GY 302: Crystallography & Mineralogy

Lecture 11: Oxides and Hydroxides
Part 1

Instructor: Dr. Douglas Haywick
Last Time

Sulfides and Sulfosalts

1. Properties of more sulfides/sulfosalts
2. Economics (resources, reserves, extraction)

Featured minerals: Molybdenite, Cinnabar
Sulfide Minerals

**Molybdenite (MoS₂)**

Crystal: Hexagonal  
Pt. Group: 6/m 2/m 2/m  
Habit: hexagonal plates, scales  
SG: 4.7  
H: 1-1.5  
L: metallic  
Col: silver to lead grey  
Str: green-grey  
Clev: perfect basal (001)

Name derivation: from the Greek *molybdos* meaning “lead”
Cinnabar (HgS)
Crystal: Hexagonal (trigonal)
Pt. Group: 32
Habit: massive, rarely rhombohedral
SG: 8.1
H: 2.5
L: dull to adamantine
Col: scarlet red
Str: scarlet
Clev: perfect (100)

Name derivation: from the Persian *zinjifrah* meaning red resin
Cinnabar Mineralization

Fig. 2. Relationship between Au-As-Hg and other types of gold mineralization for Au-As-Hg-Sb-Tl ore-forming systems.
Mining (Copper)

City of Butte

Berkley Pit (1 mile wide, 900 feet deep)
Molybdenite Emplacement

The current owners (Phillips Dodge) are doing environmental work on the mine, the tailings and the surrounding area.
Sulfide Refining

Extraction → Processing → Smelting → Conversion

Blasting Extraction Transport → Crushing Concentration Slurried → Roasting in an oxidizing furnace → Roasting in an reducing furnace

CuFeS₂ (1%) → CuFeS₂ (30%) → CuO + slag + SO₂ → Cu + slag + SO₂

Blister Copper

Electrolysis → 99% pure Cu

Fire Refining

Final removal of S and O
Today’s Agenda

Oxides and Hydroxides

1. Properties of select minerals
2. The chemistry of oxides/hydroxides
3. Banded Iron Formation

Featured minerals: Iron
# Oxides

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Formula</th>
<th>System</th>
<th>Specimen Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxides</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anatase</td>
<td>TiO₂</td>
<td>Tetragonal</td>
<td>f, f,g</td>
</tr>
<tr>
<td>Bauxite</td>
<td>Al₂O₃</td>
<td>Aggregate</td>
<td>f(x6)</td>
</tr>
<tr>
<td>Cassiterite</td>
<td>SnO₂</td>
<td>Tetragonal</td>
<td>f(x3), g,g</td>
</tr>
<tr>
<td>Chromite</td>
<td>FeCr₂O₄</td>
<td>Isometric</td>
<td>g(x6)</td>
</tr>
<tr>
<td>Chrysoberyl</td>
<td>BeAl₂O₄</td>
<td>Orthorhombic</td>
<td>g</td>
</tr>
<tr>
<td>*Columbite</td>
<td>(Fe,Mn)Nb₂O₆</td>
<td>Orthorhombic</td>
<td>g</td>
</tr>
<tr>
<td>Corundum</td>
<td>Al₂O₃</td>
<td>Hexagonal</td>
<td>g, g, g</td>
</tr>
<tr>
<td>Cuprite</td>
<td>Cu₂O</td>
<td>Isometric</td>
<td>p.f.f.g.g</td>
</tr>
<tr>
<td>Franklinite</td>
<td>(Zn,Mn²⁺,Fe²⁺)(Fe³⁺,Mn³⁺)₂O₄</td>
<td>Isometric</td>
<td>g(x3)</td>
</tr>
<tr>
<td>*Hematite (v. BIF)</td>
<td>Fe₂O₃</td>
<td>Hexagonal</td>
<td>g</td>
</tr>
<tr>
<td>Hematite (v. earthy)</td>
<td>Fe₂O₃</td>
<td>Hexagonal</td>
<td>g, g</td>
</tr>
<tr>
<td>Hematite (v. Specular)</td>
<td>Fe₂O₃</td>
<td>Hexagonal</td>
<td>g, g, g</td>
</tr>
<tr>
<td>Ilmenite</td>
<td>FeTiO₃</td>
<td>Hexagonal</td>
<td>g(x5)</td>
</tr>
<tr>
<td>Magnetite</td>
<td>Fe₃O₄</td>
<td>Isometric</td>
<td>f, g,g</td>
</tr>
<tr>
<td>*Manganese nodules</td>
<td>MnO₂, Fe₂O₃</td>
<td>Aggregate</td>
<td>g,g</td>
</tr>
<tr>
<td>Psilomelane</td>
<td>(Ba,H₂O)₂Mn₅O₁₀</td>
<td>Monoclinic</td>
<td>g, g</td>
</tr>
<tr>
<td>Pyrochlore</td>
<td>(Na,Ca)₂Nb₂O₆(OH,O)</td>
<td>Isometric</td>
<td>f</td>
</tr>
<tr>
<td>*Pyrolusite (v. dendrite)</td>
<td>MnO₂</td>
<td>Tetragonal</td>
<td>g</td>
</tr>
<tr>
<td>Pyrolusite</td>
<td>MnO₂</td>
<td>Tetragonal</td>
<td>f(x3), g(x3)</td>
</tr>
<tr>
<td>Rutile</td>
<td>TiO₂</td>
<td>Tetragonal</td>
<td>f, g, g</td>
</tr>
<tr>
<td>Spinel</td>
<td>MgAl₂O₄</td>
<td>Monoclinic</td>
<td>g</td>
</tr>
<tr>
<td>Stibiconite</td>
<td>Sb₃O₆(OH)</td>
<td>Isometric</td>
<td>f,f, g,g</td>
</tr>
<tr>
<td>*Uraninite</td>
<td>UO₂</td>
<td>Isometric</td>
<td>restricted</td>
</tr>
<tr>
<td>Zincite</td>
<td>(Zn, Mn)O</td>
<td>Hexagonal</td>
<td>g, g, g</td>
</tr>
</tbody>
</table>
Oxides

- Oxides involve a strong ionic bond between metal cations and $O^{2-}$. 
Oxides

- Oxides involve a strong ionic bond between metal cations and $O^{2-}$.
- Classification is done on the basis of valancy (AX types).

$$A_2X: \quad \text{e.g., } Cu_2O \text{ (cuprite)}$$

$$AX: \quad \text{e.g., } MgO \text{ (periclase)}$$

$$AB_2X_4: \quad \text{e.g., } FeCr_2O_4 \text{ (FeO} \cdot Cr_2O_3\text{) (chromite)}$$

$$Fe_3O_4 \text{ (FeO} \cdot Fe_2O_3\text{) (magnetite)}$$
Oxides

- Oxides involve a strong Ionic bond between metal cations and O${}^{2-}$.
- Classification is done on the basis of valancy (AX types).

\[ \text{A}_2\text{X: e.g., Cu}_2\text{O (cuprite)} \]
\[ \text{AX: e.g., MgO (periclase)} \]
\[ \text{AB}_2\text{X}_4: \text{ e.g., FeCr}_2\text{O}_4 \text{ (chromite)} \]
\[ \text{Fe}_3\text{O}_4 \text{ (magnetite)} \]

(Spinel Group = spinel, magnetite, chromite, etc.)

Isostructural (exhibits solid solution)
Oxides

- Oxides involve a strong Ionic bond between metal cations and $O^{2-}$.
- Classification is done on the basis of valancy (AX types).

$A_2X_3$: e.g., $Al_2O_3$ (corundum)
(Hematite Group = corundum, hematite, ilmenite, etc.)

$AX_2$: e.g., $SnO_2$ (Cassiterite)
(Rutile Group = cassiterite, rutile, pyrolusite, uraninite etc.)
Oxide Minerals

Hematite (Fe$_2$O$_3$)

Crystal: Hexagonal
Pt. Group: 32/m
Habit: blocky to earthy
SG: 5.25
H: 5-6
L: metallic to earthy
Col: red, brown-red, steel grey
Str: brown-red
Clev: none; parting on {001} and {101} due to twinning

Name derivation: After "haimatos" (Greek) blood - because one form is the colour of blood
Hematite ($\text{Fe}_2\text{O}_3$)

**Occurrence:** weathering and/or hydrothermal alteration of iron-bearing minerals; Banded Iron Formations

**Associated Mins:** lots!

**May be confused with:** goethite, cinnabar, cuprite

**Uses:** ore of iron, jewelry
Corundum (Al₂O₃)

Crystal: Hexagonal
Pt. Group: 32/m
Habit: platy
SG: 3.98-4.02
H: 9
L: vitreous to adamantine
Col: white, grey, red, yellow, blue
Str: white (difficult to obtain)
Clev: none; parting on {001} and {101} due to twinning

Name derivation: From "kurundum" (Tamil); "rubeus" (Latin) red; "sappheiros" (Greek) lapis lazuli
Corundum (Al$_2$O$_3$)

Occurrence: rare secondary mineral in Si-poor igneous rocks like syenites; more common in metamorphosed rocks, esp. carbonates

Associated Mins: spinel, zoisite, micas

May be confused with: not much (hardness is a giveaway)

Uses: abrasives; jewelry
Oxide Minerals

“Bauxite”
Al$_2$O$_3$+Al(OH)$_3$

Crystal: mixed
Pt. Group: n/a
Habit: massive
SG: 2 to 2.5
H: 1 to 3
L: dull to earthy
Col: white, grey, red, yellow
Str: white
Clev: n/a

Name derivation: From “Beauxite”, for the village of Les Beaux in France by P. Dufrenoy in 1847
# Oxide Minerals

## Aluminum (bauxite) (millions of tonnes)

<table>
<thead>
<tr>
<th>Country</th>
<th>Mine production 2013</th>
<th>Mine production 2014</th>
<th>Reserves</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>NA</td>
<td>NA</td>
<td>20,000</td>
</tr>
<tr>
<td>Australia</td>
<td>81,100</td>
<td>81,000</td>
<td>6,500,000</td>
</tr>
<tr>
<td>Brazil</td>
<td>32,500</td>
<td>32,500</td>
<td>2,600,000</td>
</tr>
<tr>
<td>China</td>
<td>46,000</td>
<td>47,000</td>
<td>830,000</td>
</tr>
<tr>
<td>Greece</td>
<td>2,100</td>
<td>2,100</td>
<td>600,000</td>
</tr>
<tr>
<td>Guinea</td>
<td>18,800</td>
<td>19,300</td>
<td>7,400,000</td>
</tr>
<tr>
<td>Guyana</td>
<td>1,710</td>
<td>1,800</td>
<td>850,000</td>
</tr>
<tr>
<td>India</td>
<td>15,400</td>
<td>19,000</td>
<td>540,000</td>
</tr>
<tr>
<td>Indonesia</td>
<td>55,700</td>
<td>500</td>
<td>1,000,000</td>
</tr>
<tr>
<td>Jamaica</td>
<td>9,440</td>
<td>9,800</td>
<td>2,000,000</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>5,400</td>
<td>5,500</td>
<td>160,000</td>
</tr>
<tr>
<td>Russia</td>
<td>5,320</td>
<td>5,300</td>
<td>200,000</td>
</tr>
<tr>
<td>Suriname</td>
<td>2,700</td>
<td>2,700</td>
<td>580,000</td>
</tr>
<tr>
<td>Venezuela</td>
<td>2,160</td>
<td>2,200</td>
<td>320,000</td>
</tr>
<tr>
<td>Vietnam</td>
<td>250</td>
<td>1,000</td>
<td>2,100,000</td>
</tr>
<tr>
<td>Other countries</td>
<td>4,570</td>
<td>4,760</td>
<td>2,400,000</td>
</tr>
<tr>
<td><strong>World total (rounded)</strong></td>
<td><strong>283,000</strong></td>
<td><strong>234,000</strong></td>
<td><strong>28,000,000</strong></td>
</tr>
</tbody>
</table>

**World Resources:** Bauxite resources are estimated to be 55 to 75 billion tons, in Africa (32%), Oceania (23%), South America and the Caribbean (21%), Asia (18%), and elsewhere (6%). Domestic resources of bauxite are inadequate to meet long-term U.S. demand, but the United States and most other major aluminum-producing countries have essentially inexhaustible subeconomic resources of aluminum in materials other than bauxite.
Oxide Minerals

Aluminum (millions of tonnes)

USGS Mineral Commodity Summary for 2015
## Oxide Minerals

### Aluminum (US data)

<table>
<thead>
<tr>
<th>Salient Statistics—United States:</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary</td>
<td>1,726</td>
<td>1,986</td>
<td>2,070</td>
<td>1,946</td>
<td>1,720</td>
</tr>
<tr>
<td>Secondary (from old scrap)</td>
<td>1,250</td>
<td>1,470</td>
<td>1,440</td>
<td>1,630</td>
<td>1,700</td>
</tr>
<tr>
<td>Imports for consumption (crude and semimanufactures)</td>
<td>3,610</td>
<td>3,710</td>
<td>3,760</td>
<td>4,160</td>
<td>4,150</td>
</tr>
<tr>
<td>Exports, total</td>
<td>3,040</td>
<td>3,420</td>
<td>3,480</td>
<td>3,390</td>
<td>3,260</td>
</tr>
<tr>
<td>Consumption, apparent^2</td>
<td>3,460</td>
<td>3,570</td>
<td>3,950</td>
<td>4,530</td>
<td>5,090</td>
</tr>
<tr>
<td>Price, ingot, average U.S. market (spot), cents per pound</td>
<td>104.4</td>
<td>116.1</td>
<td>101.0</td>
<td>94.2</td>
<td>104.6</td>
</tr>
<tr>
<td>Stocks:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aluminum industry, yearend</td>
<td>1,010</td>
<td>1,060</td>
<td>1,140</td>
<td>1,130</td>
<td>1,100</td>
</tr>
<tr>
<td>LME, U.S. warehouses, yearend^3</td>
<td>2,230</td>
<td>2,360</td>
<td>2,120</td>
<td>1,950</td>
<td>1,200</td>
</tr>
<tr>
<td>Employment, number^4</td>
<td>29,200</td>
<td>30,300</td>
<td>31,500</td>
<td>30,100</td>
<td>29,000</td>
</tr>
<tr>
<td>Net import reliance^5 as a percentage of apparent consumption</td>
<td>14</td>
<td>3</td>
<td>11</td>
<td>21</td>
<td>33</td>
</tr>
</tbody>
</table>

**Recycling:** In 2014, aluminum recovered from purchased scrap in the United States was about 3.63 million tons, of which about 53% came from new (manufacturing) scrap and 47% from old scrap (discarded aluminum products). Aluminum recovered from old scrap was equivalent to about 33% of apparent consumption.

**Import Sources (2010–13):** Canada, 63%; Russia, 5%; United Arab Emirates, 5%; China, 4%; and other, 23%.

USGS Mineral Commodity Summary for 2015
Cassiterite (SnO₂)

Crystal: Tetragonal
Pt. Group: 4/m 2/m 2/m
Habit: massive (placer) to prismatic
SG: 6.9-7.1
H: 6-7
L: earthy to adamantine
Col: yellow to red-brown
Str: greyish or brownish white
Clev: poor {001} and {111}

Name derivation: From "kassi-tira" (Babylonian) and "kastiram" (Sanscript) tin
Cassiterite (SnO₂)

Occurrence: rare accessory mineral in Si-rich granites; high temp hydrothermal veins; skarns; placer deposits

Associated Mins: wolframite, tourmaline, topaz, fluorite, lepidolite

May be confused with: rutile (when crystalline) and goethite (placer)

Uses: principle ore of tin (+Cu = bronze; +Pb & Sb = solder)
# Hydroxides

<table>
<thead>
<tr>
<th>Hydroxides</th>
<th>Formula</th>
<th>Structure</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>*Bindheimite</td>
<td>Pb₂Sb₂O₆(O,OH)</td>
<td>Isometric</td>
<td>g,g</td>
</tr>
<tr>
<td>Brucite</td>
<td>Mg(OH)₂</td>
<td>Hexagonal</td>
<td>g, g, g</td>
</tr>
<tr>
<td>Diaspore</td>
<td>AlO(OH)</td>
<td>Orthorhombic</td>
<td>g</td>
</tr>
<tr>
<td>Gibbsite</td>
<td>Al(OH)₃</td>
<td>Monoclinic</td>
<td>g,g,g</td>
</tr>
<tr>
<td>Goethite</td>
<td>FeO(OH)</td>
<td>Orthorhombic</td>
<td>f, g, g</td>
</tr>
<tr>
<td>Limonite</td>
<td>FeO(OH)</td>
<td>Aggregate</td>
<td>f, g(x4)</td>
</tr>
<tr>
<td>Manganite</td>
<td>MnO(OH)</td>
<td>Monoclinic</td>
<td>f, g(x4)</td>
</tr>
</tbody>
</table>

© p-poor, f-fair, g-good
Hydroxides

- Hydroxides involve a weaker ionic bond between metal cations and OH⁻ (softish)
Hydroxides

- Hydroxides involve a weaker ionic bond between metal cations and OH\(^-\) (softish)
- No real attempt to classify (many have variable chemistry, poor crystal structure)

\[
\begin{align*}
\text{AlO(OH)}: & \quad \text{diaspore, boehmite} \\
\text{Al (OH)}_3: & \quad \text{gibbsite}
\end{align*}
\]

*Typically mixed up with bauxite*
Brucite (Mg(OH)$_2$)
Crystal: Hexagonal (Trigonal)
Pt. Group: 3 2/m
Habit: hexagonal, mica-like masses
SG: 2.39
H: 2.5
L: vitreous to pearly
Col: colorless (pale shades)
Str: White
Clev: perfect on {001}

Name derivation: Named after American mineralogist, A. Bruce (1777-1818)
Brucite (Mg(OH)$_2$)

**Occurrence:** alteration product (after periclase) in marble and serpentinites

**Associated Mins:** with calcite in marble and with talc and magnesite in serpentinite

**May be confused with:** talc, gypsum, muscovite

**Uses:** refractory material
### Iron Economics

<table>
<thead>
<tr>
<th></th>
<th>Mine production</th>
<th>Reserves^7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2013</td>
<td>2014^6</td>
</tr>
<tr>
<td></td>
<td>Crude ore</td>
<td>Iron content</td>
</tr>
<tr>
<td>United States</td>
<td>53</td>
<td>6,900</td>
</tr>
<tr>
<td>Australia</td>
<td>609</td>
<td>53,000</td>
</tr>
<tr>
<td>Brazil</td>
<td>317</td>
<td>31,000</td>
</tr>
<tr>
<td>Canada</td>
<td>43</td>
<td>6,300</td>
</tr>
<tr>
<td>China</td>
<td>1,450</td>
<td>23,000</td>
</tr>
<tr>
<td>India</td>
<td>150</td>
<td>8,100</td>
</tr>
<tr>
<td>Iran</td>
<td>50</td>
<td>2,500</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>26</td>
<td>2,500</td>
</tr>
<tr>
<td>Russia</td>
<td>105</td>
<td>25,000</td>
</tr>
<tr>
<td>South Africa</td>
<td>72</td>
<td>1,000</td>
</tr>
<tr>
<td>Sweden</td>
<td>26</td>
<td>3,500</td>
</tr>
<tr>
<td>Ukraine</td>
<td>82</td>
<td>6,500</td>
</tr>
<tr>
<td>Other countries</td>
<td>127</td>
<td>18,000</td>
</tr>
<tr>
<td>World total (rounded)</td>
<td>3,110</td>
<td>190,000</td>
</tr>
</tbody>
</table>

**World Resources:** U.S. resources are estimated to be about 27 billion tons of iron contained within 110 billion tons of iron ore. U.S. resources are mainly low-grade taconite-type ores from the Lake Superior district that require beneficiation and agglomeration prior to commercial use. World resources are estimated to exceed 230 billion tons of iron contained within greater than 800 billion tons of crude ore.
Iron Economics

### Salient Statistics—United States:

<table>
<thead>
<tr>
<th></th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014$^e$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production$^2$</td>
<td>49.9</td>
<td>54.7</td>
<td>54.0</td>
<td>53.0</td>
<td>57.5</td>
</tr>
<tr>
<td>Shipments</td>
<td>50.6</td>
<td>55.6</td>
<td>52.9</td>
<td>52.7</td>
<td>54.2</td>
</tr>
<tr>
<td>Imports for consumption</td>
<td>6.4</td>
<td>5.3</td>
<td>5.2</td>
<td>3.2</td>
<td>5.5</td>
</tr>
<tr>
<td>Exports</td>
<td>10.0</td>
<td>11.1</td>
<td>11.2</td>
<td>11.0</td>
<td>13.0</td>
</tr>
<tr>
<td>Consumption:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reported (ore and total agglomerate)$^3$</td>
<td>42.3</td>
<td>46.3</td>
<td>46.9</td>
<td>48.8</td>
<td>49.5</td>
</tr>
<tr>
<td>Apparent$^4$</td>
<td>47.9</td>
<td>49.1</td>
<td>48.1</td>
<td>47.1</td>
<td>47.8</td>
</tr>
<tr>
<td>Price,$^5$ U.S. dollars per metric ton</td>
<td>98.79</td>
<td>99.45</td>
<td>98.16</td>
<td>104.90</td>
<td>101.00</td>
</tr>
<tr>
<td>Stocks, mine, dock, and consuming plant, yearend, excluding byproduct ore</td>
<td>3.47</td>
<td>3.26</td>
<td>3.11</td>
<td>2.29</td>
<td>4.50</td>
</tr>
<tr>
<td>Employment, mine, concentrating and pelletizing plant, number</td>
<td>4,780</td>
<td>5,270</td>
<td>5,420</td>
<td>5,644</td>
<td>5,750</td>
</tr>
<tr>
<td>Net import reliance$^6$ as a percentage of apparent consumption (iron in ore)</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
</tr>
</tbody>
</table>

**Recycling:** None (see Iron and Steel Scrap section).

**Import Sources (2010–13):** Canada, 71%; Brazil, 12%; Russia, 3.0%; Venezuela, 3.0%; and other, 11%.

USGS Mineral Commodity Summary for 2015
Iron Formation

Three major types of iron deposits.
Iron Formation

Three major types of iron deposits.

1) Replacement of limestone (Red Mountain Formation, Alabama); most are Jurassic in age

Clinton Type Fe Deposits
Iron Formation

Three major types of iron deposits.

1) Replacement of limestone (Red Mountain Formation, Alabama); most are Jurassic in age
   Clinton Type Fe Deposits

2) Primary hydrothermal deposits (deep sea vents); most are PreCambrian (Algoma Type Fe Deposits)
Three major types of iron deposits.

1) Replacement of limestone (Red Mountain Formation, Alabama); most are Jurassic in age
   Clinton Type Fe Deposits

2) Primary hydrothermal deposits (deep sea vents); most are PreCambrian (Algoma Type Fe Deposits)

3) Banded Iron Formations (hematite + jasper); most are Archean in age (Superior Type Fe Deposits)
BIFs

Banded iron formations (BIFs) are marine rocks composed of Fe$_2$O$_3$ and silica. They date from 3.1 billion years.
BIFs are thought to have been formed through oxygenation of sea water containing Fe$^{2+}$ (reduced iron).

\[
\text{Fe}^{2+} \rightarrow \text{Fe}^{3+}
\]

Soluble $\rightarrow$ Insoluble
Iron (Fe) and Human Uses

- Earth crust ~5% by weight (very abundant)

- ¹Steel consumption (world per capita, 1990): ~150 kg/yr

  \[ \Sigma \text{ world population steel consumption} \]
  \[ 6 \times 10^9 \text{ people} \times 1.5 \times 10^{-1} \text{ T/yr} = 9 \times 10^8 \text{ T/yr} \]

- ²Reserves of Fe ore (1990): 2.2x10¹¹ T

- Years of supply: \[ \frac{2.2 \times 10^{11} \text{ T}}{9 \times 10^8 \text{ T/yr}} = 2.4 \times 10^2 \text{ yrs} \]

- Banded Fe formations (global): 5x10¹⁴ T x 0.2 ≈ 1x10¹⁴ T

\[ \therefore \frac{\text{Global Resources}}{\text{Global Reserves}} = \frac{10^{14} \text{ T}}{2.2 \times 10^{11} \text{ T}} \approx 5 \times 10^2 \]
\[ \frac{\text{Global Resources}}{\text{Annual Fe Use}} = \frac{10^{14} \text{ T}}{10^9 \text{ T/yr}} \approx 10^5 \text{ Yrs} \]

Iron Formation

Banded Iron Formations (very low O$_2$ in atm)

10$^{14}$ Tons of banded iron formations

billions of years before present

Very Large Fe Deposits

<table>
<thead>
<tr>
<th>Continent</th>
<th>Area</th>
<th>Age ($10^6$ yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Africa</td>
<td>Transvaal, S.A.</td>
<td>2100–2600</td>
</tr>
<tr>
<td>Australia</td>
<td>Hamersley Range</td>
<td>2400–2700</td>
</tr>
<tr>
<td>Eurasia</td>
<td>Krivoi Rog, Ukraine</td>
<td>1900–2000</td>
</tr>
<tr>
<td>North America</td>
<td>Labrador Trough, Canada</td>
<td>1900–2500</td>
</tr>
<tr>
<td>South America</td>
<td>Minas Gerais, Brazil</td>
<td>2000–2700</td>
</tr>
</tbody>
</table>

http://www.ldeo.columbia.edu/edu/dees/U4735/lectures/03.html
Iron Extraction

Mt. Whaleback open pit iron mine at Newman, Western Australia.

http://www.geo.utexas.edu/courses/381R/Western%20Australia03.html
Today’s Stuff To Do

1. Assignment 6 Poster Selection (posted)

Today’s Lab

1. Quiz 4 (Natives and Sulfide minerals 12:10-12:30 PM)

On Line Lecture

1. Lecture 12 (Oxides 2)

Thursday

1. Lecture 17 (ore assessment and Assignment 7 (Group)
Mineral Quiz

- 7 minerals
- 2 easy
- 2 hard
- only have mineral note book
- no hand outs
GY 302: Crystallography and Mineralogy

Lecture 11: Oxides Part 1

Instructor: Dr. Doug Haywick
dhaywick@southalabama.edu

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