GEOLOGY, MINING, AND PROCESSING OF THE INDUSTRIAL MINERALS

SPRING 2018

Virginia McLemore
CLASS REQUIREMENTS
Goals in this class

- Importance, geology, mining, processing of industrial minerals, including critical minerals

- What is involved from exploration thru production thru marketing
  - Reports, field notes, presentations
  - Where to look for information
  - Research needed

- Sustainable development
  - We can mine within public concerns
  - Social license to operate
Goals in this class

- Understand where your world comes from
- Take pride in being part of the mining community
- Know where to find information
- Provide additional skills that will help you in your future career
Class

- The class will meet Mondays for 90-180 minutes
- Remaining time spent on field trips or in occasional extra discussion sessions (SME meetings, other presentations)
- Gives time for the presentations and project
<table>
<thead>
<tr>
<th>Month</th>
<th>Date</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>22</td>
<td>Introduction: IM definition and overview</td>
</tr>
<tr>
<td></td>
<td>29</td>
<td>Basic concepts: Geology, mining, and processing</td>
</tr>
<tr>
<td>February</td>
<td>5</td>
<td>Basic concepts: Geology, mining, and processing</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>More IM basic concepts; IM industry flow sheet, Transportation</td>
</tr>
<tr>
<td></td>
<td>19</td>
<td>Sustainable development</td>
</tr>
<tr>
<td></td>
<td>26</td>
<td>Midterm exam (Take Home) Annual SME meeting in Denver, no class</td>
</tr>
<tr>
<td>March</td>
<td>5</td>
<td>Commodities: Introduction</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>spring break NO CLASS</td>
</tr>
<tr>
<td></td>
<td>19</td>
<td>Commodities</td>
</tr>
<tr>
<td></td>
<td>26</td>
<td>Marketing, QA/QC, IM Trends</td>
</tr>
<tr>
<td>April</td>
<td>02</td>
<td>Commodities</td>
</tr>
<tr>
<td></td>
<td>09</td>
<td>New Mexico Geological Society Spring meeting, Socorro</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>Commodities</td>
</tr>
<tr>
<td></td>
<td>23</td>
<td>Commodities</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>Present research results in class</td>
</tr>
<tr>
<td>May</td>
<td>07</td>
<td>Present research results in class (15 mins); <strong>Final exam given out</strong></td>
</tr>
<tr>
<td></td>
<td>11</td>
<td><strong>Final Exam</strong> due by noon on May 11th</td>
</tr>
</tbody>
</table>
Lectures found on my web site
http://geoinfo.nmt.edu/staff/mclemoore/teaching/imclass/home.html
Textbook

Kogel, J.E, Trivedi, N.C., Barker, J.M., and Krukowski, S.T., 2006 , ed., Industrial Minerals and Rocks, 7th edition: Society for Mining, Metallurgy, and Exploration, Littleton, Colorado (use McLemore member #0154600) to get this price (save more $ than membership costs plus you should all be members of SME anyway)


Papers as assigned

http://geoinfo.nmt.edu/publications/monographs/memoirs/50/E/
Specifics

- Exams: Midterm and Final—both are take home exams that will emphasize short answer and essay questions.
- Term project—you are required to do a term/research project that will involve some original work (thesis, web page, other).
- Field trips—there will be 1 or more field trips and a trip report on each trip will be required.
- Team work and group projects/reports are encouraged, but midterm and final will be on your own.
- I will assign papers thru/out the term and each of you will get to lead the discussion each class.
<table>
<thead>
<tr>
<th>Grade</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midterm</td>
<td>25%</td>
</tr>
<tr>
<td>Final (comprehensive)</td>
<td>30%</td>
</tr>
<tr>
<td>field trip</td>
<td>5%</td>
</tr>
<tr>
<td>Term project</td>
<td>25%</td>
</tr>
<tr>
<td>Class Participation/papers</td>
<td>15%</td>
</tr>
</tbody>
</table>
Sources of data

- Internet
  - Aggregates
    - http://geopubs.wr.usgs.gov/open-file/of00-011/
  - http://www.minerals.com/
- Societies SME, Aggregate Association
Wikipedia

- Use sparingly
- Some of the information on Wikipedia is incorrect
- Some of your best data and sources of information are in the library and not in electronic form
- Be aware of using copyrighted material—get permission
Term Project

- Lesson plan, poster, and web site on importance of a specific commodity
- Take a common product and examine what minerals/rocks go into that product
- Mineral resource potential of specific mineral in a geographic area
- Flow of a commodity in our society
- Related to your thesis work
- Analytical procedures for a commodity/element
- Thesis topic
Dig A Little Deeper
How Many Minerals and Metals Does It Take to
Make A Light Bulb?

Bulb
Soft glass is generally used, made from silica, trona (soda ash), lime, coal, and salt. Hard glass, made from the same minerals, is used for some lamps to withstand higher temperatures and for protection against breakage.

Gas
Usually a mixture of nitrogen and argon to retard evaporation of the filament.

Support wires
Molybdenum wires support the filament.

Button & Button Rod
Glass, made from the same materials listed for the bulb (plus lead), is used to support and to hold the tie wires placed in it.

Heat Deflector
Used in higher wattage bulbs to reduce the circulation of hot gases into the neck of the bulb. It’s made of aluminum.

Filament
Usually is made of tungsten. The filament may be a straight wire, a coil, or a coiled-coil.

Lead-in-wires
Made of copper and nickel to carry the current to and from the filament.

Tie Wires
Molybdenum wires support lead-in wires.

Base
Made of brass (copper and zinc) or aluminum. One lead-in wire is soldered to the center contact and the other soldered to the base.

Stem Press
The wires in the glass are made of a combination of nickel-iron alloy core and a copper sleeve.

Fuse
Protects the lamp and circuit if the filament arcs. Made of nickel, manganese, copper and/or silicon alloys.

<table>
<thead>
<tr>
<th></th>
<th>Coal</th>
<th>Nuclear</th>
<th>Hydro</th>
<th>Natural Gas</th>
<th>Oil</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>54%</td>
<td>22%</td>
<td>10%</td>
<td>9%</td>
<td>4%</td>
<td>1%</td>
</tr>
</tbody>
</table>

For information about minerals in society, go to:
Mineral Information Institute, www.mii.org

Geography: Research & ID the states and countries producing these minerals.
INDUSTRIAL MINERAL RESOURCES IN NEW MEXICO

*Industrial minerals* are defined as a naturally occurring rock or mineral, exclusive of metal ores, mineral fuels, and gemstones. Industrial minerals are diverse materials and are used in virtually every aspect of modern life, providing raw materials for many industries, including building, manufacturing, and agriculture. The...
OUTLINE

- What are industrial minerals?
- Why are industrial minerals important?
- Strategic and critical minerals
- Classification of Industrial Minerals
- History of mining industrial minerals
WHAT ARE INDUSTRIAL MINERALS?
What is a mineral?
What is a mineral?

- Naturally occurring
- Inorganic
- Solid
- Homogeneous
- Crystalline material
- With a unique chemical element or compound with a set chemical formula
- Usually obtained from the ground
A crystal is composed of a structural unit that is repeated in three dimensions. This is the basic structural unit of a crystal of sodium chloride, the mineral halite.
Minerals refer to any rock, mineral, or other naturally occurring material of economic value, including metals, industrial minerals, energy minerals, gemstones, and aggregates.
What is a rock?
What is a rock?

- Naturally occurring
- Solid
- Homogeneous or heterogeneous
- Usually obtained from the ground
- Usually made up of one or more minerals
- Any naturally formed material composed of one or more minerals having some degree of chemical and mineralogic constancy
What are industrial minerals?
What are industrial minerals?

Any rock, mineral, or other naturally occurring material of economic value, excluding metals, energy minerals, and gemstones

One of the nonmetallics

Includes aggregates and many critical minerals
What are industrial minerals?

- Mined and processed from naturally occurring minerals
- Processed directly from minerals/waste=synthetic industrial minerals
- Exploited for their non-metallic value
- Wide range of industrial and domestic applications
## Typical examples of synthetic IM:

<table>
<thead>
<tr>
<th>Typical Example</th>
<th>Made From</th>
</tr>
</thead>
<tbody>
<tr>
<td>mullite</td>
<td>bauxite, kaolin</td>
</tr>
<tr>
<td>aluminas</td>
<td>bauxite</td>
</tr>
<tr>
<td>silicon carbide</td>
<td>quartz + coke</td>
</tr>
<tr>
<td>ppt calcium carbonate</td>
<td>lime &amp; CO$_2$</td>
</tr>
<tr>
<td>spinel</td>
<td>magnesite + alumina</td>
</tr>
<tr>
<td>soda ash</td>
<td>salt + limestone + coal + ammonia</td>
</tr>
<tr>
<td>fused minerals</td>
<td>alumina, magnesia, spinel</td>
</tr>
</tbody>
</table>
### Examples of IM that also have a **metallurgical** value:

<table>
<thead>
<tr>
<th>IM Value</th>
<th>Non-Metal Value</th>
<th>Metal Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>bauxite</td>
<td>cement, abrasives</td>
<td>aluminium</td>
</tr>
<tr>
<td>chromite</td>
<td>foundry sand, chemicals</td>
<td>chrome, Fe-Cr</td>
</tr>
<tr>
<td>rutile</td>
<td>white pigment</td>
<td>titanium</td>
</tr>
<tr>
<td>zircon</td>
<td>ceramics, glass</td>
<td>zirconium</td>
</tr>
<tr>
<td>manganese</td>
<td>batteries, pigments</td>
<td>manganese</td>
</tr>
<tr>
<td>quartz</td>
<td>glass, ceramics</td>
<td>silicon</td>
</tr>
<tr>
<td>stibnite</td>
<td>flame retardants</td>
<td>antimony</td>
</tr>
</tbody>
</table>

What are aggregates?
What are aggregates?

- materials used in construction, including sand, gravel, crushed stone, slag, or recycled crushed concrete
- Fillers and extenders to a certain degree
What are some examples of industrial minerals?
Includes

- Bauxite—Al ore, but also ore for alumina compounds
- Titanium—Ti ore, but also ore of TiO2, white pigments
- Sulfur—from pyrite and by-product of Cu-Pb-Zn mining
- Diamonds—gemstone, but also industrial applications
- Garnet—gemstones, but also abrasive
WHY ARE INDUSTRIAL MINERALS SO IMPORTANT?
Why are industrial minerals so important?

Because your world is made of them

Building blocks of our way of life
Why are industrial minerals so important?

the average American uses about 3 million pounds of industrial minerals, such as limestone, clay, and aggregate, over the period of a lifetime.
Every American Born Will Need...

- 27,365 lbs. Salt
- 11,655 lbs. Clays
- 15,107 lbs. Phosphate
- 6.97 million cu. ft. Natural Gas
- 72,381 gallons Petroleum
- 51,720 lbs. Cement
- 968 lbs. Copper
- 23,011 lbs. Iron Ore
- 419 lbs. Zinc
- 3,656 lbs. Bauxite (Aluminum)
- 1.88 Troy oz. Gold
- 1.42 million lbs. Stone, Sand, & Gravel
- 828 lbs. Lead
- 355,951 lbs. Coal
- plus 48,856 lbs. Other Minerals & Metals

3.188 million pounds of minerals, metals, and fuels in their lifetime

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Learn more at www.MineralsEducationCoalition.org

### Every Year

40,641 pounds of new minerals must be provided for every person in the United States to make the things we use daily.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stone</td>
<td>Used to make roads, buildings, landscaping, numerous chemical and construction uses</td>
</tr>
<tr>
<td>10,524 lbs.</td>
<td></td>
</tr>
<tr>
<td>Sand &amp; Gravel</td>
<td>Used to make concrete, asphalt, roads, blocks &amp; bricks</td>
</tr>
<tr>
<td>7,501 lbs.</td>
<td></td>
</tr>
<tr>
<td>Cement</td>
<td>Used to make roads, sidewalks, bridges, buildings, schools, houses</td>
</tr>
<tr>
<td>656 lbs.</td>
<td></td>
</tr>
<tr>
<td>Iron Ore</td>
<td>Used to make steel—buildings, cars, trucks, planes, trains, other construction, containers</td>
</tr>
<tr>
<td>292 lbs.</td>
<td></td>
</tr>
<tr>
<td>Salt</td>
<td>Used in various chemicals, highway deicing, food &amp; agriculture</td>
</tr>
<tr>
<td>347 lbs.</td>
<td></td>
</tr>
<tr>
<td>Phosphate Rock</td>
<td>Used to make fertilizers to grow food, animal feed supplements</td>
</tr>
<tr>
<td>192 lbs.</td>
<td></td>
</tr>
<tr>
<td>Clays</td>
<td>Used to make floor &amp; wall tile, dinnerware, kitty litter, bricks &amp; cement, paper</td>
</tr>
<tr>
<td>160 lbs.</td>
<td></td>
</tr>
<tr>
<td>Aluminum (Bauxite)</td>
<td>Used to make buildings, beverage containers, autos, airplanes</td>
</tr>
<tr>
<td>46 lbs.</td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td>Used in buildings, electrical &amp; electronic parts, plumbing, transportation</td>
</tr>
<tr>
<td>12 lbs.</td>
<td></td>
</tr>
<tr>
<td>Lead</td>
<td>75% used for transportation—batteries, electrical, communications</td>
</tr>
<tr>
<td>11 lbs.</td>
<td></td>
</tr>
<tr>
<td>Zinc</td>
<td>Used to make metals rust resistant, various metals &amp; alloys, paint, rubber, skin creams, health care, and nutrition</td>
</tr>
<tr>
<td>5 lbs.</td>
<td></td>
</tr>
<tr>
<td>Soda Ash</td>
<td>Used to make all kinds of glass, in powdered detergents, medicines, as a food additive, photography, water treatment</td>
</tr>
<tr>
<td>35 lbs.</td>
<td></td>
</tr>
<tr>
<td>Manganese</td>
<td>Used to make almost all steel for construction, machinery, transportation</td>
</tr>
<tr>
<td>4 lbs.</td>
<td></td>
</tr>
<tr>
<td>Other Nonmetals</td>
<td>Used in glass, chemicals, soaps, paper, computers, cell phones, etc.</td>
</tr>
<tr>
<td>523 lbs.</td>
<td></td>
</tr>
<tr>
<td>Other Metals</td>
<td>Used in electronics, TV &amp; video equipment, recreation equipment, etc.</td>
</tr>
<tr>
<td>22 lbs.</td>
<td></td>
</tr>
</tbody>
</table>

**Including These Energy Fuels**

- 918 gallons of Petroleum
- 88,503 cu. ft. of Natural Gas
- 4,517 lbs. of Coal
- 0.2 lb. of Uranium

To generate the energy each person uses in one year—

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U.S. flow of raw materials by weight 1900-2015. The use of raw materials in the U.S. increased dramatically during the last 100 years (updated from Wagner, 2002).

Figure 5. United States flow of raw materials by weight from 1900–2014. The use of raw materials increased dramatically during the last 100 years (modified from Wagner, 2002).
American manufacturers currently rely on foreign suppliers for more than half of the minerals they use in finished products.

The United States is 100% dependent on imports for 19 minerals and more than 50% import-dependent for an additional 24 minerals – many of which are industrial minerals.

As the U.S. economy continues to expand, manufacturing, construction and agriculture will drive demand for increased use of industrial minerals that will fuel the domestic engine of growth.
<table>
<thead>
<tr>
<th>Commodity</th>
<th>Percent</th>
<th>Major import sources (2012–15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARSENIC</td>
<td>100</td>
<td>China, Japan</td>
</tr>
<tr>
<td>ARSENICAL</td>
<td>100</td>
<td>Brazil</td>
</tr>
<tr>
<td>CEMENTONIS</td>
<td>100</td>
<td>Canada</td>
</tr>
<tr>
<td>FLUORSPAR</td>
<td>100</td>
<td>Mexico, China, South Africa, Mongolia</td>
</tr>
<tr>
<td>GALLIUM</td>
<td>100</td>
<td>China, Germany, United Kingdom, Ukraine</td>
</tr>
<tr>
<td>GRAPHITE (natural)</td>
<td>100</td>
<td>China, Mexico, Canada, Brazil</td>
</tr>
<tr>
<td>INDUM</td>
<td>100</td>
<td>China, France, Belgium</td>
</tr>
<tr>
<td>MANGANESE</td>
<td>100</td>
<td>South Africa, Gabon, Australia, Georgia</td>
</tr>
<tr>
<td>MICA, sheet (natural)</td>
<td>100</td>
<td>China, Brazil, Belgium, Austria</td>
</tr>
<tr>
<td>NIOBIUM (columbium)</td>
<td>100</td>
<td>China, Japan, Romania, United Kingdom</td>
</tr>
<tr>
<td>QUARTZ CRYSTAL (industrial)</td>
<td>100</td>
<td>China, Estonia, France, Japan</td>
</tr>
<tr>
<td>RARE EARTHS</td>
<td>100</td>
<td>Canada</td>
</tr>
<tr>
<td>RUBIDIUM</td>
<td>100</td>
<td>China</td>
</tr>
<tr>
<td>SCANDIUM</td>
<td>100</td>
<td>Mexico, Germany, China</td>
</tr>
<tr>
<td>STRONTIUM</td>
<td>100</td>
<td>China, Kazakhstan, Germany, Thailand</td>
</tr>
<tr>
<td>TANTALUM</td>
<td>100</td>
<td>Germany, Russia</td>
</tr>
<tr>
<td>THALLIUM</td>
<td>100</td>
<td>India, France, United Kingdom</td>
</tr>
<tr>
<td>THORIUM</td>
<td>100</td>
<td>Czech Republic, Canada, Republic of Korea, Austria</td>
</tr>
<tr>
<td>VANADIUM</td>
<td>100</td>
<td>China, Estonia, Japan, Germany</td>
</tr>
<tr>
<td>YTTRIUM</td>
<td>100</td>
<td>Belgium, South Africa</td>
</tr>
<tr>
<td>GEMSTONES</td>
<td>99</td>
<td>Israel, India, Belgium, South Africa</td>
</tr>
<tr>
<td>BISMUTH</td>
<td>95</td>
<td>China, Belgium, Peru, United Kingdom</td>
</tr>
<tr>
<td>TITANIUM MINERAL CONCENTRATES</td>
<td>91</td>
<td>South Africa, Australia, Canada, Mozambique</td>
</tr>
<tr>
<td>POTASH</td>
<td>90</td>
<td>Canada, Russia, Chile, Israel</td>
</tr>
<tr>
<td>GERMANIUM</td>
<td>85</td>
<td>China, Belgium, Russia, Canada, Canada, Chile</td>
</tr>
<tr>
<td>STONE (dimension)</td>
<td>84</td>
<td>China, Brazil, Italy, Turkey</td>
</tr>
<tr>
<td>ANTIMONY</td>
<td>83</td>
<td>China, Thailand, Bolivia, Belgium</td>
</tr>
<tr>
<td>ZINC</td>
<td>82</td>
<td>Canada, Mexico, Peru, Australia</td>
</tr>
<tr>
<td>RHENIUM</td>
<td>81</td>
<td>Chile, Poland, Germany</td>
</tr>
<tr>
<td>GARNET (industrial)</td>
<td>79</td>
<td>Australia, India, South Africa, China</td>
</tr>
<tr>
<td>BARITE</td>
<td>75</td>
<td>China, India, Morocco, Mexico</td>
</tr>
<tr>
<td>FUSED ALUMINUM OXIDE (crude)</td>
<td>&gt;=75</td>
<td>China, Canada, Venezuela</td>
</tr>
<tr>
<td>BAUXITE</td>
<td>&gt;=75</td>
<td>Jamaica, Brazil, Guinea, Guaya</td>
</tr>
</tbody>
</table>
How do industrial minerals differ from other commodities?
Mine to market supply chain

- supply sector
- logistics sector
- consuming market sector
Mine to market supply chain

**SUPPLY**
- exploration
- mineral finance
- plant engineering
- mining
- processing

**LOGISTICS**
- trading
- port handling
- mineral inspection
- freight
- warehousing/distribution

**MARKET**
- direct market mineral consumer
- intermediate market mineral consumer
- end market mineral consumer

**DEMAND**
## Price comparison of metals & IM

US$/tonne unless indicated

<table>
<thead>
<tr>
<th>Metals</th>
<th>Metals</th>
<th>Industrial minerals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold</td>
<td>392/oz</td>
<td>Salt</td>
</tr>
<tr>
<td>Silver</td>
<td>6.23/oz</td>
<td>Silica sand</td>
</tr>
<tr>
<td>Aluminium HG</td>
<td>1,645</td>
<td>Olivine</td>
</tr>
<tr>
<td>Copper A</td>
<td>2,760</td>
<td>Dead burned magnesia</td>
</tr>
<tr>
<td>Zinc</td>
<td>1,014</td>
<td>Zircon</td>
</tr>
</tbody>
</table>

Source: LME; *Mineral PriceWatch*
### US metals & IM production 2003

**tonnes; US$/tonne**

<table>
<thead>
<tr>
<th>Metals</th>
<th>Volume</th>
<th>Value</th>
<th>Industrial minerals</th>
<th>Volume</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td>2.7m.</td>
<td>4,000m.</td>
<td>Crushed stone</td>
<td>1,490m.</td>
<td>8,600m.</td>
</tr>
<tr>
<td>Gold</td>
<td>266</td>
<td>2,900m.</td>
<td>Sand &amp; gravel</td>
<td>1,158m.</td>
<td>6,366m.</td>
</tr>
<tr>
<td>Copper</td>
<td>1.1m.</td>
<td>2,000m.</td>
<td>Lime</td>
<td>18.2m.</td>
<td>1,017m.</td>
</tr>
<tr>
<td>Zinc</td>
<td>770,000</td>
<td>664m.</td>
<td>Soda ash</td>
<td>10.6m.</td>
<td>800m.</td>
</tr>
</tbody>
</table>

Source: USGS
WHAT ARE STRATEGIC AND CRITICAL MINERALS?
What are strategic and critical minerals?

- Minerals required for national defense
- Minerals that we export more than 75%
  - Beryllium
  - Aluminum
Differences between critical and strategic

- Minerals for military uses are strategic.
- Minerals for which a threat to supply could involve harm to the economy are critical.
- A critical mineral may or may not be strategic, while a strategic mineral will always be critical.
What are green technologies?

- Environmental technologies or clean technologies
- Future and existing technologies that conserve energy and natural resources and curb the negative impacts of human involvement, i.e. environmental friendly (modified from Wikipedia)
  - Alternative power (wind turbines, solar energy)
  - Hybrid and electric cars
  - Batteries
  - Magnets

- Other technologies
  - Water purification
  - Desalination
  - Carbon capture and storage
WHAT MINERALS ARE USED IN THESE TECHNOLOGIES?

Beryl

beryllium tuff (USGS OF 98-524)

Monazite
http://mineral.galleries.com

Kernite http://www.borax.com
Elements in Computer Chips
(National Research Council, 2007)

- **Elements needed in 1980s**
- **Additional elements needed today**

- **H** (Hydrogen)
- **He** (Helium)
- **Li** (Lithium)
- **Be** (Beryllium)
- **Na** (Sodium)
- **Mg** (Magnesium)
- **K** (Potassium)
- **Ca** (Calcium)
- **Sc** (Scandium)
- **Ti** (Titanium)
- **V** (Vanadium)
- **Cr** (Chromium)
- **Mn** (Manganese)
- **Fe** (Iron)
- **Co** (Cobalt)
- **Ni** (Nickel)
- **Cu** (Copper)
- **Zn** (Zinc)
- **Ga** (Gallium)
- **Ge** (Germanium)
- **As** (Arsenic)
- **Se** (Selenium)
- **Br** (Bromine)
- **Kr** (Krypton)
- **Rb** (Rubidium)
- **Sr** (Strontium)
- **Y** (Yttrium)
- **Zr** (Zirconium)
- **Nb** (Niobium)
- **Mo** (Molybdenum)
- **Tc** (Technetium)
- **Ru** (Ruthenium)
- **Rh** (Rhodium)
- **Pd** (Palladium)
- **Ag** (Silver)
- **Cd** (Cadmium)
- **In** (Indium)
- **Sn** (Tin)
- **Sb** (Antimony)
- **Te** (Tellurium)
- **I** (Iodine)
- **Xe** (Xenon)
- **Cs** (Cesium)
- **Ba** (Barium)
- **La** (Lanthanum)
- **Hf** (Hafnium)
- **Ta** (Tantalum)
- **W** (Tungsten)
- **Re** (Rhenium)
- **Os** (Osmium)
- **Ir** (Iridium)
- **Pt** (Platinum)
- **Au** (Gold)
- **Hg** (Mercury)
- **Tl** (Thallium)
- **Pb** (Lead)
- **Bi** (Bismuth)
- **Po** (Polonium)
- **At** (Astatine)
- **Rn** (Radon)
- **Fr** (Francium)
- **Ra** (Radium)
- **Ac** (Actinium)

- **Ce** (Cerium)
- **Pr** (Praseodymium)
- **Nd** (Neodymium)
- **Pm** (Promethium)
- **Sm** (Samarium)
- **Eu** (Euradamium)
- **Gd** (Gadolinium)
- **Tb** (Thulium)
- **Dy** (Dysprosium)
- **Ho** (Hollmium)
- **Er** (Erbium)
- **Tm** (Thulium)
- **Yb** (Ytterbium)
- **Lu** (Lutetium)
- **Th** (Thorium)
- **Pa** (Protactinium)
- **U** (Uranium)
- **Np** (Neptunium)
- **Pu** (Plutonium)
- **Am** (Americium)
- **Cm** (Curium)
- **Bk** (Berkelium)
- **Cf** (Californium)
- **Es** (Einsteinium)
- **Fm** (Fermium)
- **Md** (Mendelevium)
- **No** (Nobelium)
- **Lr** (Lawrencium)
Toyota Prius

2.2 lbs Nd in magnets
22-33 lbs La in batteries

http://www.molycorp.com/hybrid_ev.asp
CLASSIFICATION OF INDUSTRIAL MINERALS
Classification of Industrial Minerals

- Alphabetical
  - Obscures links between commodities
- Geologic processes
  - Igneous, sedimentary, metamorphic
  - Misses waste and processes materials
- Tectonic models
  - Important properties
  - Chemical
- Important properties
- End uses
Construction

- limestone
- dimension stone (granite, marble, flagstone, etc.)
- clay
- diatomite
- perlite
- gypsum
- lime
Chemicals

- Barite
- Dolomite
- Lithium
- Magnesite
- Phosphates

- Bauxite
- Limestone
- Pumice
- Borates
- Zeolite
Agricultural

- Phosphates
- Borates
- Clays
- Perlite
- Dolomite
- Talc
- Vermiculite
- Peat
Glass and ceramics

- Borates
- Silica
- Quartz
- Soda ash
- Kaolin
- Pyrophyllite
- Talc
- Bauxite
- Alumina
Fillers and extenders

- Barite
- Clays
- Soda ash
- Diatomite

- Titanium minerals
- Gypsum
- Limestone
Energy

- Clays
- Magnesite
- Graphite
- Lithium

- Drilling mud
- Refining additives
- Batteries
Environmental

- Bauxite
- Alumina
- Dolomite
- Limestone
- Zeolite
- Asbestos
- Perlite
- Magnesia
- Gypsum
- Pyrophyllite
Other uses

- Clays
- Dolomite
- Talc
- Magnesite
- Limestone magnesia
- Zeolites
- Nitrates
- Potash
- Salt
- Pharmaceuticals
- Drugs
- Cosmetics
- Food additives
“Without a market, an industrial mineral deposit is merely a geological curiosity.”

Demand feeds back from the end-use market, to the end product, to the intermediate end product, and finally back to the mineral supplier.
Geologically, most industrial minerals are widespread and have enormous reserves. They are easy to access and can be mined by small operations. Although they have high volume and low value, they are vital as prerequisite raw materials for a wide range of products.
Economics

- development needs less investments
- are cheaper to obtain
  - must be closer to the market
  - some specialty minerals demand a higher market price than metals
- are more effective
- Market demand drives IM supply
Technological

- needs less processing
- needs less energy
- less effect on the environment
- possess exceptionally attractive properties for the industry
The main challenge is provide society with its needs, protect future resources, limit alteration of the landscape, and affect local communities as little as possible (i.e. sustainable development).
Some of the challenges in producing industrial minerals

- How much of industrial minerals do we need?
- Are there enough materials in the pipeline to meet the demand for these technologies and other uses?
- Can any of these be recycled?
- Are there substitutions that can be used?
- Are these minerals environmental friendly—what are the reclamation challenges?

- REE and Be are nearly always associated with U and Th and the wastes from mining REE and Be will have to accommodate radioactivity and radon
Additional challenges

Are any of these minerals “conflict minerals”, i.e. minerals that fall under the Conflict Minerals Trade Act (H.R. 4128)

- Minerals that provide major revenue to armed fractions for violence, such as that occurring in the Democratic Republic of Congo (GSA, Nov. 2010)
MINING’S INFLUENCE IN HISTORIC CULTURES
Importance of minerals

- Mining began with prehistoric man who wanted to improve their way of life.
- Ancient cultures often settled time after time around areas that provided raw materials.
- 300,000-100,000 years ago mining of flint in N France and S England.
- Throughout history, wars were fought over natural resources.
Important Cultural Eras

- Stone Age (prior to 4000 B.C.)
- Bronze Age (4000 to 5000 B.C.)
- Iron Age (1500 B.C. to 1780 C.E.)
- Steel Age (1780 to 1945)
- Nuclear Age (1945 to the present)
• **Early civilisations:** fundamental importance of nonfuel minerals, metals, and materials technology and applications.
  - Stone Age, Copper Age, Bronze Age, Iron Age
  - Discovery of metals: **innovations and applications**
    • Gold (6000 BC), copper (4200 BC), silver (4000 BC), lead (3500 BC), tin (1750 BC), iron (1500 BC), mercury (750 BC)

• **Information Age:** developments in materials science and engineering, mineral exploration, and processing continue to enable and support the development of new technologies
<table>
<thead>
<tr>
<th>Period—Stage</th>
<th>Near East—Mediterranean—Africa</th>
<th>Central and Northern Europe and Great Britain</th>
<th>North and South America</th>
<th>Australasia</th>
</tr>
</thead>
<tbody>
<tr>
<td>BC</td>
<td></td>
<td>300,000–100,000 Surface mining of flint (N. France, S. England)</td>
<td></td>
<td>c.500,000 Use of fire (China)</td>
</tr>
<tr>
<td>Paleolithic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c.20,000</td>
<td>c.40,000 Hematite mined for ritual painting (Africa)</td>
<td>c.30,000 Use of fire, lamps, cave art, hunting with projectiles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Late Paleolithic</td>
<td>c.9500 Copper pendant. (Iraq)</td>
<td></td>
<td>c.10,000 Gold ornaments</td>
<td></td>
</tr>
</tbody>
</table>
When was the first mine?

Certainly after agriculture?????
How would you find the answer to this question?
When was the first mine?

- Prehistoric man used chert and flint as tools 450,000 years ago
- Nazlet Khater 4 site, Nile Valley, Upper Egypt 33,000 yr
- British flint quarries
- Krzemionki Opatowskie, Southern Poland
  - Upper Palaeolithic
  - Middle and Neolithic (4500 B.C.)
  - Early Bronze Age
When was the first underground mine?

- Bomvu Ridge, Swaziland
- Hematite
- 40,000 years old
- Crude methods of ground control, ventilation, haulage, hoisting, lighting, and rock breakage

Krzemionki
Opatowskie, Southern Poland

Fig. 1. From the left: scheme of a pit-mine, miner tools.

http://archterra.cilea.it/exhibits/archweb/pocz_gor.htm
Krzemionki
Opatowskie, Southern Poland

http://archterra.cilea.it/exhibits/archweb/pocz_gor.htm
When was the first mine?

- Prehistoric man used soapstone
- Fleur de Lys quarry, Newfoundland
- Maritime Archaic peoples used it approximately 4,000 years ago

http://www.heritage.nf.ca/environment/soapstone.html
Old Testament recognized the land of Ophir (Zimbabwe), which was somewhere in Africa, as a source of gold.
African mining sites

- Zimbabwe 20,000 to 26,000 BC
- Swaziland 50,000 BC

http://www.anvilfire.com/21centbs/stories/rsmith/biblical_1.htm
Other uses of industrial minerals in ancient societies

- Egyptians replaced water clocks with sand hour glasses
- Greek and Romans made concrete-like structures that are still standing today
- Building stones used in many ancient cultures
Ancient Egypt

- Nile River provided means of transport

- Quarried rocks for buildings
  - Limestone from Memphis
  - Quartzite from Gebel el-Ahmar
  - Alabaster
  - Granite near Aswan
  - Drilled holes, then filled with wood and wetted

- Used smelting to refine copper

- Flint used for farming tools (sickles)
Cosmetics in Egypt

- Black from galena, manganese, magnetite, cuprite, tenorite, stibnite
- Green from malachite, chrysocolla
- White cerussite
  - laurionite (a lead chlor-hydroxide)
  - phosgenite (a lead chlorocarbonate)
SALT

- NaCl
- table salt
- essential to life (man 2-5 gr/day)
- salt was used as a preservative, tanning leather, stock, mining
- salt was used to preserve Egyptian mummies
Trade in salt was very important; salt was valuable enough to be used as currency in some areas.

-Salt cakes

The Latin phrase "salarium argentum," "salt money," referred to part of the payment made to Roman soldiers.

http://www-geology.ucdavis.edu/~gel115/salt.html
Greek worshippers consecrated salt in their rituals.

In the Old and New Testaments, covenants were sealed with salt.

Jewish "KASHRUT" [hygiene] tradition and law, involves the dehydration of meat for its preservation.

Catholic Church used salt in purifying rituals.

Buddhist believed salt repeals evil spirits.

Pueblo people worship the Salt Mother.
Blocks of pure salt cut from the earth sit stacked in rows awaiting carriers in Taoudenni, as a miner removes earth from his pit mine.
Caravans across the Sahara basin carrying salt across the desert to the trading centers of Karta, Bambara, Cairo and Timbuktu.

Salt Harvesting at Geelong in the 1920’s

Salt is harvested manually by shovels......

and lifted onto conveyer belts......

Mining salt in 1920s at The Cheetham Salt mine, Australia
The star of David used to crystallise salt in salt pans in Mexico, La Concordia - from "Maya Salt Production and Trade - Antony P. Andrews," courtesy Gertrude Blom.
Salt in Austria

- Heilbad Durrnberg
- 750-150 BC
- 200 people worked the deposits
- Wealth of this small settlement is clearly evidenced by the clusters of graves which surrounded the various rectangular houses
Estancia Basin in central New Mexico

- Salt basin, few areas with edible salt
- Central to Indian Pueblos—Abo, Gran Quivira, Salinas, a total of 10 Piro pueblos
- Important in trade by 13th century
- Spanish conquest, built churches, and demanded more salt
- Spanish shipped salt to Mexico for use in processing silver
Salt and Silver Processing

Patio process developed in 1557 in Pachuca, Hidalgo, Mexico

silver ores crushed in arrastras to a fine slime

mixed with salt, water, copper sulfate, mercury

spread onto a patio and allowed to dry in the sun

silver could then amalgamate with mercury and thus be recovered
End of an Era

by the late 1670s the entire Salinas District, as the Spanish had named it, was depopulated

- Apache raids increased
- Famine
- Poor harvests
- Pueblo revolt in 1680
Is salt a critical/strategic mineral?

Is salt an industrial mineral?
What has changed from prehistorical times to today?
What minerals are considered critical and strategic minerals?
Certainly petroleum!
Strategic and critical minerals for the U.S. (Long, 2009; Long et al., 2010)

- Antimony
- Barite
- Chromite
- Cobalt
- Fluorite
- Gallium
- Graphite
- Indium
- PGE (platinum group elements)
- REE (rare earth elements)
- Rhenium
- Tantalum
- Titanium
- Tungsten
- Yttrium
- Niobium
DOD

- REE
- U
- Be
- Cr
- Co
- Mn
- Ge
- PGM
- Ta
- Sn
- W
- Zn
- Al
- Bi
- B
- Cd
- Cu
- F
- Ga
- Hf
- In
- Pb

http://www.nap.edu/catalog.php?record_id=12028
Green minor metals—basis for cleaner technology innovation

- Indium
- Germanium
- Tantalum
- PGM
- Tellurium
- Cobalt
- Lithium
- Gallium
- REE

Minerals required for clean energy technologies

- Lithium
- Cobalt
- Gallium
- REE, Y
- Indium
- Tellurium

Strategic minerals for the European Union

- Antimony
- Beryllium
- Cobalt
- Fluorspar
- Gallium
- Germanium
- Graphite
- Indium
- Magnesium
- Niobium
- PGM (platinum group metals)
- REE (rare earth elements)
- Tantalum
- Tungsten

https://pubs.er.usgs.gov/publication/pp1802
Mineral availability
Long term mineral availability (>10 Yr)

- Geologic (does the mineral resource exist)
- Technical (can we extract and process it)
- Environmental and social (can we mine and process it in environmentally and socially acceptable ways)
- Political (how does politics influence)
- Economic (can we mine and produce it at a cost the markets will pay)
Short- and medium-term availability

- Significant or unexpected increase in demand
- Small markets
- Production from a small number of mines, companies, or markets
- Minerals whose supply consist significant of byproduct production (i.e. Ga byproduct of bauxite mining)
- Markets for which there is no significant recovery from old scrap
Global challenges

- The small volumes of strategic/critical minerals utilized makes them price sensitive
- New producers need a reliable, long-term buyer
- Long-term buyers require a fixed price, but operating costs are variable
- Monopolies/oligopolies can drive out marginal producers by over-supplying the market until the competition is eliminated
Other factors

- Population
- Food
Global population, estimates and projections (billions)

Current population today: **7 billion**

2B people have risen out of poverty in Asia in the last 20 years = more consumption

Developing countries – The world is becoming Asia centric

http://dnr.alaska.gov/commis/priorities/Slides/Lance_Miller.pdf
Food Security

Agricultural international land leases

- South Korea: 2,000 thousand hectares
- China: 1,500 thousand hectares
- UAE: 710 thousand hectares
- Saudia Arabia: 620 thousand hectares
- Japan: 320 thousand hectares
- Libya: 250 thousand hectares
- Malaysia: 40 thousand hectares
- India: 10 thousand hectares

Each square represents 50,000 hectares. Values under this value are represented with one square.

http://dnr.alaska.gov/commis/priorities/Slides/Lance_Miller.pdf
DEMAND
Demand is growing partly because world population is increasing, and partly because standards of living (measured by per capita consumption) are increasing.

Iron

~4X more population than 100 years ago

~14X more production than 100 years ago

~4X more per capita consumption than 100 years ago

Production statistics mostly from USGS/USBM
Demand for nearly every mineral (and energy) commodity is high.

Copper

~22X more production than 100 years ago

~6X more per capita consumption than 100 years ago

Production statistics mostly from USGS/USBM
Demand for nearly every mineral (and energy) commodity is high.

Gold

~same per capita consumption as 100 years ago

~4X more production than 100 years ago

Production statistics mostly from USGS/USBM
China has been #1 in iron-ore production since 1992.
China has been #1 in coal production since 1985.
<table>
<thead>
<tr>
<th>Elements</th>
<th>Top three supply countries and share (%)</th>
<th>Top three share (%)</th>
<th>Metal life (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>China</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>REE Mo (Re)</td>
<td>China 95% USA 3% CIS 2%</td>
<td>100%</td>
<td>709</td>
</tr>
<tr>
<td>Sb Ga W In Bi</td>
<td>China 88% Guatemala 3% Bolivia 2%</td>
<td>95%</td>
<td>13</td>
</tr>
<tr>
<td>China 43% Germany 20% Kazakhstan17%</td>
<td>80%</td>
<td>365</td>
<td></td>
</tr>
<tr>
<td>China 58% Japan11% Canada, Korea 9%</td>
<td>78%</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>China 52% Mexico 21% Peru17%</td>
<td>90%</td>
<td>55</td>
<td></td>
</tr>
<tr>
<td><strong>South Africa</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PGE Cr V Mn Ni Li Co</td>
<td>South Africa 80% India 18% China 32% CIS 27% Australia 19%</td>
<td>96%</td>
<td>154</td>
</tr>
<tr>
<td>South Africa 38% South Africa 39% South Africa 20%</td>
<td>74%</td>
<td>&gt;24</td>
<td></td>
</tr>
<tr>
<td>South Africa 38% China 32%</td>
<td>98%</td>
<td>221</td>
<td></td>
</tr>
<tr>
<td>South Africa 20% Australia 19% China 14%</td>
<td>53%</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td><strong>Others</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ni Li Co</td>
<td>CIS 19% Chile 38% Congo 36%</td>
<td>46%</td>
<td>40</td>
</tr>
<tr>
<td>Canada 16% Australia 22% Canada 13%</td>
<td>84%</td>
<td>164</td>
<td></td>
</tr>
<tr>
<td>Australia 11% Argentina, China 12%</td>
<td>61%</td>
<td>22</td>
<td></td>
</tr>
</tbody>
</table>
The World Has Changed

For industry, the changes in the world are creating opportunities for:

exploration (domestically and worldwide, particularly in areas with potential for large deposits),

development and production (including new technologies for extracting metals from known deposits), and

sustainability (including the future of the environment, local and national economies, social and governmental stability, recycling, and substitutions of other minerals and products).

Round Mountain, NV (2007)
Need for more commodities

Technology
Fig. 1. Trade patterns in phosphate rock.
Environmental concerns
Industrial minerals are vital to our everyday life and has been since man wanted to improve his way of life.

Most industrial minerals are high volume, low value.

Industrial minerals are vital to a wide range of industrial and commercial products.

Industrial minerals are important to our economy (jobs, raw materials).
Assignment


CHOOSE YOUR COMMODITY