Minerals and their Engineering Properties

Engineering geology
Fall 2015
• 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

- $\text{SiO}_2$
- $\text{Al}_2\text{O}_3$
- $\text{Fe}_2\text{O}_3$
- $\text{CaO}$
- $\text{Na}_2\text{O}$
- $\text{K}_2\text{O}$
- $\text{MgO}$
- $\text{TiO}_2$
- $\text{MnO}$
- $\text{P}_2\text{O}_5$

$\text{Sum} = 100\%$
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.
“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.”

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 = Chalcopryrite \( \text{CuFeS}_2 \)

<table>
<thead>
<tr>
<th>Element</th>
<th>Atomic mass unit (g/mol)</th>
<th>Number of atoms</th>
<th>Total mass (g/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu</td>
<td>63.54</td>
<td>1</td>
<td>63.54</td>
</tr>
<tr>
<td>Fe</td>
<td>55.85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>32.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Sum (( \Sigma )) =</td>
</tr>
</tbody>
</table>
Identification of Minerals

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

Hexagonal pyramid (6 faces + planar base)

Hexagonal dipyramid (12 faces are isosceles triangles in perfect crystals; resembles 2 hexagonal pyramids united by their hexagon bases)

Tabular (shaped like a book)

Hexagonal dipyramid prism

Rhombohedron (a leaning block with 6 faces, each a rhombus)

Hexagonal prism

Prisms

Scalenohedron (12 faces, all scalene triangles; resembles 2 tall hexagonal prisms united by their nonplanar hexagon bases)

Dodecahedron (12 faces)

Tetrahedron (4 faces)

Octahedron (8 faces)

Needles

Blade

Pyrochrohedron (12 faces)

Dendritic

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

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*Note: The illustrations show the orientations and shapes of the broken pieces as they would appear when viewed from certain angles.*
# Hardness

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

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

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

A Arrangement of atoms in silicon-oxygen tetrahedron

B Diagrammatic representation of a silicon-oxygen tetrahedron
Olivine

\[[\text{Mg, Fe}]_2 \text{SiO}_4\]
Quartz (SiO$_2$)

- Macro-crystalline quartz (different colors due to impurities)
- Silicosis (occupational hazard)

[Links to OSHA and Bing videos]

http://www.osha.gov/SLTC/silicacrystalline/
http://www.bing.com/videos/search?q=silicosis+videos&qpt=silicosis+videos&FORM=VDRE#view=detail&mid=DF5F095E862A4129154ADF5F095E862A4129154A
Quartz (SiO$_2$)

- Micro-crystalline quartz (chert, flint, agate, jasper, opal, petrified wood)

- Alkali-Aggregate reaction

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 minerals: Needle structure (crocidolite, Blue asbestos, four other types). Does not dissolve in lungs
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)
Clay Minerals

- Tetrahedral
- Octahedral
Clay Minerals

Structure of Clays

Created by Josh Lory for www.soilsurvey.org
Clay Minerals

• Video: http://www.bing.com/videos/search?q=swelling+clays+videos&FORM=VIHE9#view=detail&mid=18AF1B596F3ABC18AE8F18AF1B596F3ABC18AE8F