Minerals and their Engineering Properties

Engineering Geology
Fall 2021

- 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 specimens
  - Examination of thin slices (0.03 mm) using optical properties of minerals

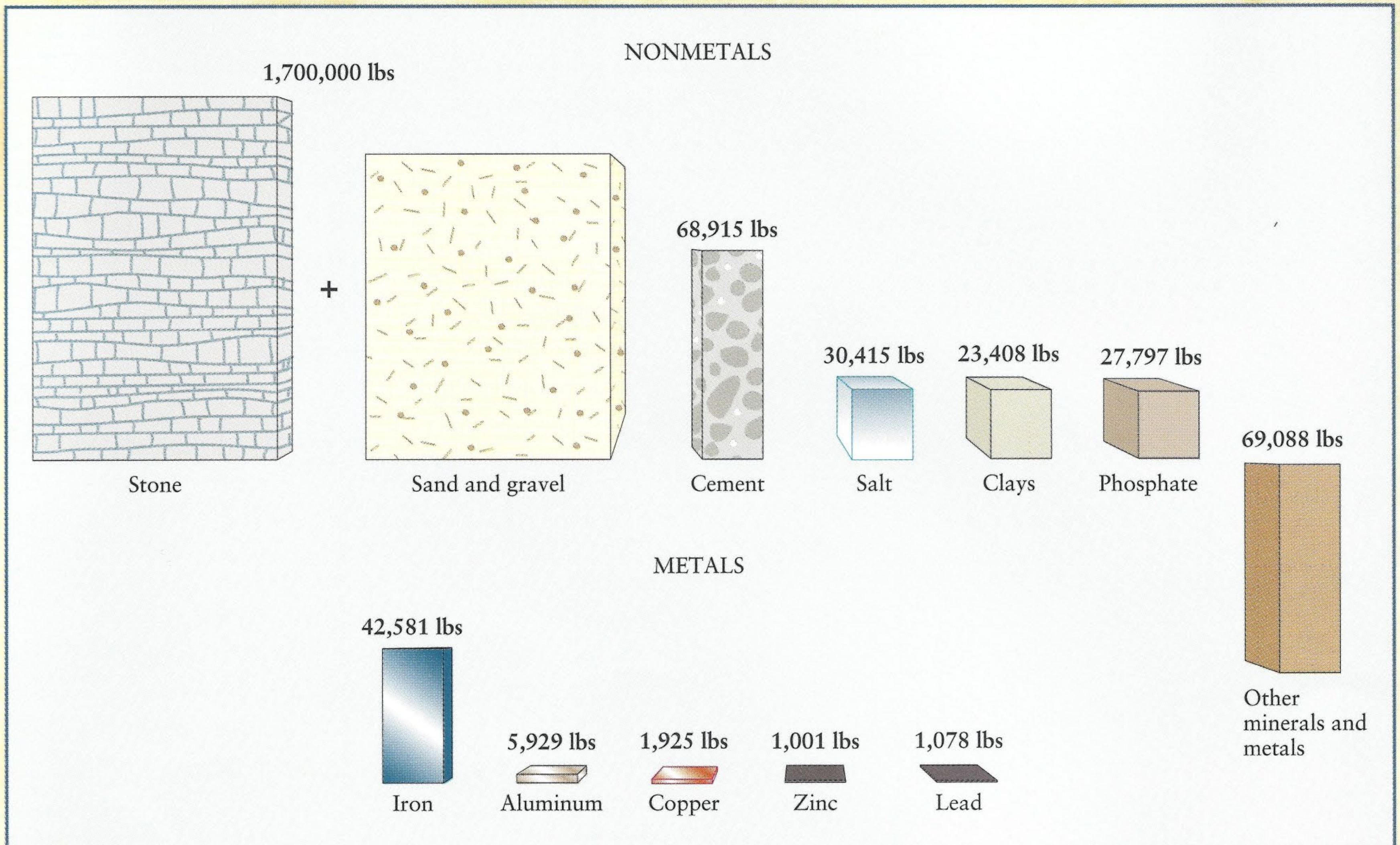


Figure 1 *Every American born will need nearly 2 million pounds of minerals and metals in a lifetime.* (*Mineral Information Institute*, 2000).

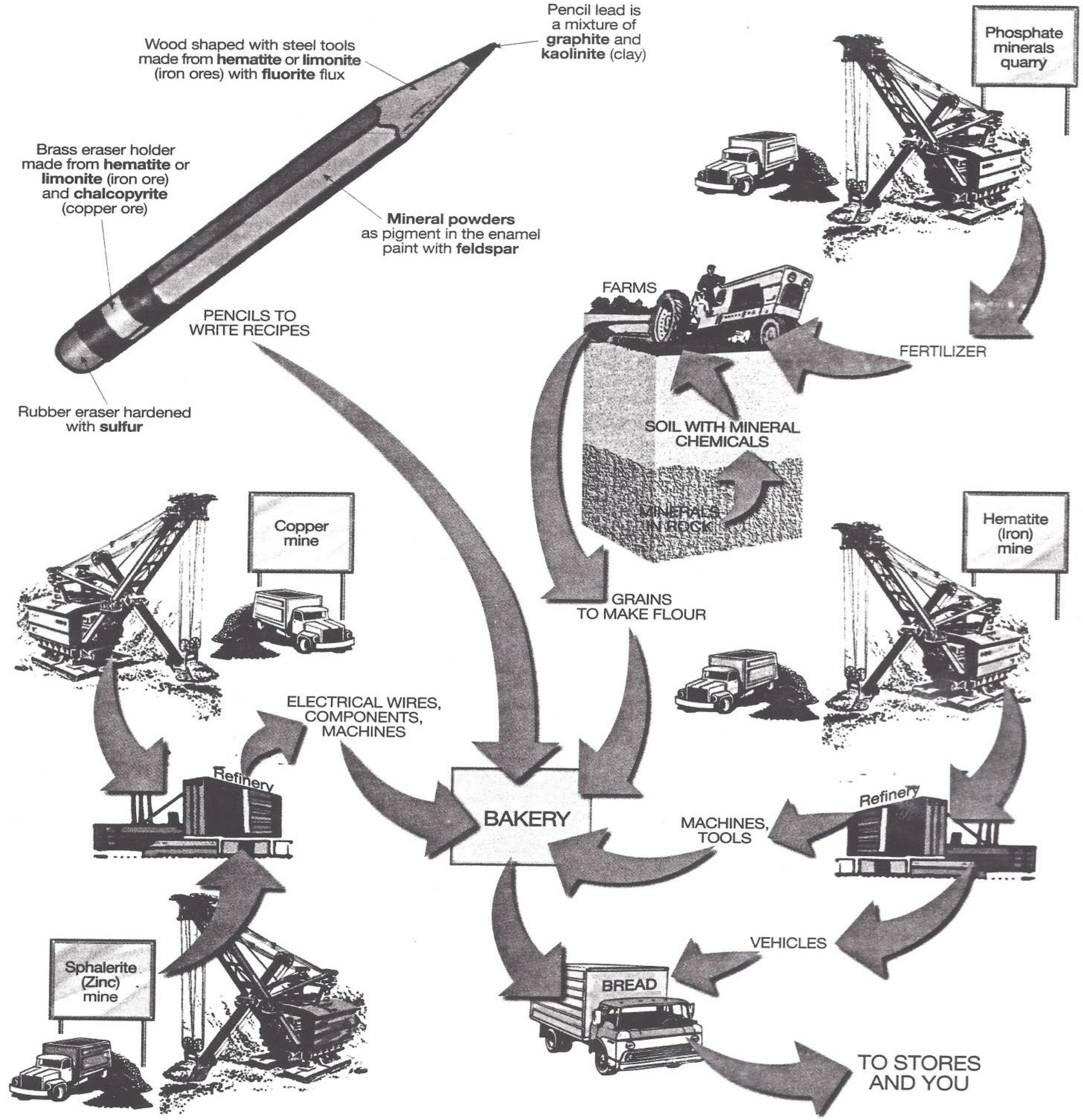
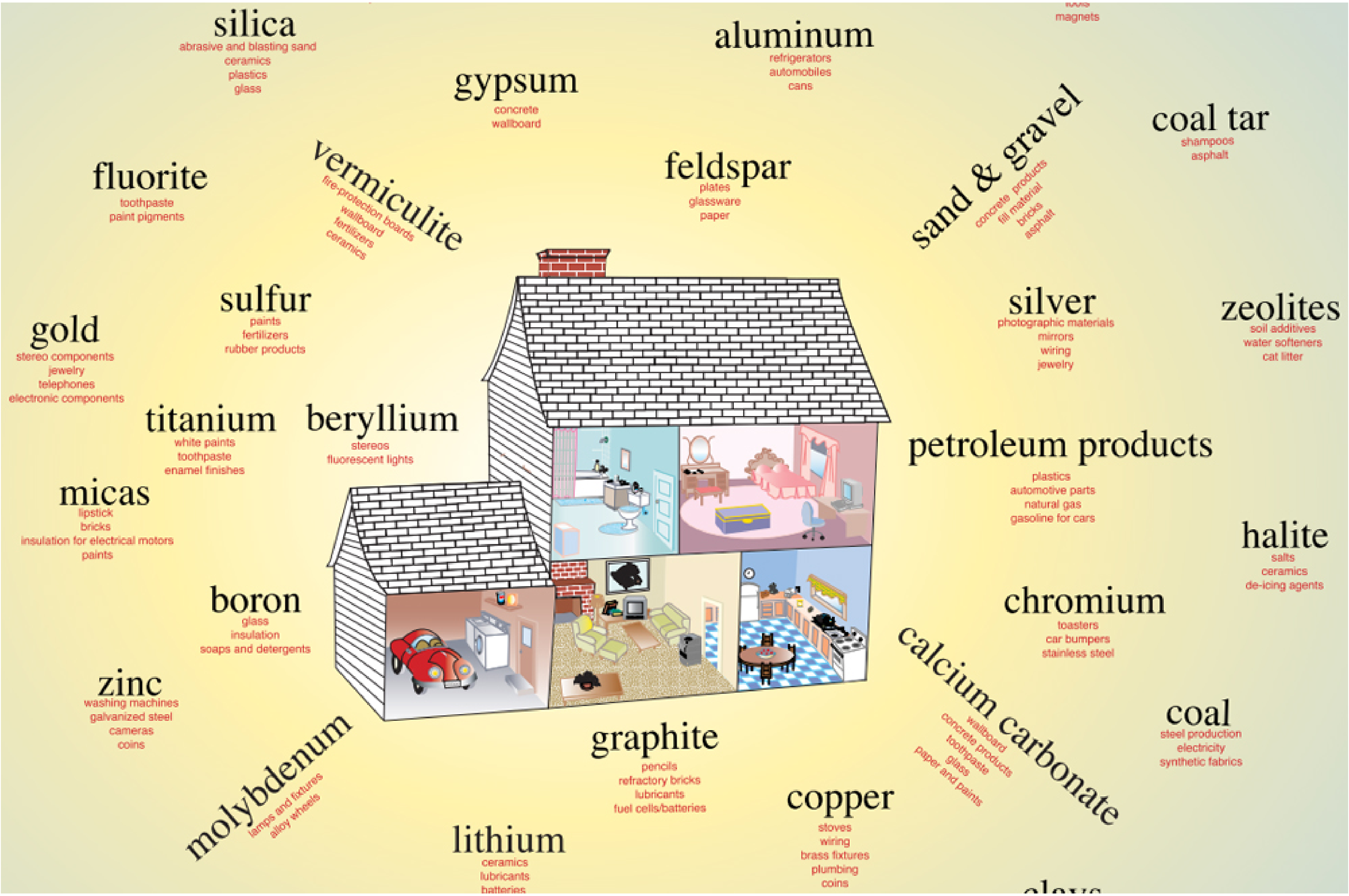
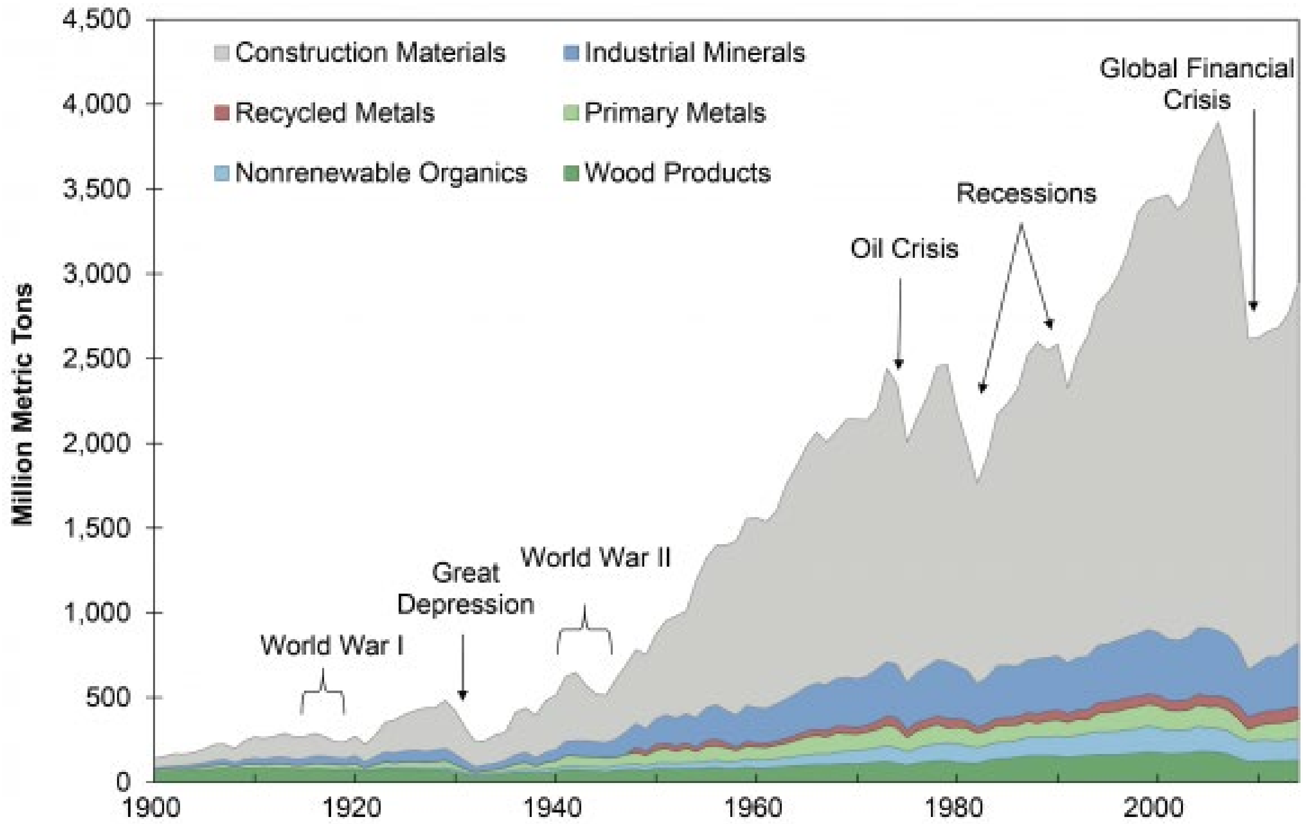


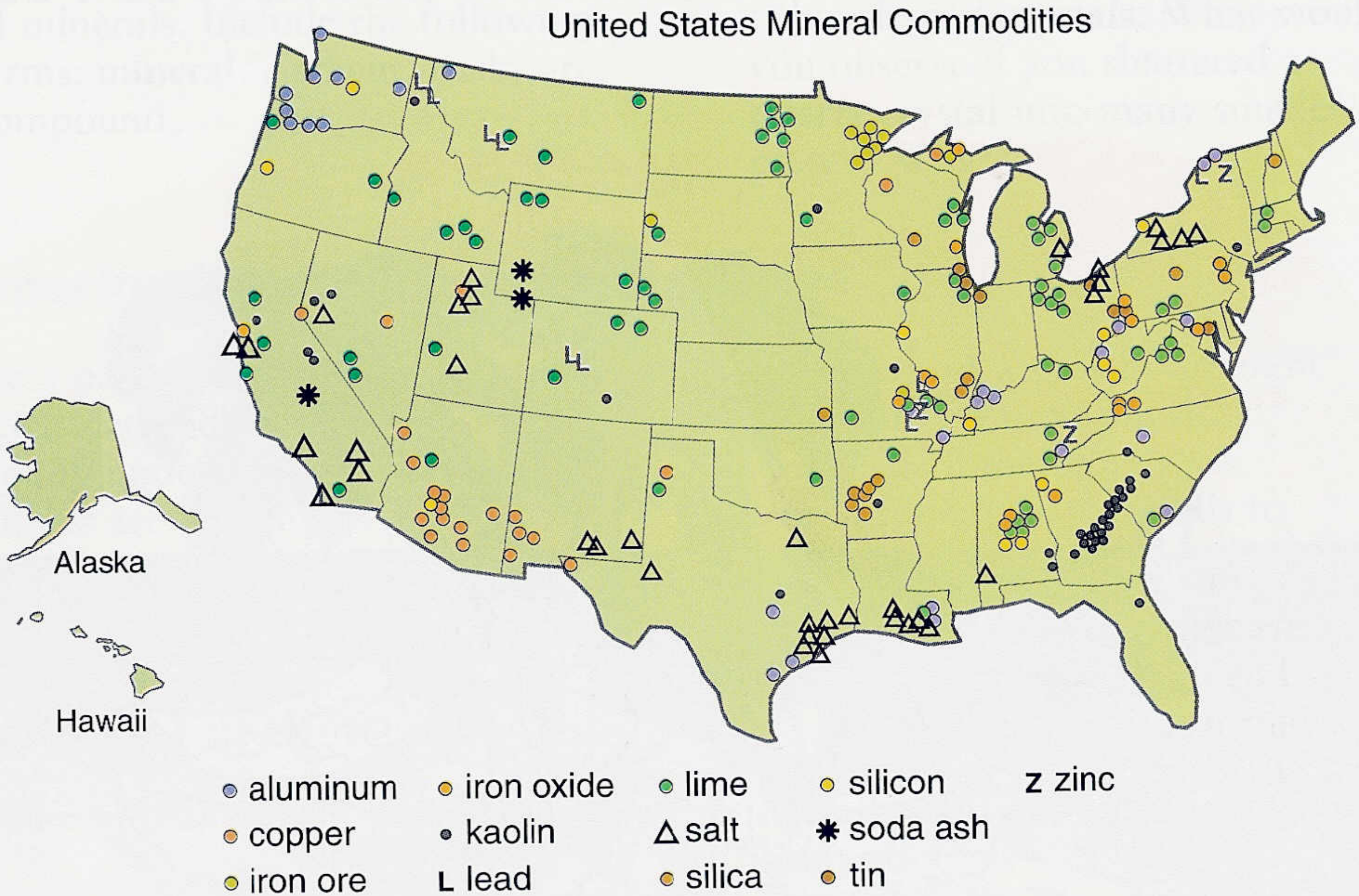
FIGURE 2.2 Descriptions of how minerals have been used to manufacture some common items that you probably use everyday.



https://mineralseducationcoalition.org/mining-mineral-statistics



https://www.usgs.gov/centers/nmic/commodity-statistics-and-information#:~:text=%20%20%201%20Ilmenite%20%28Titanium%20Mineral%20Concentrates%29,Steel%20Slag%209%20Iron%20Oxide%20Pigments%20More%20


United States Mineral Commodities
Alaska
Hawaii
Z L
aluminum
copper
iron ore
iron oxide
kaolin
L lead
lime
salt
silica
silicon
soda ash
tin
Z zinc

Your 10 lb laptop

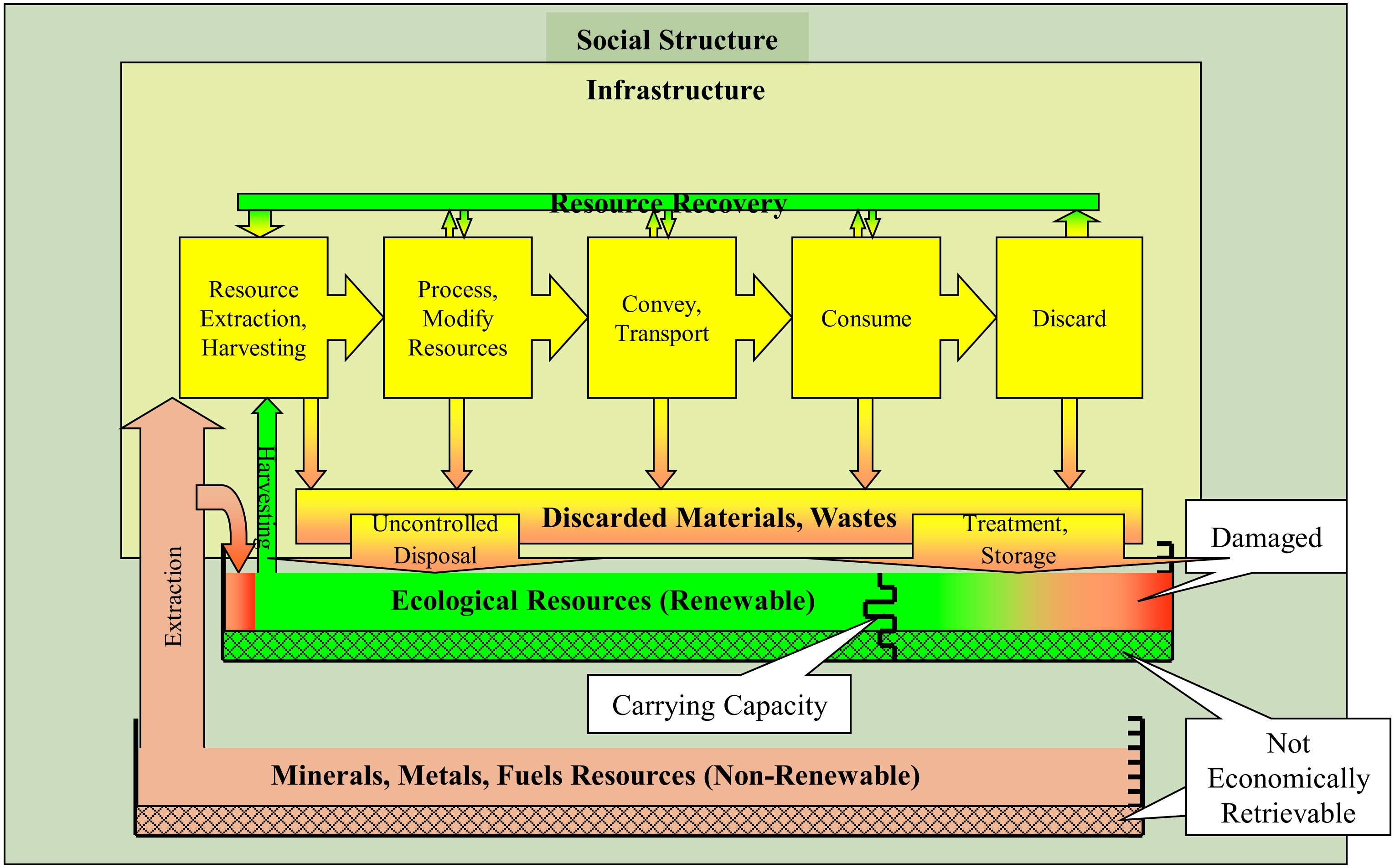
"On an all-in basis, counting everything processed and distilled into those 10 lbs, it weighs as much as 40,000 lbs, and its manufacturers, going all the way back to the mines and wellheads, created huge abuse to Earth through extractive and polluting processes to make it."

(Ray Anderson, 1998).

Today (2020), 1.8 tons (3600 lbs) of material to make a laptop computer

Production-Consumption Model

Adapted from D. Roberts and W. Wallace



Cradle to Grave (Take – Make – Waste)

Copper

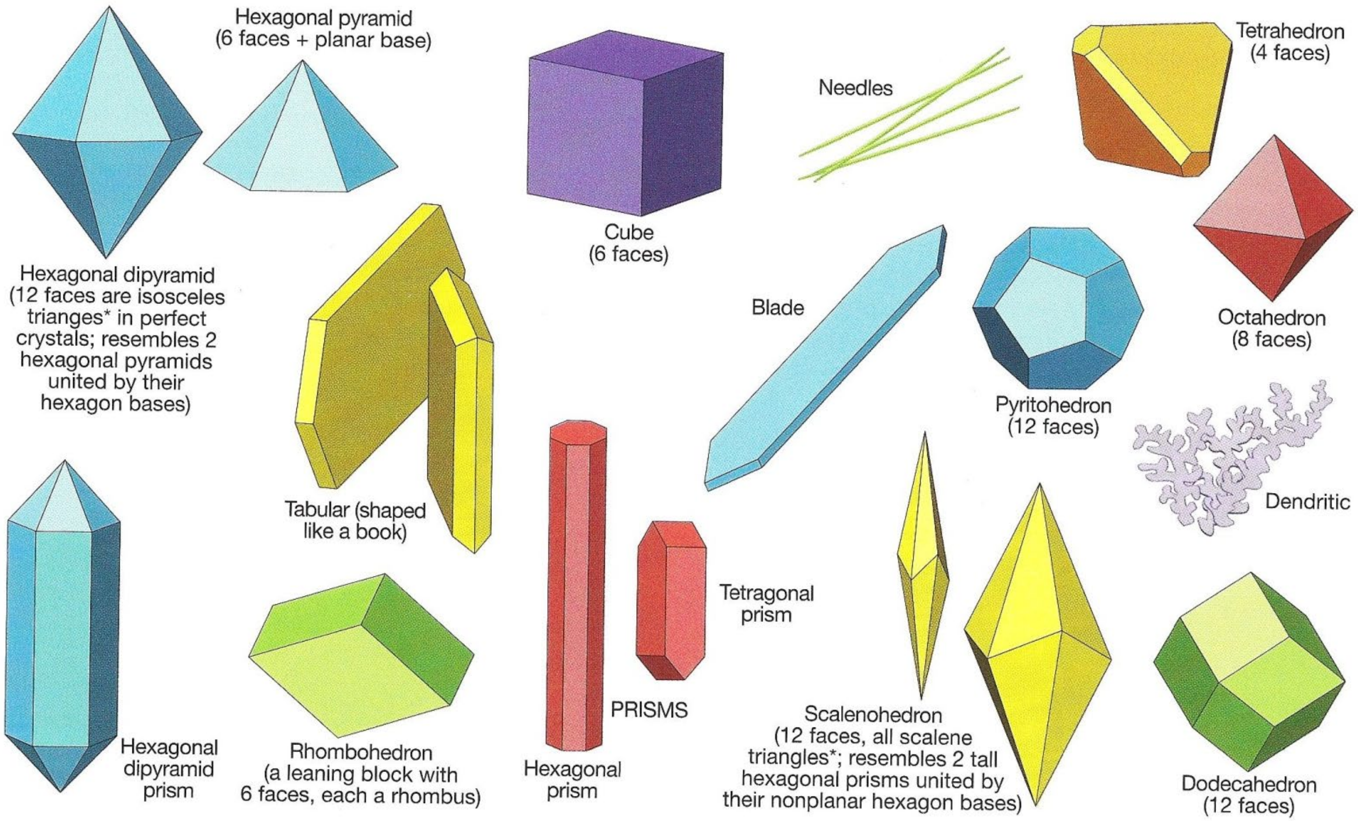
- Base metal
- 0.0058% of Earth's crust by weight
- Main rock = Chalcopyrite $CuFeS_2$

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

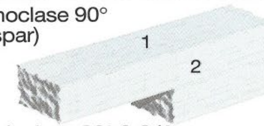
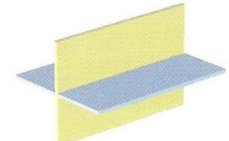
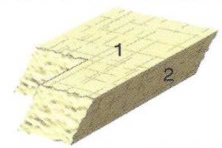
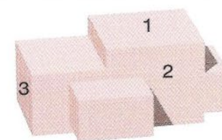
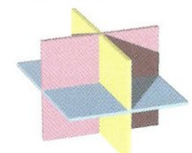
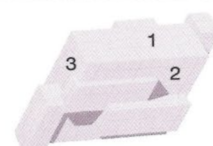
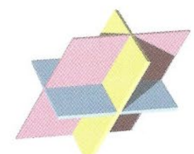
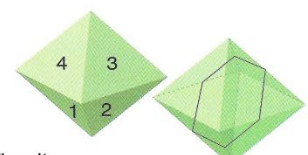
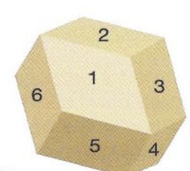
http://www.bing.com/videos/search?q=minerals+videos&FORM=VIRE13#view=detail&mid=2E1A08DEDCA54D04BA7F2E1A08DEDCA54D04BA7F

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.

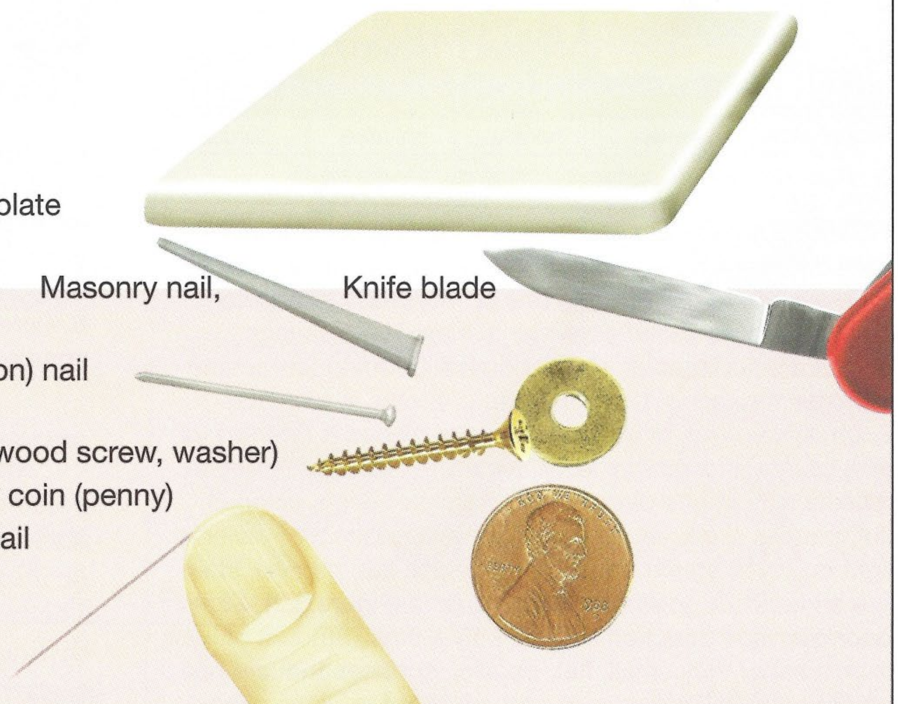
Number of Cleavages and Their Directions	Name and Description of How the Mineral Breaks	Shape of Broken Pieces (Cleavage Directions are Numbered)	Illustration of Cleavage Directions
No cleavage (fractures only)	No parallel broken surfaces; May have conchoidal fracture (like glass)	 Quartz	None (no cleavage)
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*
HARD	10 Diamond
	9 Corundum
	8 Topaz
	7 Quartz
	6 Orthoclase Feldspar
SOFT	5 Apatite
	4 Fluorite
	3 Calcite
	2 Gypsum
	1 Talc

Hardness of Some Common Objects
(Harder objects scratch softer objects)

6.5 Streak plate
5.5 Glass, Masonry nail, Knife blade
4.5 Wire (iron) nail
3.5 Brass (wood screw, washer)
3.0 Copper coin (penny)
2.5 Fingernail



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

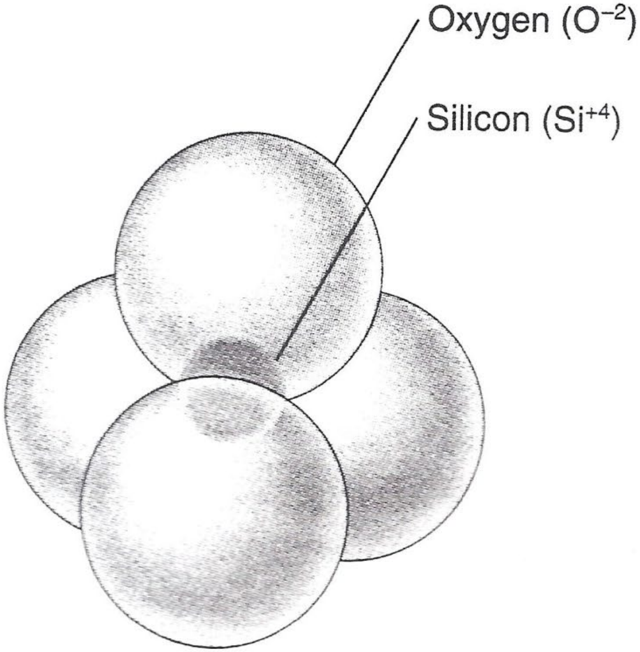
Other properties

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

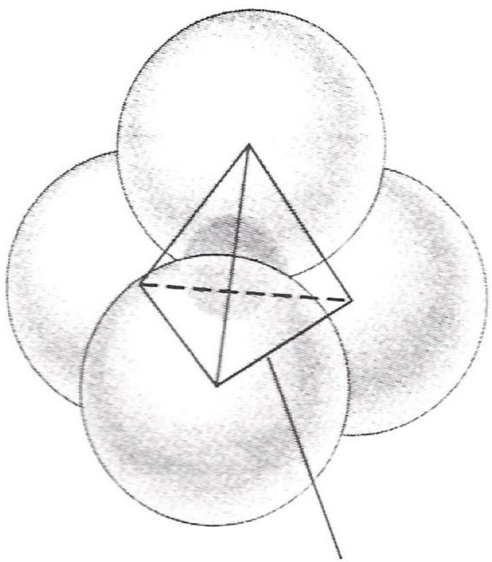
https://geology.com/minerals/

Silicates

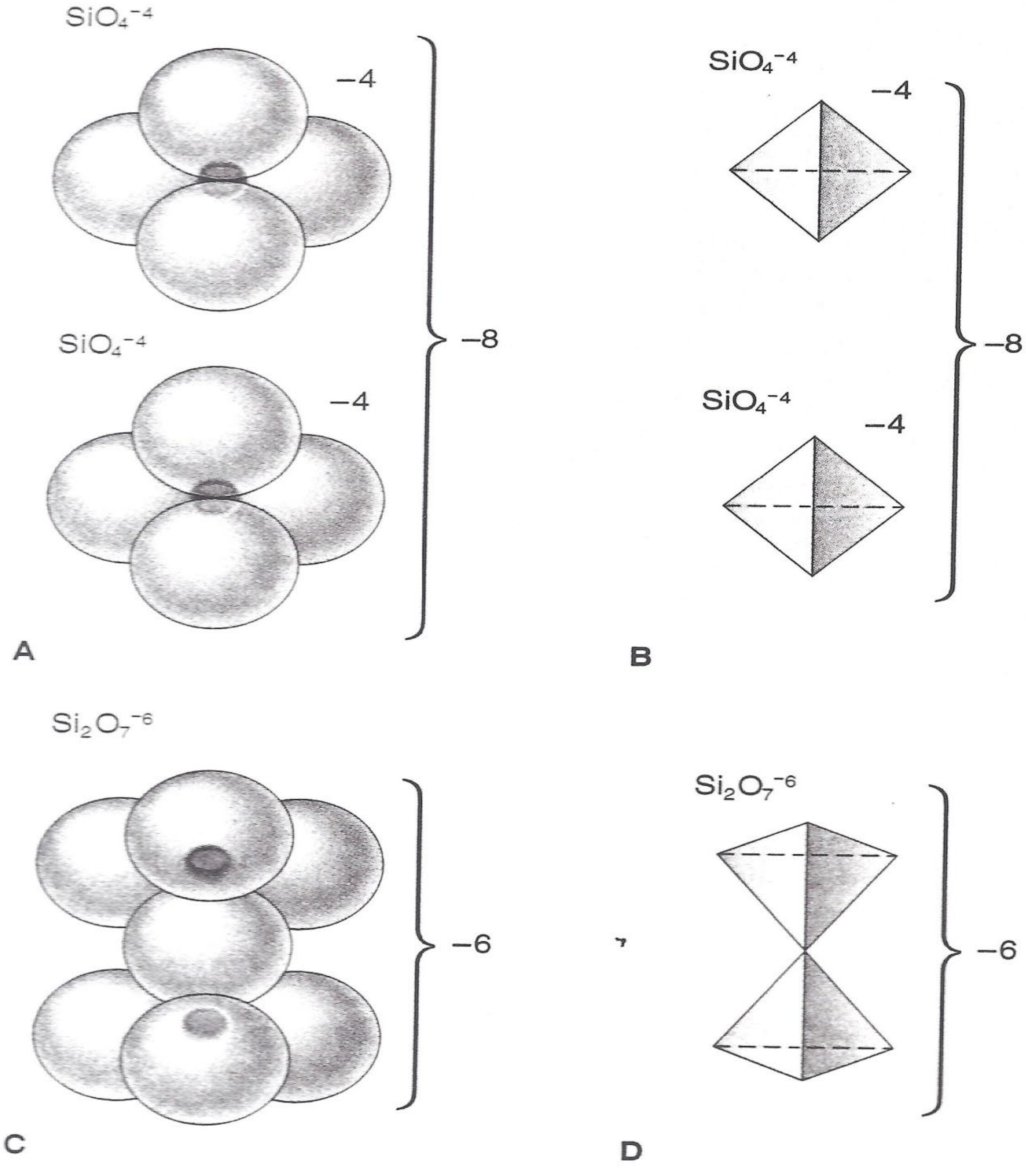
$[SiO_4]^{4-}$



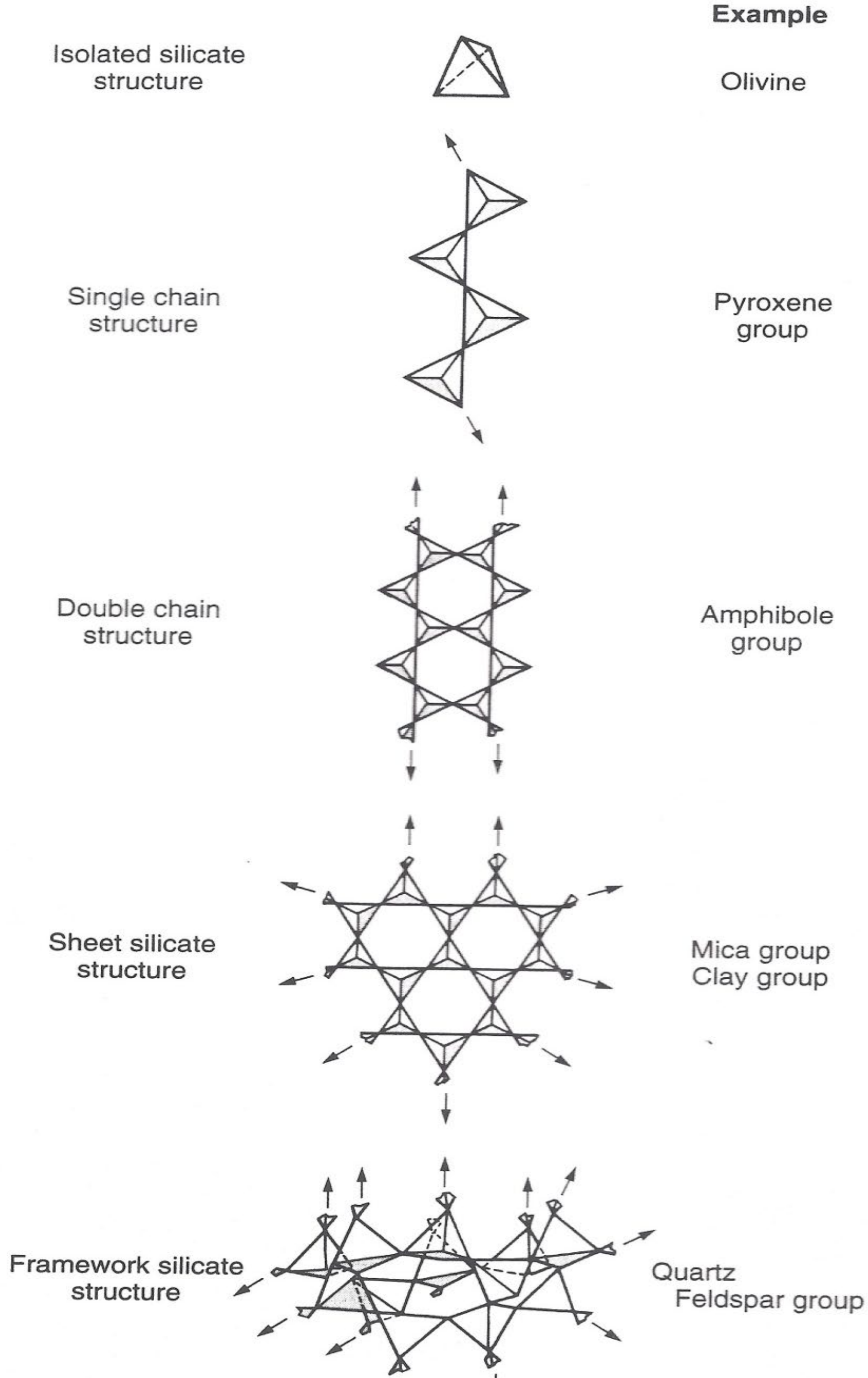
A Arrangement of atoms in silicon-oxygen tetrahedron



B Diagrammatic representation of a silicon-oxygen tetrahedron



SiO_4^{-4}
−4
SiO_4^{-4}
−4
−8
A
SiO_4^{-4}
−4
SiO_4^{-4}
−4
−8
B
$Si_2O_7^{-6}$
−6
C
$Si_2O_7^{-6}$
−6
D

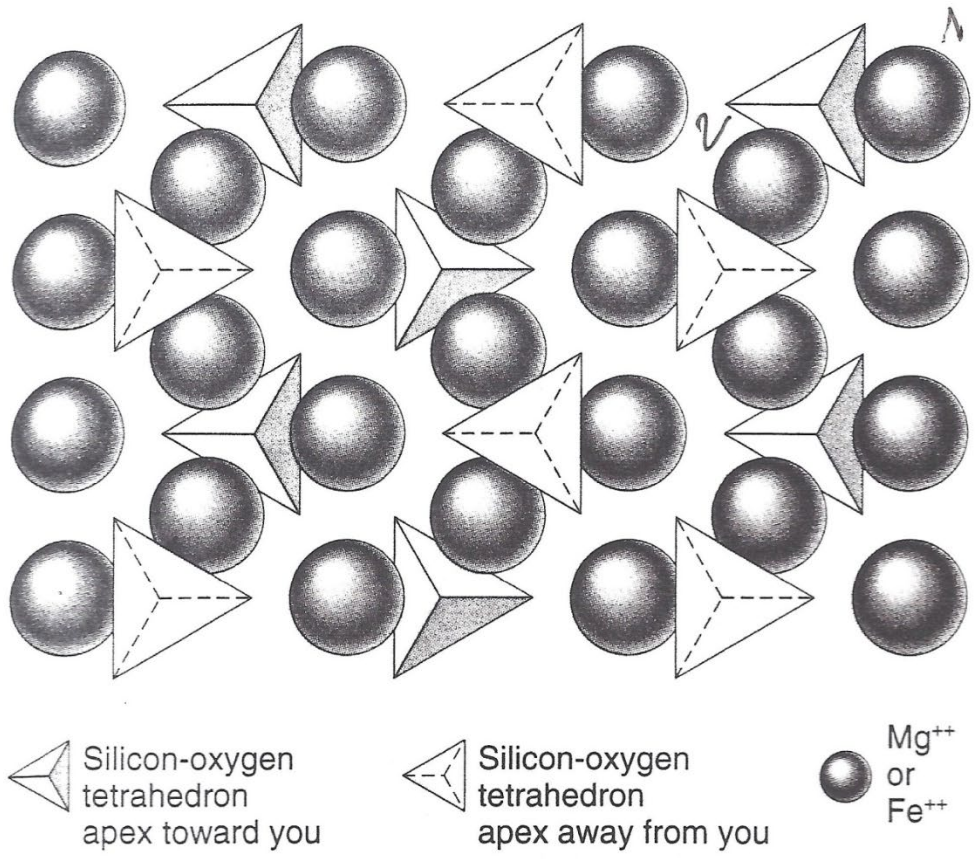

Example
Isolated silicate structure
Olivine
Single chain structure
Pyroxene group
Double chain structure
Amphibole group
Sheet silicate structure
Mica group
Clay group
Framework silicate structure
Quartz
Feldspar group


#24
Pyroxene (var. Augite)


1cm

Olivine (use)

https://www.minerals.net/mineral/olivine.aspx



$[Mg, Fe]_2 SiO_4$

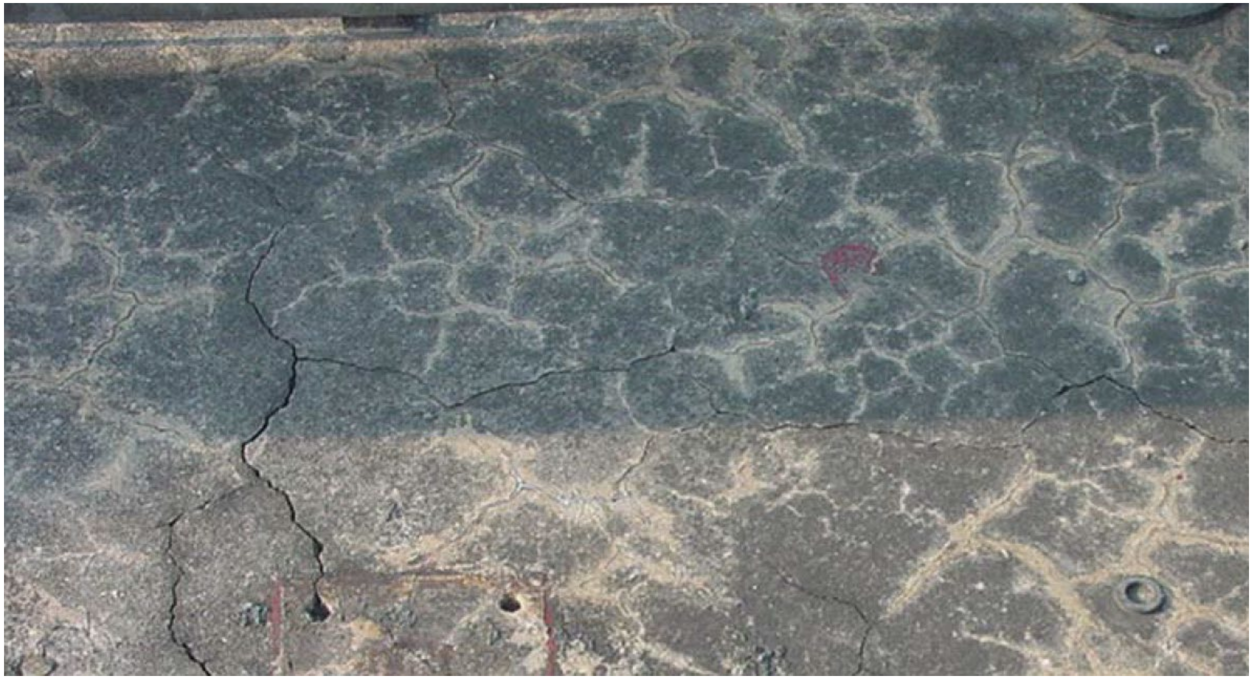
Quartz (SiO_2) (use)

- Macro-crystalline quartz (different colors due to impurities)
- Silicosis (occupational hazard)
  http://www.osha.gov (search Silicosis)
  http://www.bing.com/videos/search?q=silicosis+videos&qpvt=silicosis+videos&FORM=VDRE#view=detail&mid=DF5F095E862A4129154ADF5F095E862A4129154A



Quartz (SiO_2)

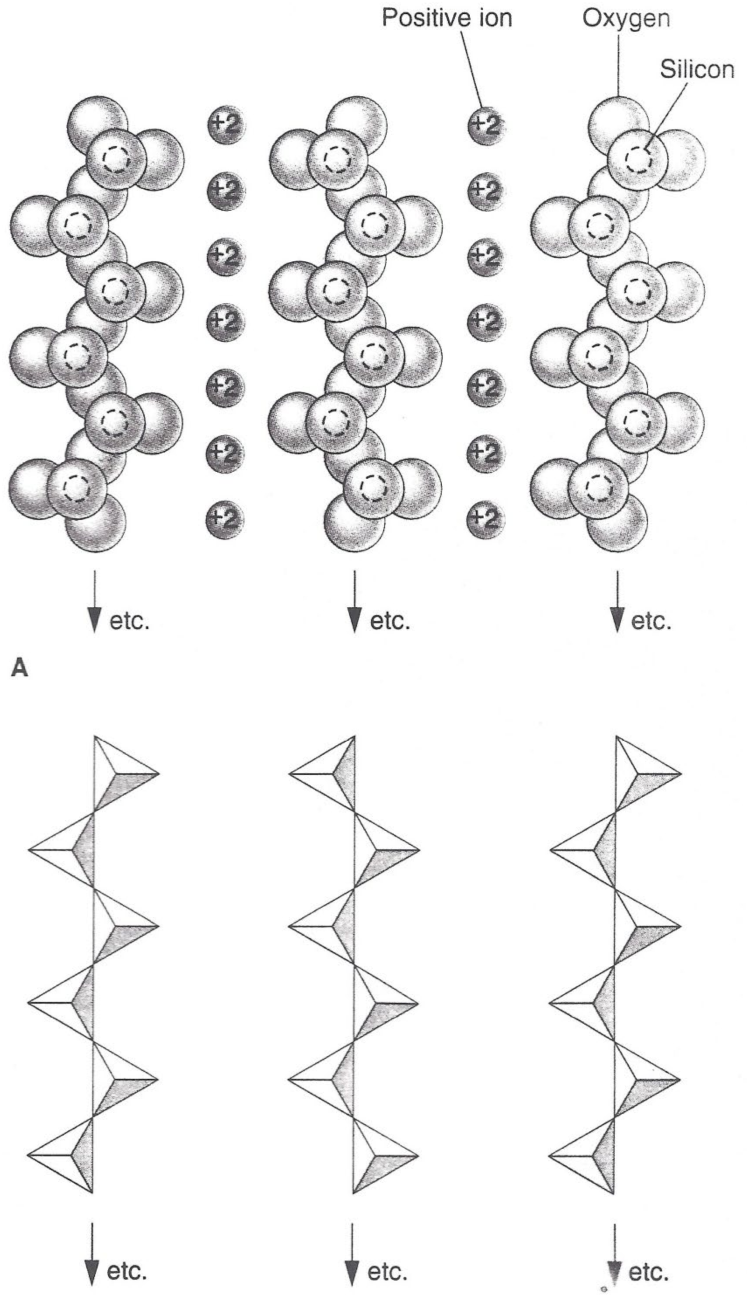
- Micro-crystalline quartz (chert, flint, agate, jasper, opal, petrified wood)
- Alkali-Aggregate Reaction (AAR) http://www.bing.com/videos/search?q=alkali+aggregate+reaction+in+concrete&qs=AS&sk=AS1&FORM=QBVR&pq=alkali%20aggregate%20reaction&sc=4-25&sp=2&qs=AS&sk=AS1#view=detail&mid=DB9BE84841C283385B0EDB9BE84841C283385B0E
- https://theconstructor.org/concrete/alkali-aggregate-reaction-in-concrete/67/



- 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



Pyroxenes
(use)

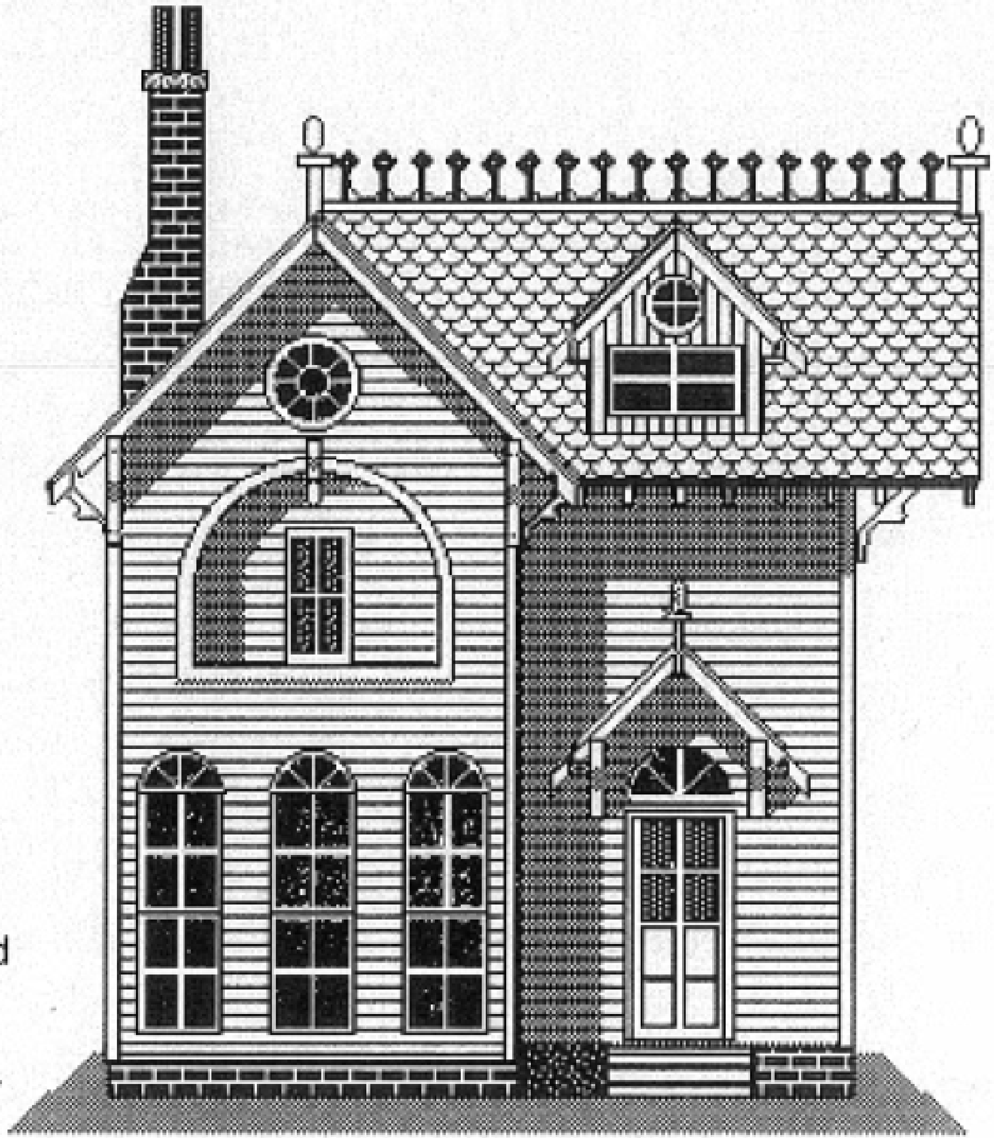
Amphiboles
(use)

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 under-ground 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)

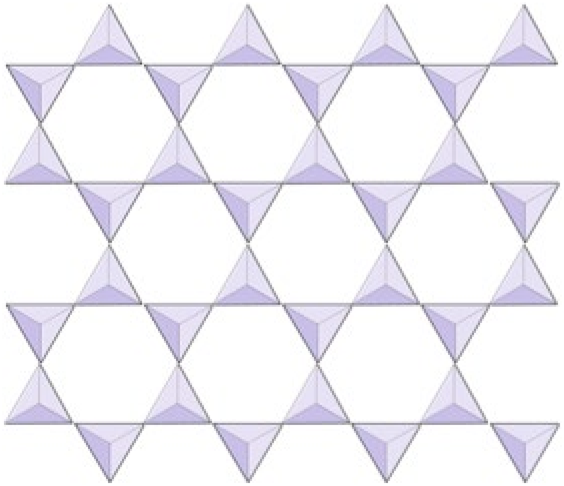
Asbestos

- Problem with misidentification of asbestos
- Regulations:
  - EPA
  - OSHA (health and safety of workers)

    http://www.osha.gov/SLTC/asbestos/

Phyllosilicates

- Sheets of tetrahedra
- Micas (Biotite and Muscovite)
- Chlorite
- Talc
- Clay Minerals



Feldspars

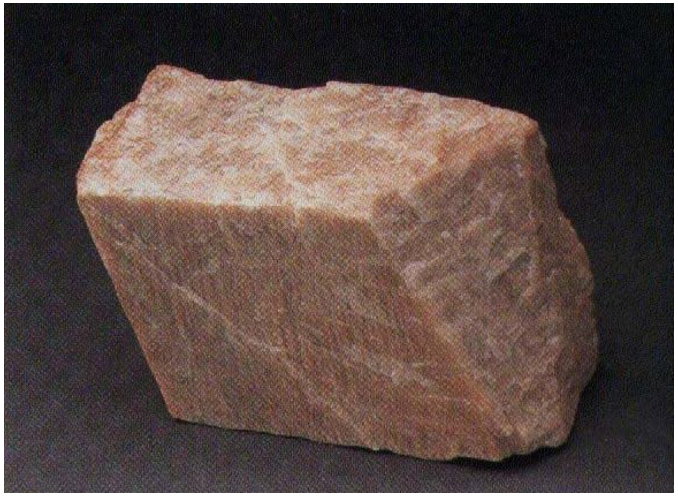
https://geology.com/minerals/feldspar.shtml

Plagioclase

- $NaAlSi_3O_8 – CaAl_2Si_2O_8$

Orthoclase

- KAlSi3O8



Chemical Weathering

Hydrolysis

Feldspars chemically break down when exposed to surface conditions, and form clay minerals through the process of *hydrolysis*

$$KAlSi_3O_8 + H^+ + H_2O \rightarrow H_4SiO_4 + KAl_3SiO_{10}(OH)_2$$

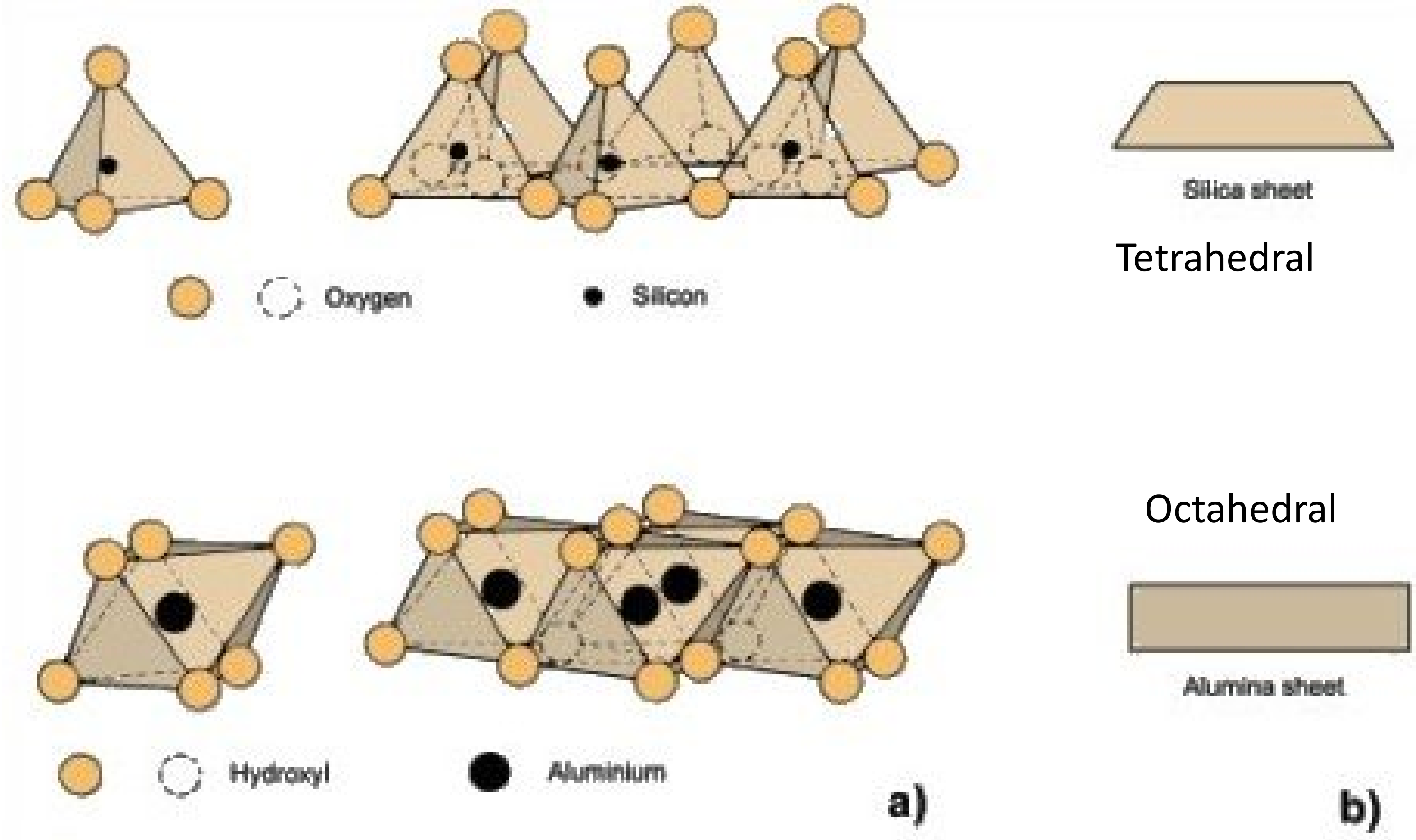
Feldspar (microcline) → Illite (clay mineral)

$$NaAlSi_3O_8 + H_2CO_3 + H_2O \rightarrow Na + H_4SiO_4 + Al_4Si_4O_{10}(OH)_8$$

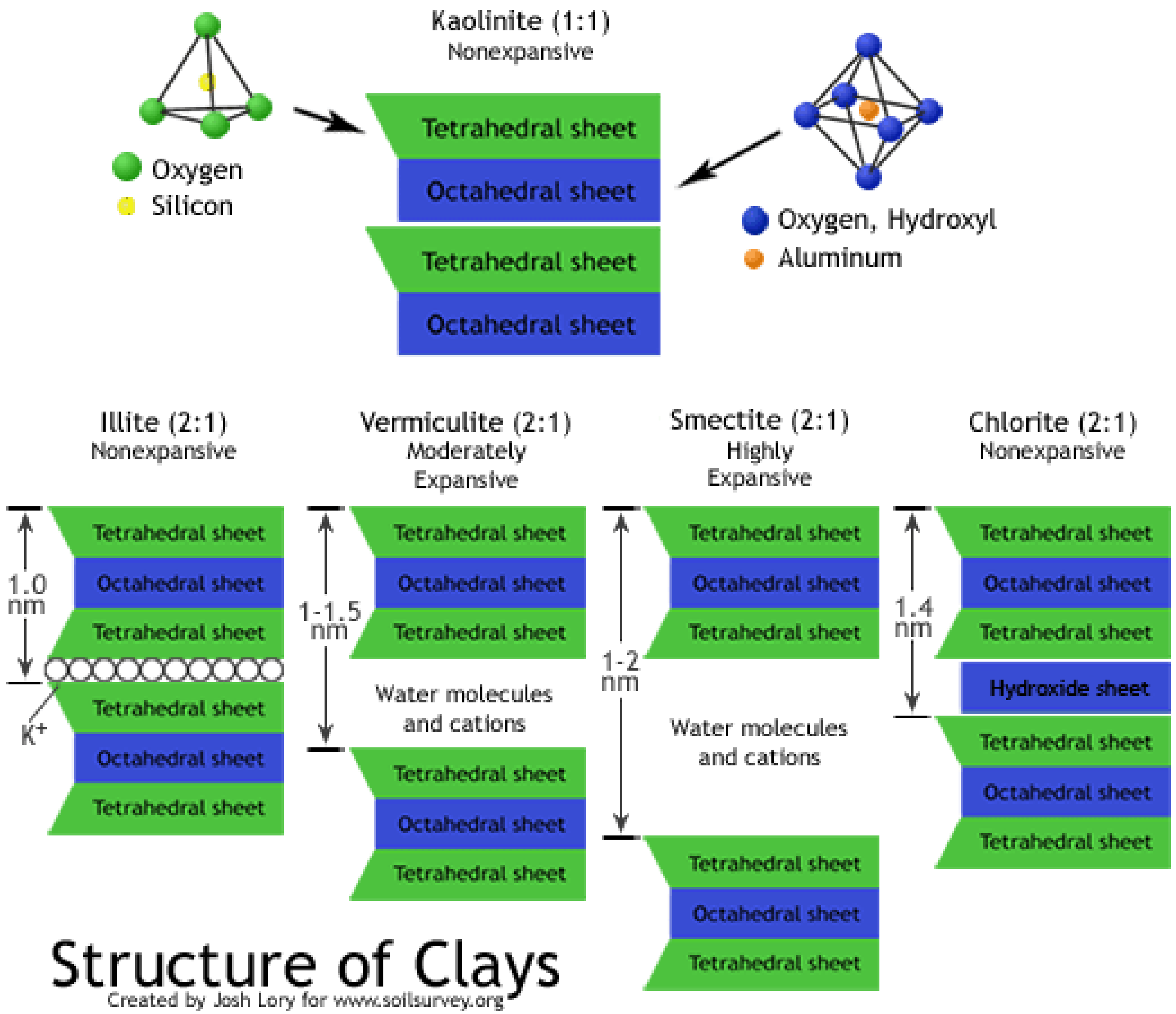
Feldspar (albite) → Kaolinite (clay mineral)

Other common clay minerals: *schmectite, gibbsite, montmorillonite, etc.*

Clay Minerals

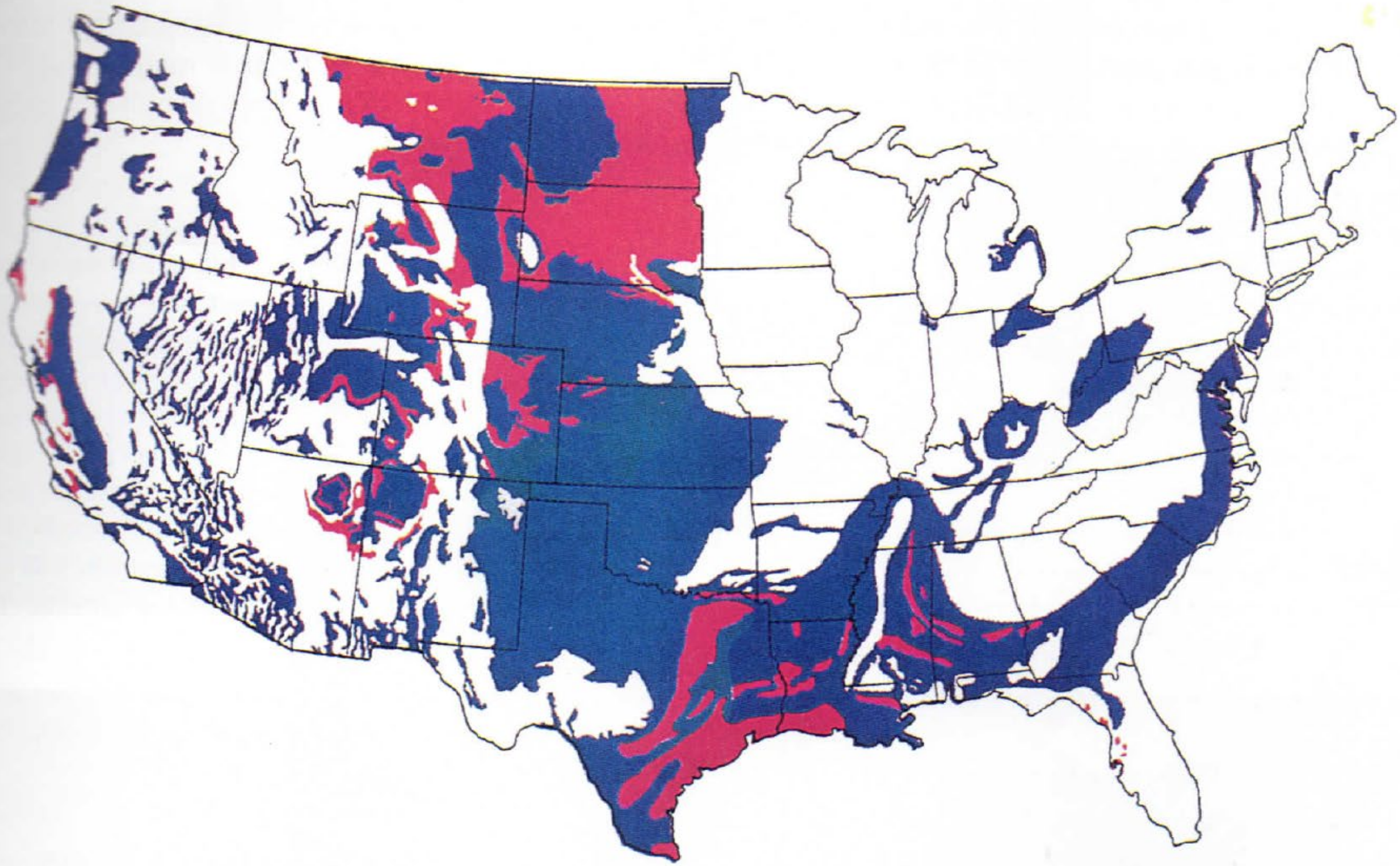


Clay Minerals



Clay Minerals

- Videos: http://www.bing.com/videos/search?q=swelling+clays+videos&FORM=VIRE9#view=detail&mid=18AF1B596F3ABC18AE8F18AF1B596F3ABC18AE8F

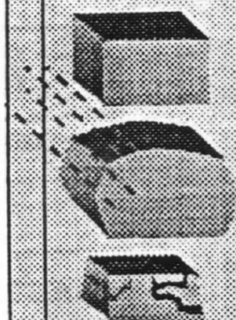


Swelling soils, heaving bedrock

Expansive clay soils and possibly heaving bedrock damage buildings and public works in the southwest metro area. Roads ride like rollercoasters, sidewalks and drywall crack, foundations buckle and walls bulge.

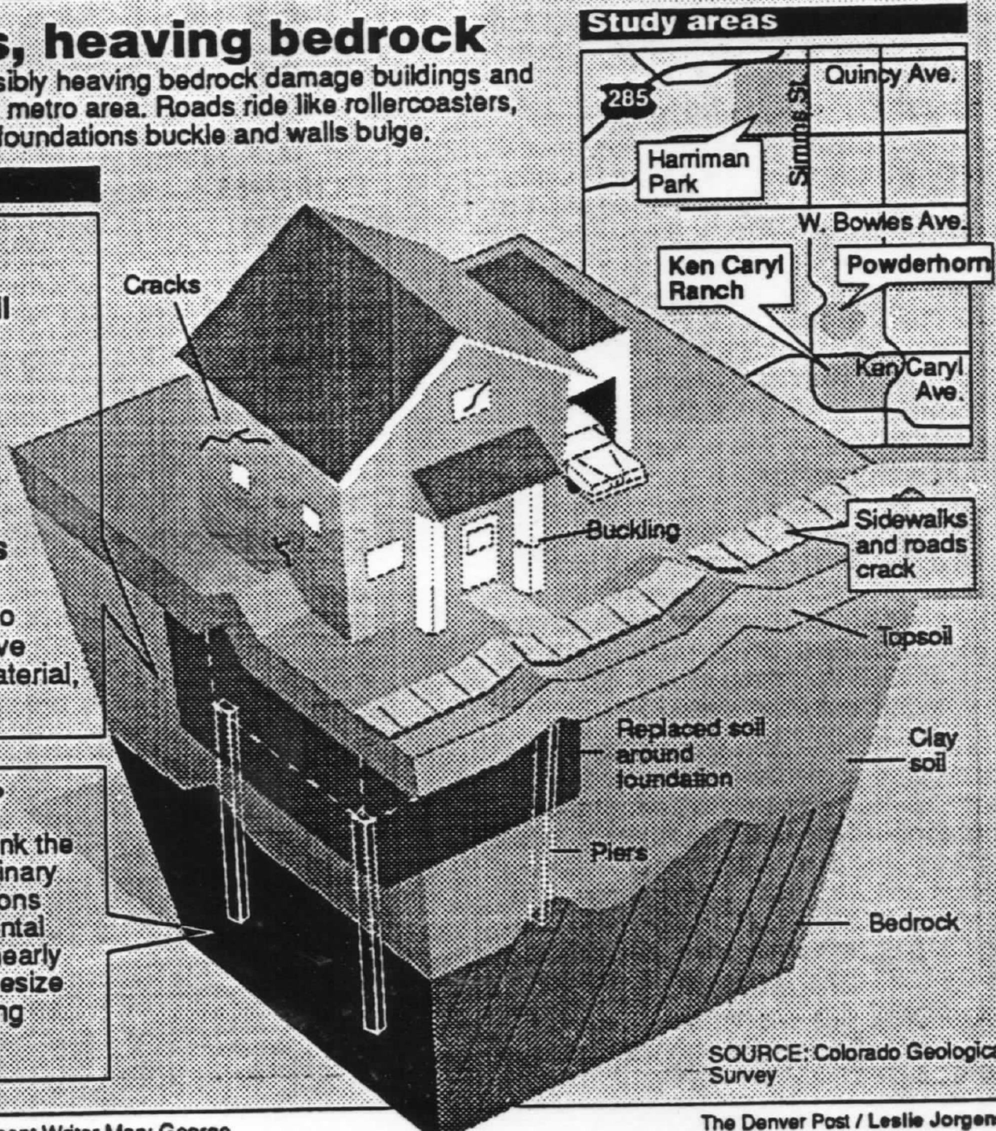
Causes

Swelling clay soil



1. Clay soil
2. Clay swells when wet
3. Shrinks and cracks when dry.

Remedies: Sink piers to bedrock, replace expansive soils with non-swelling material, improve drainage.



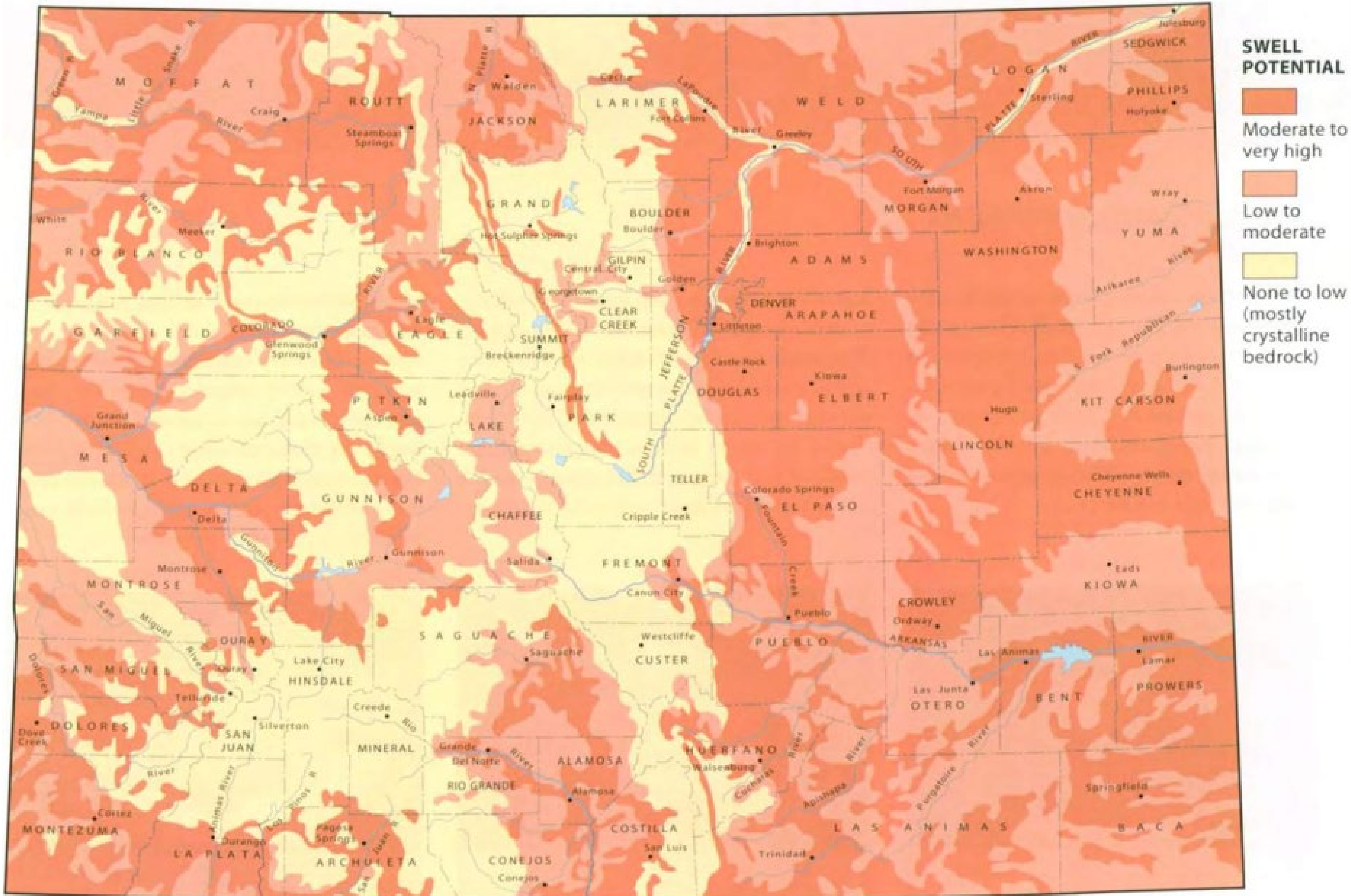
Heaving bedrock?

In this area scientists think the bedrock may be foiling ordinary remedies. Bedrock formations usually have stable, horizontal beds. Here, the beds are nearly vertical. Geologists hypothesize they slip and heave, causing surface "kicks."

SOURCE: Colorado Geological Survey

RESEARCH BY: Denver Post Environment Writer Mary George

The Denver Post / Leslie Jorgensen



This is a generalized map. The swell potential of soils at any specific location can only be determined by site-specific testing.
Map modified from "Shrink–Swell Potential" map, Colorado Land Use Commision, 1973.

Generalized distribution of swelling soil and bedrock in Colorado.

https://coloradogeologicalsurvey.org/2017/28869-swelling-expansive-soils-video/

Micas

Biotite
https://geology.com/minerals/biotite.shtml

Muscovite
https://geology.com/minerals/muscovite.shtml

Talc

https://geology.com/minerals/talc.shtml

Chlorite

https://geology.com/minerals/chlorite.shtml

Carbonates

Calcite $CaCO_3$

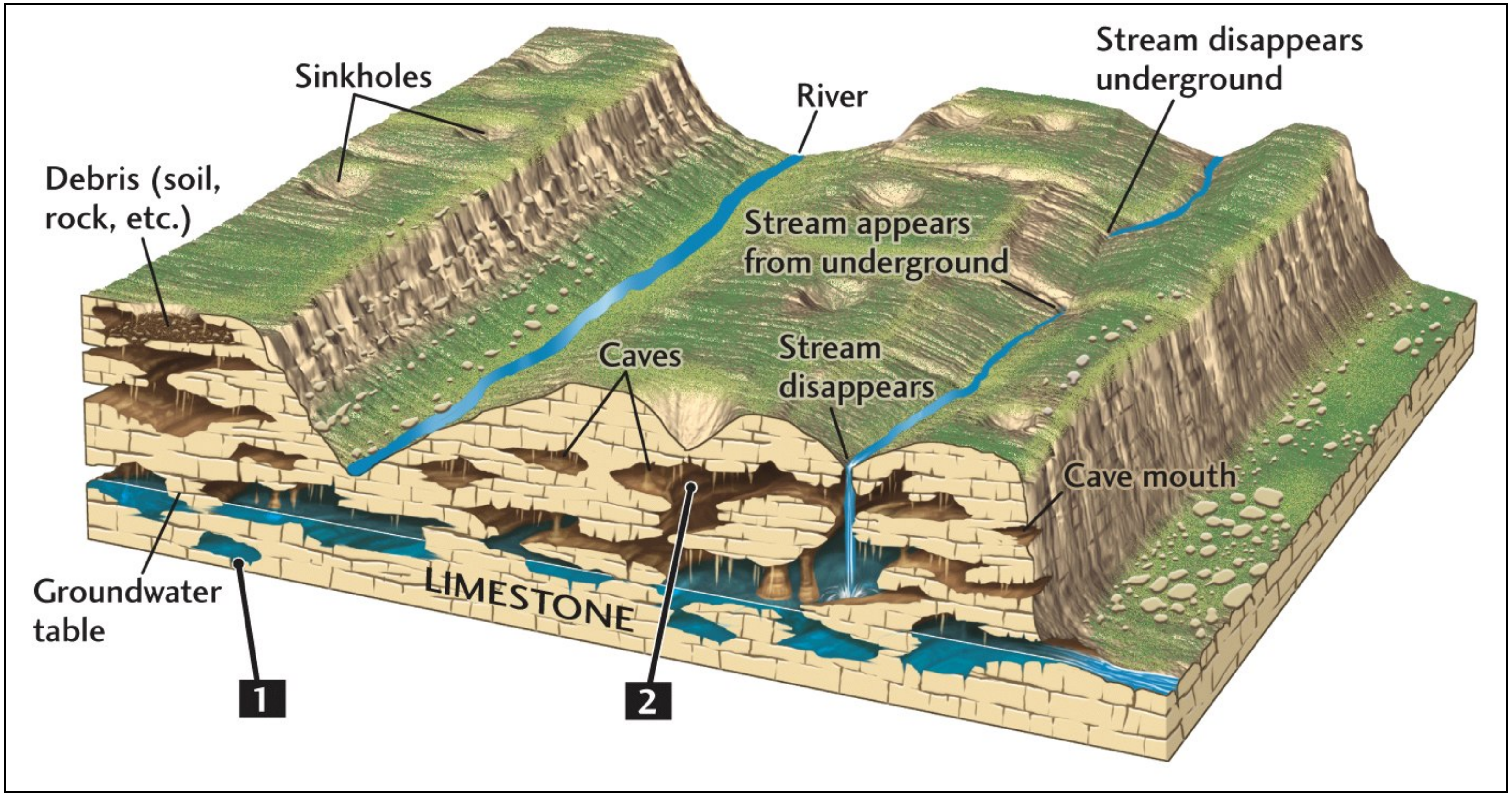
- https://geology.com/minerals/calcite.shtml

Dolomite $CaMg(CO_3)_2$.

- https://geology.com/minerals/dolomite.shtml

Karst Topography

- **Dissolution of carbonate rocks**



Evaporites - Sulfates

Anhydrite $CaSO_4$
https://geology.com/minerals/anhydrite.shtml

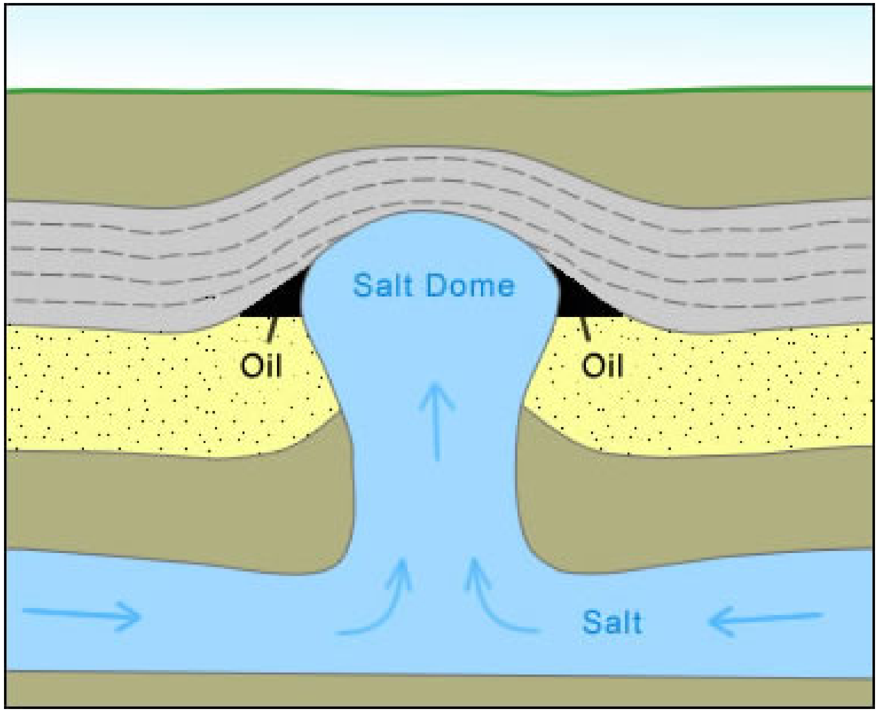
Gypsum $CaSO_4 \cdot 2H_2O$
https://geology.com/minerals/gypsum.shtml

https://www.understanding-cement.com/sulfate.html
https://www.bing.com/videos/search?q=sufates+and+concrete&&view=detail&mid=A4D1AB6DA9EDF0E099E8A4D1AB6DA9EDF0E099E8&&FORM=VDRVRV

Evaporites

Halite NaCl
https://geology.com/minerals/halite.shtml

Salt Dome



https://www.pbs.org/wgbh/nova/article/solving-nuclear-waste-with-wipp/

Video

Metallic Ore Minerals

- Pyrite (FeS_2): https://geology.com/minerals/pyrite.shtml
  Acid Mine Drainage
- Chalcopyrite ($CuFeS_2$): ore of copper
- Galena (PbS): ore of lead
- Sphalerite (ZnS): ore of zinc
- Magnetite (Fe_3O_4): richest ore of iron
- Uraninite (UO_2)
  Radon Gas, Mitigation Technique

Acid Drainage - A Consequence of the Sulfide Oxidation Reaction

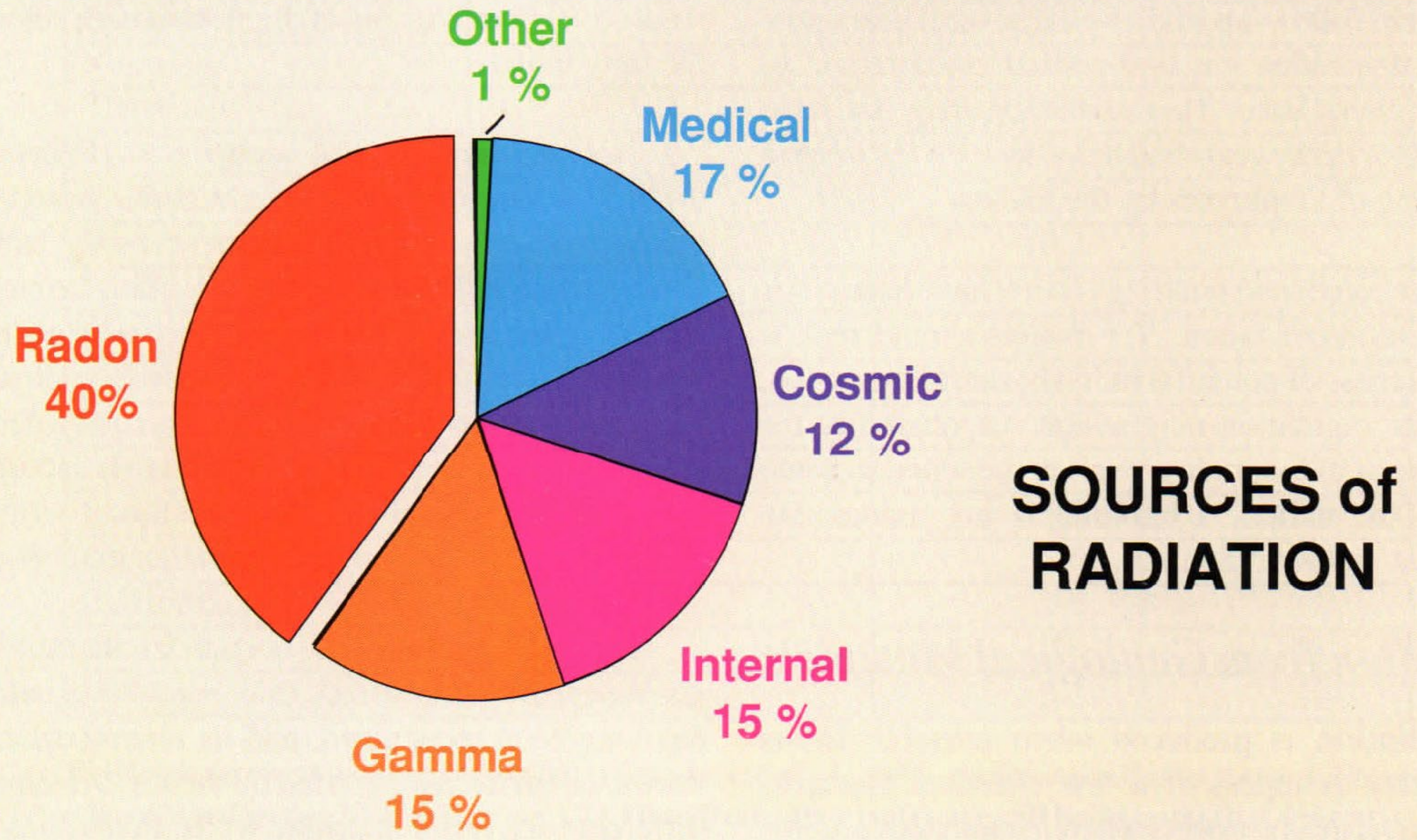
The same oxidation of iron sulfides that produces soil expansion causes widespread damage to streams and lakes in the form of *acid drainage*. Acid drainage (often called "acid mine drainage" because of its frequent occurrence at coal mines) occurs when sulfide minerals, particularly pyrite (iron sulfide - FeS_2) and marcasite (another iron sulfide - FeS_2), react with air and water to produce the sulfuric acid and iron sulfate minerals. Iron sulfide minerals are widely distributed. Those most likely to produce acid drainage occur in waste rock from mines, in coal, and in black shales. The sulfate minerals oxidize further to yield a rusty-red iron hydroxide sludge and sulfuric acid. An overall expression of the chemical reaction is:

$$4FeS_2 + 14H_2O + 15O_2 \longrightarrow 4Fe(OH)_3 + 8H_2SO_4$$

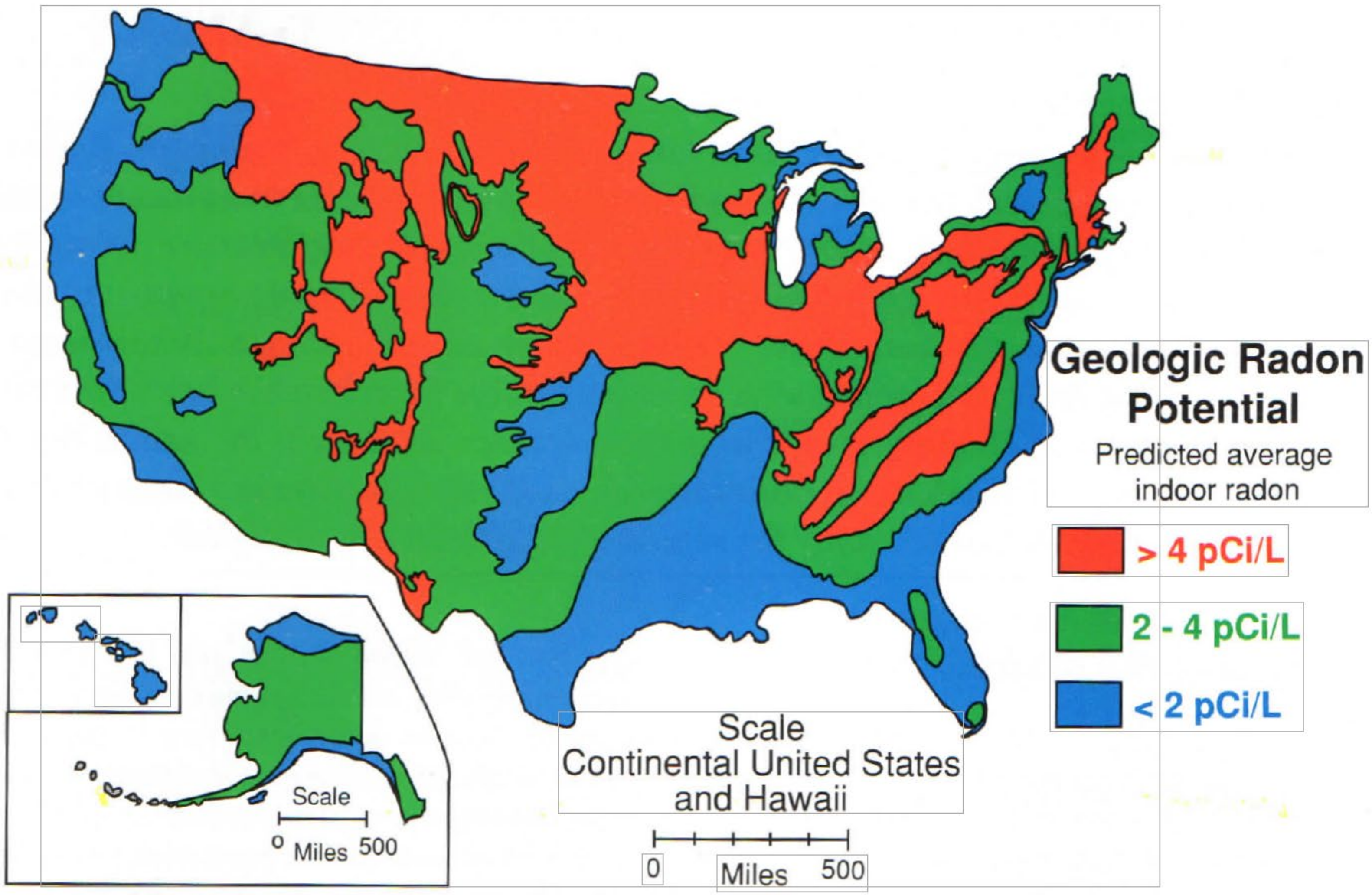
which means

Pyrite plus **water** plus **oxygen** from the air makes **iron hydroxide** and **sulfuric acid.**

When this reaction occurs, the sulfuric acid pollutes the water, and reddish iron hydroxide sludges choke streams and reservoirs. The acid waters kill aquatic life and attack man-made structures such as concrete bridge piers, retainer walls, concrete drains, utility and sewer pipes and well casings. Estimates vary between 5,000 and 10,000 linear miles for streams in the United States that have been ruined by acid drainage. The reaction costs mining industries over 1 million dollars a day simply to control it, and cumulative damages have been estimated at between 15 and 50 billion dollars. In nature, the reaction takes place quickly in the presence of the bacterium, *Thiobacillus ferrooxidans*. This species of bacteria derives its energy from the sulfide-oxidation process and serves to speed the reaction above by rates over one hundred times what they would be in bacteria-free conditions. The reaction also produces great quantities of heat and causes problems when coal that contains reactive pyrite is stockpiled or shipped. Natural weathering of rock exposes only a little reactive iron sulfide at a time, and thus the above reaction is not usually a problem until major excavations by humans quickly expose large volumes of sulfide-rich material. Then the reactions proceed quickly and great volumes of acid may form.



Radon accounts for about 40% of the radiation dose received by the average American (after Toohey, 1987).


Geologic Radon Potential
Predicted average indoor radon
> 4 pCi/L
2 - 4 pCi/L
< 2 pCi/L
Scale
Continental United States and Hawaii
0 Miles 500
Scale
0 Miles 500

State	Average Concentration pCi/L	% greater than 4 pCi/L	Rank
Iowa	8.8	71.1	1
North Dakota	7	60.7	2
Nebraska	5.5	53.5	3
Minnesota	4.8	45.4	4
Colorado	5.2	41.5	5
Pennsylvania	7.7	40.5	6
Maine	4.1	29.9	7
Ohio	4.3	29	8
Indiana	3.7	28.5	9
Wisconsin	3.4	26.6	10
Wyoming	3.6	26.2	11
Massachusetts	3.4	22.7	12
Kansas	3.1	22.5	13
New Mexico	3.1	21.8	14
Rhode Island	3.2	20.6	15
Idaho	3.5	19.3	16
Connecticut	2.9	18.5	17
Kentucky	2.7	17.1	18
Missouri	2.6	17	19
Vermont	2.5	15.9	20
Tennessee	2.7	15.8	21
West Virginia	2.6	15.7	22
Michigan	2.1	11.7	23
Nevada	2	10.2	24
Alaska	1.7	7.7	25
Georgia	1.8	7.5	26
North Carolina	1.4	6.7	27
Arizona	1.6	6.5	28
Alabama	1.8	6.4	29
South Carolina	1.1	3.7	30
Oklahoma	1.1	3.3	31
California	0.9	2.4	32
Louisiana	0.5	0.8	33
Hawaii	0.1	0.4	34