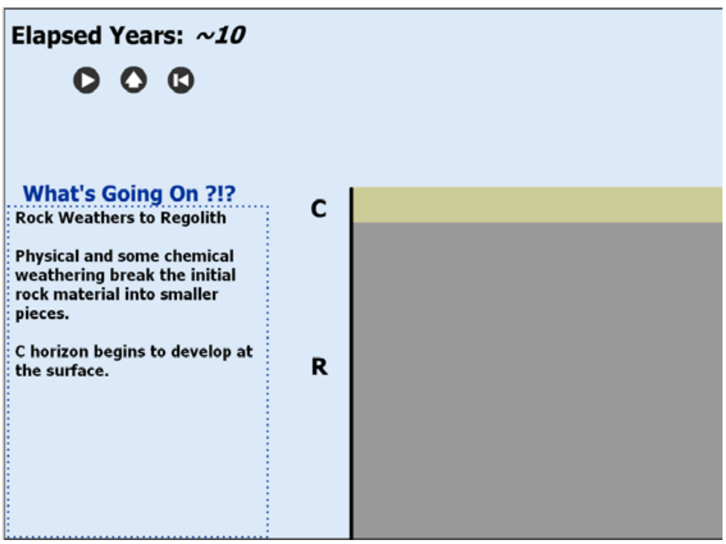
  - dolomite [$Ca(MgCO_3)_2$]– Mg from sea water, like limestone (doesn't fizz)

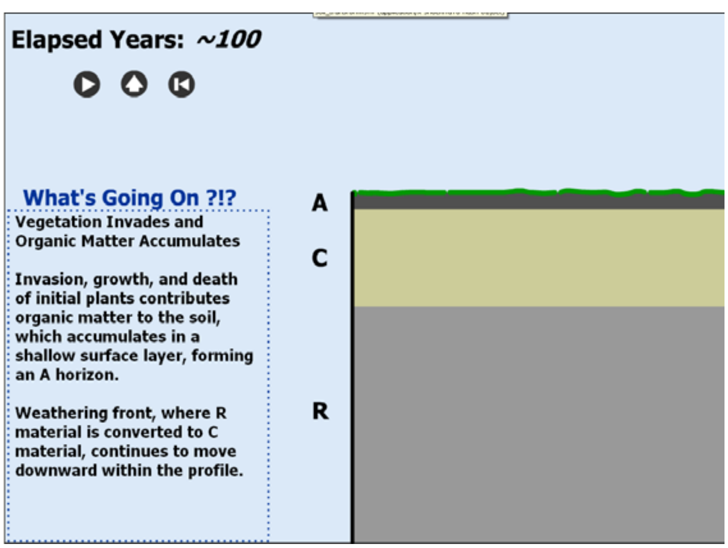
- chert -- SiO_2
  - siliceous ooze (esp. diatoms), waxy luster, conc. frac., often w/ chalk
  - chalcedony, flint, jasper

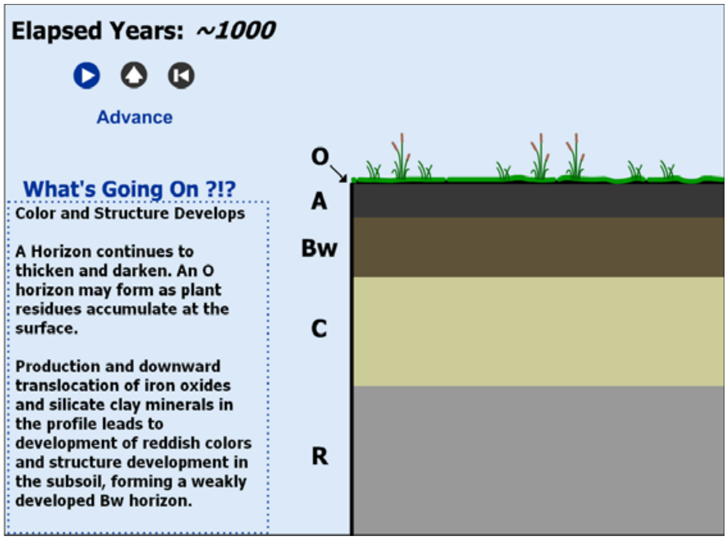
- evaporates -- drying of inland lakes and seas
  - halite – salt domes (diapers)
  - gypsum

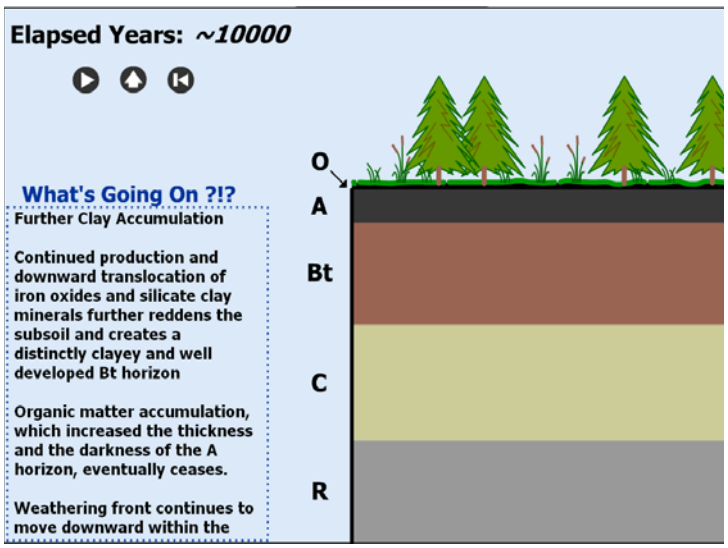


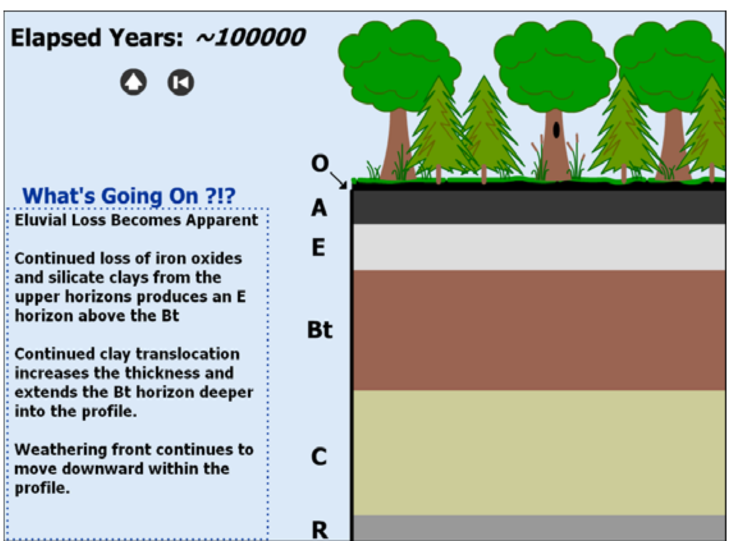

Elapsed Years: ~0
What's Going On ?!?
A "typical" progression of profile development is illustrated as a soil forms from consolidated parent material in awarm, humid climates.
R


Elapsed Years: ~10
What's Going On ?!?
Rock Weathers to Regolith
Physical and some chemical weathering break the initial rock material into smaller pieces.
C horizon begins to develop at the surface.
C
R


Elapsed Years: ~100
What's Going On ?!?
Vegetation Invades and Organic Matter Accumulates
Invasion, growth, and death of initial plants contributes organic matter to the soil, which accumulates in a shallow surface layer, forming an A horizon.
Weathering front, where R material is converted to C material, continues to move downward within the profile.
A
C
R







http://courses.soil.ncsu.edu/resources/soil_classification_genesis/soil_formation/soil_transform.swf

Weathering

Review from Sed. Rx

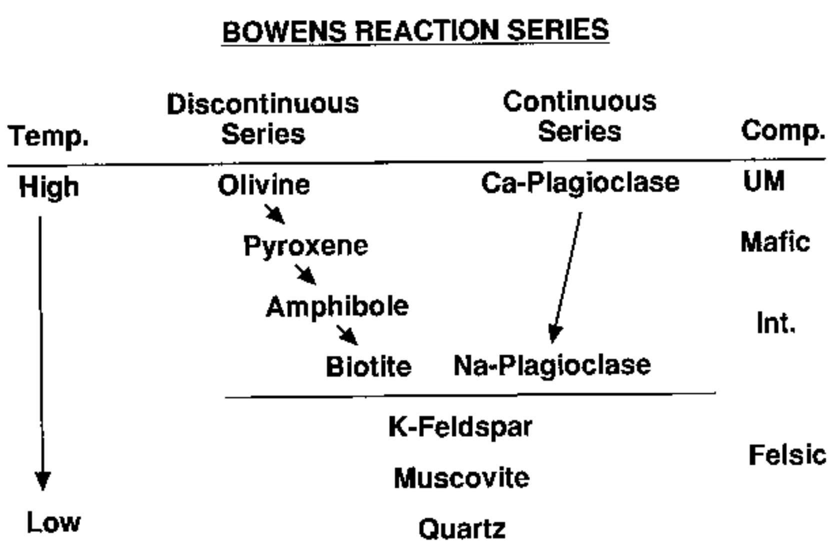
1) **Mechanical wx** = physical disintegration of rx
    a) Thermal shattering
    b) Frost wedging
    c) Abrasion (rubbing)
    d) Plants – roots, chemicals (e.g. lichen)
    e) Animal & insect burrows (*biotubation*)

2) **Chemical wx** = dissolving of ions in the rx
    a) Affects some ions :. some minerals more susceptible
        i) mafic & feldspars → silt & clay
        quartz → sand

Wx. effects –

1) sheeting – caused by relief of overburden
2) exfoliation ("outside leaf") – rounding off of edges, curved sheets
    a. domes (Ex. Half Dome)
    b. slabs a danger to climbers
3) spheroidal wx – as above but operates on all sides of isolated boulders

Minerals Wx. in same order they xlize in Bowen's Reaction Series



(anorthite)

(hornblende)

(albite)

Soil Formation

Regolith == whole surface covered by wx products (sed.)

Soil == sed. with organic matter that can support vegitation
(There's no such thing as "dirt")

The Soil Profile

- Formed over long time (~10,000yrs)
- Grow deeper with time (as underlying bedrock "decays")

Horizon	Notes
O horizon – organic,decomposed veg.	• Loam, humus
A horizon – leached layer	• "Top soil", "plow layer" ~20 cm • leached = ions and clays removed • dark in color
B horizon – enriched layer	• ions and clay from above • hardpan, subsoil
C horizon – partially wx. bedrock	• saprolite (rotten rock)
	• bedrock • "parent material"

Soil Types – depends on:

1) climate
2) parent material
3) age
4) organic matter
5) slope (tendency to erode)

Types

1) laterite
    a. wet tropics, rain forests
    b. intense leaching (even SiO_2)
    c. leaves Fe, Al, oxides (bauxite)
    d. brick red
    e. lousy farmland, nutrient poor

2) pedalfer (Greek *pedon* = soil; "alfe" = Al Fe)
    a. These soils are rich in Al and Fe.
    b. They form in humid climates (>64 cm/yr), forests
    c. southeastern U.S.

3) pedocal ("cal" = calcium)
    a. rich in Ca.
    b. form in arid climates (< 64 cm/yr) e.g. southwestern U.S.
    c. where evap. rate is high contain **caliches** (or hardpan), a calcium carbonate deposit which accumulates in the soil
    d. southwestern U.S.

4) podzol (Russian = "under ashes") (podzolization)
    a. subarctic pine forests (U.S. Canada, Eurasia)
    b. pine needles makes percolating water acidic
    c. removes metallic cations (Na, Ca, K, Mg, Al, Fe) from A-horizon
    d. leaching of clays to B-horizon
    e. color banded red, yellow or black over gray.

Metamorphic Rocks

<u>Metamorphism</u> ("change form") == solid state change in rock structure and mineralogy caused by heat, pressure, or chemically active fluids.

- Higher T & P than lithification
- **New minerals** form by solid-state recrystallization
- **No change to bulk composition** (same atoms present)
- like cooking – NO MELTING

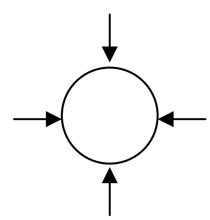
<u>Heat</u> (150°C – 900°C)

- Geothermal Gradient -Temp. change w/ depth = 15° – 30°C / km [30°C / km * 30km = **900°C**]
- Cause chemical reactions – atoms move, recombine, bonds break and reform.
- Weakens xls and allows plastic flow

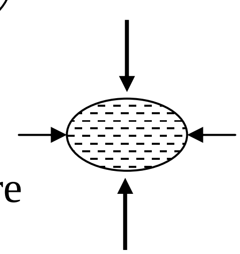
<u>Pressure</u> (up to 10,000 atms. (10 kilobars))

- Pressure Gradient – change w/ depth = ~ 250 bars/km
- 5km – 35km depth [250 bars/km * 35km = 9 kbar)
- caused by burial & tectonic stress
- recrystallization into closer packing order "high pressure minerals" (polymorphs)

- Lithostatic stress – burial, equal in all directions



- Differential stress – maximum compressive stress
    - "uneven" stress causes folds and foliation (layers)
    - platy mineral xls grow in direction of lower pressure :. foliation



<u>Fluids</u>

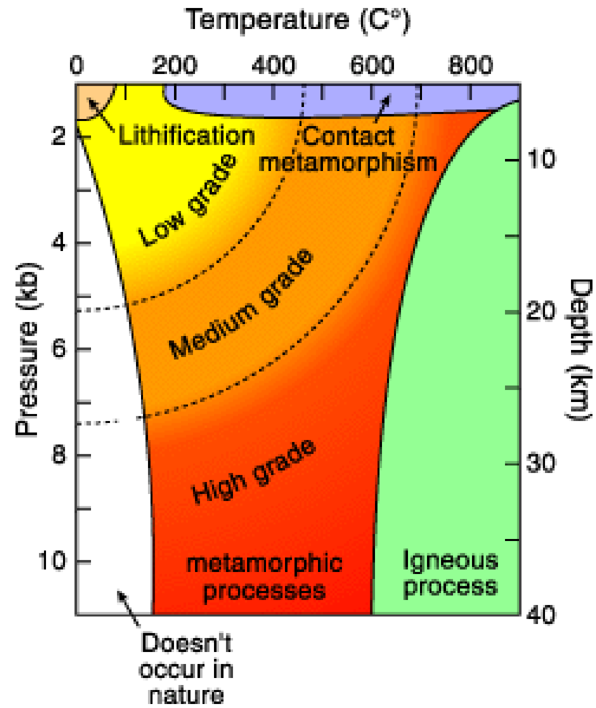
- Hot water (also: CO_2, oil & methane)
    - Dissolve ions,
    - Transport ions from high pressure to low pressure (km's)

- Origin: water in buried sed., dehydration of minerals, magmatic intrusion

Metamorphic Grade

== intensity of metamorphism: how high the T & P

- Low grade – lower T & P
- High grade – higher T & P
- higher grade = more changed



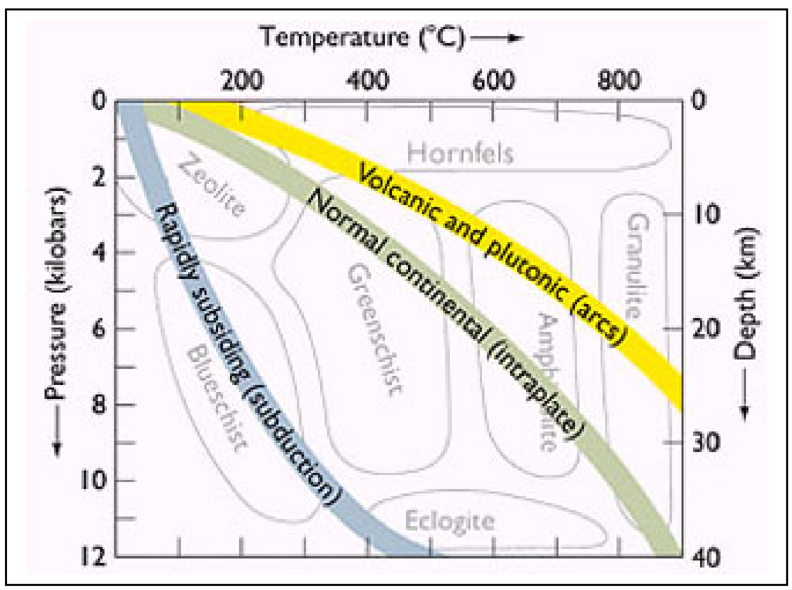
Particular minerals exist under particular T

- High & low pressure or temp. miner
- ∴ some <u>combinations</u> of minerals ar
- minerals present tell of max. T & P conditions
- areas can show bands of meta zones or ***facies*** (fig. 9.21, pg 263)

<-- Increasing Grade –

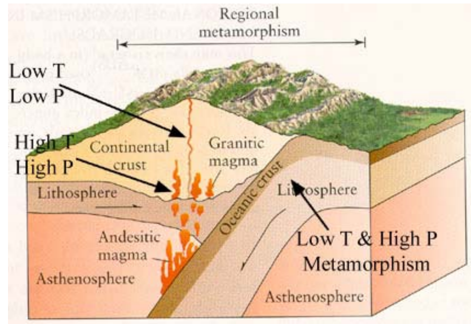
Index Minerals

chlorite
muscovite
biotite
garnet
staurolite
kyanite
sillimanite

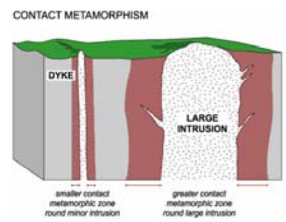


Types of metamorphism (settings)

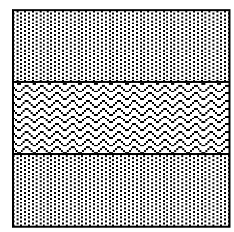
1) regional ("Barrovian") (baking) – most common
    a. compressive stress due to:
        i. burial (lithostatic)
        ii. plate tectonic stress (differential)
            1. behind subduction zones
            2. continental collisions
    b. large scale, over 1,000's of kms
    c. often with belts of differing grades



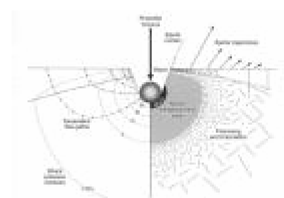
2) contact (frying)
    a. country rock around intrusions



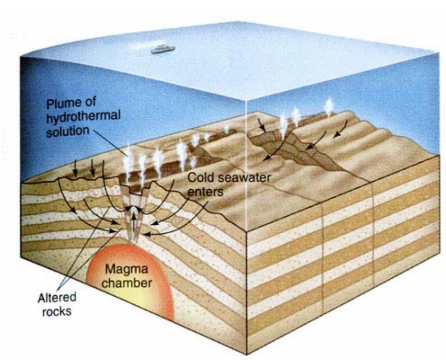
3) shear
    a. ground rock under high pressure in shear zone of fault
    b. slickensides – polished striated surface
    c. cataclastic texture
        i. shallow = fault breccia (*cataclasite*)
        ii. deep = *mylonite*



4) shock
    a. meteor impacts
    b. stishovite (High-P quartz) only here (and deep)
    c. KT boundary enriched with microtektites? (*Chicxulub*)



5) hydrothermal alteration
    a. mid-ocean ridges, hot springs
    b. economic mineral deposits Cu, Au, Pb, Zn



Identification of Metamorphic Rocks (Lab #7)

Based on….

- texture – most important (foliated vs. nonfoliated)
- mineral content (grade of minerals, index minerals)

Foliated rx (L “*leaf*” folio) (**not** the same as bedding)

- Foliation perpendicular to greatest stress direction
  also perpendicular to fold axies (“schistosity”)

Examples:

<-- Increasing Grade -

- **slate** – fine grained, platy minerals (mica) align, form planes of weakness
- **phyllite** – imperfect slatey cleavage w/ shiny mica “sheen”
- **schist** – coarser grained, bigger xl, >50% platy minerals (mica), *shiny*, some mineral segregation (dark/light layers)
- **gneiss** – mineral segregation, banded some times w/ phorphyroblasts “augen” *eyes*, doesn’t split
- **migmatite** – (“mixed”) partial melting of qz & feldspar, cross between gneiss & granite

Nonfoliated rx (generally equigranular)

<-- Increasing Grade -

- **skarn** – calcite + garnet, pyroxene, etc. Contact meta. (lmstone)
- **quartzite** – massive, fine grained sugary texture, from sandstone
- **marble** – light colored, granular, from limestone (will fizz)
- **hornfels** – v. fine xls, contact meta., like slate without foliation
- **granulite** – pyroxene & garnet
- **amphibolite** – interlocking hornblende (amphibole) xls

Generally higher grade = coarser grained (more xl growth)
Names modified by predominant minerals

1. garnet gneiss
2. muscovite schist

Table of geologic time

International Commission on Stratigraphy

http://en.wikipedia.org/wiki/Geologic_time_scale

Eon	Era	Period[1]	Series/ Epoch	Major Events	Start, Million Years Ago[2]
Phane-rozoic	Cenozoic	Neogene[3]	Holocene	End of recent glaciation and rise of modern civilization	0.011430 ± 0.00013 [9]
			Pleistocene	Flourishing and then extinction of many large mammals (Pleistocene megafauna); Evolution of fully modern humans	1.806 ± 0.005 *
			Pliocene	Intensification of present ice age. Cool and dry climate; Australopithecines appear, many of the existing genera of mammals, and recent molluscs appear	5.332 ± 0.005 *
			Miocene	Moderate climate; Mountain building in northern hemisphere; Modern mammal and bird families became recognizable. Horses and mastodonts diverse. Grasses become ubiquitous. First hominoids appear.	23.03 ± 0.05 *
		Paleogene[3]	Oligocene	Warm climate; Rapid evolution and diversification of fauna, especially mammals. Major evolution and dispersal of modern types of angiosperms	33.9±0.1 *
			Eocene	Archaic mammals (e.g. Creodonts, Condylarths, Uintatheres, etc) flourish and continue to develop during the epoch. Appearance of several "modern" mammal families. Primitive whales diversify. First grasses. Reglaciation of Antarctica; start of current ice age.	55.8±0.2 *
			Paleocene	Climate tropical. Modern plants; Mammals diversify into a number of primitive lineages following the extinction of the dinosaurs. First large mammals (up to bear or small hippo size)	65.5±0.3 *
	Mesozoic	Cretaceous	Upper/Late	Flowering plants appear, along with new types of insects. More modern teleost fish begin to appear. Ammonites, belemnites, rudists, echinoids and sponges all common. Many new types of dinosaurs (e.g. Tyrannosaurs, Titanosaurs, duck bills, and horned dinosaurs) evolve on land, as do modern crocodilians; and mosasaurs and modern sharks appear in the sea. Primitive birds gradually replace pterosaurs. Monotremes, marsupials and placental	99.6±0.9 *
			Lower/Early		145.5 ± 4.0

				mammals appear. Break up of Gondwana.	
		Jurassic	Upper/Late	Gymnosperms (especially conifers, Bennettitales and cycads) and ferns common. Many types of dinosaurs, such as sauropods, carnosaurs, and stegosaurs. Mammals common but small. First birds and lizards. Ichthyosaurs and plesiosaurs diverse. Bivalves, Ammonites and belemnites abundant. Echinoids very common, also crinoids, starfish, sponges, and terebratulid and rhynchonellid brachiopods. Breakup of Pangea into Gondwana and Laurasia.	161.2 ± 4.0
			Middle		175.6 ± 2.0 *
			Lower/Early		199.6 ± 0.6
		Triassic	Upper/Late	Archosaurs dominant and diverse on land, include many large forms; cynodonts become smaller and more mammal-like. First dinosaurs, mammals, pterosaurs, and crocodilia. Dicrodium flora common on land. Many large aquatic temnospondyl amphibians. Ichthyosaurs and nothosaurs common in the seas. Ceratite ammonoids extremely common. Modern corals and teleost fish appear.	228.0 ± 2.0
			Middle		245.0 ± 1.5
			Lower/Early		251.0 ± 0.4 *
	Paleozoic	Permian	Lopingian	Landmass unites in the supercontinent of Pangea. Synapsid reptiles become common (Pelycosaurs and Therapsids), parareptiles and temnospondyl amphibians also remain common. Carboniferous flora replaced by gymnosperms in the middle of the period. Beetles and flies evolve. Marine life flourishes in the warm shallow reefs. Productid and spiriferid brachiopods, bivalves, foraminifera, and ammonoids all abundant. End of Permo-carboniferous ice age. At the end of the period the Permian extinction event- 95% of life on Earth becomes extinct	260.4 ± 0.7 *
			Guadalupian		270.6 ± 0.7 *
			Cisuralian		299.0 ± 0.8 *
		Carbon-iferous[4] / Pennsyl-vanian	Upper/Late	Winged insects appear and are abundant, some growing to large size. Amphibians common and diverse. First reptiles, coal forests (Lepidodendron, Sigillaria, Calamites, Cordaites, etc), very high atmospheric oxygen content. In the seas, Goniatites, brachiopods, bryozoa, bivalves, corals, etc all common.	306.5 ± 1.0
			Middle		311.7 ± 1.1
			Lower/Early		318.1 ± 1.3 *
		Carbon-iferous[4] / Missis-sippian	Upper/Late	Large primitive trees, first land vertebrates, brackish water and amphibious eurypterids; rhizodonts dominant fresh-water predators. In the seas primitive sharks common and very diverse, echinoderms (especially crinoids and blastoids) abundant, Corals, bryozoa, and and brachiopods (Productida, Spriferida, etc) very	326.4 ± 1.6
			Middle		345.3 ± 2.1
			Lower/Early		359.2 ± 2.5 *

				common; Goniatites common, trilobites and nautiloids in decline. Glaciation in East Gondwana.	
		Devonian	Upper/Late	First clubmosses and horsetails appear, progymnosperms (first seed bearing plants) appear, first trees (Archaeopteris). In the sea strophomenid and atrypid brachiopods, rugose and tabulate corals, and crinoids are abundant. Goniatite ammonoids are common, and coleoids appear. Trilobites reduced in numbers. Ostracoderms decline; Jawed fish (Placoderms, lobe-finned and ray-finned fish, and early sharks) important life in the sea. First amphibians (but still aquatic). "Old Red Continent" (Euramerica)	385.3 ± 2.6 *
			Middle		397.5 ± 2.7 *
			Lower/Early		416.0 ± 2.8 *
		Silurian	Pridoli	First vascular land plants, millipedes and arthropleurids, first jawed fish, as well as many types of armoured jawless forms. sea-scorpions reach large size. tabulate and rugose corals, brachiopods (Pentamerida, Rhynchonellida, etc), and crinoids all abundant; trilobites and molluscs diverse. Graptolites not as varied.	418.7 ± 2.7 *
			Ludlow		422.9 ± 2.5 *
			Wenlock		428.2 ± 2.3 *
			Llandovery		443.7 ± 1.5 *
		Ordovician	Upper/Late	Invertebrates very diverse and include many new types. Early corals, Brachiopods (Orthida, Strophomenida, etc), bivalves, nautiloids, trilobites, ostracods, bryozoa, many types of echinoderms (cystoids, crinoids, starfish, etc), branched graptolites, and other taxa all common. Conodonts were primitive planktonic vertebrates that appear at the start of the Ordovician. Ice age at the end of the period. First very primitive land plants.	460.9 ± 1.6 *
			Middle		471.8 ± 1.6
			Lower/Early		488.3 ± 1.7 *
		Cambrian	Furongian	Major diversification of life in the Cambrian Explosion; more than half of modern animal phyla appear, along with a number of extinct and problematic forms. Archeocyatha abundant in the early Cambrian. Trilobites, Priapulida, sponges, inarticulate brachiopods, and many other forms all common. First chordates appear. anomalocarids are top predators. Edicarian animals rare, then die out.	501.0 ± 2.0 *
			Middle		513.0 ± 2.0
			Lower/Early		542.0 ± 1.0 *
Proter-ozoic [5]	Neo-proterozoic	Ediacaran	First multi-celled animals. Edicarian fauna (vendobionta) flourish worldwide. Simple trace fossils from worm-like animals. First sponges.		630 +5/-30 *
		Cryogenian	Possible snowball Earth period, Rodinia begins to break up		850 [6]

		Tonian	First acritarch radiation	1000 [6]
	Meso-proterozoic	Stenian	Narrow highly metamorphic belts due to orogeny as Rodinia formed.	1200 [6]
		Ectasian	Platform covers continue to expand	1400 [6]
		Calymmian	Platform covers expand	1600 [6]
	Paleo-proterozoic	Statherian	First complex single-celled life. Columbia (supercontinent).	1800 [6]
		Orosirian	Atmosphere became oxygenic. Vredefort and Sudbury Basin asteroid impacts. Much orogeny.	2050 [6]
		Rhyacian	Bushveld Formation formed. Huronian glaciation.	2300 [6]
		Siderian	banded iron formations formed	2500 [6]
Archean [5]	Neoarchean		Stabilization of most modern cratons, possible mantle overturn event	2800 [6]
	Mesoarchean		First stromatolites	3200 [6]
	Paleoarchean		First known oxygen producing bacteria	3600 [6]
	Eoarchean		Simple single-celled life	3800
Hadean [5,7]	Lower Imbrian			c.3850
	Nectarian			c.3920
	Basin groups		4100 MYA - Oldest known rock	c.4150
	Cryptic[8]		4400 MYA - Oldest known mineral; 4570 MYA - Formation of Earth	c.4570

1. Paleontologists often refer to faunal stages rather than geologic periods. The stage nomenclature is quite complex. See Harland for an excellent time ordered list of faunal stages.
2. Dates are slightly uncertain with differences of a few percent between various sources being common. This is largely due to uncertainties in radiometric dating and the problem that deposits suitable for radiometric dating seldom occur exactly at the places in the geologic column where they would be most useful. The dates and errors quoted above are according to the International Commission on Stratigraphy 2004 time scale. Dates labeled with a * indicate boundaries where a Global Boundary Stratotype Section and Point has been internationally agreed upon.
3. Historically, the Cenozoic has been divided up into the Quaternary and Tertiary sub-eras, as well as the Neogene and Paleogene periods. However, the International Commission on Stratigraphy has recently decided to stop endorsing the terms Quaternary and Tertiary as part of the formal nomenclature.
4. In North America, the Carboniferous is subdivided into Mississippian and Pennsylvanian Periods.
5. The Proterozoic, Archean and Hadean are often collectively referred to as Precambrian Time, and sometimes also as the Cryptozoic.
6. Defined by absolute age (Global Standard Stratigraphic Age).
7. Though commonly used, the Hadean is not a formal eon and no lower bound for the Eoarchean has been agreed upon. The Hadean has also sometimes been called the Priscoan.
8. These four era names were taken from Moon geology. Their use for Earth geology is unofficial.
9. The start time for the Holocene epoch is here given as 11,430 years ago ± 130 years. For further discussion of the dating of this epoch, see Holocene.

Geologic Time

Early ideas…

Catastrophism – Earth formed by sudden unique events.

- Creation
- Noah's flood
- Ussher chronology – Earth 6,000 yrs old. (4004 bc)

James Hutton , Scottish doctor, farmer, chemist, natural philosopher (1726-1797) Text convoluted, popularized by his friend John Playfair, post mortem.

Uniformitarianism (Gradualism) = "the present is the key to the past."

- Earth was formed by processes we see active today.
  - erosion of mountains
  - isostatic uplift and subsidence
  - deposition of sedimentary layers
- Indicates great age.

Strict uniformitarianism hindered acceptance of plate tectonics.

Now we believe but both are true. Examples of catastrophes:

- Formation of Earth
- Density segregation of Earth ("iron catastrophe")
- Formation of moon (probably by meteor impact)
- Mass extinctions ~9 (e.g. K-T impact, 65ma, 25% of animal families)
- Earthquakes & volcanoes

Principles of Stratigraphy

Used to establish relative ages (order) and geologic history.

1) **Original horizontality** = sediments are deposited in approx. horizontal beds.
2) **Superposition** = upper beds are younger, lower older
3) **Cross cutting relationships** = intrusion or fault is younger than the rock it intrudes or offsets.

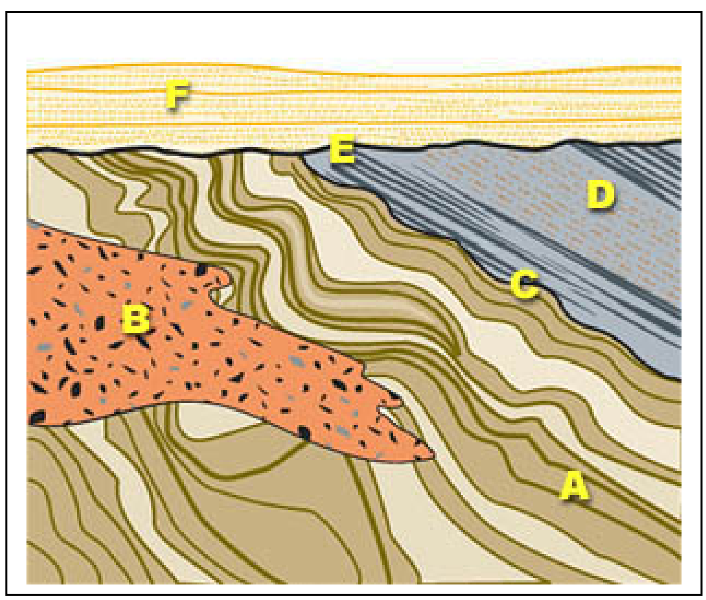
But… sedimentation is not uniform or continuous

Unconformity – time gap in the stratigraphic sequence:

1) **angular unconformity**
   layers above and below are not parallel (eroded surface)
2) **disconformity**
   gap in time between parallel sedimentary layers (hard to see)
3) **nonconformity**
   sediment on erosion surface of metamorphic or igneous rx

Cross cutting relationships
= intrusion or fault is younger than the rock it intrudes or offsets.

Inclusions older



Stratigraphic Column

Formation = distinctive sequence of layers that can be recognized and mapped. Usu. similar rock type or fossil assemblage.

Correlation = matching formations from one area to another.
(Can be lateral changes in lithology and thickness.)

- continuity – they connect
- similarity – same sequence, marker beds

Gotchas

Transgressive & regressive sequences

Faunal Succession (Wm. Smith)
= fossils appear and disappear in a definite order.

Index fossils = fossil with wide range but short duration.
Rock band analogy – Grateful Dead vs. Hanson

Geologic Time Scale

- Based on piecing together stratigraphic columns worldwide.
- Big divisions based on change in fossil sequences :. match mass extinctions (probably caused by big climate changes)

End of…	Marine invert species killed
Ordovician	22%
Devonian	21%
Permian	57%
Triassic	20%
K-T	15%

Smaller mass extinctions at end of: Precambrian, Cambrian, Eocene, Pleistocene.

Absolute Geologic Time

Early attempts to date the earth:

- Salinity of oceans
- Rate of erosion
- Cooling of the earth

Radiometric Dating

Radioactivity discovered in 1896 (Becquerel & Curie)

Ernest Rutherford (1905) suggested using radioactive decay to date rx

Radioactive decay

- Some elements have radioactive isotopes (# of neutrons)
- spontaneously decay over time of *parent element* to a stable *daughter element*
    - Ex. K^{40} --> Ar^{40} (neutron = proton + electron[β-particle])
- random for each atom but **average** is constant for each element (analogy: people live to diff. ages but avg. ~78)
- not affected by T, P, or chemistry (unless contaminated, leaks)
- when igneous or metamorphic rock xlizes the clock starts running (hard with sed. rx)
- each isotope has a different half-life

Half-life = time for half of the parent to decay.
:. ratio of parent/daughter element yields the age.

1 ½ ¼ 1/8 1/16 1/32 1/62 1/128 1/256

Parent Isotope	Daughter	Half-life	Range
Rb^{87}	Sr^{87}	47 by	10my – 4.6by
U^{238}	Pb^{206}	4.5 by	“
K^{40}	Ar^{40}	1.3 by	50,000 – 4.6by
C^{14}	C^{14}	5730	100 – 70,000

:. Can put absolute ages on the geologic time scale

Structural Geology (Rock Deformation)

<u>Stress & Strain</u>

Stress == force (per unit area) on rock
Strain == response of rock (change in shape or volume, deformation)

Compression Tension Shear

<u>Types of Strain (response to stress)</u>

- Elastic – reversible, will "spring" back if elastic limit is not exceeded (Ex: rubber band, seismic waves thru rock)

- Ductile (plastic) – flows, deformation is permanent (no loss of cohesion) → folds (Ex: pipe cleaner, wire)

- Brittle – breaks, fractures (loss of cohesion)→ faults

Response of rx depends on…

1. Rock type (rigidity)

2. Temperature ($\propto$ depth)

3. Confining pressure (lithostatic pressure) :. $\propto$ depth

4. Rate of deformation (silly putty example)

5. Presence of water – wet rx more ductile

Earthquakes only in shallow crust where brittle fracture is possible.

Brittle Shear

No deformation brittle deformation ductile deformation

Maximum shear stress is at 45° angle.

Rock's "angle of internal friction" makes fractures closer to 30° / 60°.

:. Joints and faults indicate the direction of maximum compressive stress.

Faults (again)

Strike-slip

Normal

Reverse

Thrust

Blind Thrust

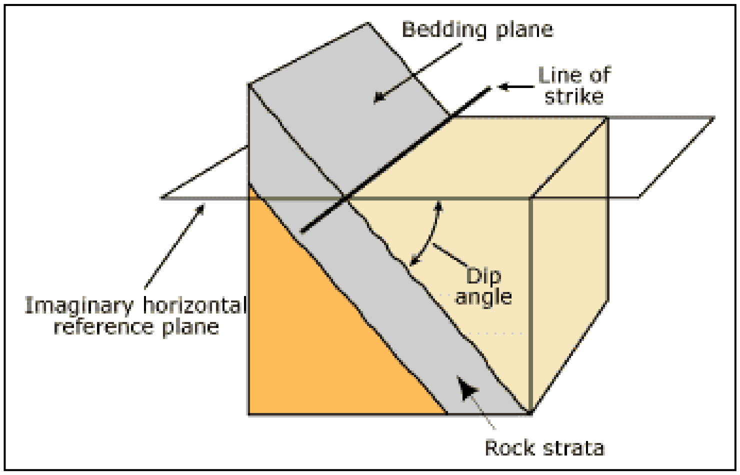
Detachment

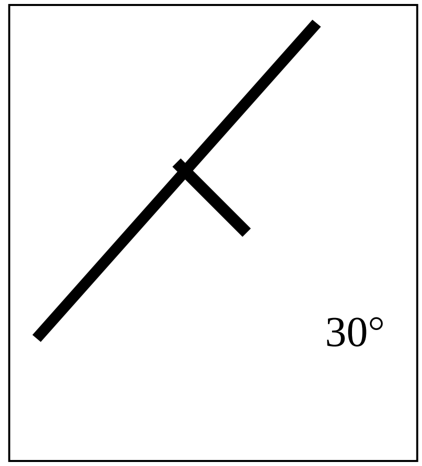
Footwall – the wall underfoot
Hanging wall – the wall "overhead"

Horst & graben (series of normal faults) Basin & Range

Thrust belts

Description of planar features (beds, faults, joints, etc.)





Description of folds (limbs, axial plane)

Anticline

Syncline

Monocline

Overturned

Recumbant

Plunging folds

Dome & Basin

Earth Resources

Virtually everything you consume depends on earth resources.

<u>Catagories</u>

1. Energy
   a. Oil & gas (H + C :. Hydrocarbons) } Fossil Fuels
   b. Coal (carbonized plant matter) } Fossil Fuels
   c. Uranium ^{235}U (*pitchblende, carnotite*)
   d. Geothermal (renewable)

2. Mineral
   a. Metals – Cu, Fe, Al, Au, etc.
   b. Non-metallic
      i. Sand & gravel
      ii. Cement (limestone)
      iii. Gems, abrasives, fertilizers, salt, chemicals, etc.

3. Not generally included
   a. Water
   b. Soil

Earth resources are generally NONRENEWABLE

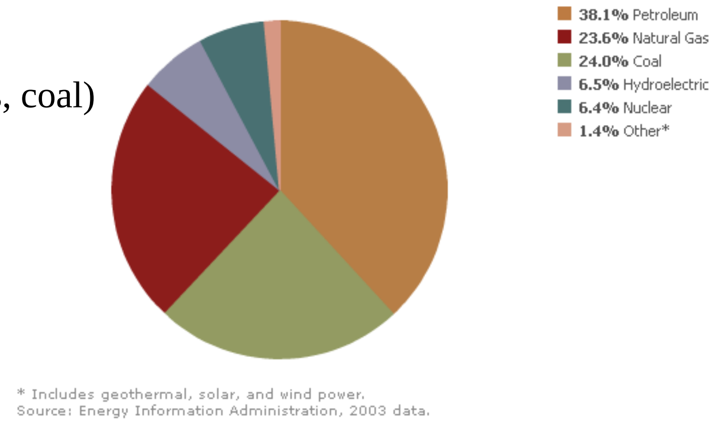
<u>Reserves</u> = amount of a resource that is <u>known</u> to exist (discovered) and can be economically used.

<u>Resources</u> = amount of a resource that is <u>estimated</u> to exist. Includes future discoveries and currently non-economic deposits.

Resources >> reserves

Energy Resources

World Energy Production



1. Non-renewable
    a. Fossil fuels (oil, gas, coal)
    b. Uranium (nuclear)

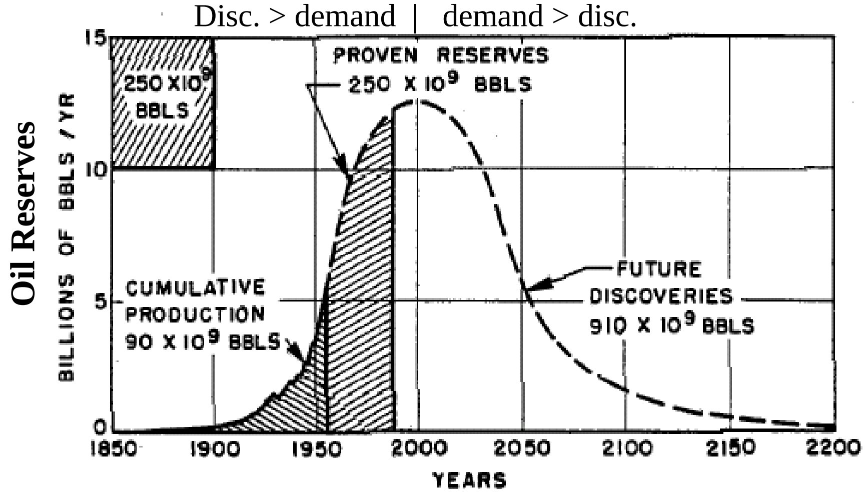
2. Renewable
    a. Hydro
    b. Solar
    c. Wind
    d. Wave & Tide
    e. Biomass

Petroleum (Oil)

Remember: reserves << resources – calculation is controversial

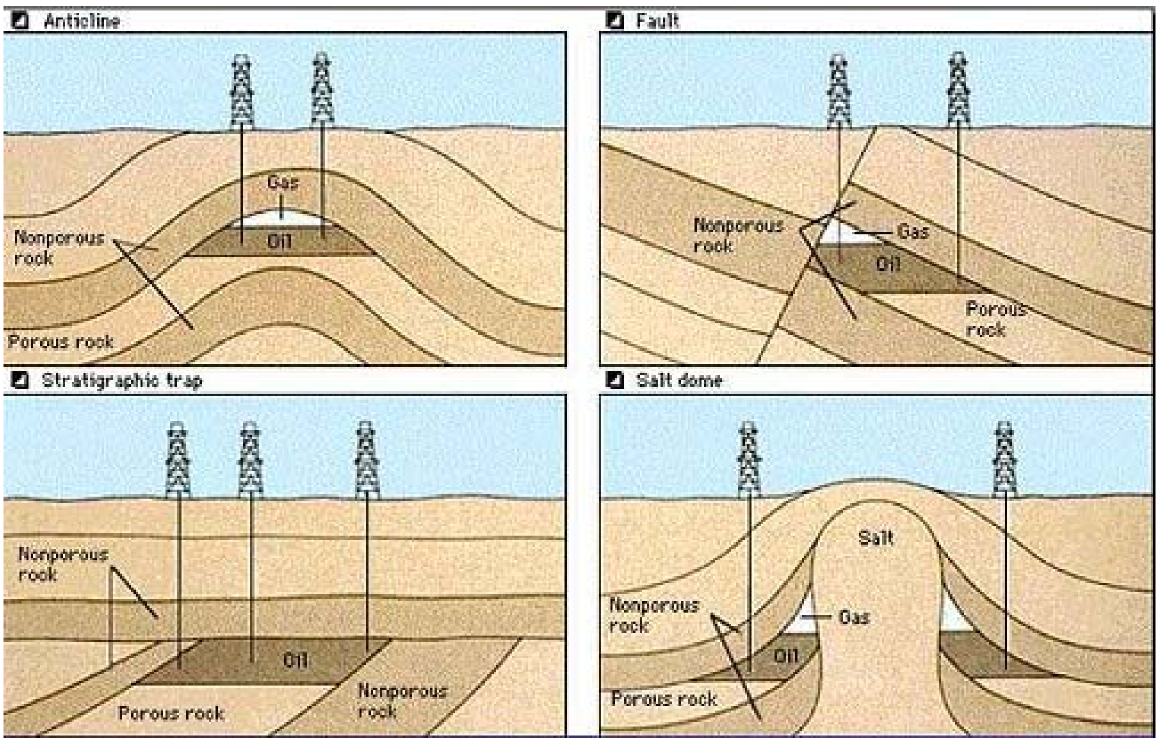
- World consumes
    - 81 Mbbl/day, 30 Gbbl/year
- U.S. consumes
    - 20 Mbbl/day, 7.3 Gbbl/year (24%)
    - 60% of our oil is imported (~16% from Canada)
    - 200 gigabarrels (31 km^3) 1859 and 1968
- Estimated reserves – Hubbert Curve
    - Discovery < increase in demand :. Reserve decreasing
    - "outgo" > "income" :. Spending "savings"
    - Will still last ~100 year

Disc. > demand | demand > disc.



Geology of Petroleum

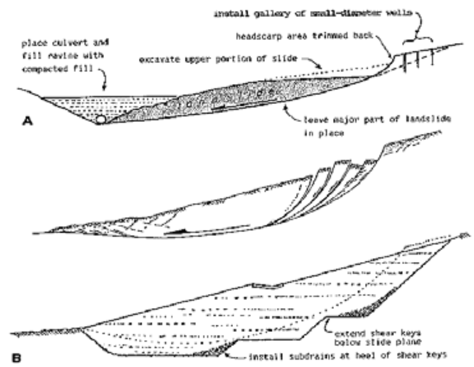
1. Plankton grows in shallow ocean (solar energy)
2. Dies, sinks, quickly buried (else would oxidize)
3. Accumulates in great thickness – ooze → shale (source rock)
4. Organics "cooked" into hydrocarbons:
    a. Deeper than 2000m
    b. tar → oil → natural gas
5. Expansion causes pressure, oil flows upward (migrates)
6. Accumulates in structural traps; ss & ls (reservoir rock)



Mass Wasting Mitigation

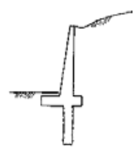
1. Debris Flows (mud flows)

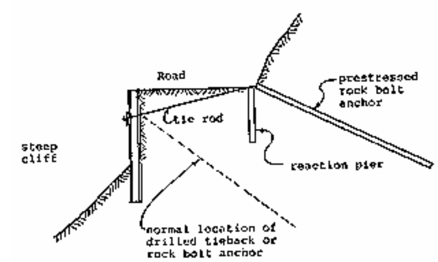
    a. Revegitation after fires (grasses – may slow natural recovery)
    b. Flood control
        i. Debris basins
        ii. Diversion channels
        iii. Plastic sheeting (small areas)



2. Slides & Slumps

    a. Dewatering (subdrainage)
    b. Pins, columns, anchors
    c. Trim head & buttressing toe
    d. Remove & compact whole slide mass
    e. Retaining walls





reaction pier tieback

3. Rock Falls
    a. Barriers - walls and fences (I-5 to 110)
    b. Chain-link covers
    c. Shot-crete

4. Engineering (building codes, grading)

    a. Mapping and zoning
    b. Limits on buildable slopes (varies by jurisdiction, ~25%)
    c. Proper design
    d. 90% compaction of fill
    e. Monitoring

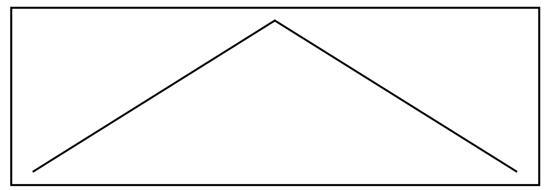
Mass Wasting

== downslope movement of soil, sediment, and rock.

- Causes more damage in the U.S. each year than earthquakes, volcanoes, tornadoes, and hurricanes combined. Avg. 25-50 deaths & $2 billion.
- Increasing because of more hillside development

Gravity driven ∴ slope is important

<u>Angle of repose</u> – natural slope of a loose pile of sediment.
~ 35° for dry sand



Stability of a material depends on:

1) grain size
2) angularity
3) cohesiveness (usu. moisture content)
   sand castle example

Slope becomes **unstable** (will move) if angle of repose is exceeded by:

a) adding material to top
b) removing material from bottom
c) changing moisture content
d) changing mass (saturate with water)
e) shaking

Types of Mass Wasting

1) Rock falls
   a) sediment (from wx.) simply tumble down slope
   b) forms **talus** slope at base

Cass History
Yosemite (Happy Isles) rock fall – July 10, 1996

- **68,000 tons of rock broke loose above Happy Isles Nature Center**
- **Slid 500 feet and launched into a 1700 foot free fall**
- **Hit the ground 100 feet from the base of the cliff at 160 mph**
- **Impact registered ~ Ml = 2.1**
- **The crushed rock buried 10 acres**
- **Air blast damaged 10 acres more, uprooting & snapping 200 trees**
- **One person was killed by trees, a number of others injured**

2) Slides
   a) down-slope movement of rock or soil on a slide plane (may be fast or slow)
      i) planes of weakness
         (1) bedding planes
         (2) joints
         (3) clay layers
      ii) spoon shaped glide plane (amphitheater-shaped head-scarp)

   b) triggers
      i) saturation (rainfall, irrigation, vegetation loss, etc.)
      ii) earthquakes
      iii) undermining (wave or river erosion, road building, mining)

Case History
Turnagain Heights – Anchorage Alaska, 1964

- **triggered by Good Friday earthquake (ML 8.6)**
- **Bootlegger Cove clay (~7m thick) was glide plane (liquefaction)**
- **7 blocks slid as much as 600m (2,000 ft), took ~ 5 min.**
- **75 homes destroyed, 130 acres**

3) Flows
   a) water saturated sediment – flows like water
   b) types:
      i) mudflows
      ii) debris flows (> ½ coarser than sand)
      iii) lahars – cool volcanic ash

Case Histories…
Armero, Columbia --- Nevado Del Ruiz, 1985

- **lahar caused by rapid thaw of snow on volcano**
- **15 m high, 70 km/hr**
- **flowed 48 km down river valley and inundated town**
- **buried ~25,000 people**

Shields Canyon - 1978

4) Creep
   a) slow downhill creep of surface layer (1-10mm/yr)
   b) signs of creep
      i) tilted posts, walls, trees, etc.
      ii) cracks upslope
   c) Special type – solifluction
      i) permafrost creeps because of freeze-thaw (frost heave)

Prevention and Mitigation

1) Limits on hillside development
2) Building codes & engineering (grading)
   a) limits on slopes
   b) compaction of fill
   c) retaining walls, anchors
   d) vegetation
   e) drainage
      i) prevent infiltration
      ii) dewatering

Groundwater (NOT in underground lakes and rivers!)

← Belt of soil moisture (few meters)
- wetted zone (held by surface tension)
- used by plants

← Zone of aeration – not normally saturated
"vadose" zone

← Capillary fringe (wet towel example)

← Water table
- top of zone of saturation
- varies with season, rainfall, pumping

← Zone of saturation – contains "groundwater"

All rocks below this are saturated (juvenile & volcanic water vs. meteoric)

Recharge happens where water infiltrates into water table
- general infiltration
- influent streams and lakes
- man-made settling ponds (recharge basins)

Discharge where water is removed from water table
- effluent streams and lakes
- marshes, swamps & springs
- wells (withdrawl)

Porosity ≡ open space between grains
ratio of **volume** of void to solid (e.g. sand ~25%)

Depends on:
1. sorting – better sorted = more porous
2. packing – looser packed = more porous
3. rounding – more rounded = more porous
(grain size is not a factor)

Permeability ≡ how easily water can flow through material.
(volume thru unit X-section with given pressure)

When pumping you care about:

Specific yield ≡ how much of the water you can get out
Specific retention ≡ what you can't get out (suck a sponge – it's still wet)

Porosity = Specific Yield + Specific Retention

Material	Porosity	Specific Yield	Specific Retention	Permeability
soil	55%	40%	15%	good
clay	50%	2%	48%	poor
sand	25%	22%	3%	excellent
gravel	20%	19%	1%	good
limestone	20%	18%	2%	poor - excell.
sandstone	11%	6%	5%	poor - good
granite	0.10%	0.09%	0.01%	very poor

Based on Table 16.1, pg. 426

∴ High porosity does NOT mean high permeability (see clay).

<u>Darcy's Law</u> describes **rate** of groundwater flow

$$V = K * h/\ell$$

Where:
- V = velocity of flow
- K = hydraulic conductivity (∝permiablility)
- h = drop in head
- ℓ = distance
- h/ℓ = "hydralic gradiant"

Greater head (pressure) = higher velocity

Example: how long for a contaminant to reach a well.

Typically a few cm/day, max. about 15 cm/day

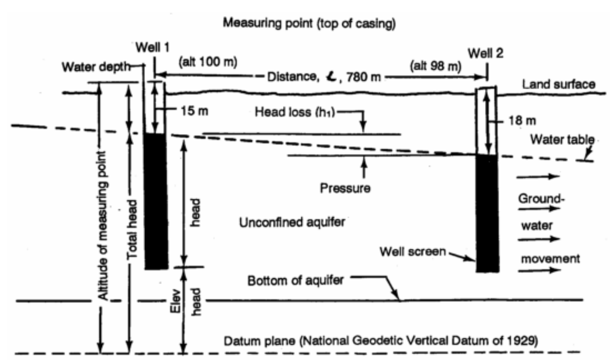


Figure 2-11. Hydraulic gradient

Aquifer ≡ permeable layer (groundwater can flow through it)
Unconfined – not under pressure (top is water table)
Confined – under pressure (artesian wells)

Aquiclude ≡ impermeable layer (barrier to groundwater flow) “confining layer

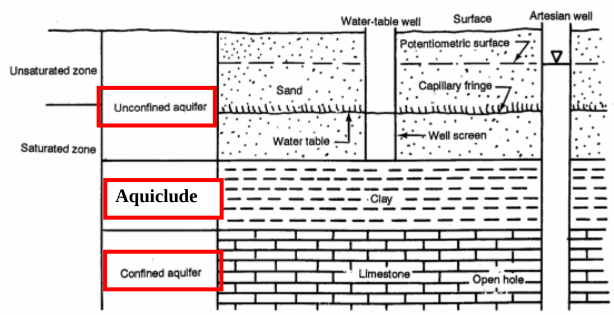


Figure 2-12. Unconfined aquifer

http://www.globalsecurity.org/military/library/policy/army/fm/5-484/Ch2.htm

Artesian wells

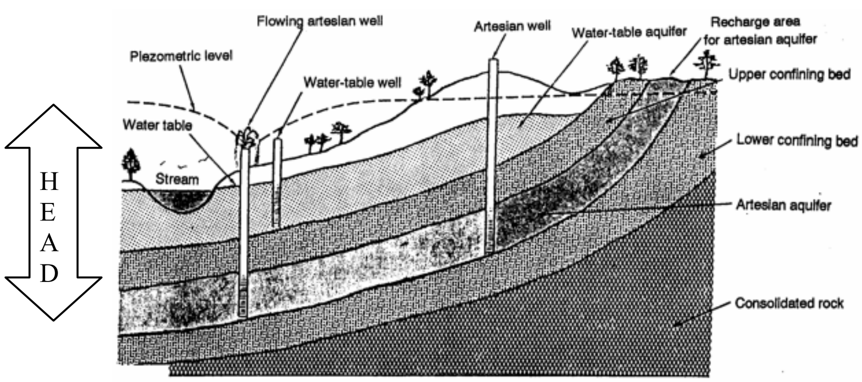


Figure 2-13. Flowing artesian well

Springs

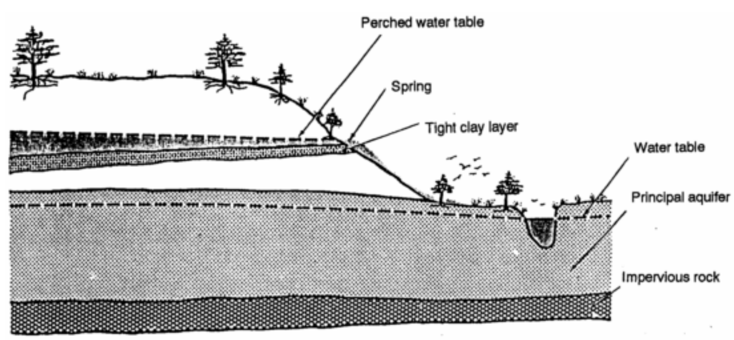


Figure 2-14. Perched water table

Oases

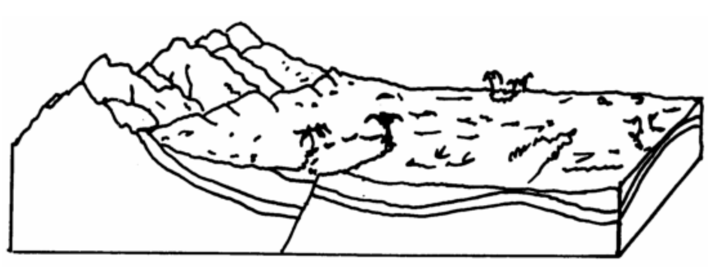
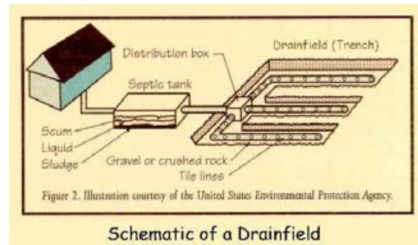


Figure 2-37. Oasis

Ground water problems

1) Contamination (pollution)

- industrial leaks, spills and intentional dumping
  - o tetrachloroethlyene, PCE or "perc." (dry cleaning fluid)
    - ▪ 900 wells in Calif. – 5% of water supply
  - o Perchlorate (explosives, rocket fuel)
  - o Erin Brockovich – "hexavalent chromium"
- land fills – clay or plastic lining
- leaky underground storages tanks
- agricultural runoff – pesticides & fertilizers
- poorly designed septic tanks

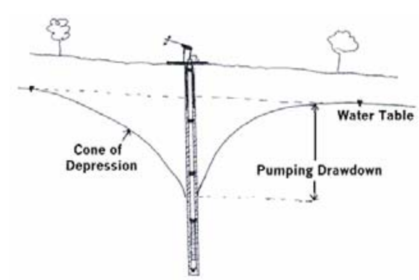


Schematic of a Drainfield

> San Gabriel Valley
> - 170-square-mile, 45 water suppliers
> - 90% of water to > 1,000,000 people
> - >59 wells (of > 400) were found to be contaminated

2) Subsidence ≡ compaction of aquifer caused by withdrawal

- Ground surface can drop several meters
  - o annual U.S. damage ~ $400 million
  - o San Joaquin Valley – 9m in 50 yrs
  - o Imperial Valley, Indian Wells Valley
  - o Texas, Florida
- Porosity is reduced forever

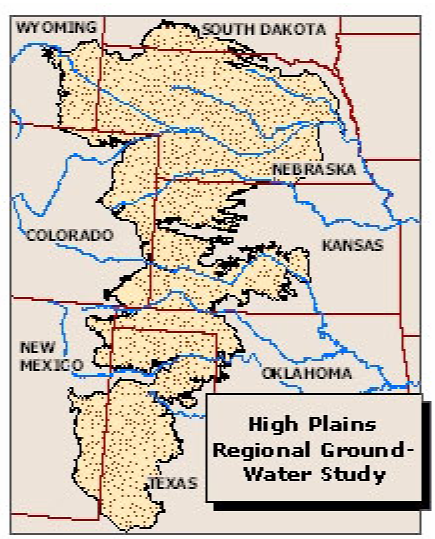


3) Lowering of water table (cone of depression)

4) Water mining (withdrawl >> recharge)
Mining water from ice ages.

- Example: Ogallala aquifer,
  - o dropped > 15m in 30yr in places

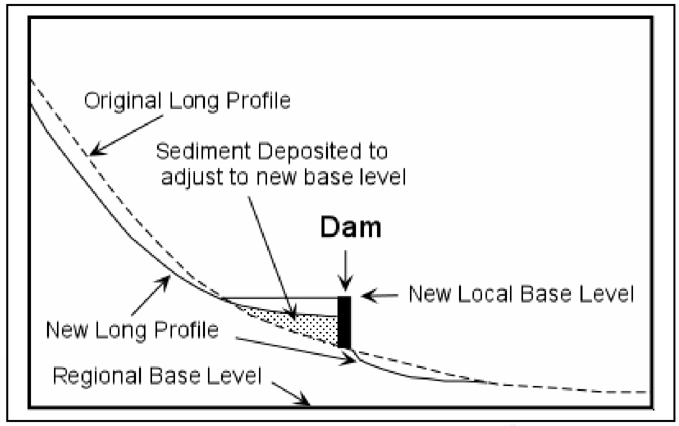
5) Saltwater intrusion

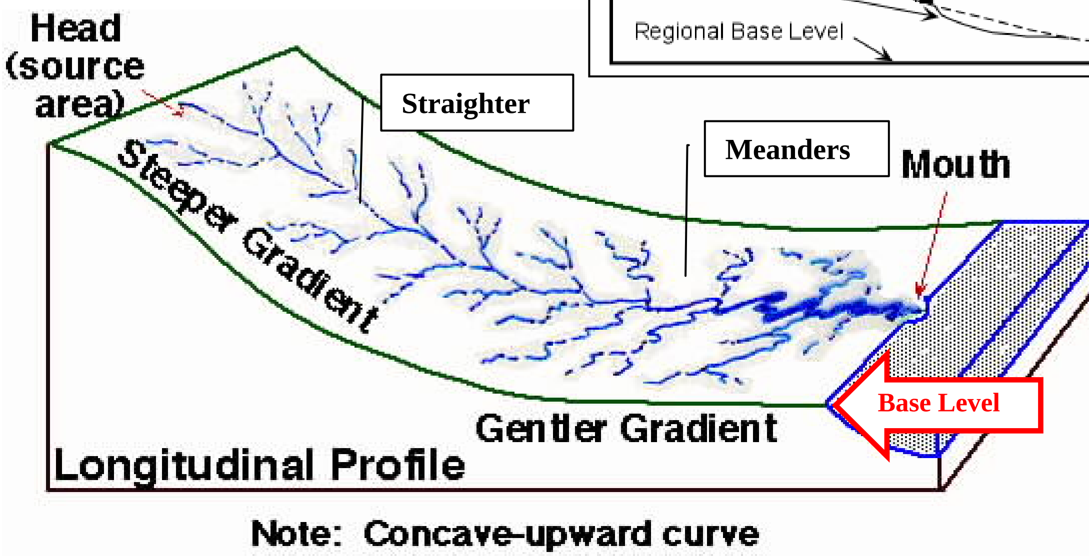


Streams

The Graded Stream = at equilibrium
Just enough energy to carry its load

Gradient - Slope concave-up
longitudinal profile





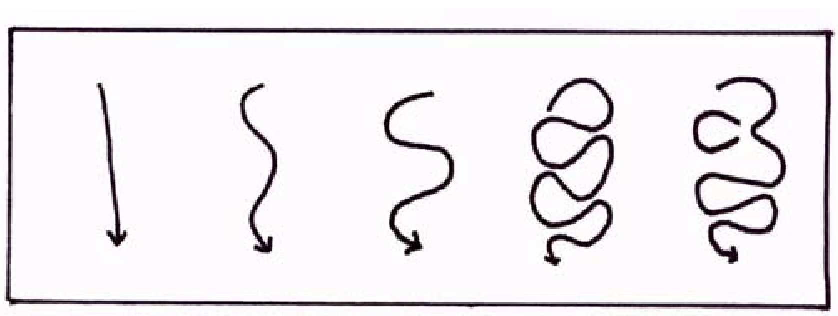
Base level – level below which a river cannot erode.

- Local base level – dam, lake, resistant rock ("fall line")
- Ultimate base level – ocean, inland basin

Stream will erode or deposit to maintain grade.

Meander development (Maiandros River, Turkey)

Streams straight where gradient is steep and fast



Meander where gradient is low

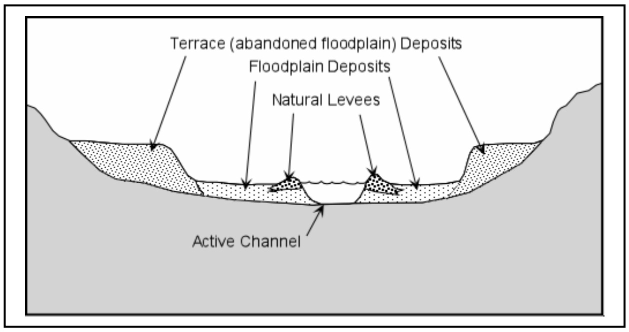
Meanders

- lengthen river, reduce grade
- migrate downstream
- alluvial fans

Flood plains

Natural Levees

- thickest, coarsest sed. deposited close to channel during floods
- finer sed. dep. on flood plain :. fertile – silt, clay
- many river towns are BELOW the level of the river water!
- man-made levees make floods less frequent but worse when they happen



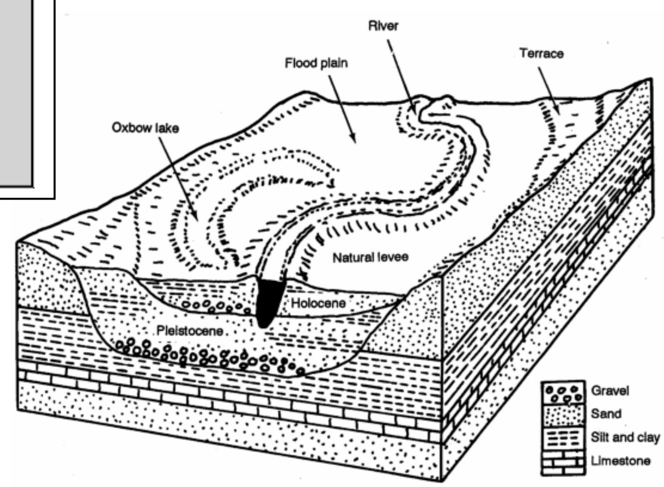
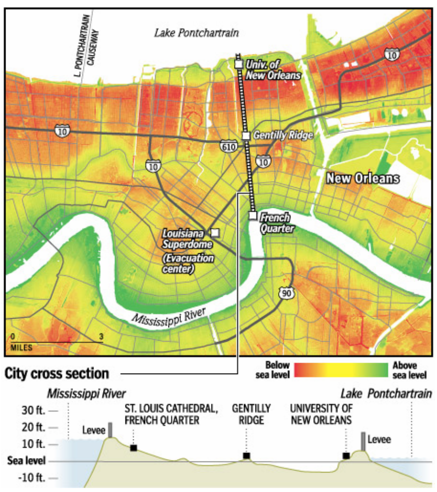


Figure 2-18. Alluvial valley



Orleans, LA is below sea level

Braided Streams

- large variation in volume
- large sediment load
- alluvial fans, glacial outwash

Sediment Transport

Discharge ≡ total volume of water (m^3/sec)

- depends on channel x-sect and velocity
- Mississippi – 1400 m^3/sec – 57,000 m^3/sec (avg. 18,000)

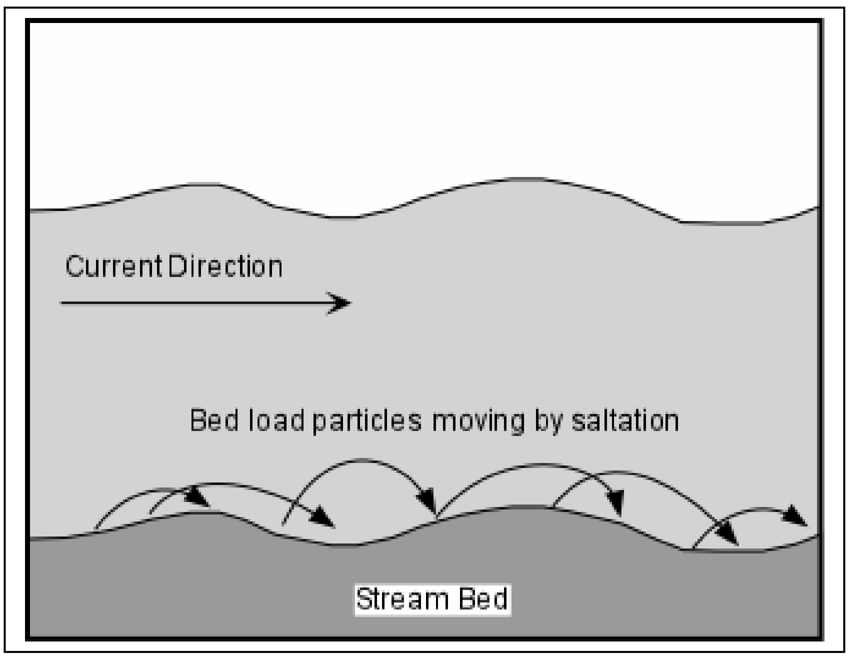
Capacity ≡ total volume of sediment

- ∝ discharge
- most rivers don't carry max. capacity because its not available
- **load** ≡ actual sediment carried

Competence ≡ largest particle transported

- ∝ velocity

All change for a stream along course, over time, with seasons, etc.

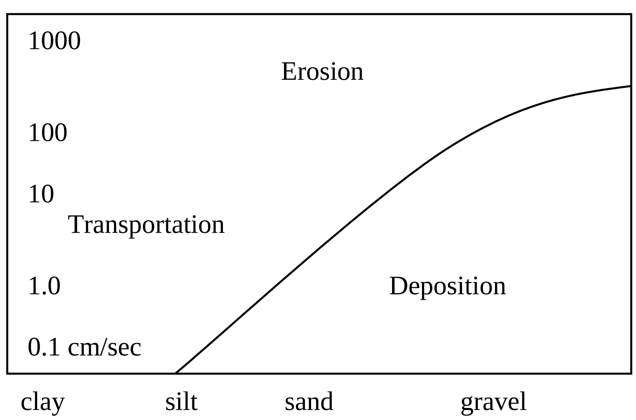


Dissolved load (ions)
 * chemical wx.
Suspended load
 * silt, clay
Bed load
 * rolling
 * saltation
 * lift (Bernoulli's principle)

Velocity vs. grain size

Silt & clay is "sticky"
Gravel is heavy

Sand easiest to erode & transport
:. beaches



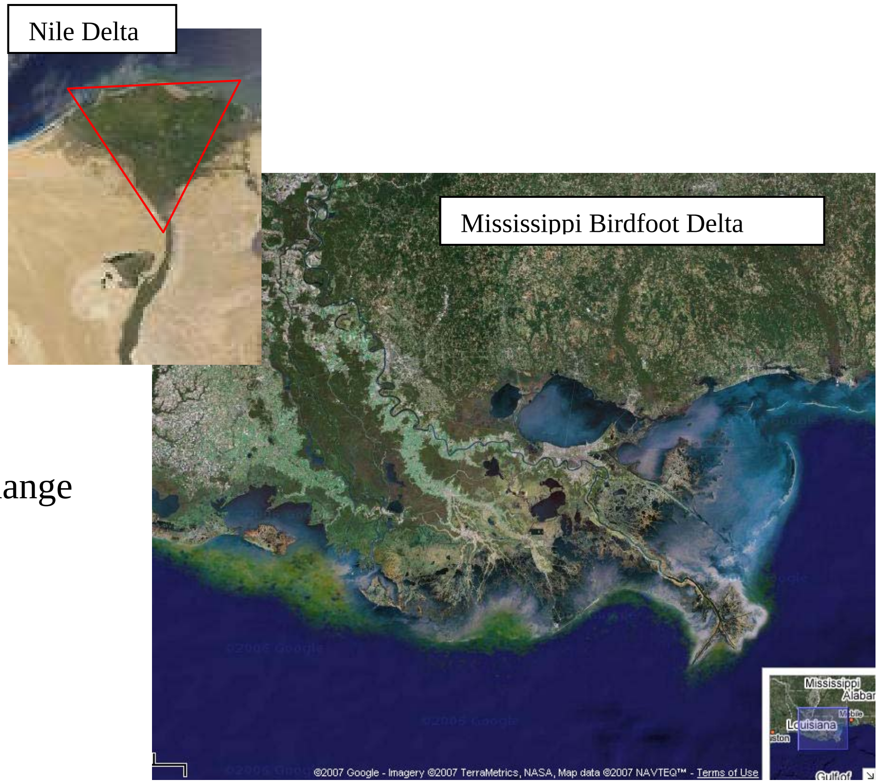
Deltas

Named for Greek Δ

Existance and type depend on:

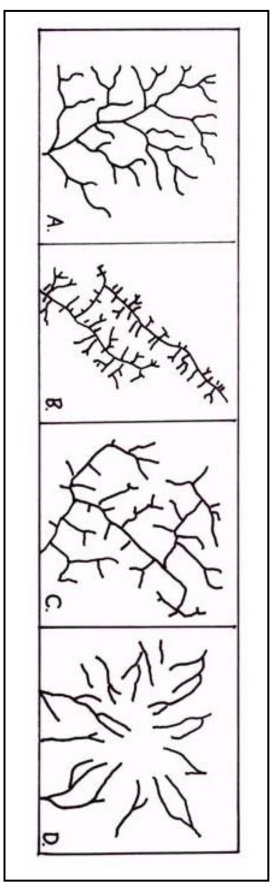
- river discharge and sed. load
- wave action
- tidal range

Distributary channels change over time



Drainage patterns

Depend on underlying geology. Geologic structure may “steer” the drainage.



Dendritic

- relatively uniform rock

Trellis

- parallel ridges caused by tilted sed. layers

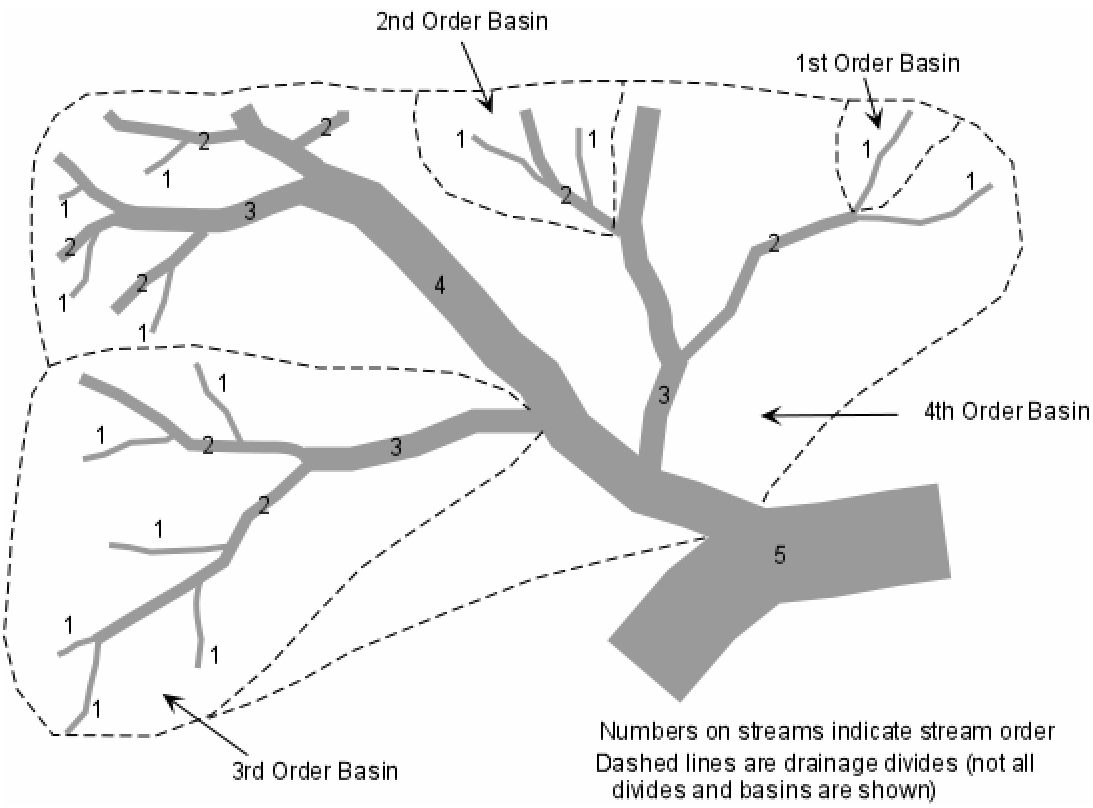
Rectangular

- joints and faults

Radial

- domes and volcanoes

Catchment Basins (Watersheds)



- Basins are separated by "**divides**" which are generally on ridges.
- Tributaries of smaller order join larger order
- Acute "V" in a branch points upstream

<u>Continental Divide</u> <u>(Great Divide)</u> = separates the watersheds of the Pacific Ocean from those of the Atlantic

North America has four continental divides:

1. The Great Divide (Continental Divide)
   = Atlantic/Pacific
2. The Northern Divide (Laurentian Divide)
   = Atlantic/Arctic
3. The St. Lawrence Seaway Divide
   = Great Lakes/Atlantic Ocean
4. The Eastern Continental Divide
   = Gulf of Mexico/Atlantic Ocean