Geology 3015

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Geology 3015: Introductory Geology for Engineers
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Text: Geology for Engineers & Environmental Scientists, Alan E. Kehew
Lab Manual: Zumberge's Laboratory Manual for Physical Geology, 14th Edition, Robert H. Rutford and James L. Carter

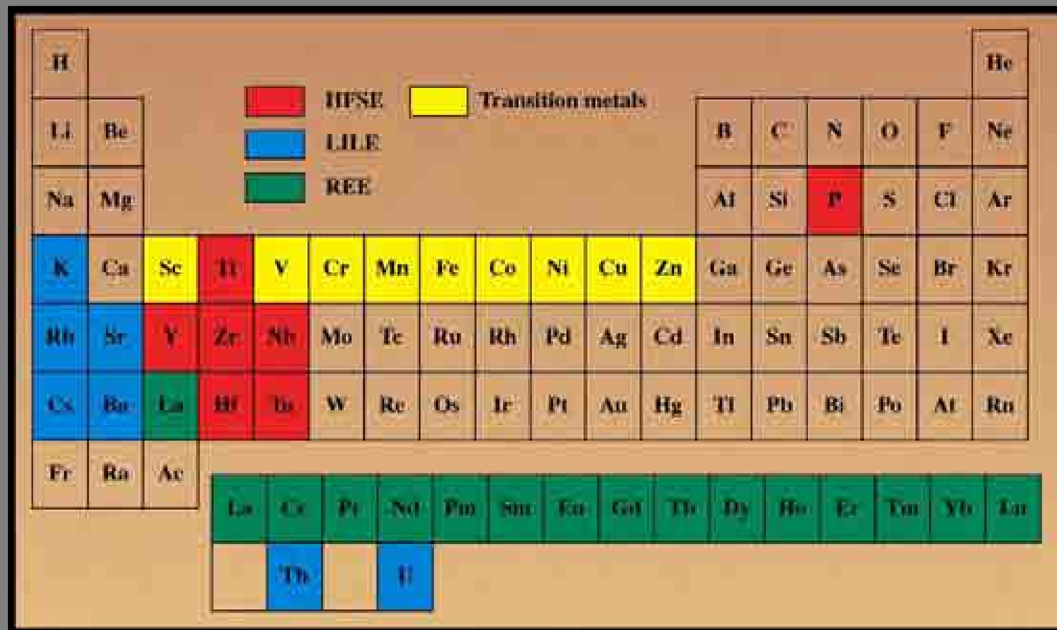
Marks:		
	Lecture Midterm	20%
	Lecture Final	30%
	Lab Midterm	20%
	Lab Exercises	10%
	Lab Final	20%
		100%

What is Geology?

- Two broad areas:
  - Historical Geology – origins and evolution of the Earth, its continents, atmosphere and life
  - Physical Geology – rocks, minerals and the processes that affect them

- There are a broad range of sub-disciplines within geology many of which are related to other sciences while others have a direct influence on human activity :
  - Geophysics
  - Geochemistry
  - Paleontology

Geochemistry



- By crushing and analyzing rocks we can measure their chemical composition
- This can be used to determine the tectonic setting in which the rocks formed

Geophysics

- We can measure the physical properties of rocks with a variety of methods
  - Seismic waves
  - Gravity
  - Electromagnetic characteristics
- These can be used to investigate the subsurface properties of the planet

Paleontology (Biology)

- Probably the most 'glamorous' field of geology

Economic Geology

- "If it can't be grown it's got to be mined"
- Metals, fossil fuels & industrial minerals

Diavik Diamond Mine, NWT

Environmental geology

- Geological, climatic and man-made hazards all fall into this field

- Volcanoes
- Earthquakes
- Landslips
- Meteorites
- Avalanches
- Tsunami

- Floods
- Landslips
- Avalanches
- Global warming?

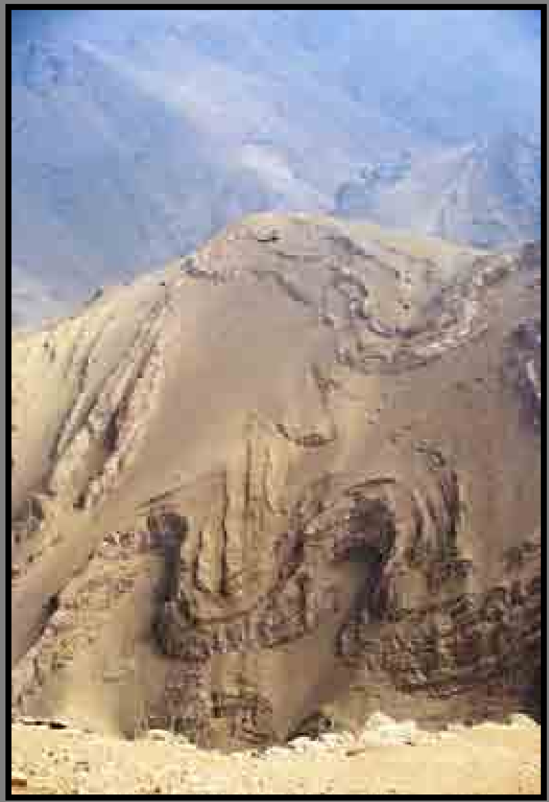
- Floods
- Landslips
- Avalanches
- Pollution
- Global warming?

Volcanology

- Monitor active volcanoes
- Predict eruptions
- Hazard mapping
- Dramatic scenery
- High risk/high casualty rate

Structural Geology

- Measuring the orientation of geological structures
- Geological mapping
- Unravelling complex terranes



Domeyko Fault System, North Chile

Hydrogeology

- Flood prediction and prevention
- Water resource management
- Groundwater

Flooding in Bangladesh

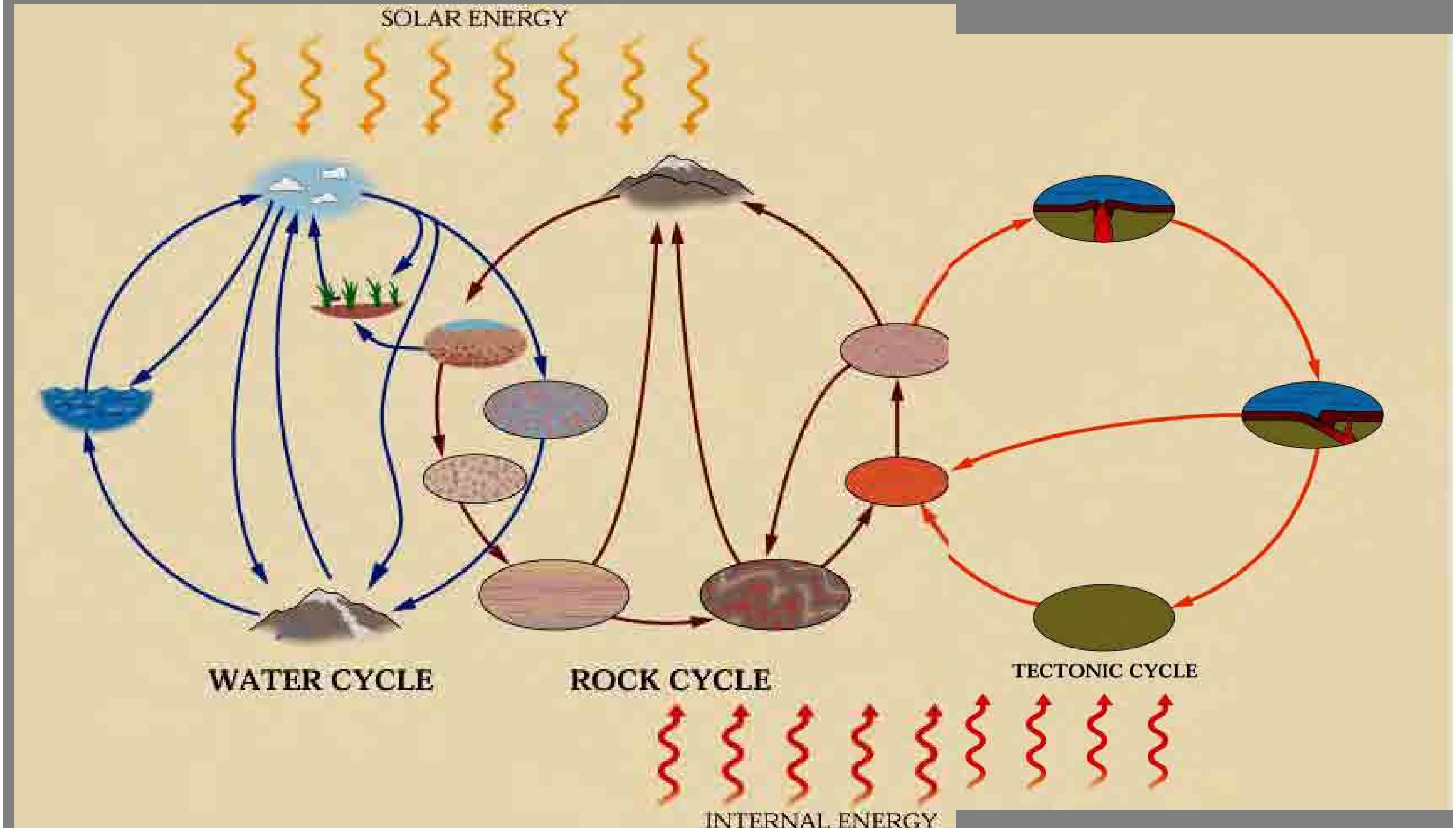
Red River flood, Manitoba

Working as a geologist

- Mining
- Exploration
- Environmental
- Petroleum industry
- Hydrology
- Academic
- Government

Topics to be covered

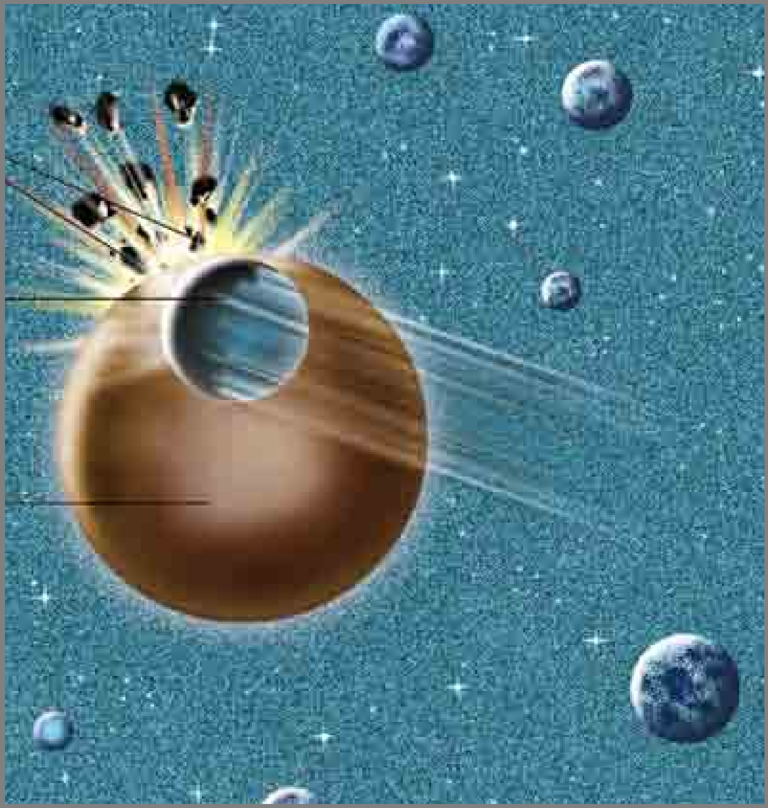
- Rocks & minerals
- Geologic time
- Plate tectonics
- Weathering & soils
- Mass wasting
- Rivers & flooding
- Glaciation
- Deserts
- Coastlines
- Earthquakes
- Environmental geology
- Economic geology
- Mountain belts



Murck and Skinner (1999)

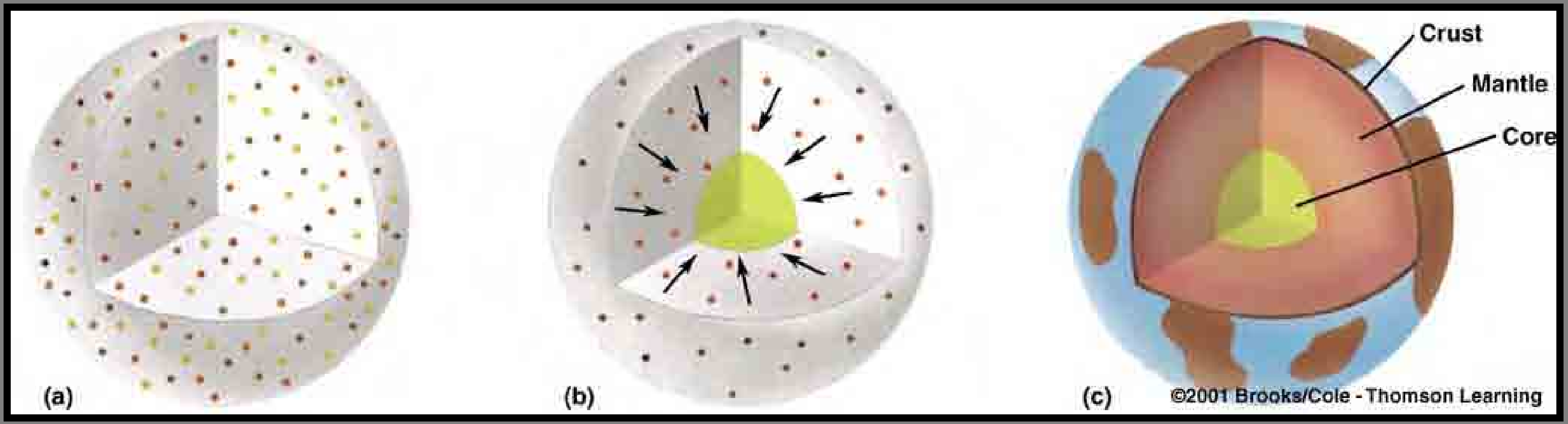
Formation of the planets

- Dust particles drawn together by random collisions and gravity
- Particles eventually form planetesimals
- These coalesce by a process called planetary accretion
- The Earth formed 4.56 billion years ago

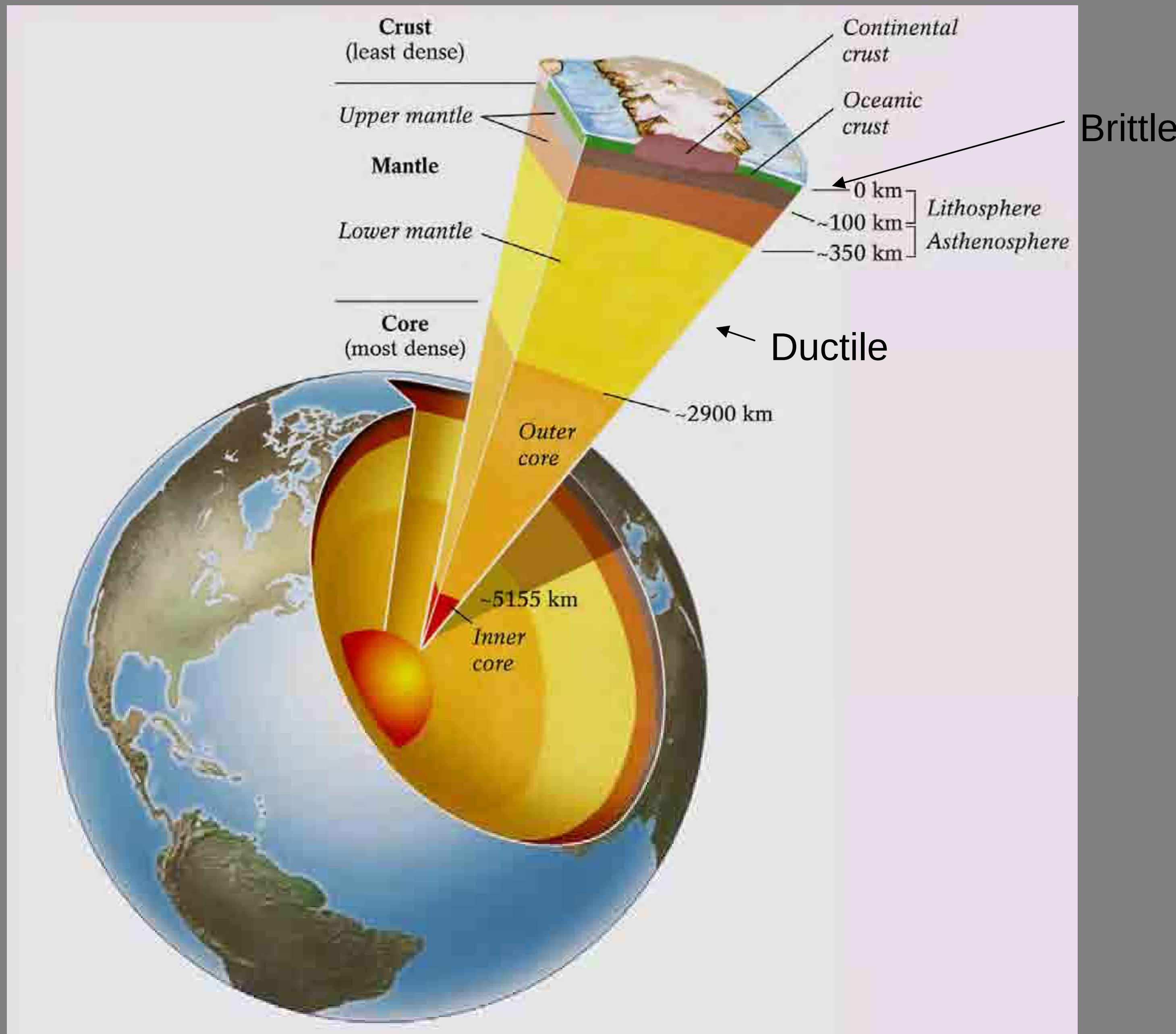


Chernicoff and Whitney (2002)

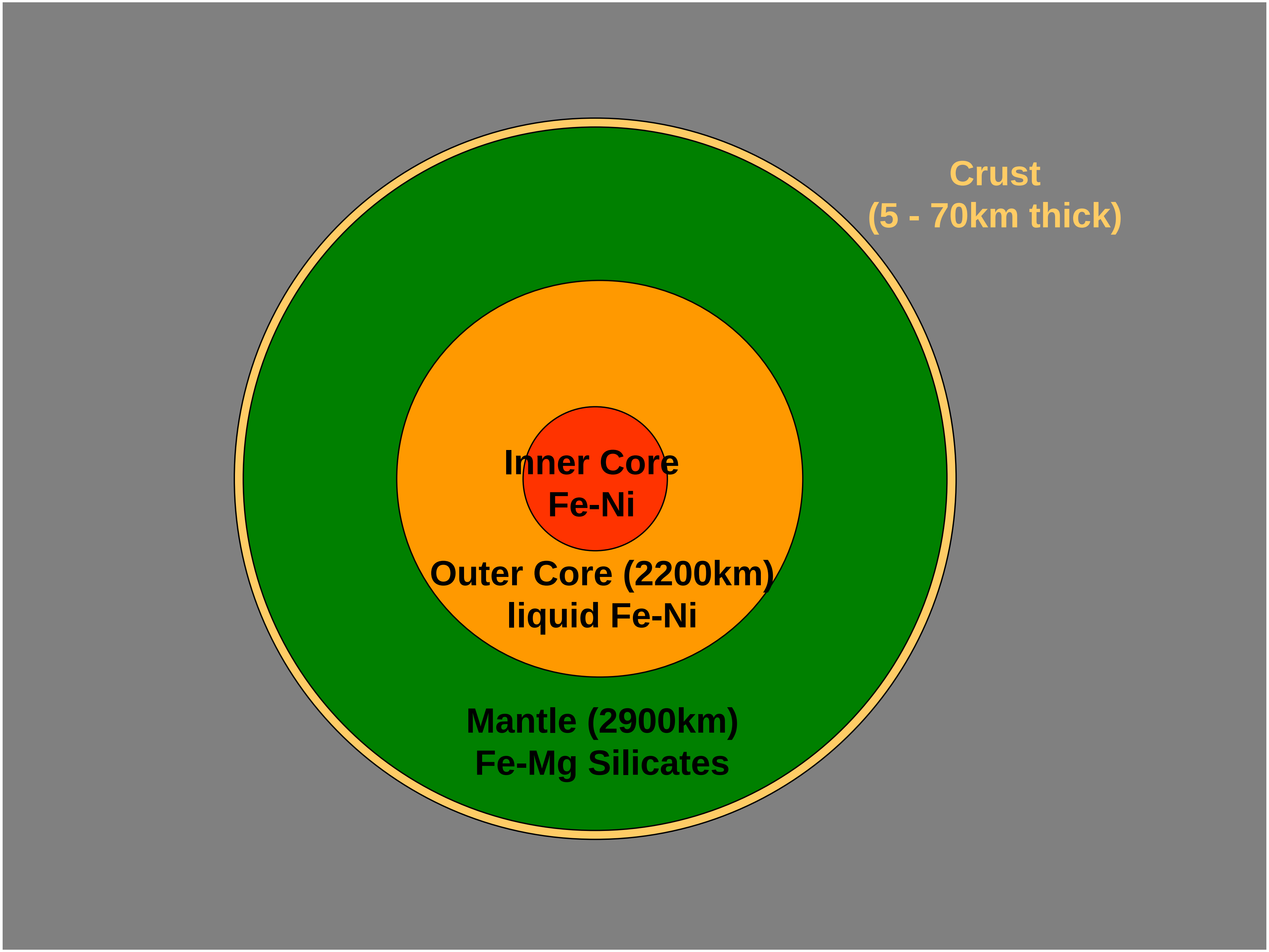
Formation of the Earth



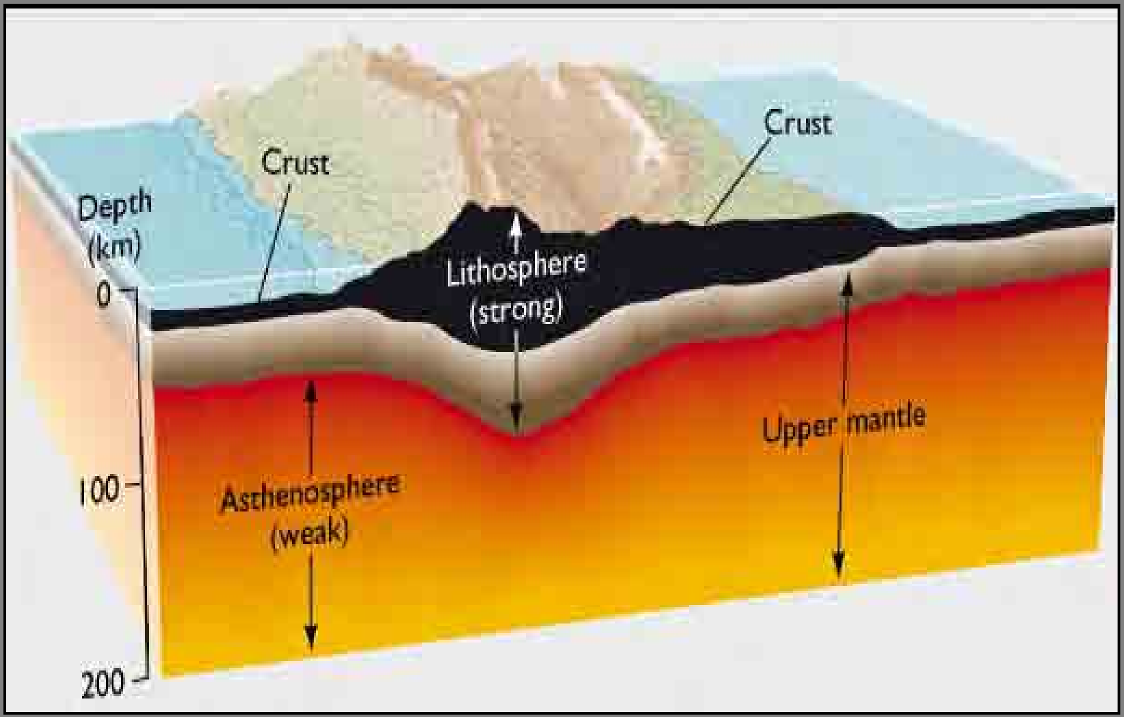
- Early Earth (4.6 b.y.) had uniform composition and density
- Heat generated by gravitational contraction, collisions with debris in its orbital path and decay of radioactive elements results in (partial) melting; during molten phase dense elements (Fe and Ni) sink to collect in core and lighter silicate minerals flow upward to form mantle and crust
- Differentiation results in layered planet, and emission of gases supplies material for early atmosphere and oceans



Chernicoff and Whitney (2002)


Crust
(5 - 70km thick)
Inner Core
Fe-Ni
Outer Core (2200km)
liquid Fe-Ni
Mantle (2900km)
Fe-Mg Silicates

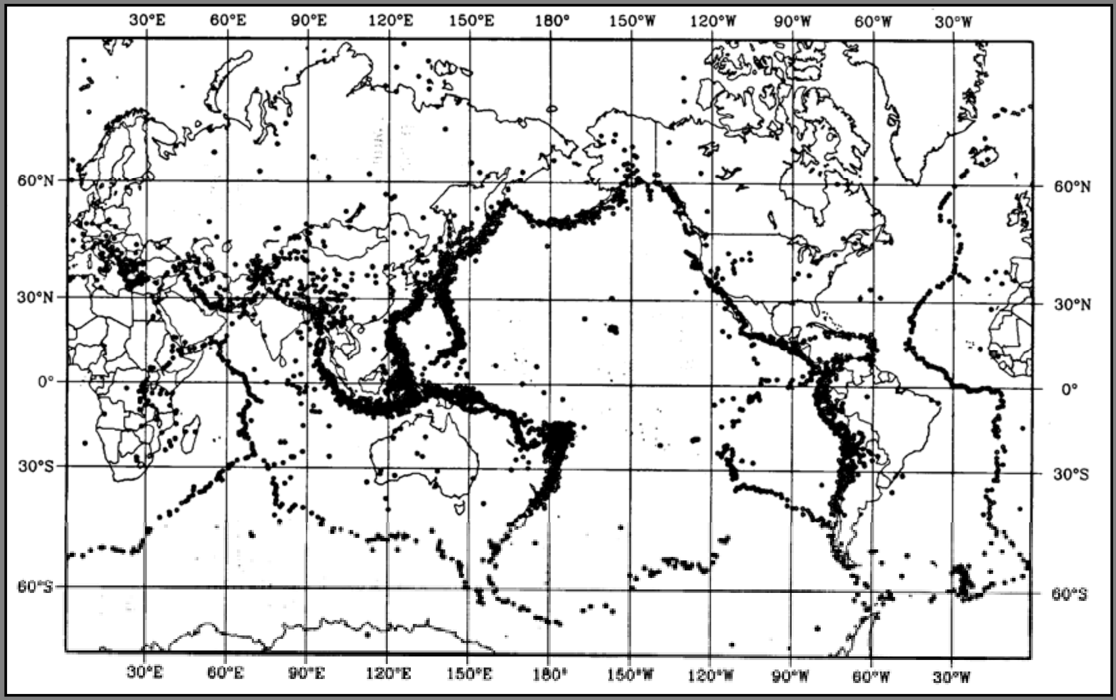
Crust and Lithosphere



- The average crustal thickness in continental areas is approximately 35 km
- The Earth's crust ranges from 5-10km thick beneath the ocean basins to in excess of 70km beneath the major mountain ranges.

- The crust rides upon a relatively stiff layer in the upper mantle. The combination of the crust and the stiff upper mantle layer is called the lithosphere.
- Beneath the lithosphere is a weaker mantle layer, the asthenosphere

Plates of the Earth



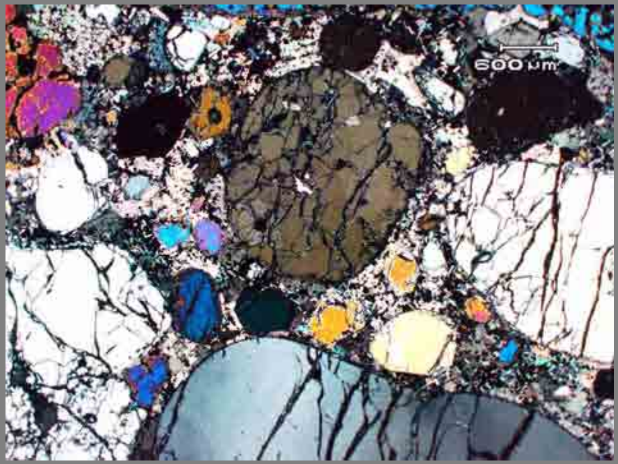
- The Earth's lithosphere is divided into approximately 15 rigid plates that can move across the underlying asthenosphere
- The global distribution of earthquakes clearly highlights the tectonic plate boundaries.

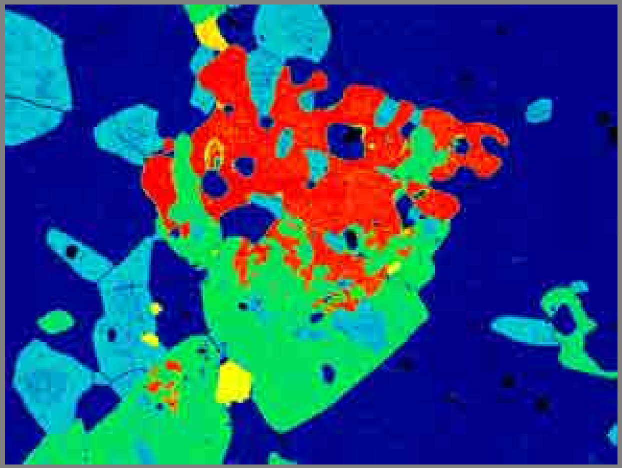
Part 1: Rocks and Minerals

What is the difference between a rock and a mineral?

- Mineral: a naturally occurring crystalline, inorganic, homogenous solid with a chemical composition that is either fixed or varies within certain fixed limits, and a characteristic internal structure manifested in its exterior form and physical properties
- Rock: A consolidated or unconsolidated aggregate of mineral grains consisting of one or more mineral species and having some degree of chemical and mineralogic constancy

Minerals and Rocks…





Minerals are an integral part of the planet which we use for many things…..

Gold on quartz, Bendigo, http://www. Exceptionalminerals.com/

2 carat diamond in the rough, A.Banas, U of A

Many minerals are essential to life, however others can be very harmful..

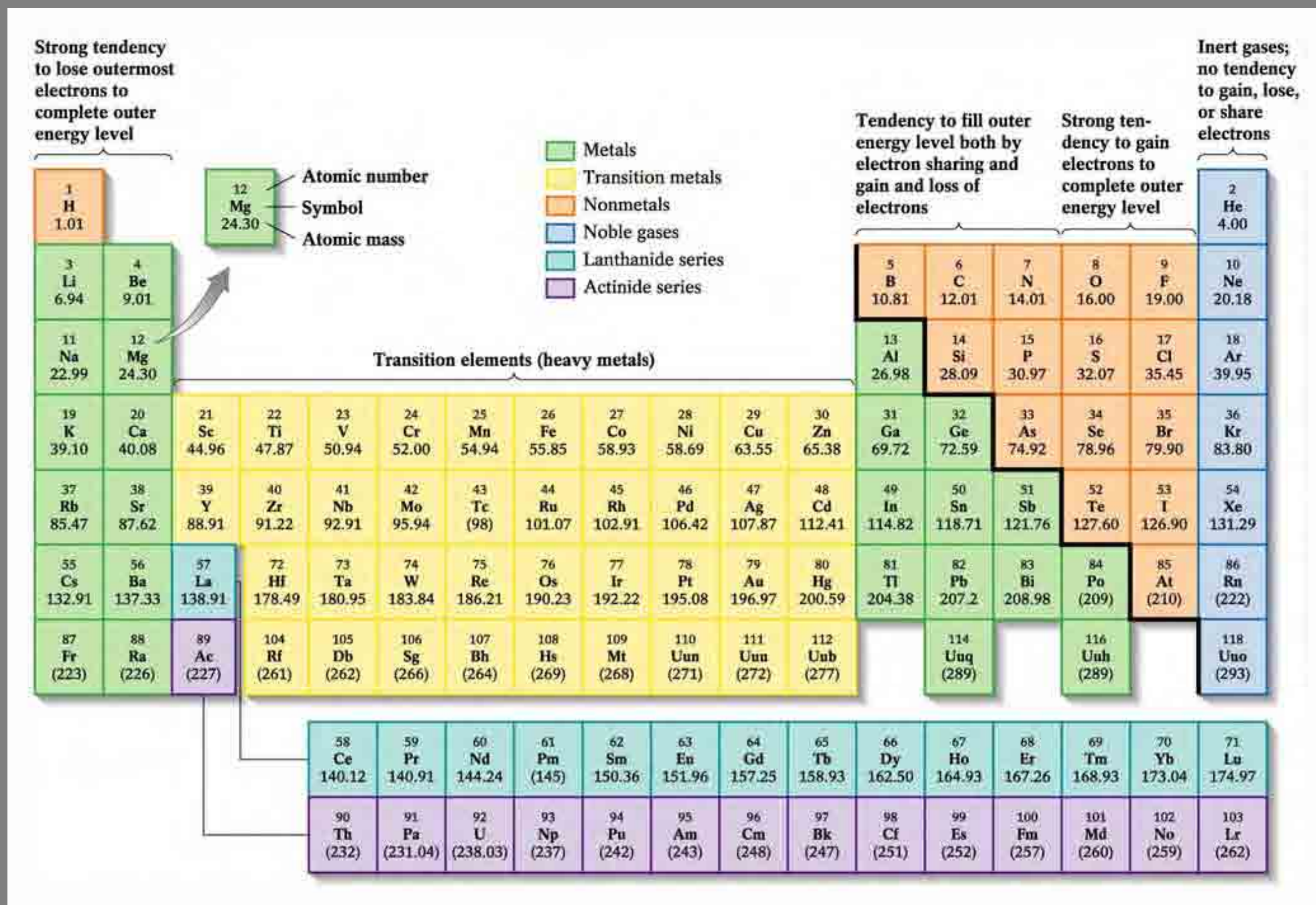
Silicosis: a form of lung disease caused by the inhalation of crystalline silica dust (first recognized in 1705!!!) When silica is cut, broken, crushed, drilled or ground the fine silica dust is airborne. Possibly a probem for miners at Hemlo.

Chrysotile: the most common form of asbestos, a fibrous silicate mineral in the serpentine group. It causes lung disease at high concentrations.

Murck and Skinner (1999)

What makes up minerals?

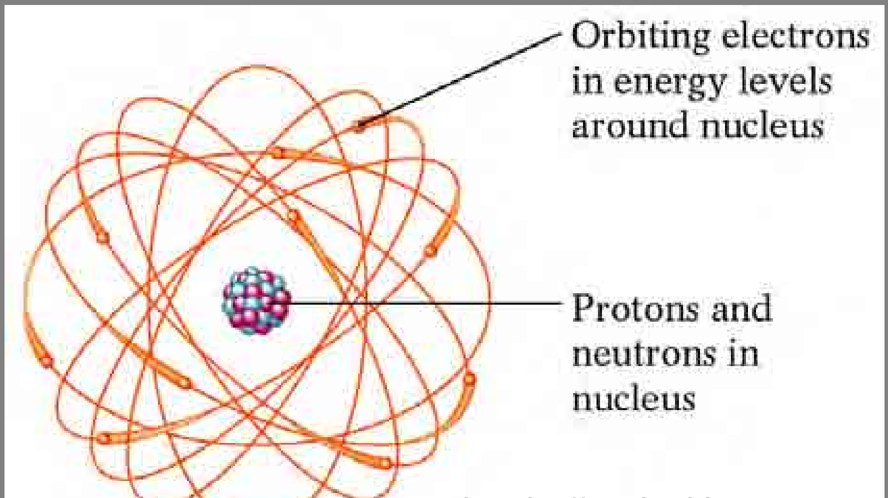
- Combinations of the 90 naturally occurring elements



Chernicoff and Whitney, 2001

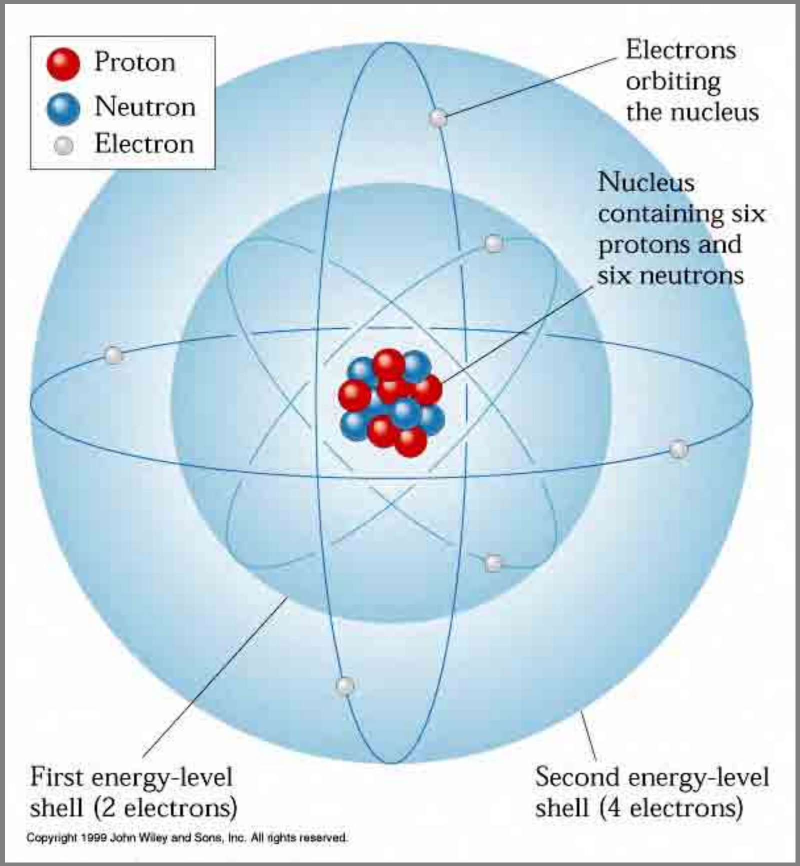
The internal structure of minerals

- Minerals have a regular internal structure
- Minerals form a regular arrangement of particles within a solid
- Atom: the smallest amount of the element that retains it's characteristic properties
- Elements are composed of atoms



Chernicoff and Whitney, 2002

*The nucleus is positively charged, and the electrons are negatively charged.



Murck and Skinner (1999)

- The positive charges concentrate in the protons. The # of protons = atomic # of the element
- Example of Sodium (Na): 11 protons in the nucleus are balanced by the 11 negatively charged electrons in the outer shells
- Neutrons have no charge, and have the same mass of a proton. Therefore: the atomic mass of a atom is basically the mass of protons + the mass of neutrons
- Neutrons hold the nucleus together

Isotopes

- While all atoms of an element have the same number of protons the number of neutrons can vary
- This means that the mass of the atoms of a particular element can vary
  - For example- Uranium-238 (^{238}U) - most commonly occurring form of U- weighs 238 atomic mass units comprised of 92 protons and 146 neutrons
  - ^{235}U - rare isotope (0.7%) with 92 protons but 143 neutons
  - Similarly Carbon exists a C^{12}, C^{13} & C^{14}
- Many important geological uses such as geochronology

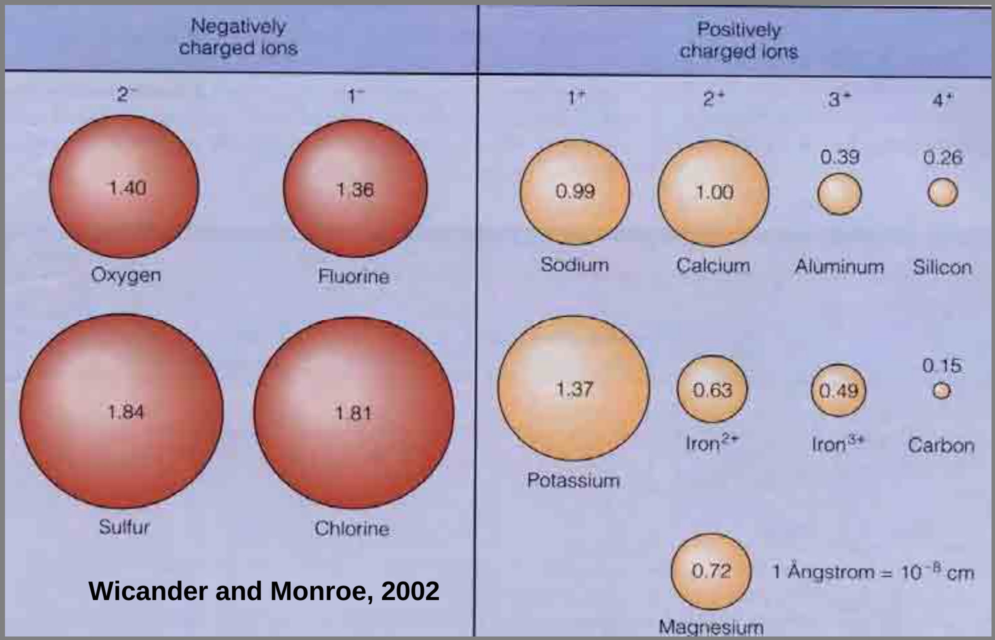
Ions

- Ideally an atom has an equal number of protons and electrons (neutral charge)
- Chemical reactions involve the sharing or transfer of electrons
- The loss or addition of electrons results in +ve or -ve charged atoms called ions

+ve = cation

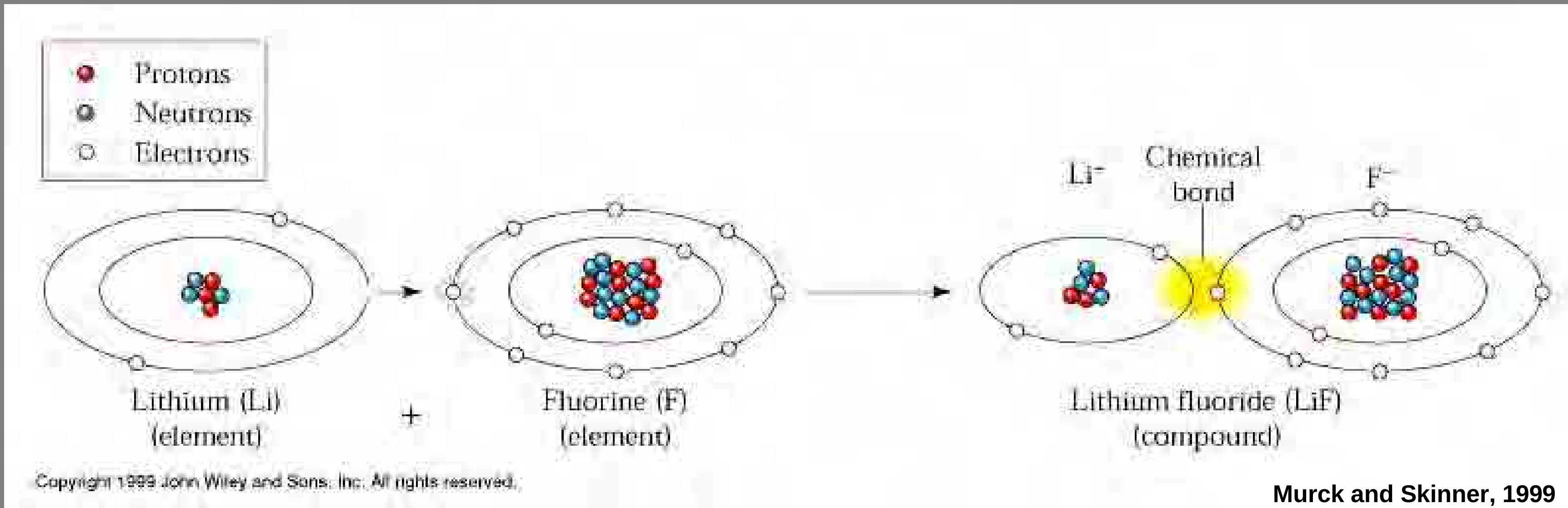
-ve = anion

Chart showing relative sizes of cations and anions of the more abundant elements



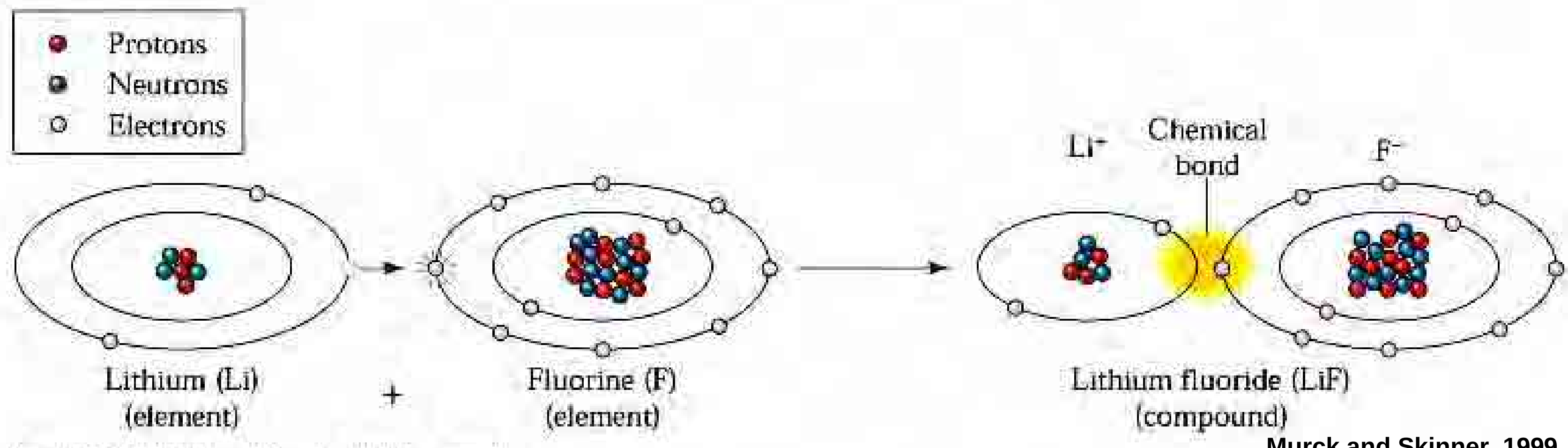
How does this apply to minerals?

- Crystal structures may be thought of as a periodic arrangement of anions, with small cations filling the interstitial spaces
- Lithium loses an electron to become +ve, while Fluorine takes an electron and becomes –ve



Murck and Skinner, 1999

Ions and compounds



Murck and Skinner, 1999

- When atoms of one element combine with atoms of another they form a chemical compound, in this case LiF
- H_2O is another example - two hydrogens to one oxygen

Chernicoff and Whitney, 2002

(a) Crystalline structure of NaCl

Compounds

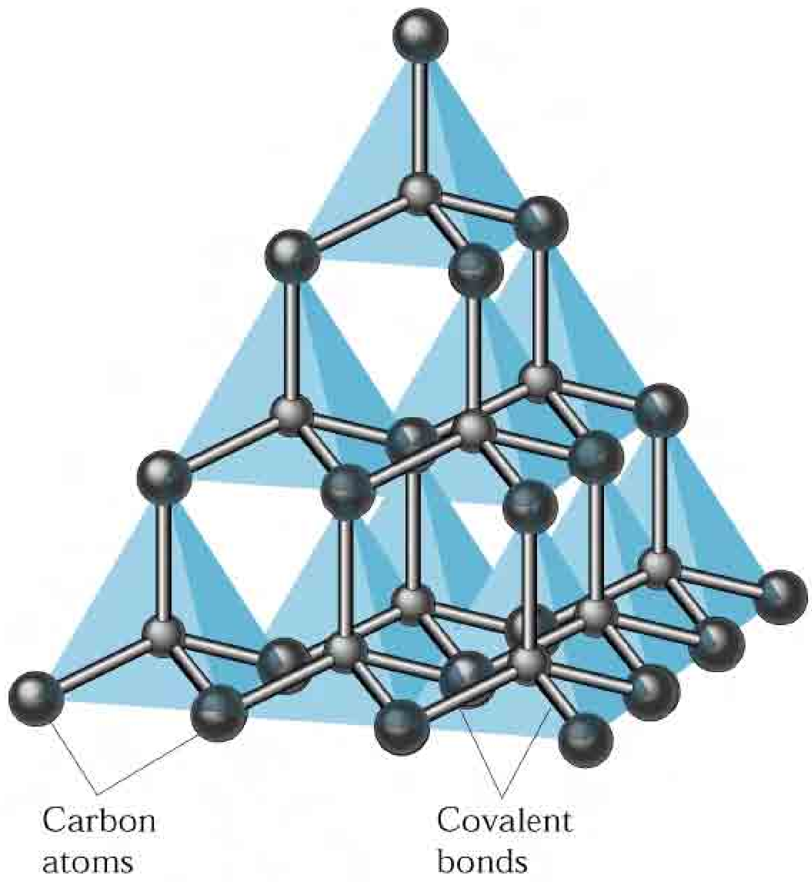
- Compounds generally have quite different properties to their constituent elements.
  - Na & Cl are toxic - NaCl is not
- Molecule - smallest component that has the properties of a compound (comparable to an atom)
- Bonding - the force that holds the atoms of a compound together

Bonding for stability

- In order to fill shells and reach a stable state atoms share and transfer electrons
- They bond in four different ways to do this
  - Ionic bonding
  - Covalent bonding
  - Metallic bonding
  - Van der Waals bonding

Ionic Bonding: (a.k.a "electron transfer") One atom donates one or more electrons to an atom of another element. Ex: NaCl on the previous slide

Covalent Bonding



Murck and Skinner, 1999

- Rather than swapping electrons some elements share electrons through a covalent bond

- A good example is diamond (pure carbon)

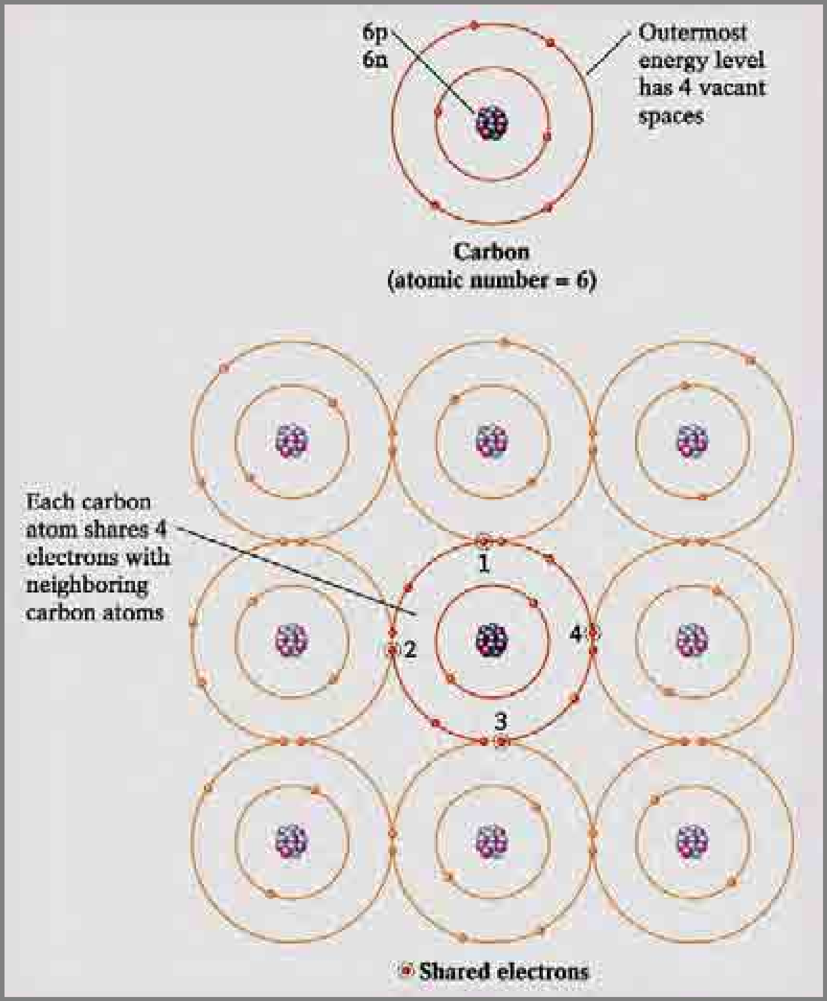
- There is a very good reason why diamond is the hardest mineral on earth!

Covalent Bonding cont.

- Highest energy level shell has 4 electrons but needs 8 for stability

- Each C atom shares two electrons with four other C atoms

- Forms a strong hard bond and subsequently a girl's best friend!



Chernicoff and Whitney, 2002

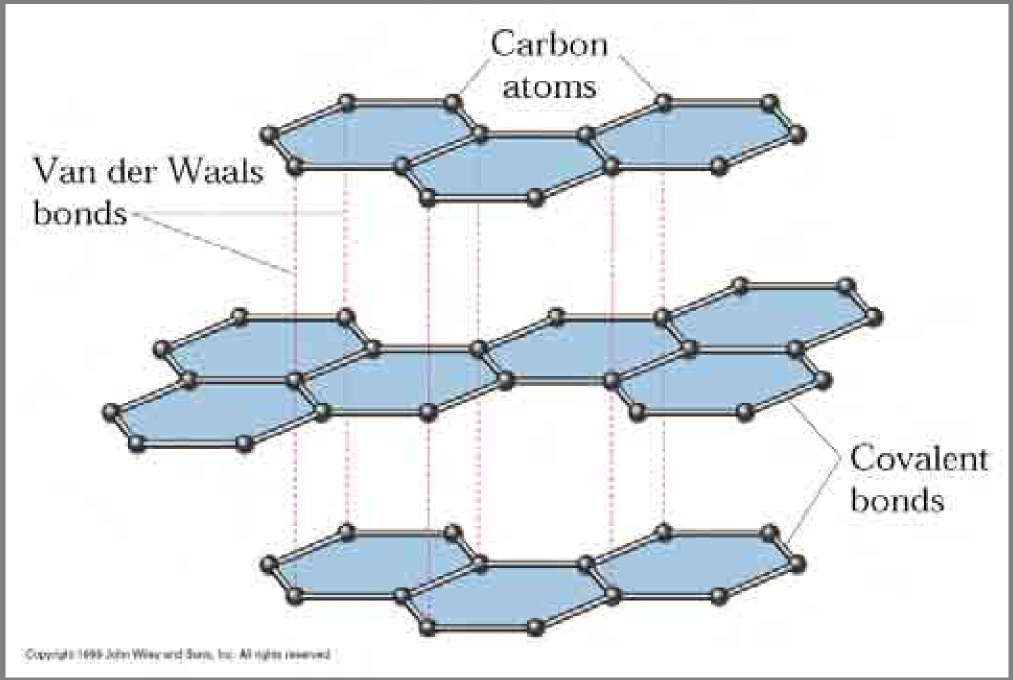
Metallic Bonding

- This form of bonding is unique to metals
- Atoms are closely packed
- Electrons in the outer shells are shared between several atoms
- They drift between atoms
- Makes them good conductors of heat and electricity

Native copper Cornelai Mine, Arizona, http://www.johnbetts-fineminerals.com/

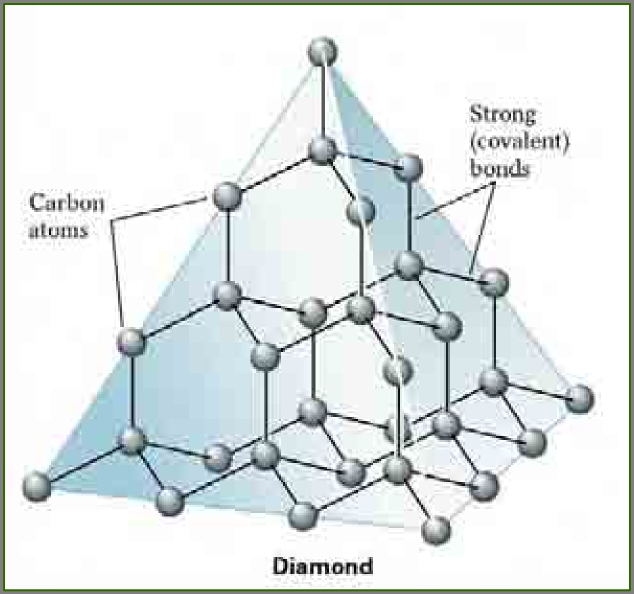
Van der Waals Bonding

- This is a weak bond formed from the secondary attraction of molecules as a result of the transfer or sharing of electrons
- Graphite is a good example
- Strong covalently bonded sheets held together by weak Van der Waals bonds

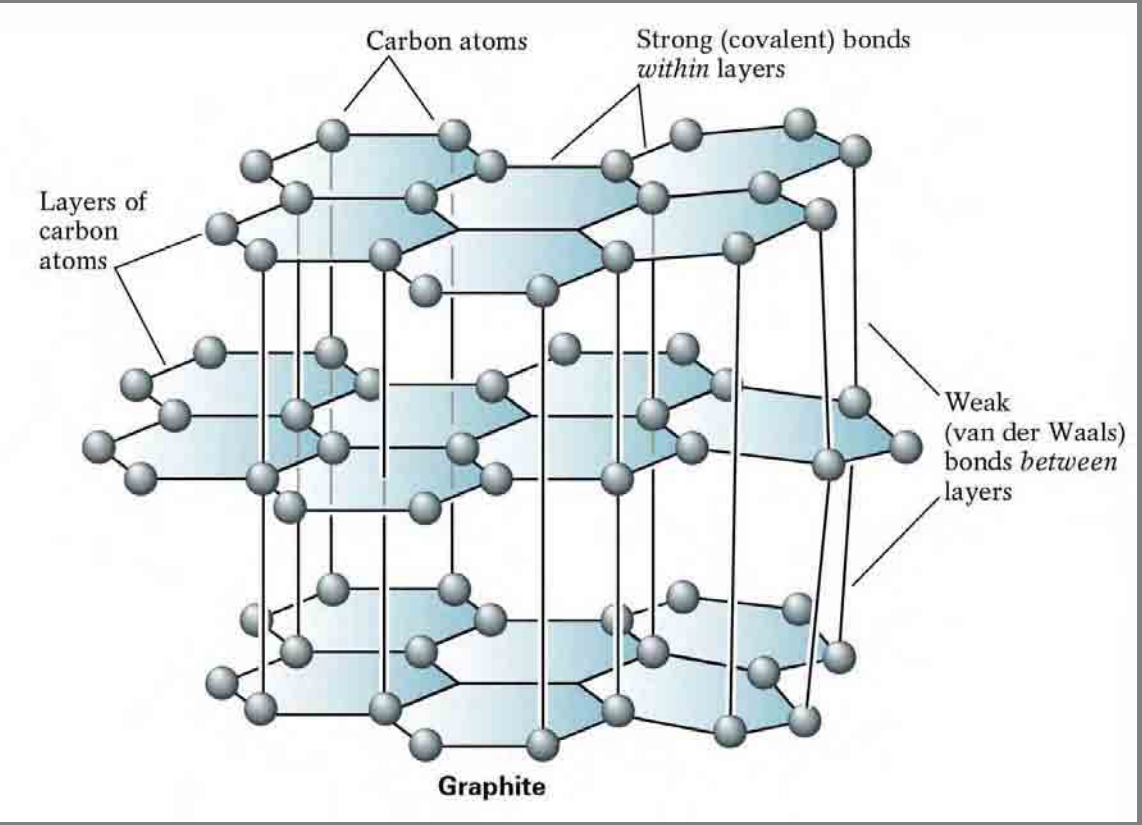


Murck and Skinner, 1999

Diamond and Graphite: The ultimate example



Wicander and Monroe, 2002



Your text: pg. 77

Why ?

- The material we have covered today is important because it can tell us how minerals are put together
- It also allows us to predict mineral behaviour

Gold in quartz, Jamestown district, California
http://www.johnbetts-fineminerals.com

The 5 requirements to become and official mineral

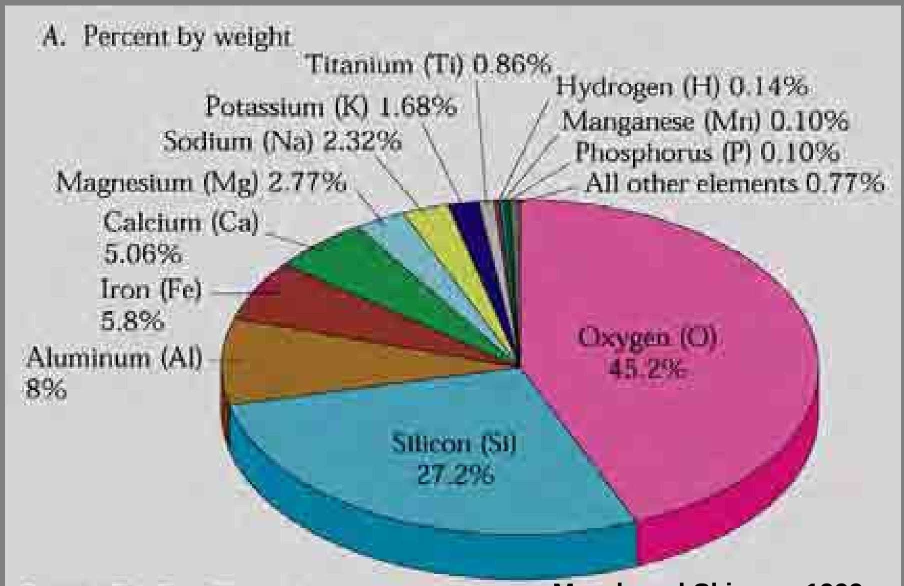
- Naturally formed
- Solid
- Formed by inorganic processes
- Specific chemical composition
- Characteristic crystal structure

Clinopyroxene megacryst, Diavik kimberlites

Zurevinski et al. 2008

Mineral Groups

- Thousands of mineral species have been identified
- Only ~20 make up the earth's crust….



Murck and Skinner, 1999

Only 12 elements occur at >0.1%....meaning that those 12 elements make up 99% of the earth's crust.

Elemental Abundance

- Given that oxygen is so abundant it is hardly surprising that it is present in many minerals
- It occurs as oxides (compounds that contain the O^{2-} anion) and as silicate anions (SiO_4^{4-}) in silicate minerals
- Less commonly it occurs as carbonates (CO_3^{2-}), sulfates (SO_4^{2-}) a phosphates (PO_4^{3-})

Rock forming Minerals

- A few silicates and oxides in conjunction with calcium sulphate and calcium carbonate comprise the majority of the Earth's crust
- These are the rock forming minerals
- Found in rocks, soils, sediments and construction materials
- Quartz and feldspar = ~75% of the Earth's crust

Accessory Minerals

- These are present in common rocks but at low abundances
- They do not determine the property of the rock but may be important sources of metals
- Trace minerals occur at even lower abundances but are also important, ex. zircon or diamond

Zircon, North Cheyenne County, Colorado, http://www.johnbetts-fineminerals.com/

Mineral Groups

MINERAL GROUP	REQUIRED ION	EXAMPLES	COMPOSITION
Carbonate	$(CO_3)^{-2}$	Calcite	$CaCO_3$
Halide	Cl^{-2}, Fl^{-1}	Halite	$NaCl$
Native Elements	not appl.	Gold	Au
Oxide	O^{-2}	Hematite	Fe_2O_3
Silicate	$(SiO_4)^{-4}$	Quartz	SiO_2
Sulfate	$(SO_4)^{-2}$	Anhydrite	$CaSO_4$
Sulfide	S^{-2}	Pyrite	FeS_2

Physical Properties of Minerals

- Very good review of this in your lab manual
- Luster: Metallic Luster or Non-metallic Luster

Gold in quartz, Jamestown district, California
http://www.johnbetts-fineminerals.com/

Physical Properties of Minerals

Colour

- on a fresh surface in reflected light
- The colour or lack of colour may be diagnostic
- Be careful- it can vary due to small differences in chemical composition!
- Small impurities may also change the colour

Hardness

- The resistance to abrasion (scratchability)
- Determined by either trying to scratch a mineral of unknown hardness with a substance of known hardness or by using the unknown mineral to scratch a substance of known hardness.
- Mohs Scale of hardness: 10 minerals arranged by hardness (page 83 in your text)

Physical Properties of Minerals

Cleavage

- Defined as the tendency of a mineral to break along definite planes of weakness that exist in the internal structure
- It is almost impossible to break some minerals in such a way that cleavage planes do not develop. Calcite and pyrite are great examples
- A well defined cleavage plane will reflect light off of it's very smooth surface
- Look for repetitions in the breaks of the crystal
- Do not be confused with mineral growth faces, such as quartz!
- If there is no cleavage, there is fracture. ex: conchoidal fracture patterns in obsidian (Fig 3.12 pg 82), or the fibrous fracture of asbestos

Physical Properties of Minerals
Streak

- The colour of a mineral powder, produced from rubbing the mineral against a porcelain streak plate, either black or white
- Some minerals have a very unique colour ex: hematite
- In general, metallic minerals have a unique streak colour
- Limitation: the streak plate hardness is ~7

Physical Properties of Minerals

Tenacity

- An index of a mineral's resistance to be broken…or bent..
- Many terms are used to describe tenacity, some examples in your lab manual are brittle, elastic, flexible

Diaphaneity

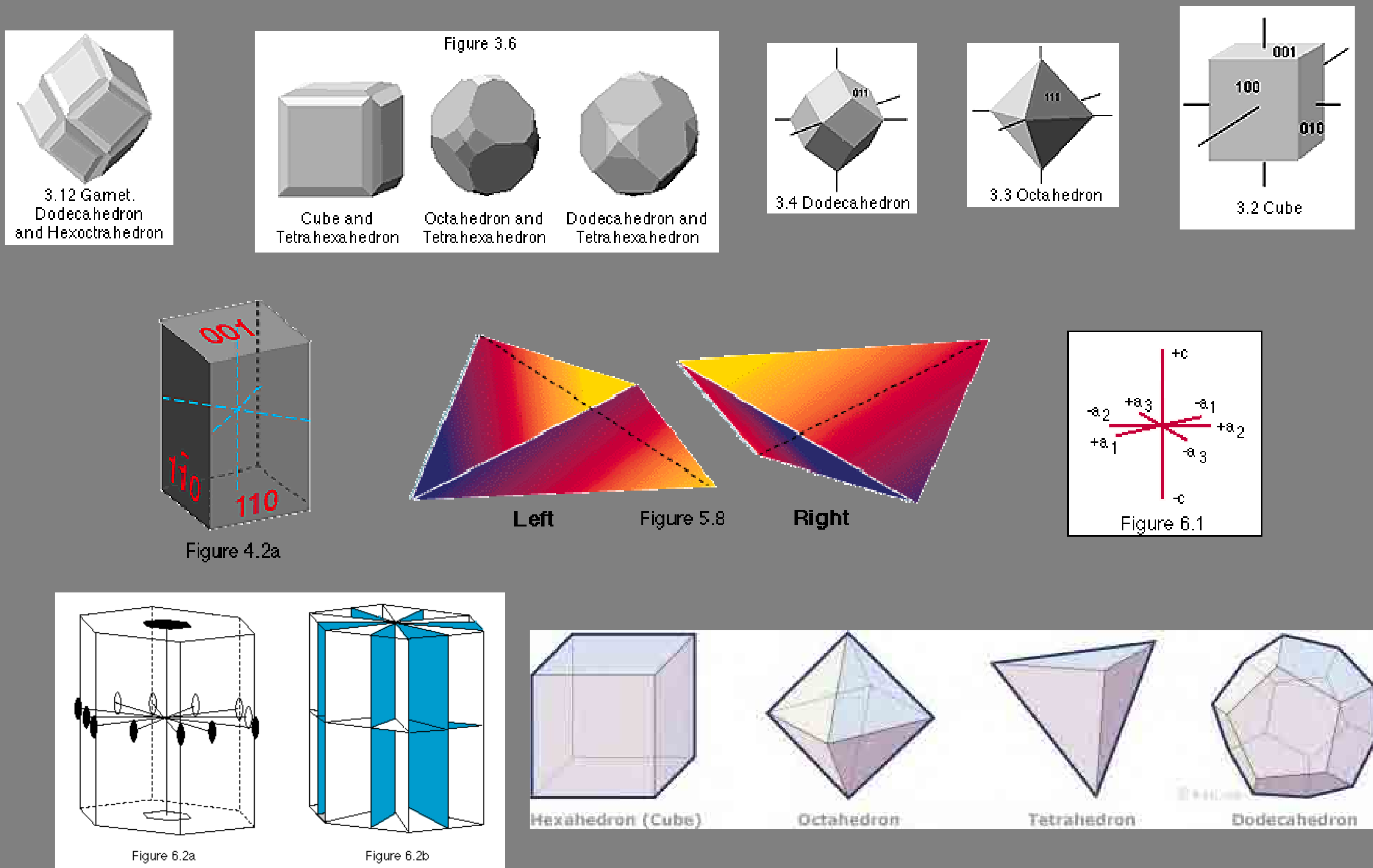
- The ability of a mineral to transmit light
- Transparent, translucent, opaque
- Limitation: some minerals change properties with differing thicknesses..

Physical Properties of Minerals

Crystal Form

- The assemblage of crystal faces that constitute the exterior surface of the crystal
- Crystal Symmetry is the geometric relationship between the crystal faces
- Opposite: Amorphous
- 6 main crystal systems: Cubic (or isometric), tetragonal, hexagonal, orthorhombic, monoclinic, triclinic

Crystallography in a nutshell



Bobsrocks.com

Physical Properties of Minerals

“Others”

- Magnetism

  Lodestone compasses
- Double refraction (very cool, Calcite)
- Taste (Rock Salt, NaCl)
- Odor (Sulfur, Sphalerite ZnS)
- Feel (talc is greasy,hornblende is rough)
- Chemical reaction with HCL

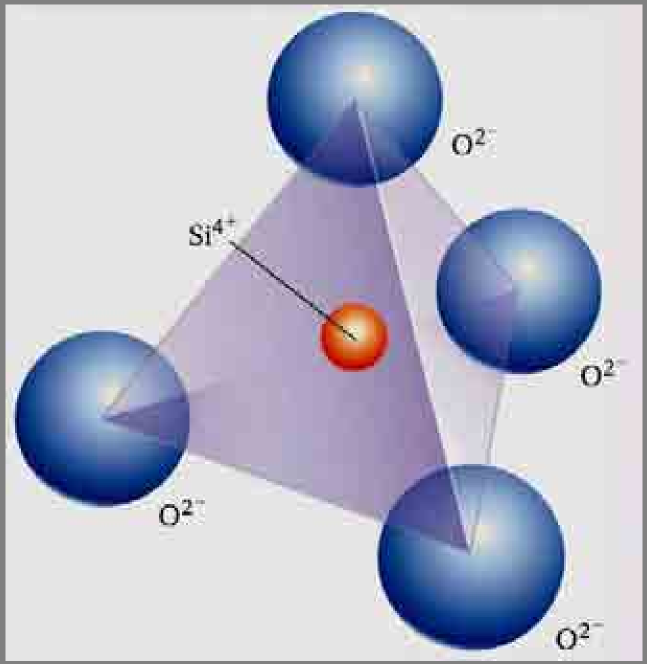
Returning to the Mineral Groups:

Minerals can be divided into several groups. Members of a group all contain the same negatively charged ion or ion group

MINERAL GROUP	REQUIRED ION	EXAMPLES	COMPOSITION
Carbonate	$(CO_3)^{-2}$	Calcite	$CaCO_3$
Halide	Cl^{-2}, Fl^{-1}	Halite	$NaCl$
Native Elements	not appl.	Gold	Au
Oxide	O^{-2}	Hematite	Fe_2O_3
Silicate	$(SiO_4)^{-4}$	Quartz	SiO_2
Sulfate	$(SO_4)^{-2}$	Anhydrite	$CaSO_4$
Sulfide	S^{-2}	Pyrite	FeS_2

The Silicates

- Given that O and Si are the most abundant elements it is not surprising that they form an important compound - the silicate anion
- The basic building block is the tetrahedra
- This is an unbalanced anion
- Pg 85 Fig. 3.14



Chernicoff & Whitney, 2001

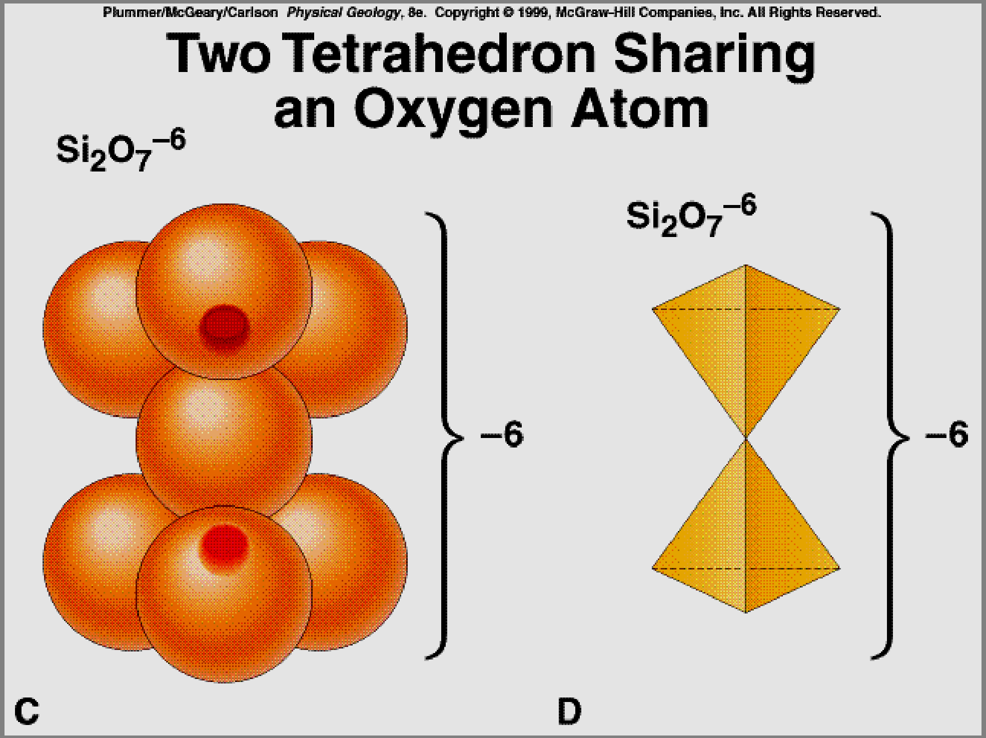
The Silicates

- The tetrahedra bond in many ways

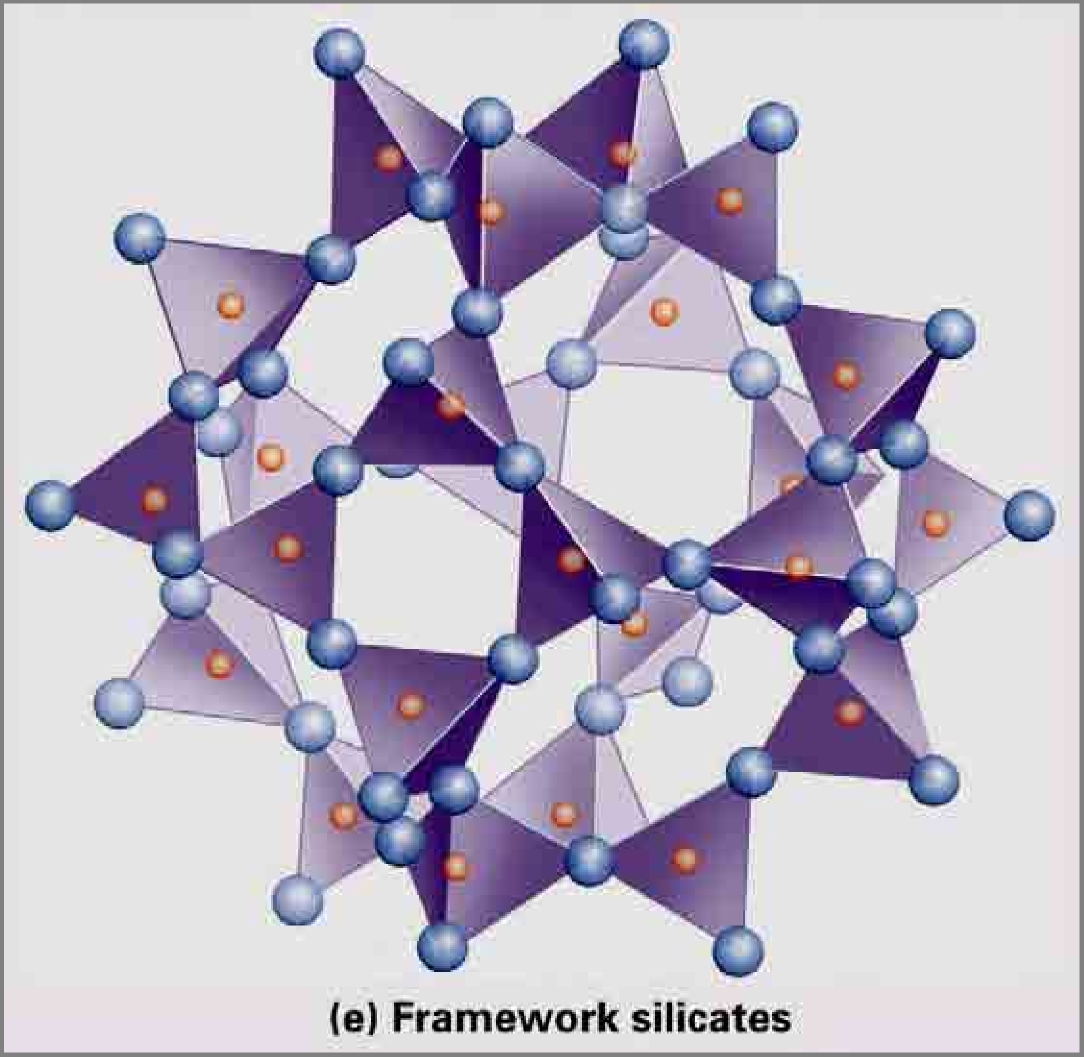
•Polymerisation: the sharing of the O between the tetrahedra

•It is how they bond that define each of the members of the silicate group

•They are also defined by the cations that occupy the site, as well as how the cations are distributed

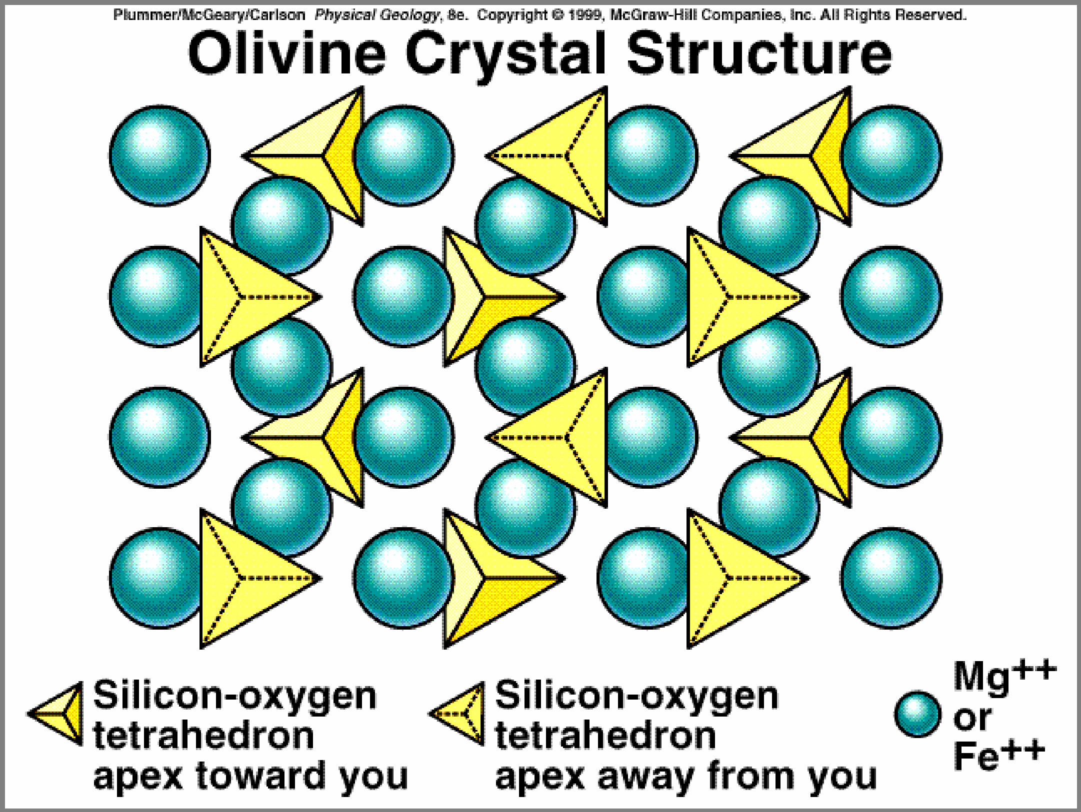


Plummer et al. 2001



Chernicoff and Whitney, 2002

- Quartz
- Feldspar
- Si:O = 1:2



Plummer et al. 2001

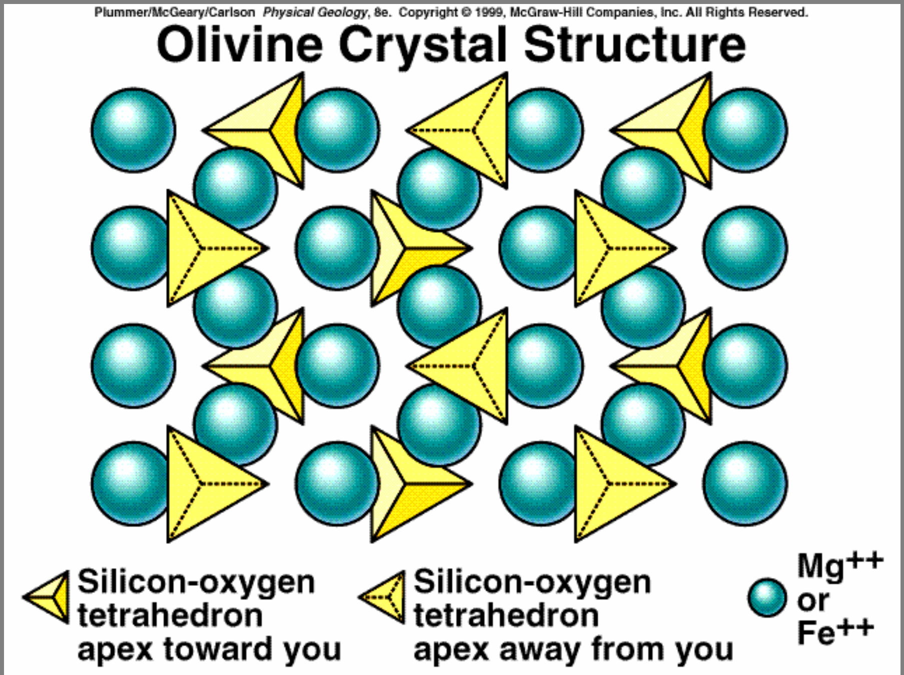
Another way: Individual tetrahedra bond together by positive ions (pg. 86 Fig. 3.15)

Murck and Skinner, 1999

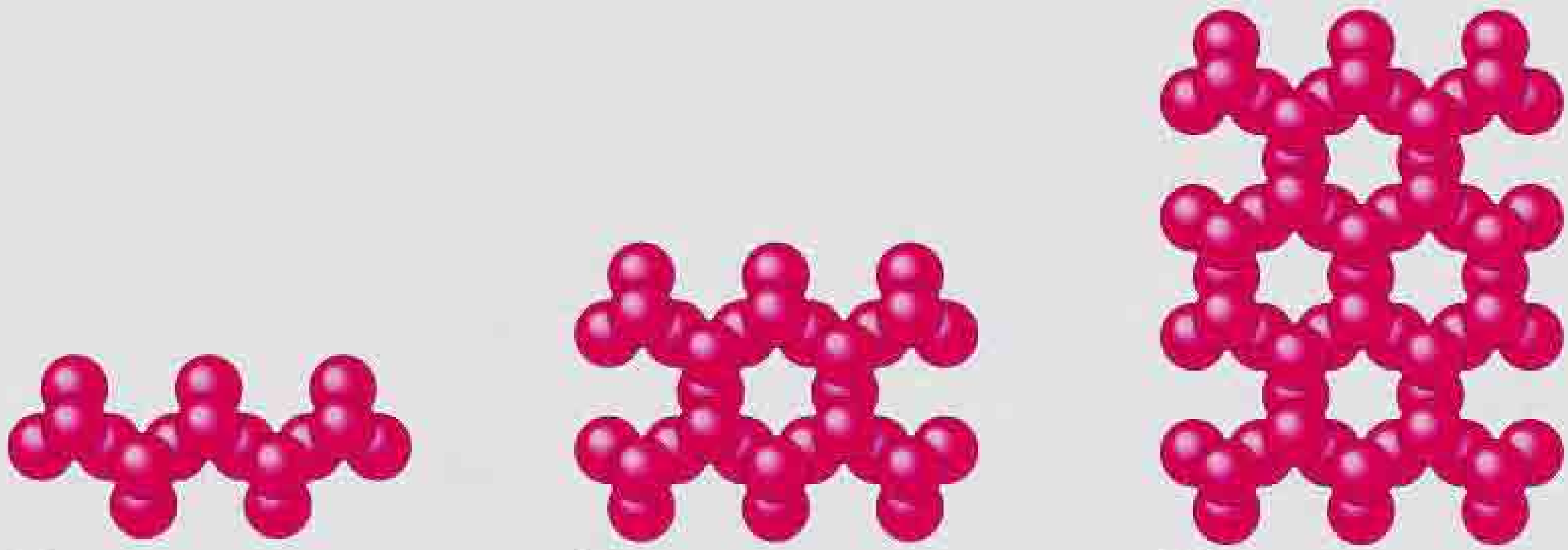
Olivine

- a very important mineral on earth
- $(Mg,Fe)_2SiO_4$
- alpha, beta, gamma olivine
- Si:O = 1:4

- Mg and Fe share some of the O with the Si atoms to form a neutral compound



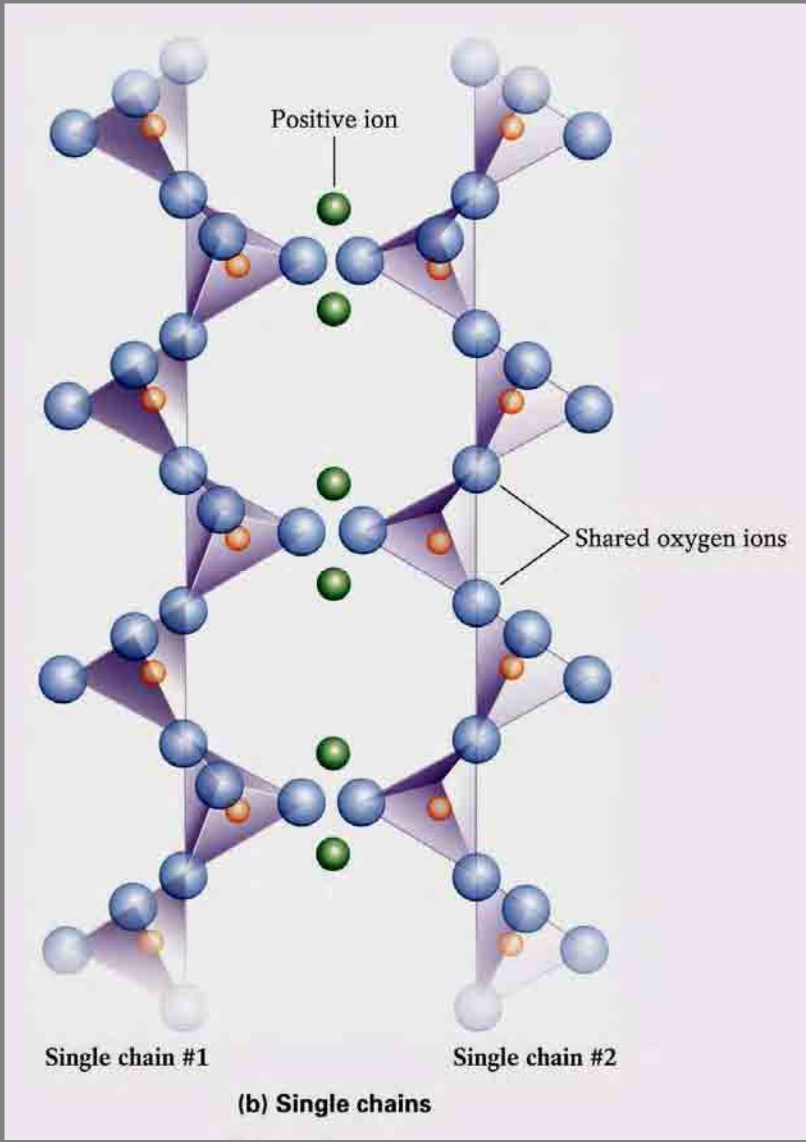
Silicates


A. Single chain
B. Double chain
C. Sheet

Murck and Skinner, 1999

Chain Silicates

- Two O atoms of each tetrahedra are joined
- Chains bound by +ve ions
- Gives minerals a columnar, needle or fibre shape
- Si:O = 1:3
- example : Pyroxene
- pg. 88, Fig. 3.16

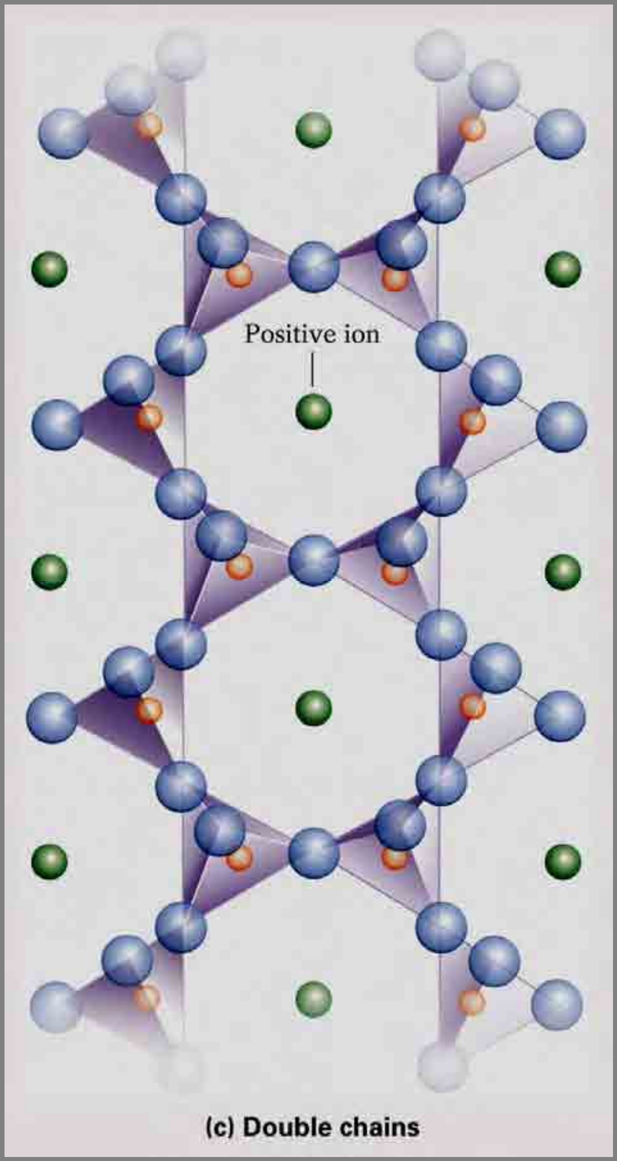


Chernicoff and Whitney, 2002

Double Chain Silicates

- Alternate tetrahedra share a third O atom
- Chains bound by +ve ions
- Minerals tend to be elongate

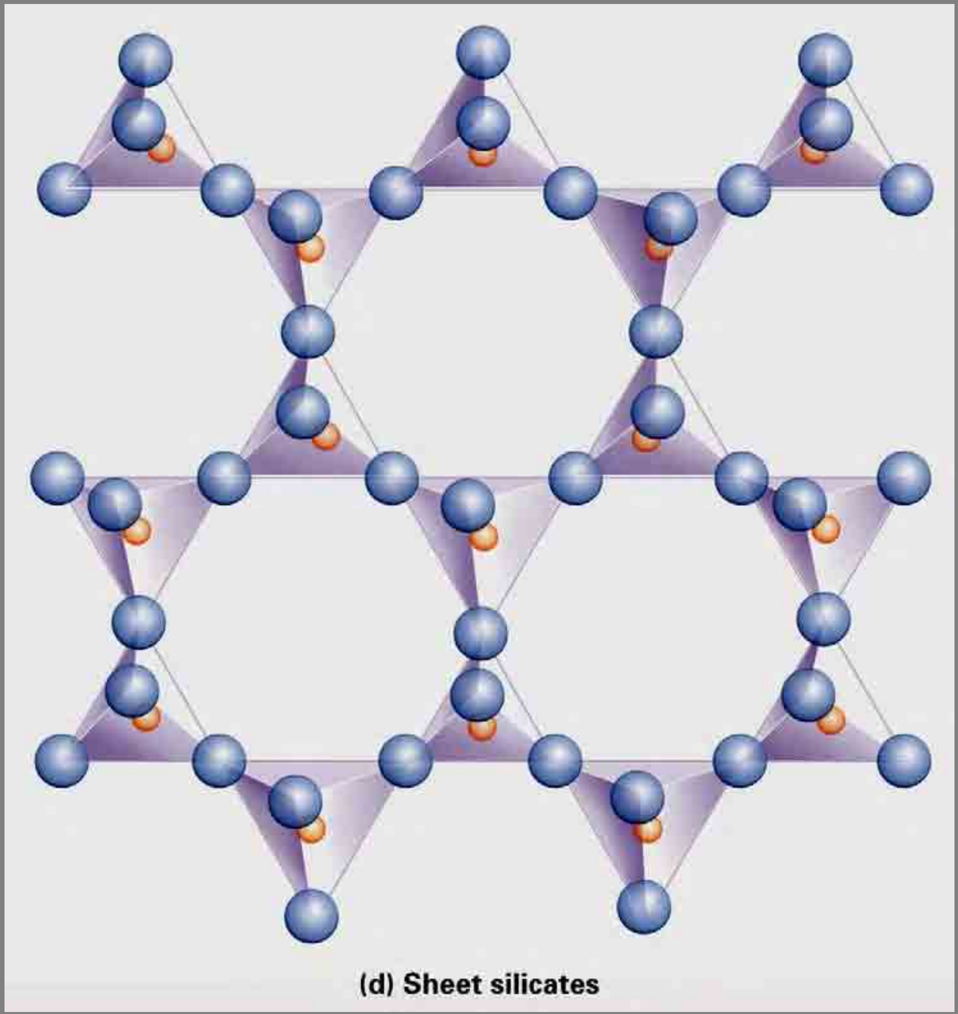
- Amphibole



Chernicoff and Whitney, 2002

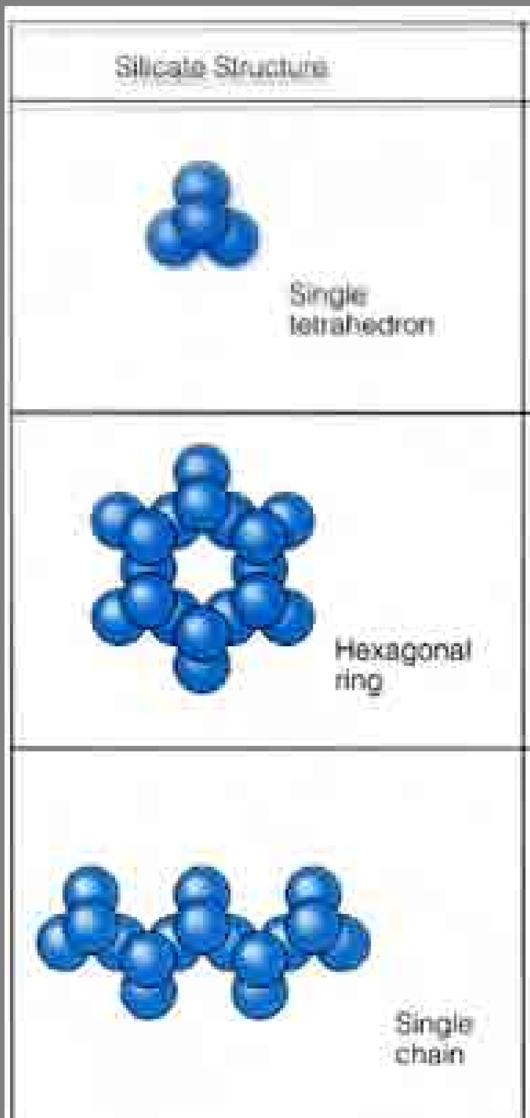
Sheet Silicates

•Tetrahedra share three O atom
•Sheets bound by +ve ions
•Minerals tend to be platy or flakey
• pg 89, Fig. 3.18 and 3.19



Chernicoff and Whitney, 2002

A review of the Silicate Structure and minerals



Murck and Skinner, 1999

Olivine
Mg_2SiO_4

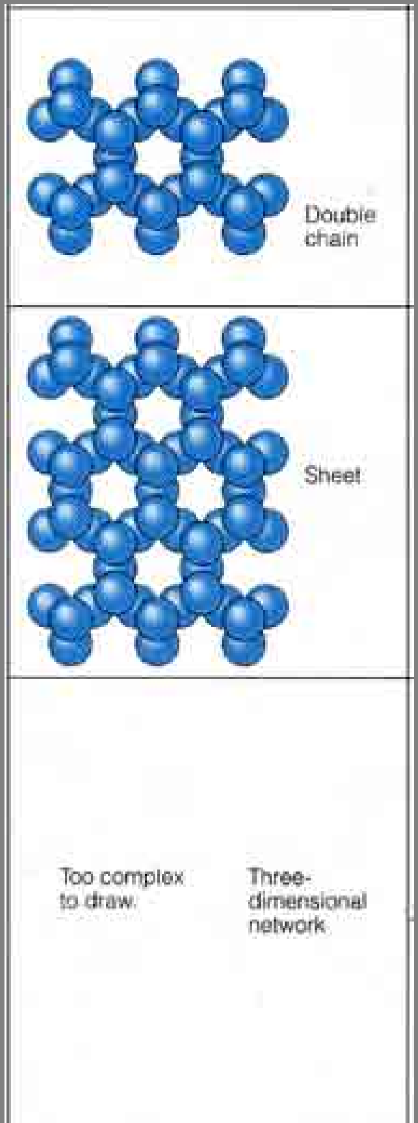
Peridot Soppat, Pakistan http://www.exceptionalminerals.com

Beryl
$Be_3Al_2Si_6O_{18}$

Beryl, Skardu, Pakistan
http://www.johnbetts-fineminerals.com/

Pyroxenes
$CaMg(SiO_3)_2$

Diopside, Nanbu Oho, Japan, http://www.johnbetts-fineminerals.com/



Murck and Skinner, 1999

Amphibole group

$Ca_2Mg_5(Si_4O_{11})_2(OH)_2$


Chernicoff and Whitney, 2002

Mica group

K-Feldspar

$KAlSi_3O_8$


Chernicoff and Whitney, 2002

Other mineral groups

- Oxides - the second most abundant mineral group
- The O^{2-} anion is bonded to common cations in a variety of ways
- Two of the more common are magnetite (Fe_3O_4) and hematite (Fe_2O_3)

Oxides

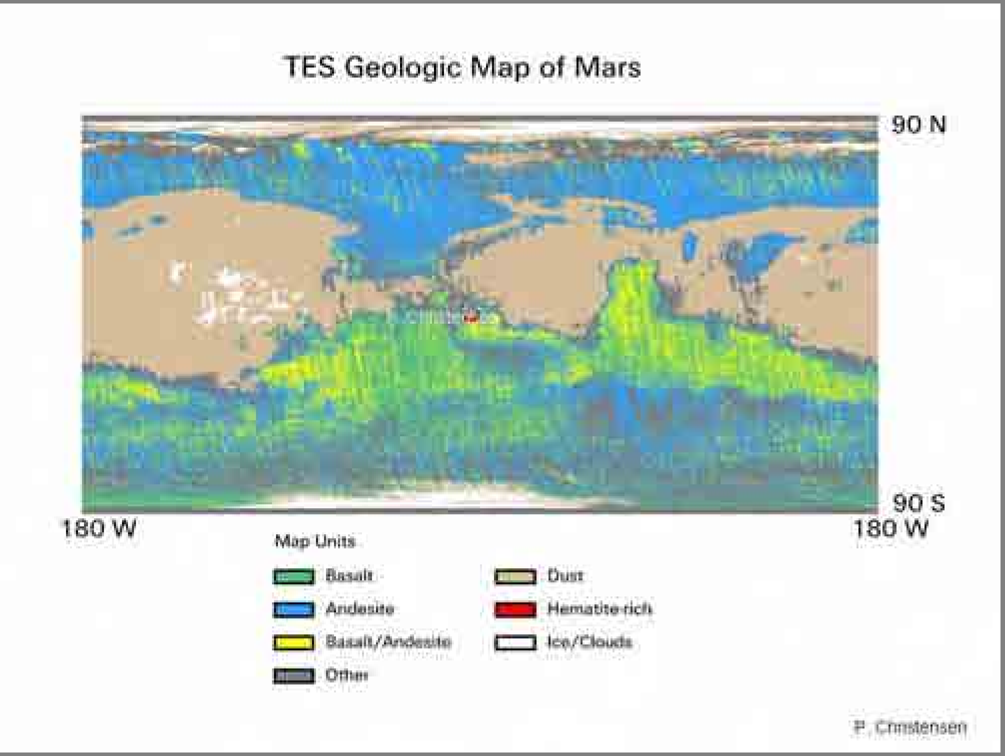
Hematite
Fe_2O_3

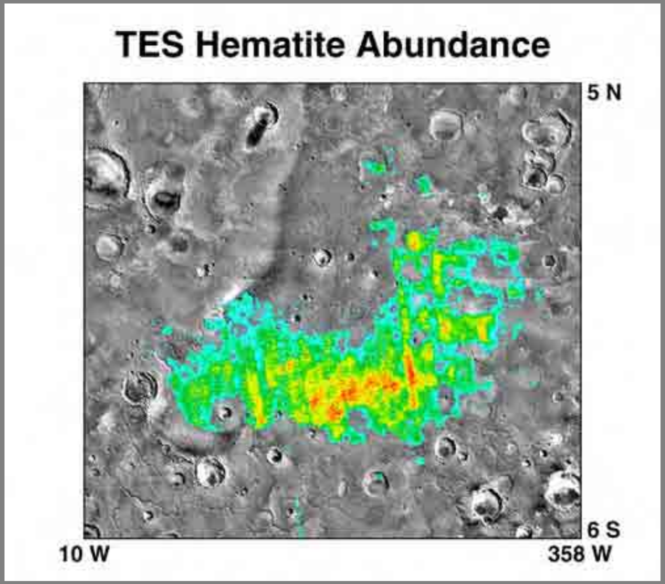
Magnetite
Fe_3O_4

http://www.johnbetts-fineminerals.com/

Oxides

Hematite: it's pretty and it's important- even on Mars! It forms from a precipitate where there is standing water, and from volcanic activity.





http://marsrovers.nasa.gov/spotlight/images/hematite

Other important oxides:

- – Uraninite (UO_2)
- – Cassiterite (SnO_2)
- – Rutile (TiO_2)

Cassiterite, Schlaggenwald, Czech Republic http://www.johnbetts-fineminerals.com/

Sulphides

Sphalerite, Pyrite and Galena, Eagle Mine, Colorado
http://www.johnbetts-fineminerals.com/

Pyrrhotite, Calcite & Quartz, El Potosi Mine, Mexico
http://www.johnbetts-fineminerals.com/

Carbonates

Calcite , San Giovanni Mine, Italy
http://www.johnbetts-fineminerals.com/

Calcite and Dolomite, Tsumeb Mine, Namibia
http://www.johnbetts-fineminerals.com/

Calcite $CaCO_3$


Andrew Alden, About.com


Crystalcure.com

Calcite in the form of white marble was the primary stone used in the Supreme Court building. © iStockphoto and Gary Blakeley.

Carbonates

Cerussite, Tsumeb Mine, Namibia
http://www.johnbetts-fineminerals.com/

Azurite, Tsumeb Mine, Namibia
http://www.johnbetts-fineminerals.com/

Lead and Copper carbonates

Phosphates

Fluorapatite, Emmons Quarry, Maine
http://www.johnbetts-fineminerals.com/

Vanadinite, Mibladen, Morocco
http://www.johnbetts-fineminerals.com/

Sulfates

Gypsum, Paris Basin, France
http://www.johnbetts-fineminerals.com/

Naica Crystal cave, Ag mine, Mexico

Native elements: Copper

Copper, Keweenaw Peninsula, Lake Superior, Michigan http://www.johnbetts-fineminerals.com/

Native Copper, White Pine Mine, Michigan http://www.johnbetts-fineminerals.com/

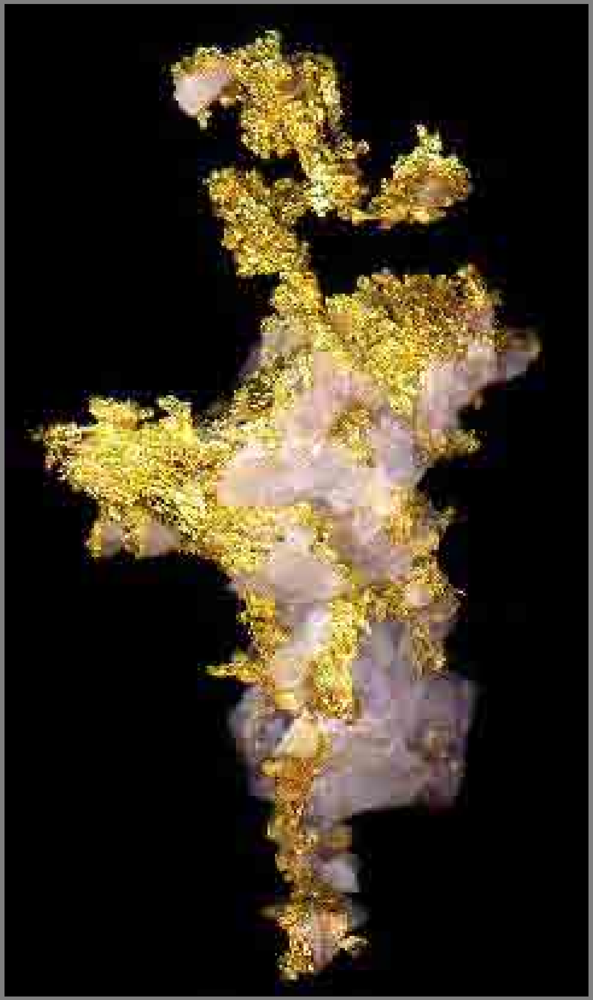
Native elements: Silver

Silver, La Nevada Mine, Mexico
http://www.johnbetts-fineminerals.com/

Silver, Kongsberg, Norway
http://www.johnbetts-fineminerals.com/

Silver ‘cobra’,
Uchucchacua Mine*,*
Peru
http://www.exceptionalminerals.com/

Native elements: Gold



Gold, Sierra County, California
http://www.johnbetts-fineminerals.com/

Gold in quartz, Jamestown district, California
http://www.exceptionalminerals.com/

Common uses of minerals in industry pgs.95-104 text

- Abrasives: Industrial diamond
- Aggregates: Limestone, dolomite
- Cements: Asbestos, gypsum
- Ceramics: Feldspar, barite, REMs
- Drilling Fluids: Barite
- Electronics: Beryllium, graphite, REMs
- Fertilizers: Limestone, nitrates, phosphates
- Absorbants: Kaolinite, talc
- Glass: Felspar, silica, borates
- Insulation: Asbestos, mica group
- Lubricants: Graphite

Metals

- 35 metallic elements in total
- 6 are abundant: Si, Al, Fe, Mg, Ti, Mn
- Expensive to mine, must have high tonnage
- The Al example: bauxite ore (form by weathering processes in tropical climates)

http://gccweb.gccaz.edu/earthsci/imagearchive/picture3.htm

BIFs: Banded Iron Formations

A banded-iron formation (BIF) rock recovered from the Temagami greenstone belt in Ontario, Can., and dated to 2.7 billion years ago. Dark layers of iron oxide are intercalated with red chert.
Prof. Dr. Michael Bau/Jacobs University Bremen

BIFs

- Date back from Early Proterozoic time (2.8 to 1.6 Ga)
- Lack of O_2 in the atmosphere during this period
- With O_2, Fe will precipitate in ferric (+3) form, however, low O_2 conditions Fe is mobile (by weathering processes) and dissolves in rivers and streams, eventually precipitating out in the layers
- Photosynthesis began to release O_2 in the atmosphere, therefore, Fe became immobile
- Metamorphosed
- Lake Superior
- Pgs 96-97 text, Fig. 3.27 and 3.28

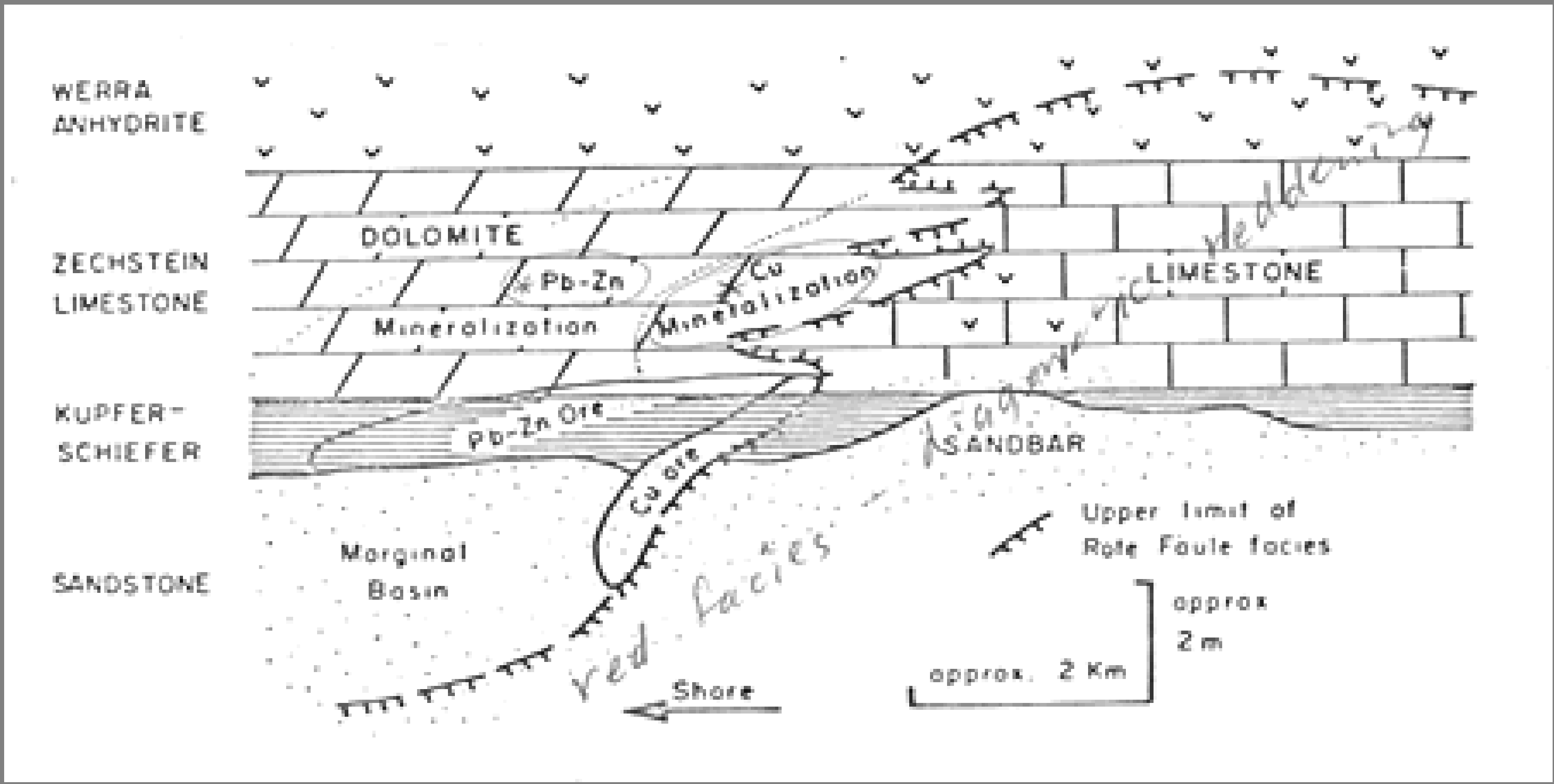
The scarce metals:

- Extraction is only feasible with high conc.
- 4 groups: ferro-alloy, base metals, precious and special metals
- Ferro-alloy metals: Cr, Co, Mo, Ni, W, V are added to Fe to make industrial minerals
- Base Metals: Cd, Cu, Zn, Pb, Sn, useful for electronics and coins (brass, bronze)
- Au, Ag, and PGEs are the precious metals
- Specials are from the rare metals

MVTs: Mississippi Valley Type Pb-Zn deposits

- Carbonate hosted Pb and Zn ore deposits
- Former marine basins
- Dissolution and transportation or the ore fluid
- Precipitation out of solution
- Large cavities and voids in the carbonate
- Sphalerite (ZnS) and Galena (PbS)

MVTs



www.dmtcalaska.org/

Construction

Next Class:

- Igneous rocks and processes
- Ch. 4