Minerals and their Engineering Properties

Engineering Geology
Fall 2016

- Rock = Σ minerals
- About 2000 minerals and 100 chemical elements
- Mineral = inorganic crystalline structure
- Homogeneous substance, definite chemical composition, definite internal structure
- Under ideal conditions = crystals

Ten critical elements found in most rocks and soils

SiO_2
Al_2O_3
Fe_2O_3
CaO
Na_2O
K_2O
MgO
TiO_2
MnO
P_2O_5

Sum = 100%

Element Bonding

- Ionic bonds – weak and can be attacked by water molecules
  Minerals: reactive, soluble, breakdown
- Covalent bonds – strong
  Minerals: durable and inert

Paragenesis

- Community of minerals
  - Igneous
  - Sedimentary
  - Metamorphic
- Identification of Minerals
  - Examination of hand specimen
  - Examination of thin slices (0.03 mm) using optical properties of minerals

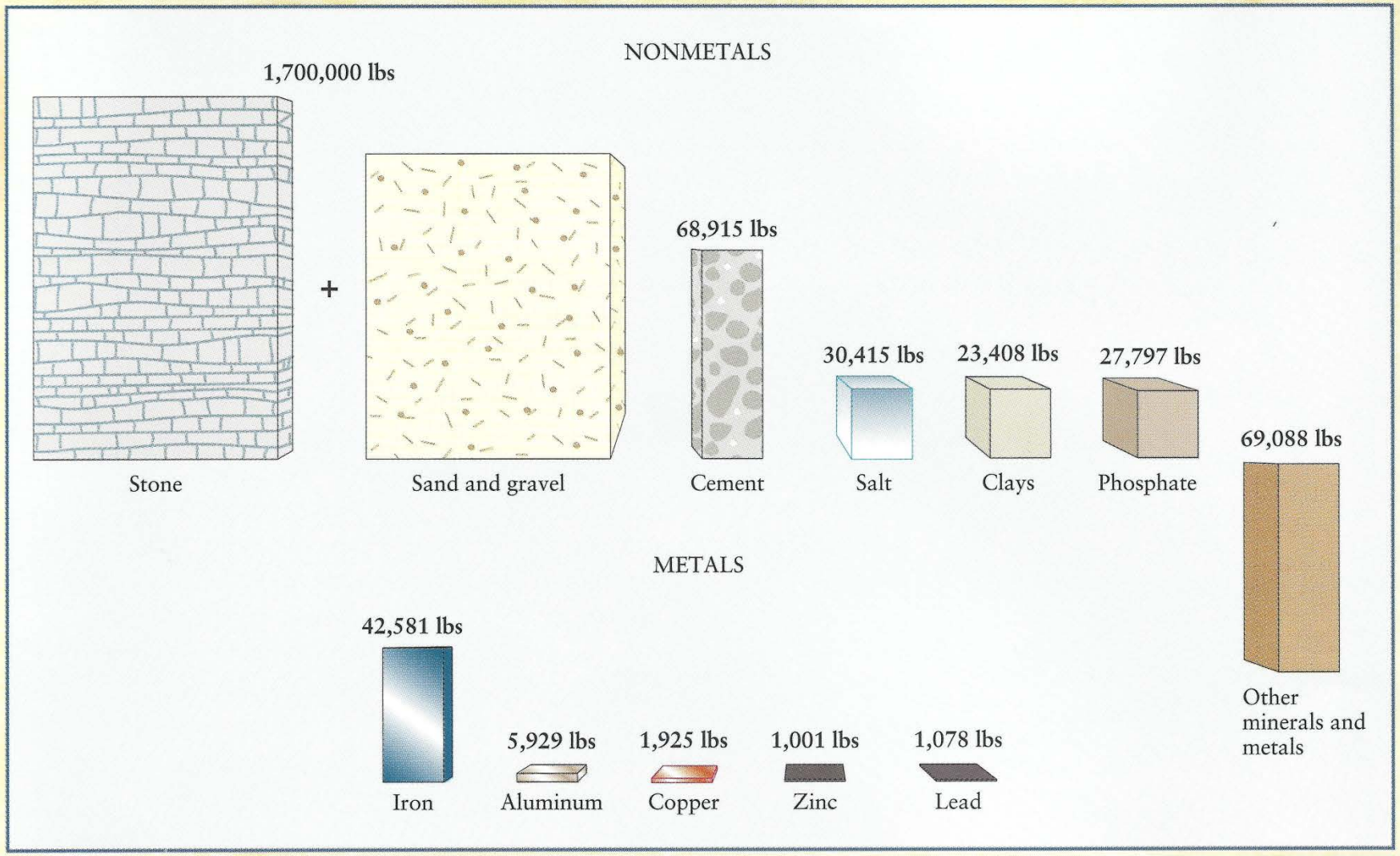


Figure 1 *Every American born will need nearly 2 million pounds of minerals and metals in a lifetime.* (*Mineral Information Institute*, 2000).

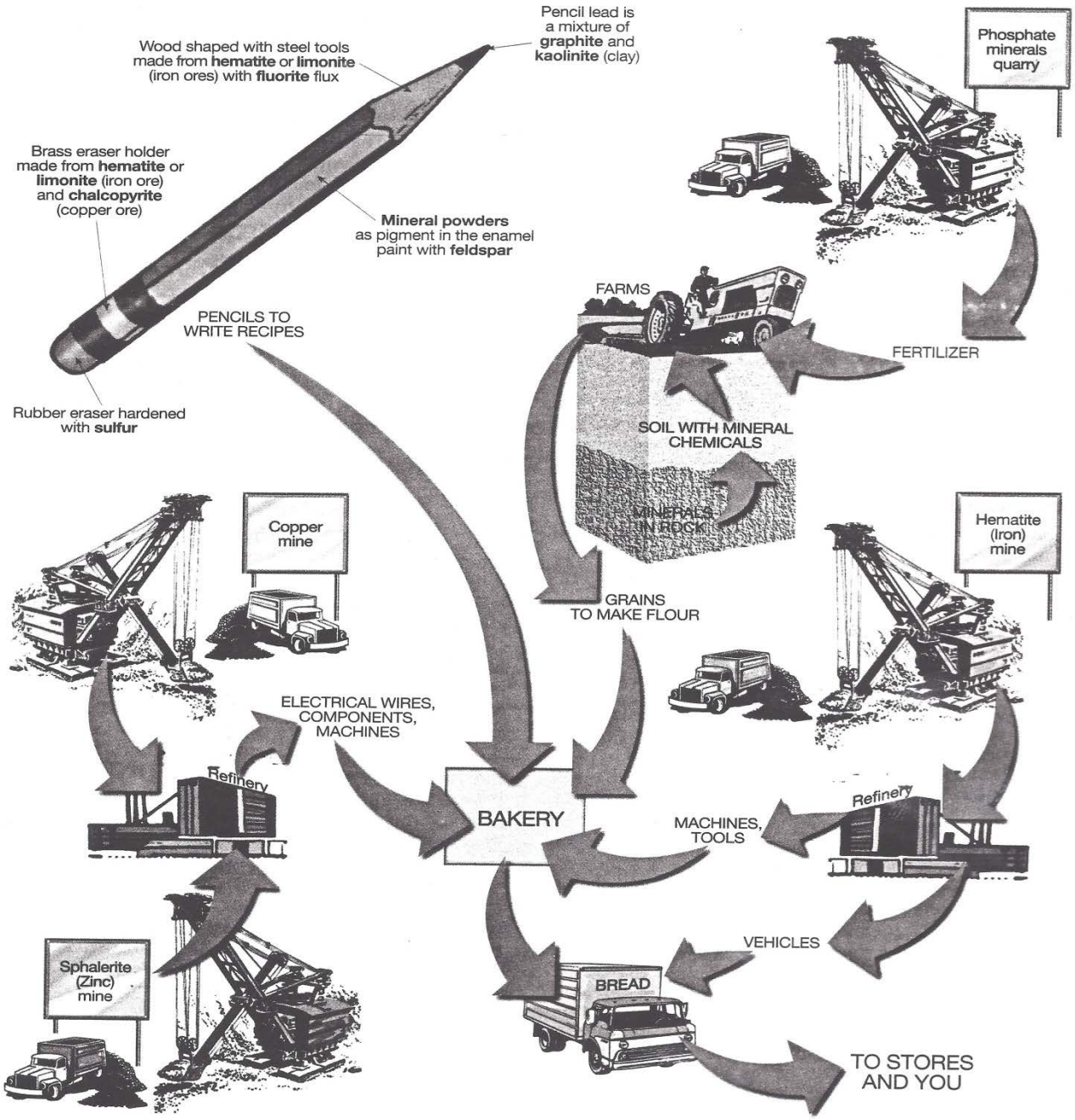
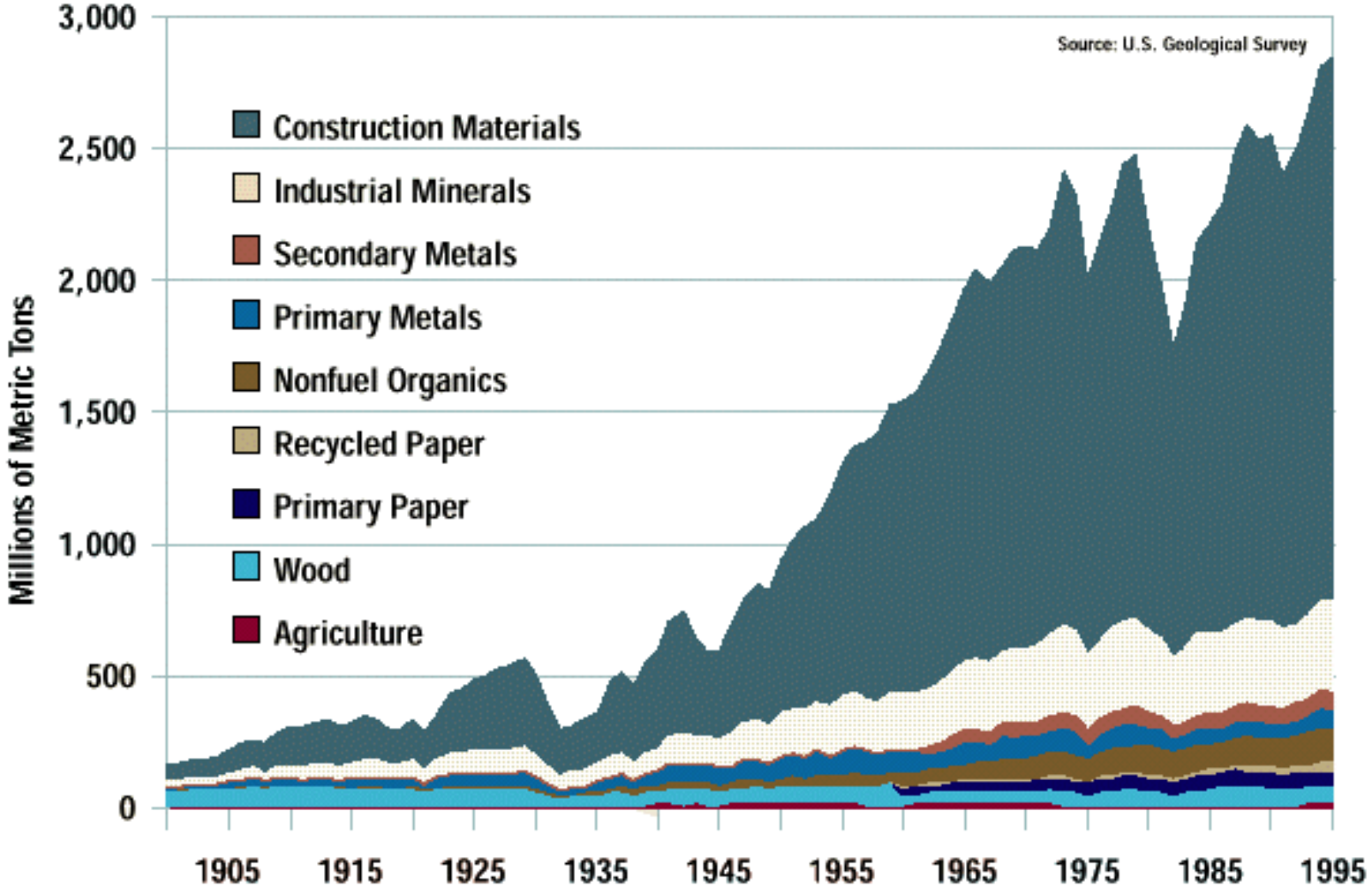
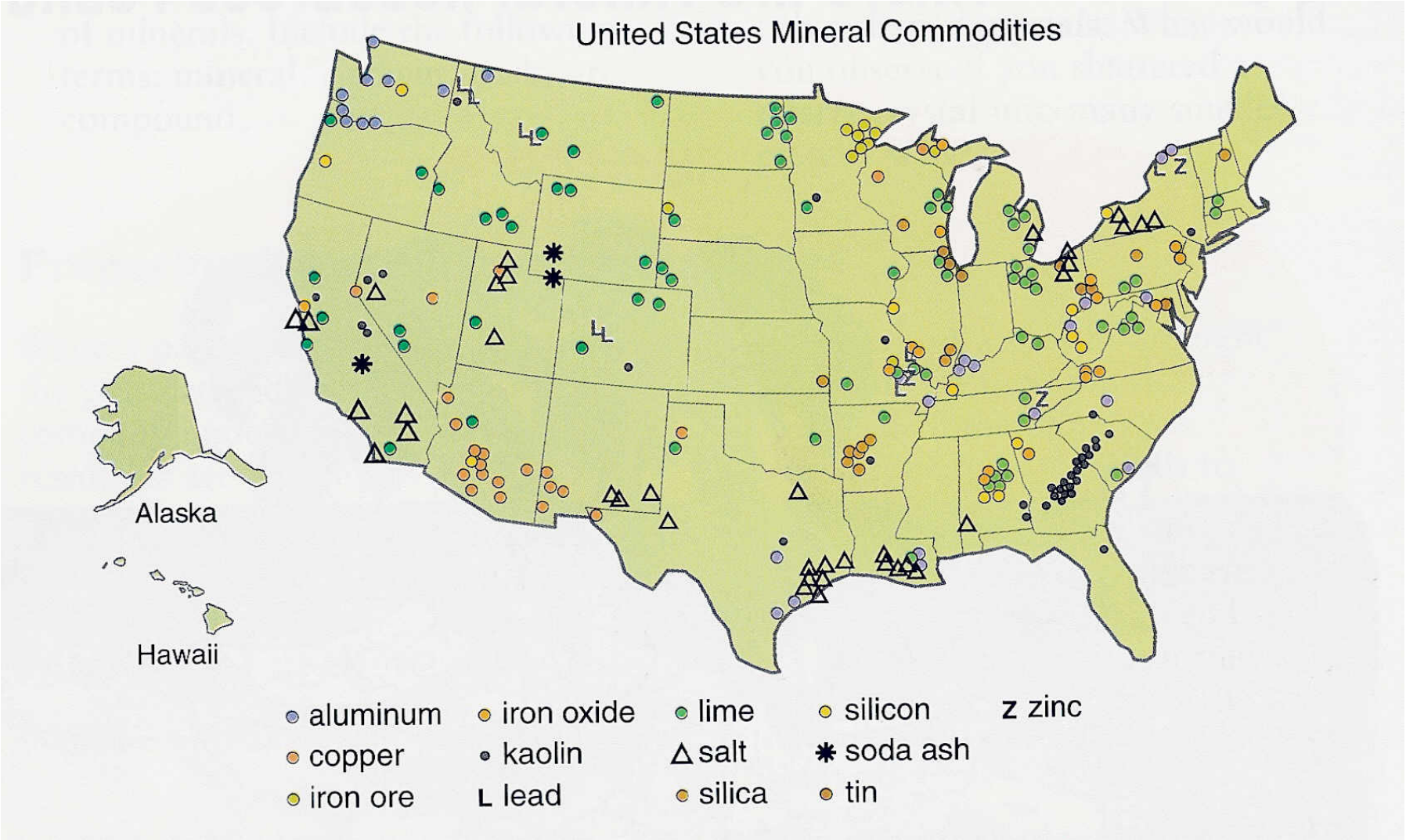


FIGURE 2.2 Descriptions of how minerals have been used to manufacture some common items that you probably use everyday.



[Additional Maps]



http://minerals.usgs.gov/

http://pubs.usgs.gov/of/2014/1082/pdf/ofr2014-1082.pdf

Display

A mobile device's glass screen is very durable because glassmakers combine its main ingredient, **silica** (silicon dioxide or quartz) **sand**, with ceramic materials and then add potassium.

Layers of indium-tin-oxide are used to create transparent circuits in the display. Tin is also the ingredient in circuit board solder, and **cassiterite** is a primary source of tin.

Gallium provides light emitting diode (LED) backlighting. **Bauxite** is the primary source of this commodity.

Sphalerite is the source of indium (used in the screen's conductive coating) and germanium (used in displays and LEDs).

Banner image courtesy of freevector-archive.com

Electronics and Circuitry

The content of copper in a mobile device far exceeds the amount of any other metal. Copper conducts electricity and heat and comes from the source mineral **chalcopyrite**.

Tetrahedrite is a primary source of silver. Silver-based inks on composite boards create electrical pathways through a device.

Silicon, very abundant in the Earth's crust, is produced from the source mineral quartz and is the basis of integrated circuits.

Arsenopyrite is a source of arsenic, which is used in radio frequency and power amplifiers.

Tantalum, from the source mineral **tantalite**, is added to capacitors to regulate voltage and improve the audio quality of a device.

Wolframite is a source of tungsten, which acts as a heat sink and provides the mass for mobile phone vibration.

Battery

Spodumene and subsurface brines are the sources of lithium used in cathodes of lithium-ion batteries.

Graphite is used for the anodes of lithium-ion batteries because of its electrical and thermal conductivity.

Speakers and Vibration

Bastnaesite is a source of rare-earth elements used to produce magnets in speakers, microphones, and vibration motors.

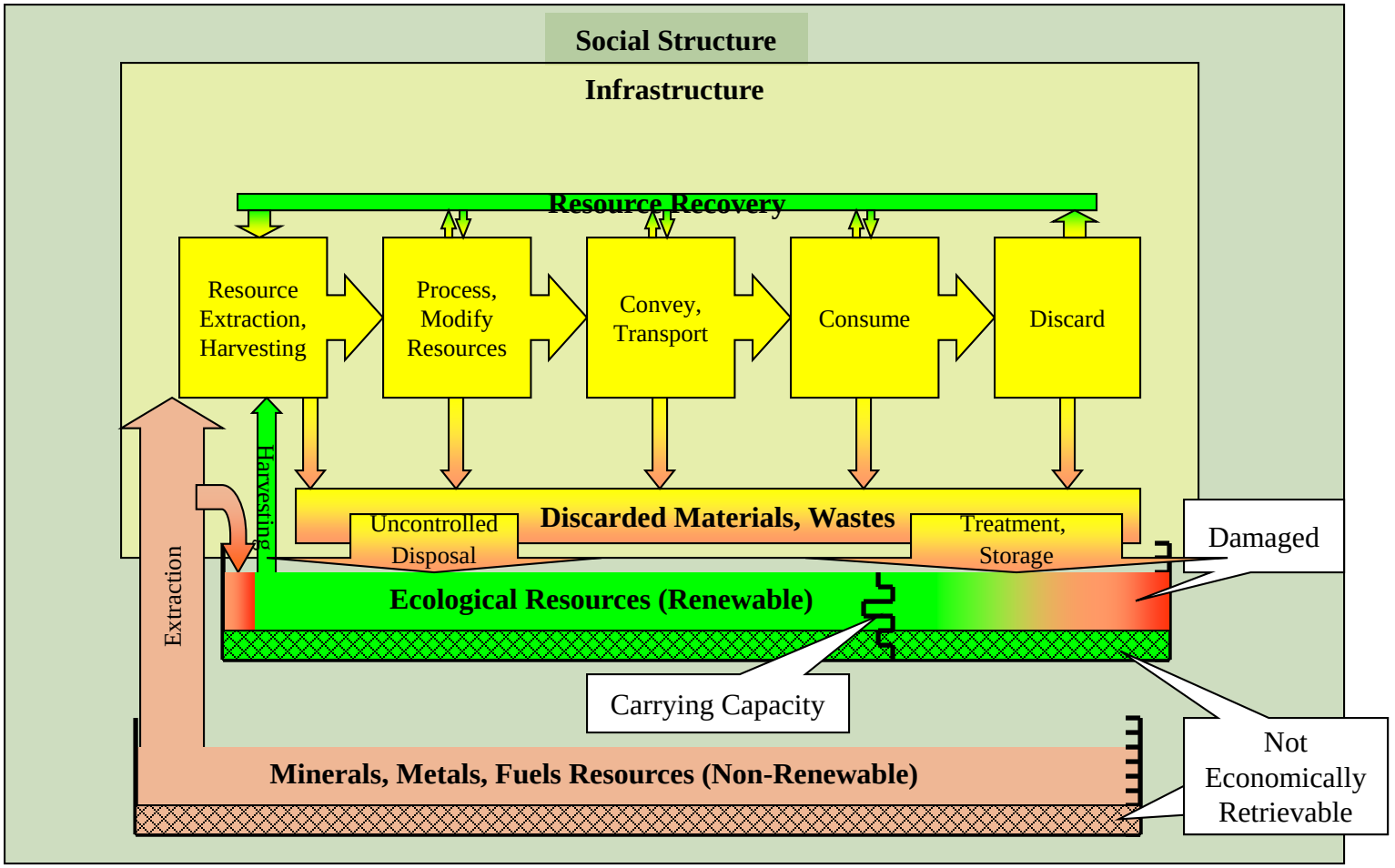
Laptop Computer

"On an all-in basis, counting everything processed and distilled into those 10 lbs, it weighs as much as 40,000 lbs, and its manufacturers, going all the way back to the mines and wellheads, created huge abuse to Earth through extractive and polluting processes to make it."

(Ray Anderson, 1998).

Production-Consumption Model

Adapted from D. Roberts and W. Wallace



Cradle to Grave (Take – Make – Waste)

Copper

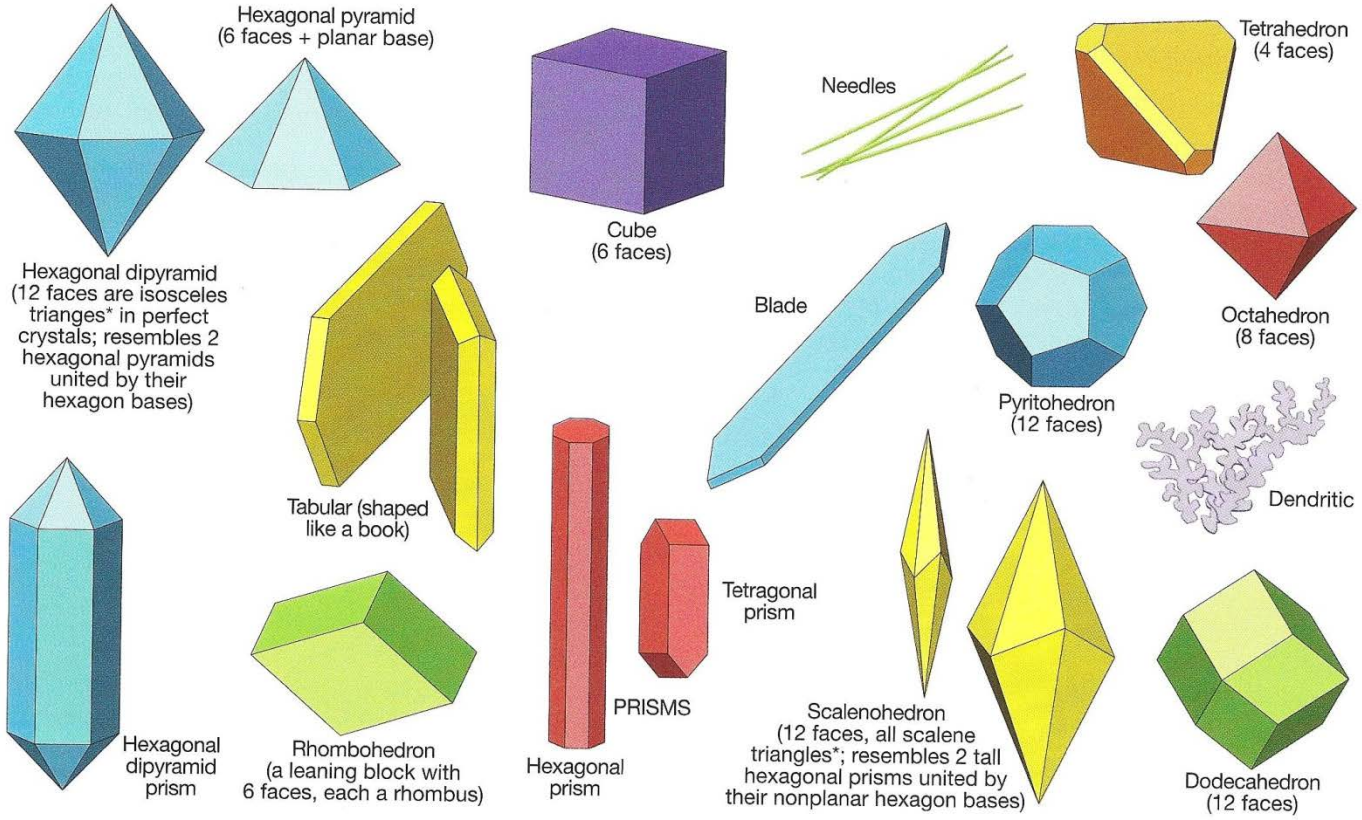
- Base metal
- 0.0058% of Earth's crust by weight
- Main rock = Chalcopyrite $CuFeS_2$

Element	Atomic mass unit (g/mol)	Number of atoms	Total mass (g/mol)
Cu	63.54	1	63.54
Fe	55.85		
S	32.06		
			Sum (∑) =

Identification of Minerals

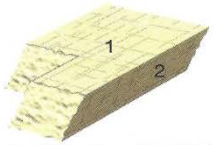
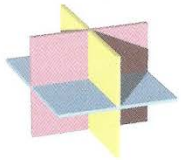
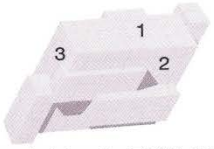
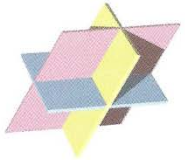
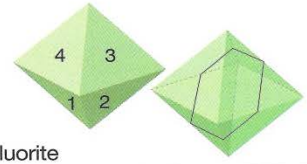
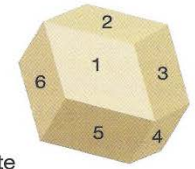
http://www.bing.com/videos/search?q=minerals+videos&FORM=VIRE13#view=detail&mid=2E1A08DEDCA54D04BA7F2E1A08DEDCA54D04BA7F

Crystal symmetry



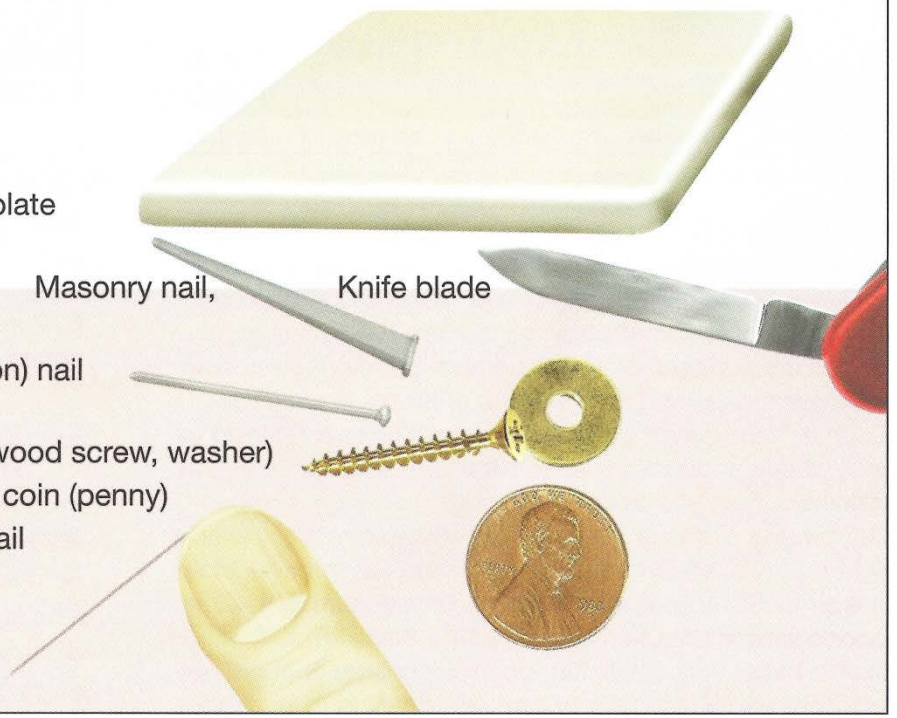
*Isosceles triangles have two sides of equal length and scalene triangles have no sides of equal length.

FIGURE 3.3 Some *crystal forms* (geometric shapes) or habits. The flat outer surfaces of these forms are called *crystal faces*. Crystal form is an external feature of mineral crystals. *Massive* form refers to cases where mineral crystals are so tightly intergrown that no distinguishing crystal form is visible.

Number of Cleavages and Their Directions	Name and Description of How the Mineral Breaks	Shape of Broken Pieces (Cleavage Directions are Numbered)	Illustration of Cleavage Directions
No cleavage (fractures only)	No parallel broken surfaces; May have conchoidal fracture (like glass)	 Quartz	None (no cleavage)
1 cleavage	**Basal (book) cleavage** "Books" that split apart along flat sheets	 Muscovite, biotite, chlorite (micas)	
2 cleavages intersect at or near 90°	**Prismatic cleavage** Elongated forms that fracture along short *rectangular* cross sections	Orthoclase 90° (K-spar)  Plagioclase 86° & 94°, pyroxene (augite) 87° & 93°	
2 cleavages do not intersect at 90°	**Prismatic cleavage** Elongated forms that fracture along short *parallelogram* cross sections	 Amphibole (hornblende) 56° & 124°	
3 cleavages intersect at 90°	**Cubic cleavage** Shapes made of cubes and parts of cubes	 Halite, galena	
3 cleavages do not intersect at 90°	**Rhombohedral cleavage** Shapes made of rhombohedrons and parts of rhombohedrons	 Calcite and dolomite 75° & 105°	
4 main cleavages intersect at 71° and 109° to form octahedrons, which split along hexagon-shaped surfaces; may have secondary cleavages at 60° and 120°	**Octahedral cleavage** Shapes made of octahedrons and parts of octahedrons	 Fluorite	
6 cleavages intersect at 60° and 120°	**Dodecahedral cleavage** Shapes made of dodecahedrons and parts of dodecahedrons	 Sphalerite	

Hardness

	Mohs Scale of Hardness*	Hardness of Some Common Objects (Harder objects scratch softer objects)
HARD	10 Diamond	
	9 Corundum	
	8 Topaz	
	7 Quartz	
	6 Orthoclase Feldspar	6.5 Streak plate
SOFT	5 Apatite	5.5 Glass, Masonry nail, Knife blade
	4 Fluorite	4.5 Wire (iron) nail
	3 Calcite	3.5 Brass (wood screw, washer)
	2 Gypsum	3.0 Copper coin (penny)
	1 Talc	2.5 Fingernail



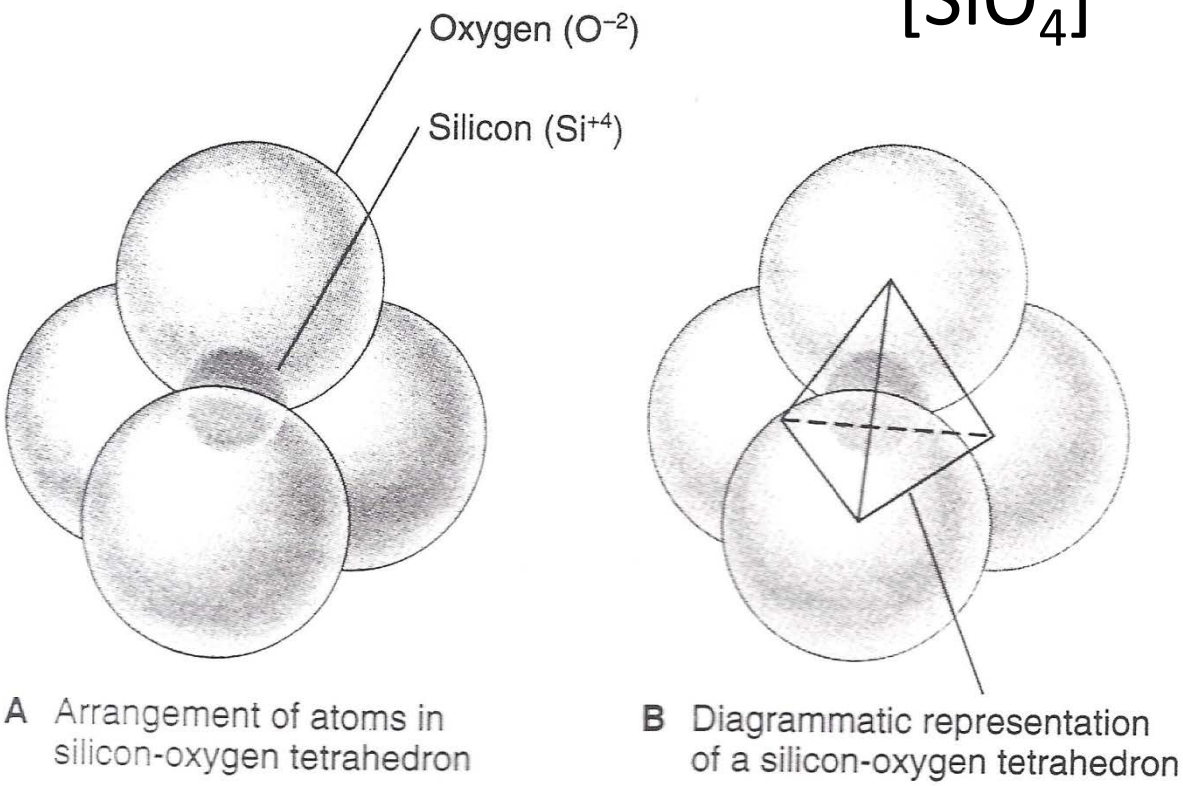
* A scale for measuring relative mineral hardness (resistance to scratching).

Other properties

- Color and streak
- Specific gravity
- Transparency
- Reaction to HCL
- Magnetism
- Taste

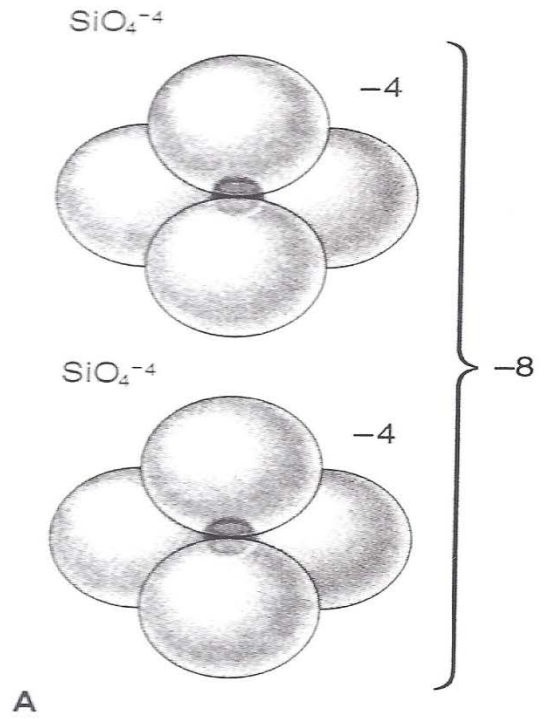
Silicates

$[SiO_4]^{4-}$

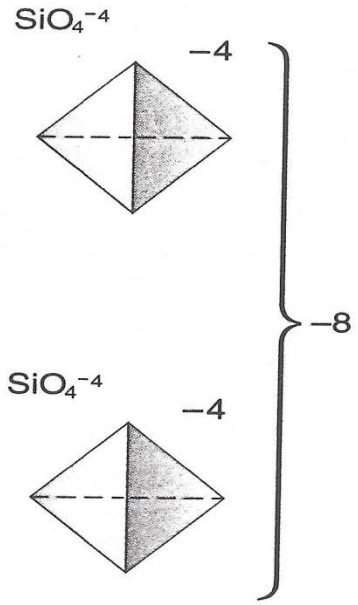


A Arrangement of atoms in silicon-oxygen tetrahedron

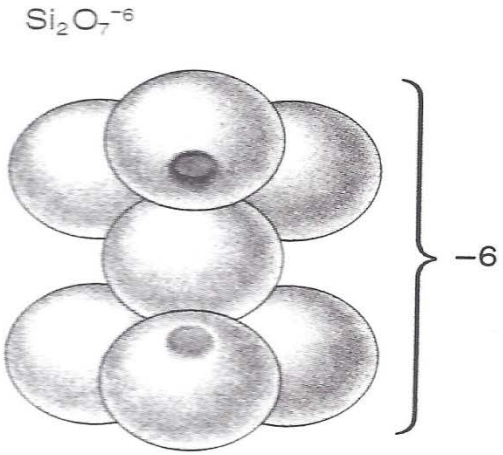
B Diagrammatic representation of a silicon-oxygen tetrahedron



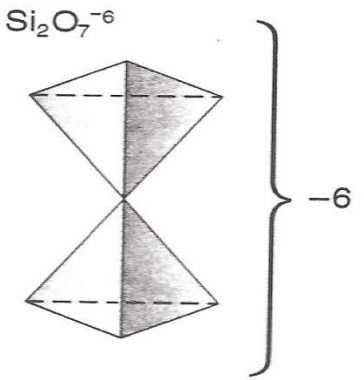
A



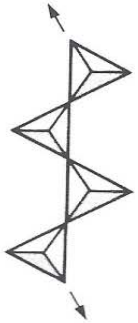
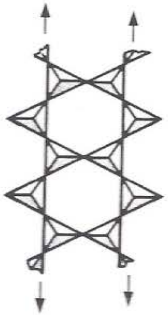
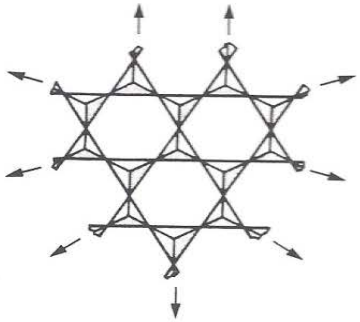
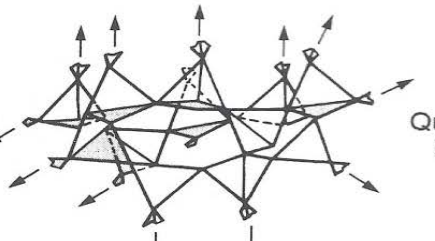
B



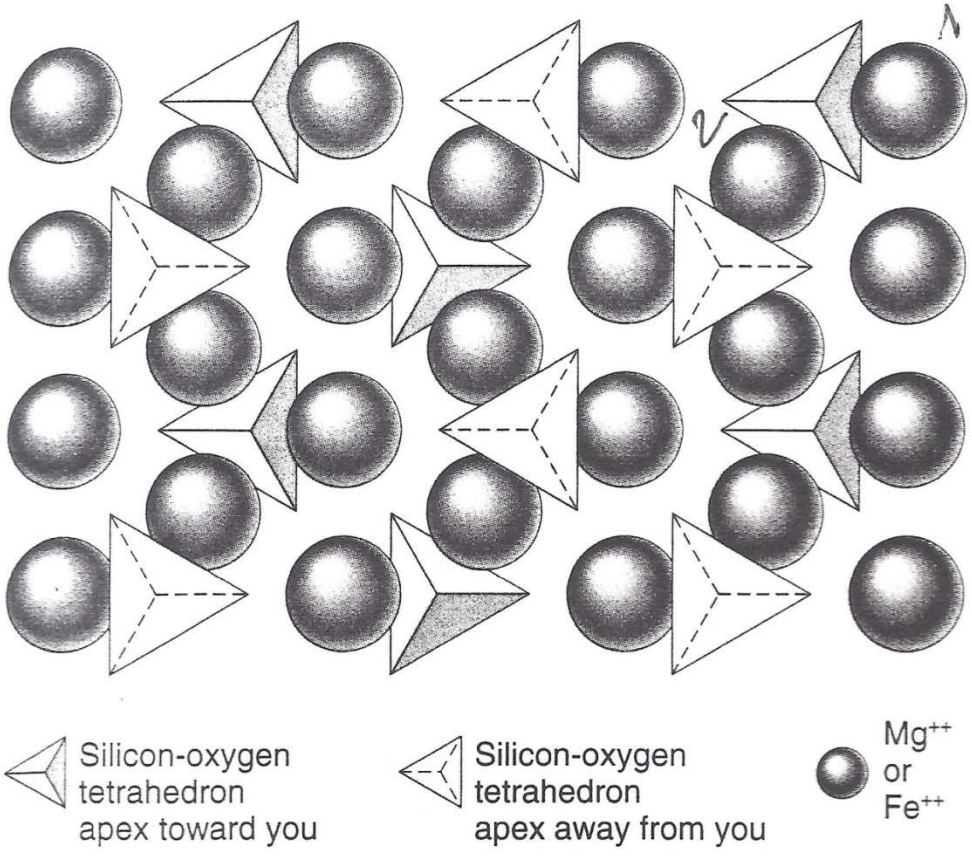
C



D

		Example
Isolated silicate structure		Olivine
Single chain structure		Pyroxene group
Double chain structure		Amphibole group
Sheet silicate structure		Mica group Clay group
Framework silicate structure		Quartz Feldspar group

Olivine



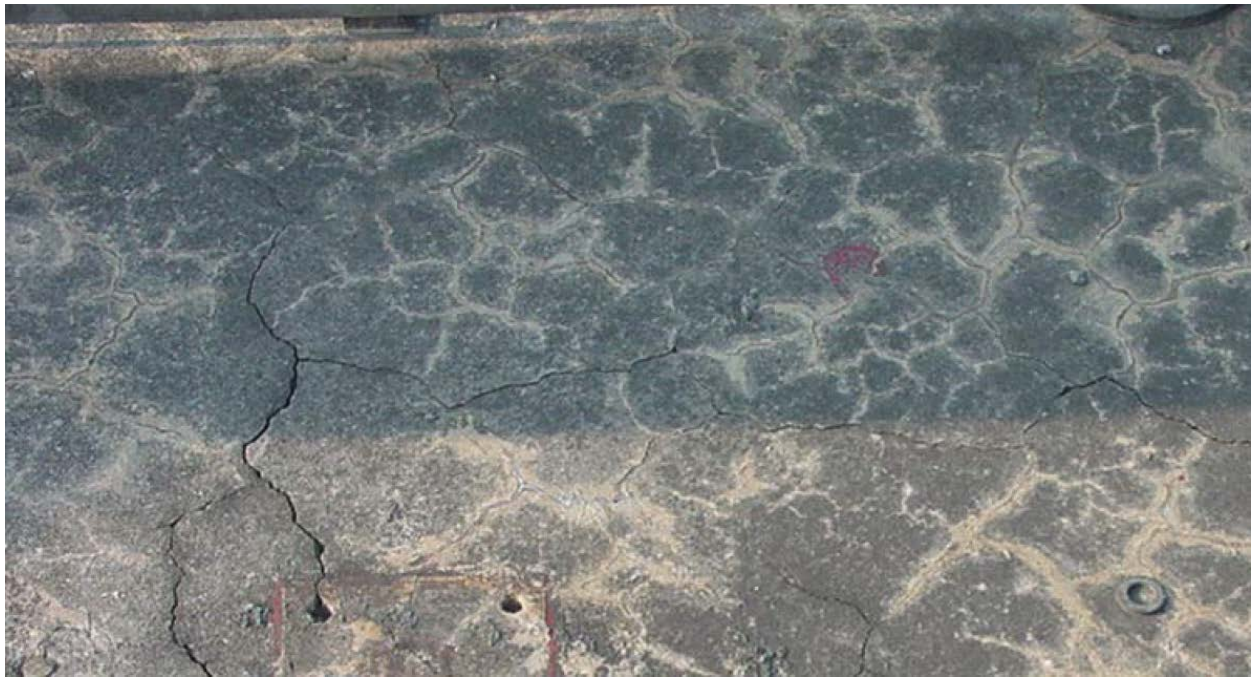
$[Mg, Fe]_2 SiO_4$

Quartz (SiO_2)

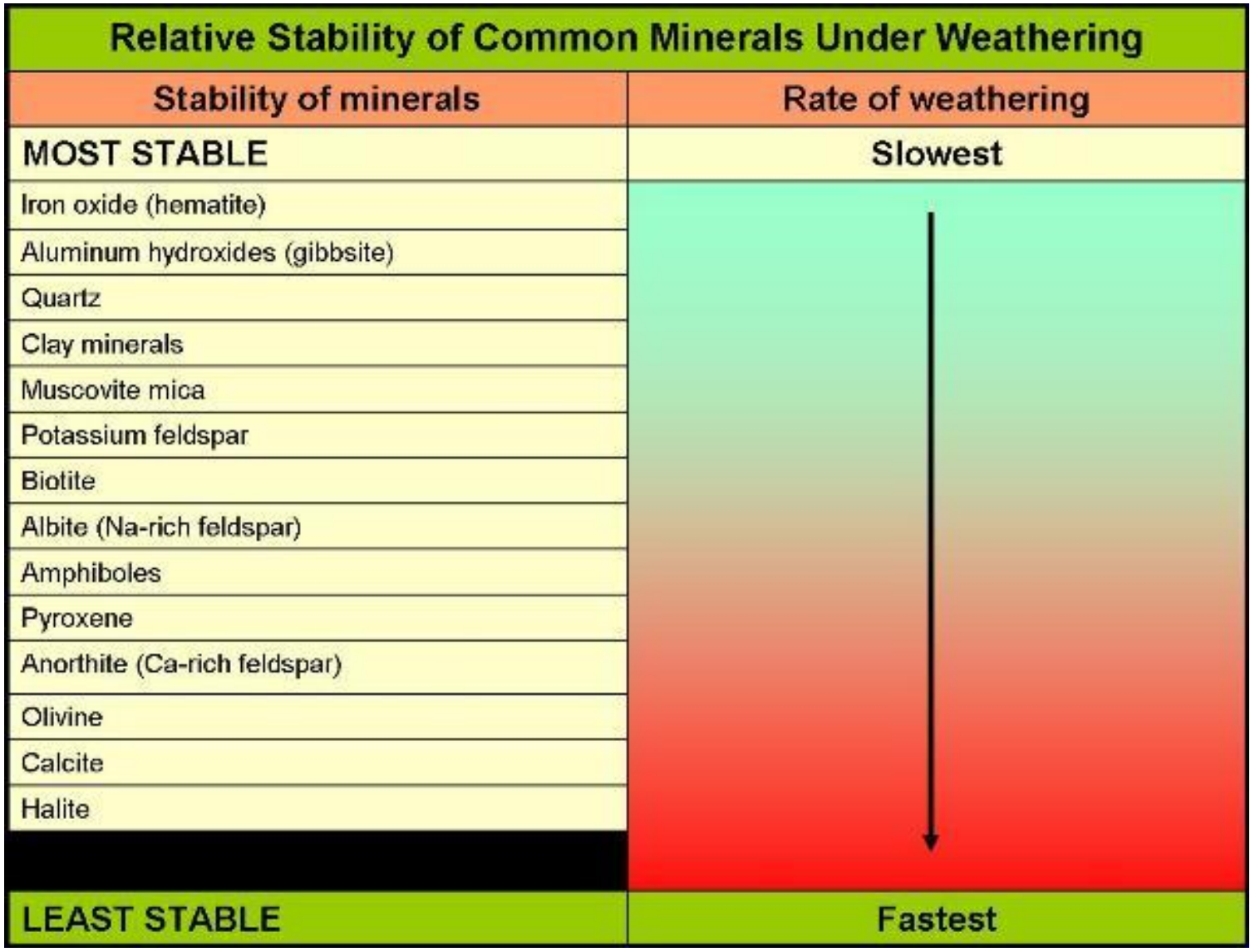
- Macro-crystalline quartz (different colors due to impurities)
- Silicosis (occupational hazard)
  https://www.osha.gov/dsg/topics/silicacrystalline/index.html
  https://www.youtube.com/watch?v=GtYErK9KjQ8c

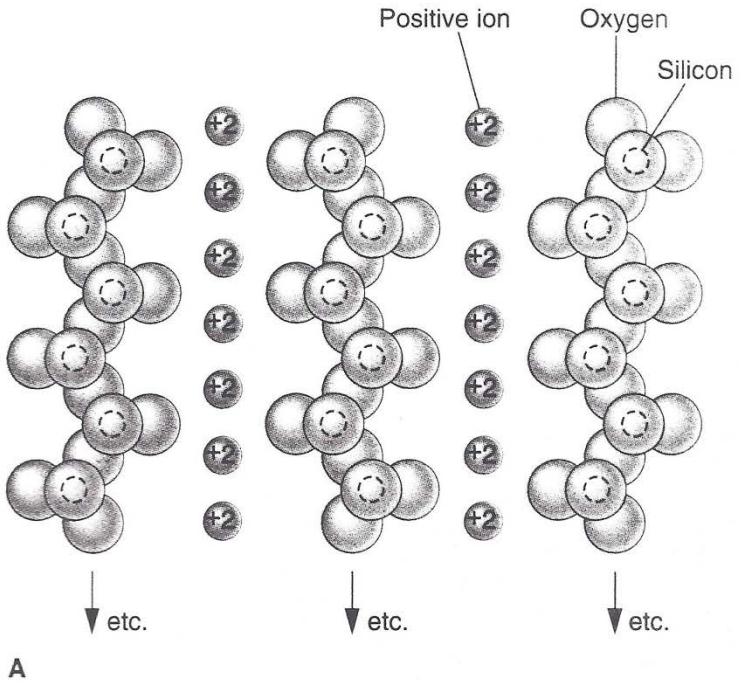
Quartz (SiO_2)

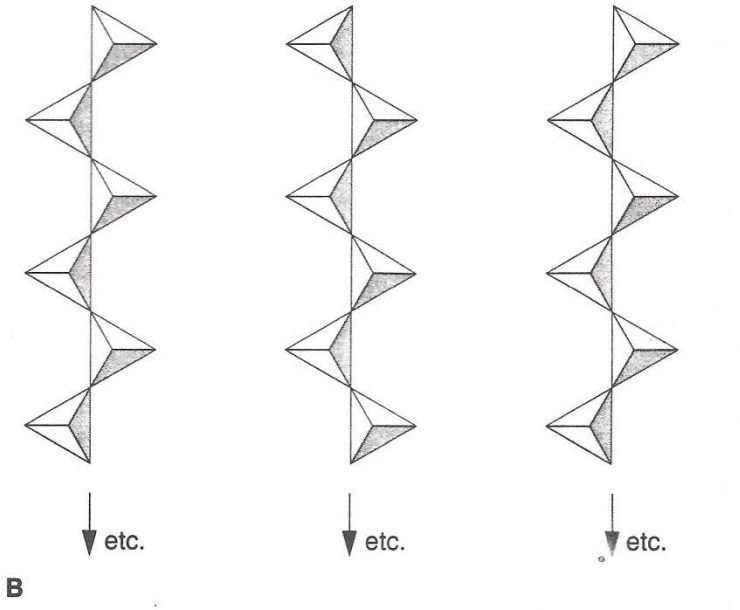
- Micro-crystalline quartz (chert, flint, agate, jasper, opal, petrified wood)
- Alkali-Silica Reaction (ASR) https://www.concrete.org/topicsinconcrete/topicdetail/Alkali%20Aggregate%20Reaction#onlinelearning



- Concrete Quality
  - Loss of strength, stiffness, impermeability
  - Affect concrete durability and appearance
  - Premature failure of concrete structures
- Economic Costs
  - Maintenance cost increased
  - The life of concrete structure is reduced
- Overall Result
  - No concrete structures had collapsed due to ASR damage
  - Some concrete structures/members were demolished because of ASR


Relative Stability of Common Minerals Under Weathering
Stability of minerals
Rate of weathering
MOST STABLE
Slowest
Iron oxide (hematite)
Aluminum hydroxides (gibbsite)
Quartz
Clay minerals
Muscovite mica
Potassium feldspar
Biotite
Albite (Na-rich feldspar)
Amphiboles
Pyroxene
Anorthite (Ca-rich feldspar)
Olivine
Calcite
Halite
LEAST STABLE
Fastest





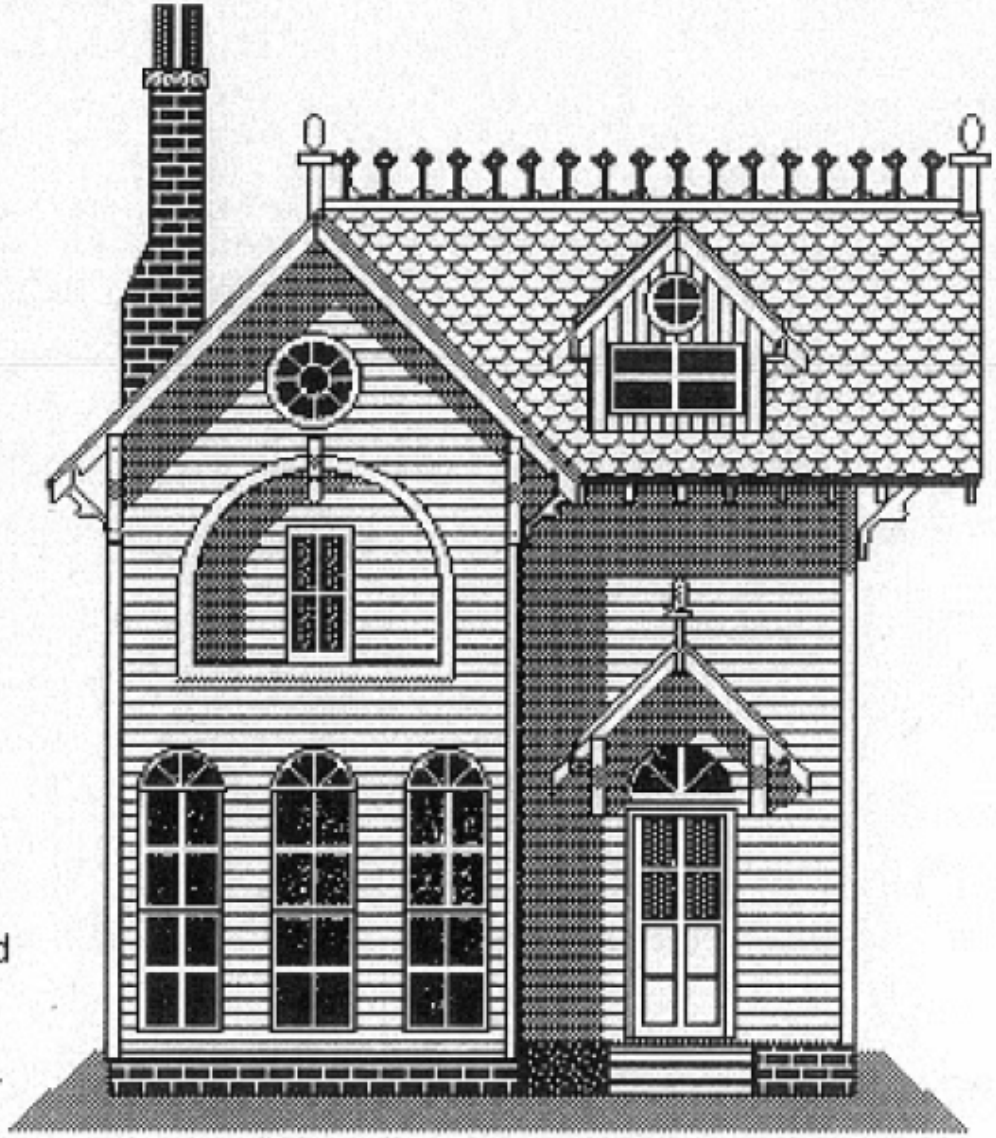
Pyroxenes
Amphiboles

Asbestos

Loosely used commercial term for fibrous minerals in heat-resistant fabric,

- Chrysotile (**White asbestos**): sheet structure, 95% of asbestos. Dissolves in lungs (in one year)
- Amphibole asbestos (**Blue** Asbestos) minerals: Needle structure (crocidolite, Blue asbestos, four other types). Does not dissolve in lungs

* Heating ducts, furnace grout/ insulation, water pipe coverings.
* Ceramic plumbing fixtures.
* Room and corridor insulation and fireproofing in buildings on floors, walls, ceilings and trim.
* Floor tile and tile cements.
* Asbestos plaster used for trim in buildings.
* Roof coatings, sealants, cement sheets and underground sewage and water pipes.
* Flower pots, rugs, draperies, designer coats, buttons, mailbags, table covers, place mats.



* Fire-proof clothing and gloves.
* Artificial snow to decorate Christmas trees and window displays.
* Acoustical tiles.
* Phonograph records.
* Liners for ovens, toasters, hair dryers, washing machines, refrigerators, and vacuum cleaners.
* Brake linings for automobiles and motorcycles.
* Gaskets and seals in various applications.
* Exhaust packings.
* Acetylene cylinders.
* Sealing tapes.
* Shingles and siding.
* Fireproofing for steel structural members in buildings.

Places where asbestos has been encountered in the home.

(graphic Victorian House from Public Domain Exchange)

Chrysotile

Blue Asbestos

Asbestos

- Problem with misidentification of asbestos
- Regulations:
  - EPA
  -OSHA (health and safety of workers)
  http://www.osha.gov/SLTC/asbestos/
  https://www.osha.gov/Publications/OSHA3507.pdf

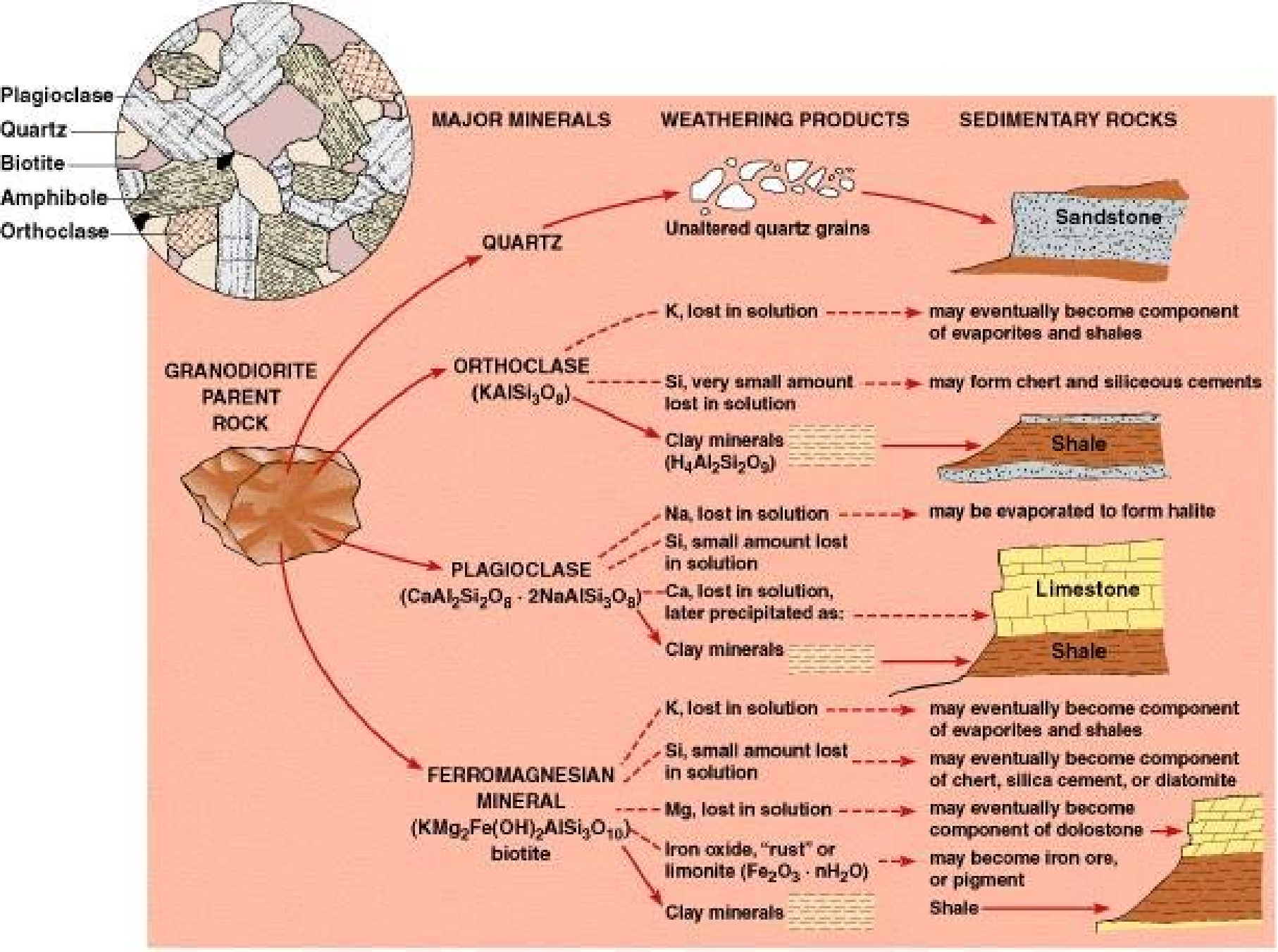
Phylosilicates

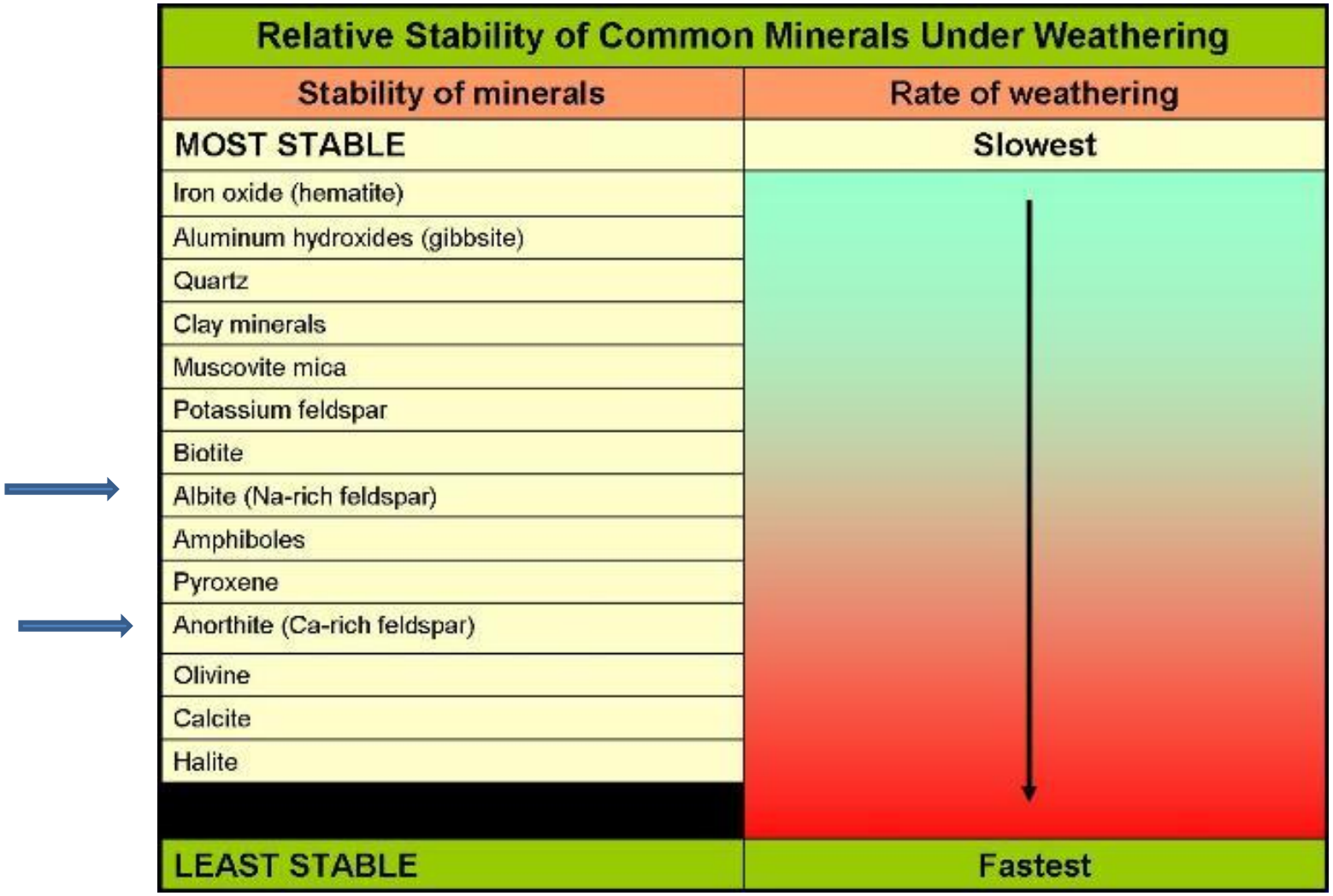
- Sheets of tetrahedron units
- Micas (Biotite and Muscovite)
- Chlorite
- Talc
- Clay Minerals (swelling and non-swelling)

Micas

Biotite

Muscovite


Plagioclase
Quartz
Biotite
Amphibole
Orthoclase
MAJOR MINERALS
WEATHERING PRODUCTS
SEDIMENTARY ROCKS
GRANODIORITE PARENT ROCK
QUARTZ
Unaltered quartz grains
Sandstone
ORTHOCLASE
(KAlSi3O8)
K, lost in solution
may eventually become component of evaporites and shales
Si, very small amount lost in solution
may form chert and siliceous cements
Clay minerals
(H4Al2Si2O9)
Shale
PLAGIOCLASE
(CaAl2Si2O8 · 2NaAlSi3O8)
Na, lost in solution
may be evaporated to form halite
Si, small amount lost in solution
Ca, lost in solution, later precipitated as:
Limestone
Clay minerals
Shale
FERROMAGNESIAN MINERAL
(KMg2Fe(OH)2AlSi3O10)
biotite
K, lost in solution
may eventually become component of evaporites and shales
Si, small amount lost in solution
may eventually become component of chert, silica cement, or diatomite
Mg, lost in solution
may eventually become component of dolostone
Iron oxide, "rust" or limonite (Fe2O3 · nH2O)
may become iron ore, or pigment
Clay minerals
Shale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Olivine
Calcite
Halite
LEAST STABLE
Fastest

Hydrolysis

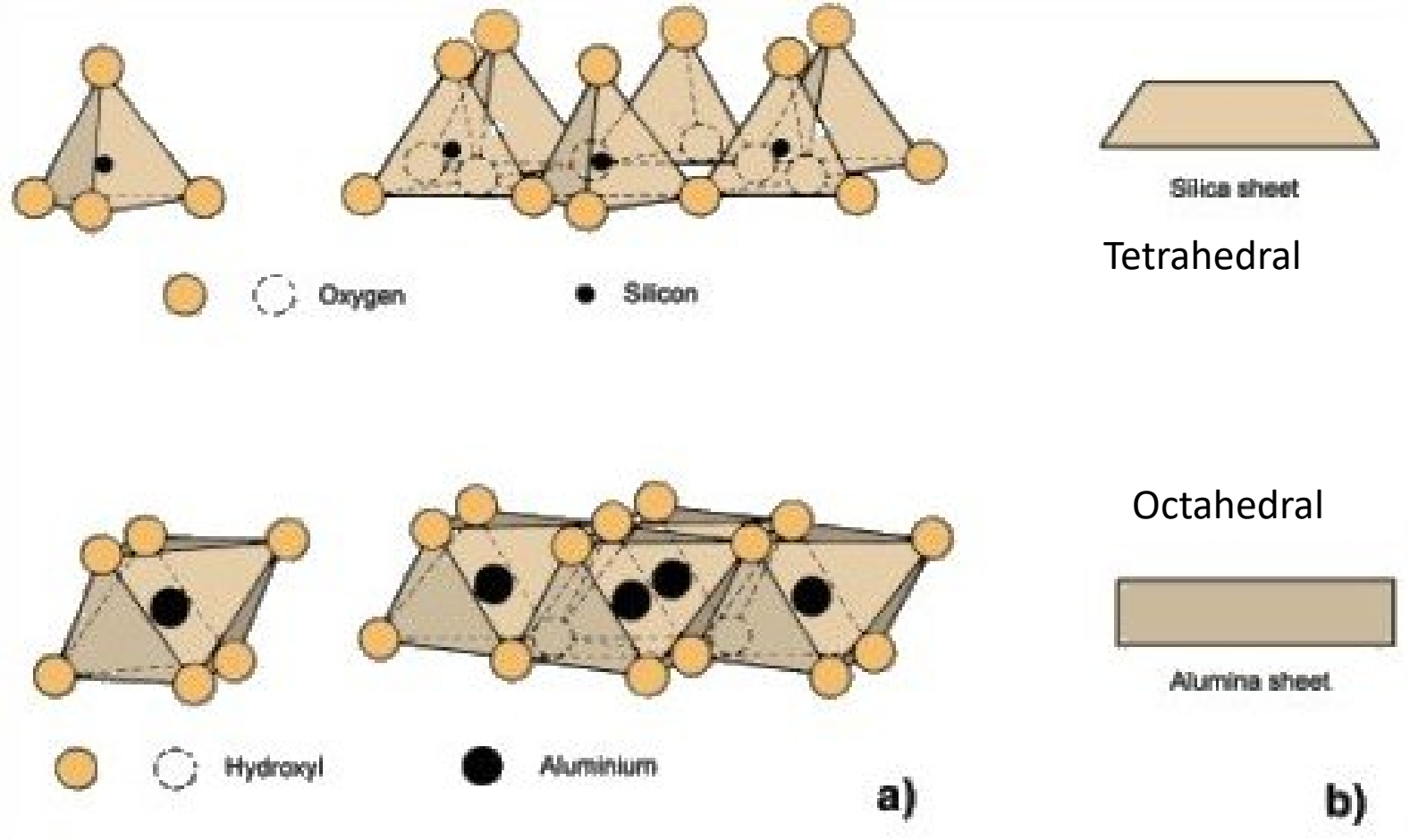
$$2KAlSi_3O_8 + 2H^+ + 9H_20 \rightarrow H_4Al_2Si_2O_9 + 4H_4SiO_4 + 2K^+$$

(orthoclase + water → kaolinite + silicic acid + potassium)

Plagioclase feldspar + 4 water + 4 hydrogen ion
→ sodium ion + aluminum ion + 3 silicic acid

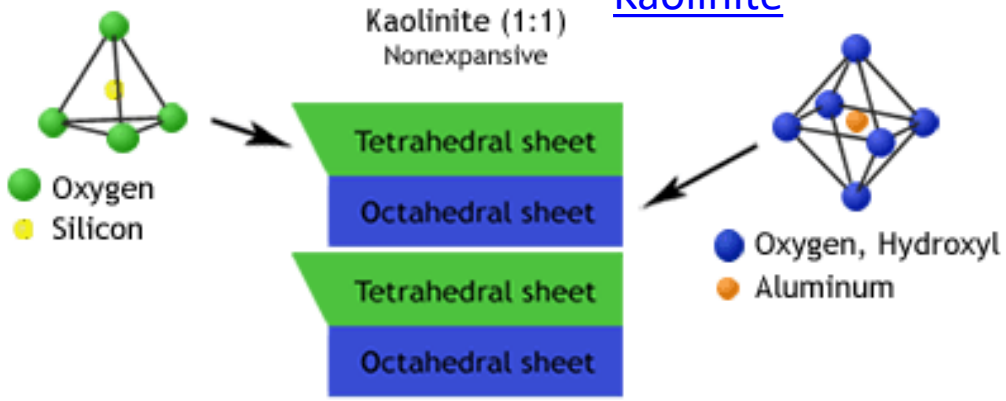
$$NaAlSi_3O_{8(s)} + 4H_2O_{(l)} + 4H^+_{(aq)} \rightarrow Na^+_{(aq)} + Al^{3+}_{aq} + 3H_4SiO_{4(aq)}$$

Clay Minerals

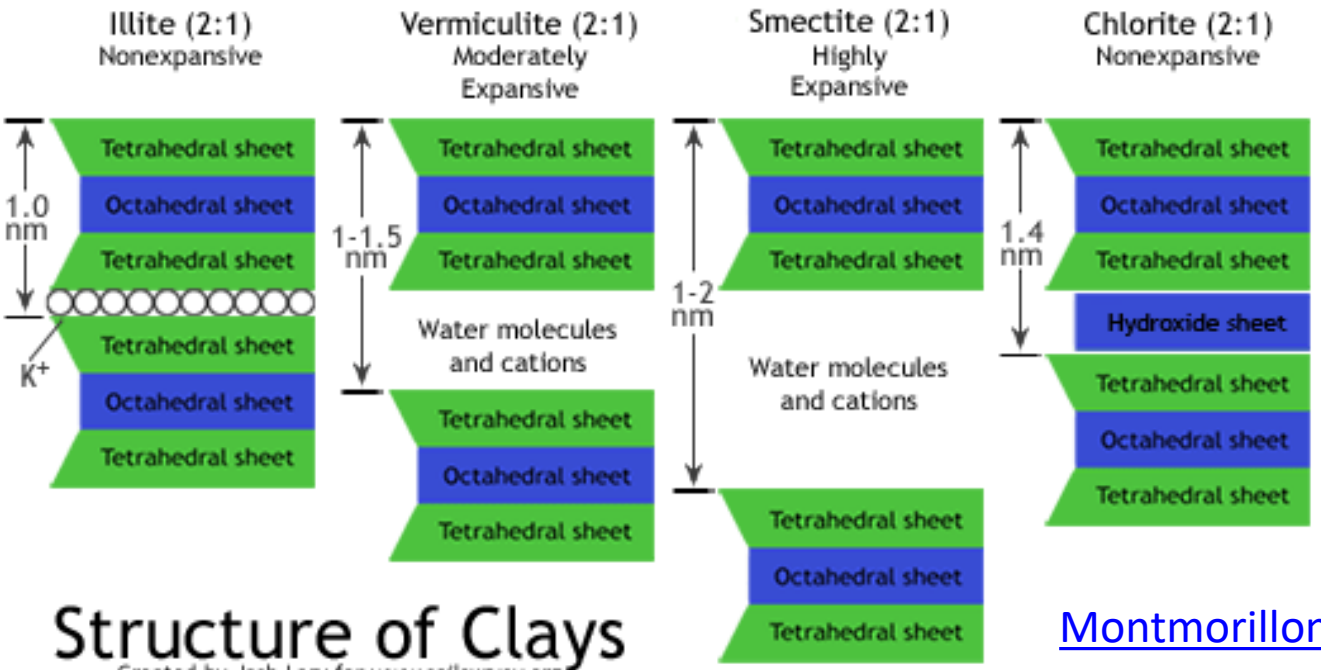


Clay Minerals

Kaolinite



Illite



Structure of Clays

Created by Josh Lory for www.soilsurvey.org

Montmorillonite

Clay Minerals

- Videos:

(1) https://www.bing.com/videos/search?q=swelling+clays+videos&qpvt=swelling+clays+videos&view=detail&mid=5CC835922F54CF71368F5CC835922F54CF71368F&FORM=VRDGAR

(2) https://www.bing.com/videos/search?q=house+foundations+on+swelling+clays&&view=detail&mid=F700D4D39556526E54C7F700D4D39556526E54C7&FORM=VRDGAR

(3) https://www.bing.com/videos/search?q=swelling+clays+videos&view=detail&mid=CA39BD89DFDEA04A75A6CA39BD89DFDEA04A75A6&FORM=VIRE

(4) https://www.bing.com/videos/search?q=swelling+clays+videos&&view=detail&mid=3F6C2C2EC67157A034B13F6C2C2EC67157A034B1&rvsmid=CA39BD89DFDEA04A75A6CA39BD89DFDEA04A75A6&fsscr=-2310&FORM=VDFSRV