ME571/Geol571 Advanced Topics
Geology and Economics of Strategic and Critical Minerals

Virginia T. McLemore
CLASS REQUIREMENTS
Goals in this class

• Importance, geology, mining, processing of strategic and critical minerals

• What is involved from exploration thru production thru marketing—mines have a life cycle(beginning and end)
  – Reports, field notes, presentations
  – Where to look for information
  – Research needed

• Sustainable development
  – We can mine within public concerns
  – Social license to operate
Class

• The class will meet one day per week for 90-180 minutes
• Remaining time spent on field trips or in occasional extra discussion sessions (SME meetings, other presentations)
• May require extra time for the project presentations
Lectures found on my web site
http://geoinfo.nmt.edu/staff/mclemore/home.html
Textbooks

• 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 as recommendation) to get this price (save more $ than membership costs plus you should all be members of SME anyway)


• Papers as assigned
MINERAL COMMODITY SUMMARIES 2014

Class Details

• 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.

• Field trips—there will be 2 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.
Grades

- Midterm 25%
- Final (comprehensive) 30%
- Lab/field exercise 5%
- Term project 25%
- Class Participation, field trips 15%
Sources of data

• Internet
• http://minerals.usgs.gov/minerals/pubs/commodity/myb/
• http://www.minerals.com/
• Societies (SME, others)
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
- Mineral resource potential of specific mineral in a geographic area
- Flow/life cycle of a commodity in our society
- Related to your thesis work
- Sampling and Analytical procedures for a commodity/element
- Detailed analysis of a commodity
Dig A Little Deeper
How Many Minerals and Metals Does It Take to Make A Light Bulb?

Science: What makes the bulb work?

Predict: Design light bulbs for the future.

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

Geography: Research & ID the states and countries producing these minerals.

Math/Art: Explore shapes & sizes. Light bulb picture collage.

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.

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.

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.

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

Table:

<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>Percentage</td>
<td>54%</td>
<td>22%</td>
<td>10%</td>
<td>9%</td>
<td>4%</td>
<td>1%</td>
</tr>
</tbody>
</table>
STRATEGIC OR CRITICAL 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.
1. Metals - rare, difficult to find, expensive

2. Energy minerals – coal, oil and natural gas

3. Industrial minerals - non-metallic, such as salt, china clay, fluorspar
   - occur in large quantities in a few places
   - require specialised processing and are expensive

4. Construction minerals - sand and gravel, crushed rock, brick clay
   - deposits are extensive and common
   - transportation is economical over short distances only
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
What are strategic and critical minerals?
Strategic and critical minerals

- Minerals needed for military, industrial or commercial purposes that are essential to renewable energy, national defense equipment, medical devices, electronics, agricultural production and common household items
- Minerals that are essential for use but subject to potential supply disruptions
- Minerals that perform an essential function for which few or no satisfactory substitutes exist
- The absence of which would cause economic or social consequences
- 33-50% minerals are classified as such
Demand
- Material composition increasingly complex
- Potential rapid growth in demand for some minerals

Supply
- Seemingly increasingly fragile
- More fragmented supply chains, US import dependence, export restrictions on primary raw materials, resource nationalism, increased industry concentration
Criticality is context specific:

- What is critical for a given manufacturer or product may not be critical for another, what is critical for a state may not be critical for a country, and what is critical for national defense may be different than what is necessary to make a television brighter or less expensive.

- Recent studies have expanded the scope of criticality to include environmental and technological factors.

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.
History of strategic and critical minerals

- 1918: end of WW1 Harbord List developed
- 1938: Naval Appropriations Act
- 1939: Strategic Minerals Act
- 1940 Reconstruction Finance Corp formed to acquire and transport materials
- 1944: Surplus Property Act authorized strategic materials stockpile
- Became the Defense National Stockpile Center (DNSC)
- 1992: Congress ordered DNSC to sell the bulk of the stockpiles
What are green technologies?
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
Why are minerals so important?
Why are minerals so important?

Your world is made of them!

The average American uses about two million pounds of industrial minerals, such as REE, potash, and aggregate, over the period of a lifetime.

Building blocks of our way of life
Every American Born Will Need...

- 32,796 lbs. Salt
- 12,776 lbs. Clays
- 1.09 million lbs. Stone, Sand, & Gravel
- 467 lbs. Zinc
- 73,884 gallons Petroleum
- 857 lbs. Lead
- 16,904 lbs. Phosphate Rock
- 529,097 lbs. Coal
- 5,064 lbs. Bauxite (Aluminum)
- 27,810 lbs. Iron Ore
- 38,638 lbs. Cement
- 1.460 Troy oz. Gold
- 935 lbs. Copper
- 6.28 million cu. ft. Natural Gas
- plus 40,508 lbs. Other Minerals & Metals

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

Learn more at www.mii.org

©2011 Mineral Information Institute, SME Foundation
Every Year—38,052 pounds of new minerals must be provided for every person in the United States to make the things we use every day.

- 8,509 lbs. **Stone** used to make roads, buildings, bridges, landscaping, and for numerous chemical and construction uses.
- 5,559 lbs. **Sand & Gravel** used to make concrete, asphalt, roads, blocks and bricks.
- 496 lbs. **Cement** used to make roads, sidewalks, bridges, buildings, schools and houses.
- 357 lbs. **Iron Ore** used to make steel—buildings, cars, trucks, planes, trains; other construction; containers.
- 421 lbs. **Salt** used in various chemicals: highway deicing; food & agriculture.
- 217 lbs. **Phosphate Rock** used to make fertilizers to grow food; and as animal feed supplements.
- 164 lbs. **Clays** used to make floor & wall tile; dinnerware; kitty litter; bricks and cement; paper.
- 65 lbs. **Aluminum (Bauxite)** used to make buildings, beverage containers, autos, and airplanes.

- 12 lbs. **Copper** used in buildings; electrical and electronic parts; plumbing; transportation.
- 11 lbs. **Lead** 97% used for batteries for transportation; also used in electrical, communications and TV screens.
- 6 lbs. **Zinc** used to make metals rust resistant; various metals and alloys, paint, rubber, skin creams, health care and nutrition.
- 36 lbs. **Soda Ash** used to make all kinds of glass; in powdered detergents; medicines; as a food additive; photography; water treatment.
- 5 lbs. **Manganese** used to make almost all steels for construction, machinery and transportation.
- 332 lbs. **Other Nonmetals** have numerous uses: glass, chemicals, soaps, paper, computers, cell phones.
- 24 lbs. **Other Metals** have the same uses as nonmetals but also electronics, TV and video equipment, recreation equipment, and more.

**Including These Energy Fuels**

- 951 gallons of **Petroleum**
- 6,792 lbs. of **Coal**
- 80,905 cu. ft. of **Natural Gas**
- 1/4 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 1900-2000. The use of raw materials in the U.S. increased dramatically during the last 100 years (from Wagner, 2002).
Elements in Computer Chips
(National Research Council, 2007)

- Green: elements needed in 1980s
- Yellow: additional elements needed today

H

Li Be

Na Mg

K Ca Sc Ti V Cr Mn Fe Co Ni Cu Zn Ga Ge As Se Br Kr

Rb Sr Y Zr Nb Mo Tc Ru Rh Pd Ag Cd In Sn Sb Te I Xe

Cs Ba La Hf Ta W Re Os Ir Pt Au Hg Tl Pb Bi Po At Rn

Fr Ra Ac

Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Yb Lu

Th Pa U Np Pu Am Cm Bk Cf Es Fm Md No Lr
Geologically, most minerals

- are widespread
- have enormous reserves
- are easy accessible
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).
DEMAND
Demand is growing partly because world population is increasing, and partly because standards of living (measured by per capita consumption) are increasing.

- ~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 production (metric tons)
- World population (millions)
- Per capita consumption (10X mg/person)

- ~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.

Percentage of Annual Coal Production by Country, 1930-2008

Year


Production statistics mostly from DOE/EIA. For 2008, world coal figures estimated to rise at the same percentage as China.
<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>REE China 95% USA 3% CIS 2%</td>
<td>100%</td>
<td>709</td>
</tr>
<tr>
<td></td>
<td>Mo (Re) USA 32% China 25% Chile 22%</td>
<td>78%</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td>Sb China 88% Guatemala 3% Bolivia 2%</td>
<td>95%</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>Ga China 43% Germany 20% Kazakhstan 17%</td>
<td>80%</td>
<td>365</td>
</tr>
<tr>
<td></td>
<td>W China 75% CIS 6% Canada 5%</td>
<td>86%</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>In China 58% Japan 11% Canada, Korea 9%</td>
<td>78%</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>Bi China 52% Mexico 21% Peru 17%</td>
<td>90%</td>
<td>55</td>
</tr>
<tr>
<td><strong>South Africa</strong></td>
<td>PGE South Africa 80% CIS 12% Canada 4%</td>
<td>96%</td>
<td>154</td>
</tr>
<tr>
<td></td>
<td>Cr South Africa 38% India 18% Kazakhstan 18%</td>
<td>74%</td>
<td>&gt;24</td>
</tr>
<tr>
<td></td>
<td>V South Africa 39% China 32% CIS 27%</td>
<td>98%</td>
<td>221</td>
</tr>
<tr>
<td></td>
<td>Mn South Africa 20% Australia 19% China 14%</td>
<td>53%</td>
<td>40</td>
</tr>
<tr>
<td><strong>Others</strong></td>
<td>Ni CIS 19% Canada 16% Australia 11%</td>
<td>46%</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Li Chile 38% Australia 22% Argentina, China 12%</td>
<td>84%</td>
<td>164</td>
</tr>
<tr>
<td></td>
<td>Co Congo 36% Canada 13% Australia 12%</td>
<td>61%</td>
<td>22</td>
</tr>
<tr>
<td>Commodity</td>
<td>Percent</td>
<td>Major import sources (2009–12)</td>
<td></td>
</tr>
<tr>
<td>---------------------------------</td>
<td>---------</td>
<td>-------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>ARSENIC</td>
<td>100</td>
<td>Morocco, China, Belgium, Canada, Brazil</td>
<td></td>
</tr>
<tr>
<td>ASBESTOS</td>
<td>100</td>
<td>Canada, Brazil</td>
<td></td>
</tr>
<tr>
<td>BAUXITE AND ALUMINA</td>
<td>100</td>
<td>Jamaica, Brazil, Guinea, Australia</td>
<td></td>
</tr>
<tr>
<td>CESIUM</td>
<td>100</td>
<td>Canada</td>
<td></td>
</tr>
<tr>
<td>FLUORSPAR</td>
<td>100</td>
<td>Mexico, China, South Africa, Mongolia</td>
<td></td>
</tr>
<tr>
<td>GRAPHITE (natural)</td>
<td>100</td>
<td>China, Mexico, Canada, Brazil</td>
<td></td>
</tr>
<tr>
<td>INDIUM</td>
<td>100</td>
<td>Canada, China, Japan, Belgium</td>
<td></td>
</tr>
<tr>
<td>MANGANESE</td>
<td>100</td>
<td>South Africa, Gabon, Australia, Georgia</td>
<td></td>
</tr>
<tr>
<td>MICA, sheet (natural)</td>
<td>100</td>
<td>China, Japan, Gabon, Australia, Georgia</td>
<td></td>
</tr>
<tr>
<td>NICOBium (columbium)</td>
<td>100</td>
<td>Brazil, Canada</td>
<td></td>
</tr>
<tr>
<td>QUARTZ CRYSTAL (industrial)</td>
<td>100</td>
<td>China, Japan, and Russia</td>
<td></td>
</tr>
<tr>
<td>RUBIDIUM</td>
<td>100</td>
<td>Canada</td>
<td></td>
</tr>
<tr>
<td>SCANDIUM</td>
<td>100</td>
<td>China</td>
<td></td>
</tr>
<tr>
<td>STRONTIUM</td>
<td>100</td>
<td>Mexico, Germany, China</td>
<td></td>
</tr>
<tr>
<td>TANTALUM</td>
<td>100</td>
<td>China, Germany, Kazakhstan, Russia</td>
<td></td>
</tr>
<tr>
<td>THALLIUM</td>
<td>100</td>
<td>Germany, Russia</td>
<td></td>
</tr>
<tr>
<td>THORIUM</td>
<td>100</td>
<td>India, France</td>
<td></td>
</tr>
<tr>
<td>VANADIUM</td>
<td>100</td>
<td>Canada, Czech Rep., Rep. of Korea, Austria</td>
<td></td>
</tr>
<tr>
<td>YTTRIUM</td>
<td>100</td>
<td>China, Japan, Austria, France</td>
<td></td>
</tr>
<tr>
<td>GALLIUM</td>
<td>100</td>
<td>Germany, United Kingdom, China, Canada</td>
<td></td>
</tr>
<tr>
<td>GEMSTONES</td>
<td>99</td>
<td>Israel, India, Belgium, South Africa</td>
<td></td>
</tr>
<tr>
<td>BISMUTH</td>
<td>91</td>
<td>China, Belgium, United Kingdom</td>
<td></td>
</tr>
<tr>
<td>IODINE</td>
<td>91</td>
<td>Chile, Japan</td>
<td></td>
</tr>
<tr>
<td>DIAMOND (dust, grit, and powder)</td>
<td>88</td>
<td>China, Ireland, Rep. of Korea, Romania</td>
<td></td>
</tr>
<tr>
<td>ANTIMONY</td>
<td>85</td>
<td>China, Mexico, Belgium, Bolivia</td>
<td></td>
</tr>
<tr>
<td>GERMANIUM</td>
<td>85</td>
<td>China, Belgium, Russia, Germany</td>
<td></td>
</tr>
<tr>
<td>POTASH</td>
<td>82</td>
<td>Canada, Russia, Israel, Chile</td>
<td></td>
</tr>
<tr>
<td>RHENIUM</td>
<td>80</td>
<td>Chile, Poland, Germany</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)
New deposit types are still being found – e.g., Carlin gold (1961), Olympic Dam copper-iron-gold, South Australia (1975), HREE in kaolinite-rich laterite developed on granites in China (2000s) – and will be found in the future.

We need to be thinking about ore-forming systems and future resources – USGS Professional Paper 820 (1973).
Some of the challenges in producing critical and strategic minerals
5 Dimensions of Mineral Availability

WHAT Questions Must We Ask?

1. Geologic Availability
   - Does the mineral resource exist?

2. Technical Availability
   - Can we extract and process it?

3. Environmental & Social Availability
   - Can we produce it in environmentally and socially responsible and acceptable ways?

4. Political Availability
   - How do governments influence availability through their policy and actions?

5. Economic Availability
   - Can we produce it at a cost users are willing and able to pay?
Limits on mineral resource availability

Are more about

• Costs
• Distribution
• Time frame

Than about tons
Some of the challenges in producing critical and strategic minerals

- How much of the 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 in producing these technologies

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)
Many critical elements are produced entirely as by-products of the refining of major metals:

- Tellurium (copper)
- Indium & germanium (zinc)
- Gallium (aluminum)
- Rhenium (molybdenum)
- Cobalt (copper, nickel)

Prices are artificially low (economy of scope) until the co-production saturates.

By-product does not drive production of main product, even at high prices.

Price demand inelasticity.
Coproduction Issues - Rhenium

- Rhenium is produced as a by-product of molybdenum – there are no primary rhenium producers.

- It is used in producing specialty steels.
Rhenium

- Atomic number 75
- 0.05-1 ppb in crust
- Superalloys for combustion chambers, turbine blades, and exhaust nozzles of jet engines, petroleum-reforming catalysts
- US $4,575 per kg (2011)
- By-product of molybdenum and copper production
- Found in molybdenite—up to 0.2%
Rhenium

• 7 porphyry copper operations in US
  – Arizona, Montana, New Mexico, Utah
• Byproduct
• Value of consumption $69 million
• There are no primary rhenium mines!!!
• Chile largest Rh resources
• Research needed to understand geologic occurrence
  – Where in molybdenite?
  – What form?
  – Mineralogy?
### Salient Statistics—United States:

<table>
<thead>
<tr>
<th></th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production¹</td>
<td>5,580</td>
<td>6,100</td>
<td>8,610</td>
<td>7,910</td>
<td>8,100</td>
</tr>
<tr>
<td>Imports for consumption</td>
<td>31,500</td>
<td>33,600</td>
<td>33,500</td>
<td>40,200</td>
<td>32,000</td>
</tr>
<tr>
<td>Exports</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Consumption, apparent</td>
<td>37,100</td>
<td>39,700</td>
<td>42,100</td>
<td>48,100</td>
<td>40,000</td>
</tr>
<tr>
<td>Price,² average value, dollars per kilogram, gross weight:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metal pellets, 99.99% pure</td>
<td>7,500</td>
<td>4,720</td>
<td>4,670</td>
<td>4,040</td>
<td>3,200</td>
</tr>
<tr>
<td>Ammonium perrhenate</td>
<td>7,580</td>
<td>4,630</td>
<td>4,360</td>
<td>3,990</td>
<td>3,400</td>
</tr>
<tr>
<td>Stocks, yearend, consumer, producer, dealer</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Employment, number</td>
<td>Small</td>
<td>Small</td>
<td>Small</td>
<td>Small</td>
<td>Small</td>
</tr>
<tr>
<td>Net import reliance³ as a percentage of apparent consumption</td>
<td>85</td>
<td>85</td>
<td>80</td>
<td>84</td>
<td>80</td>
</tr>
</tbody>
</table>

### World Mine Production and Reserves:

<table>
<thead>
<tr>
<th></th>
<th>Mine production⁴</th>
<th>Reserves⁵</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2012</td>
<td>2013*</td>
</tr>
<tr>
<td>United States</td>
<td>7,910</td>
<td>8,100</td>
</tr>
<tr>
<td>Armenia</td>
<td>600</td>
<td>350</td>
</tr>
<tr>
<td>Canada</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Chile⁵</td>
<td>27,000</td>
<td>27,000</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>3,000</td>
<td>3,000</td>
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<td>Peru</td>
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</tr>
<tr>
<td>Poland</td>
<td>6,000</td>
<td>6,000</td>
</tr>
<tr>
<td>Russia</td>
<td>1,500</td>
<td>1,500</td>
</tr>
<tr>
<td>Uzbekistan</td>
<td>5,400</td>
<td>5,400</td>
</tr>
<tr>
<td>Other countries</td>
<td>1,200</td>
<td>1,500</td>
</tr>
<tr>
<td>World total (rounded)</td>
<td>52,600</td>
<td>53,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Percent</th>
<th>Major import sources (2009–12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARSENIC</td>
<td>100</td>
<td>Morocco, China, Belgium</td>
</tr>
<tr>
<td>ASBESTOS</td>
<td>100</td>
<td>Canada, Brazil</td>
</tr>
<tr>
<td>Bauxite and Alumina</td>
<td>100</td>
<td>Jamaica, Brazil, Guinea, Australia</td>
</tr>
<tr>
<td>CESIUM</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>GRAPHITE (natural)</td>
<td>100</td>
<td>China, Mexico, Canada, Brazil</td>
</tr>
<tr>
<td>INDIUM</td>
<td>100</td>
<td>Canada, China, Japan, 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, Japan, and Russia</td>
</tr>
<tr>
<td>NICBIUM (columbium)</td>
<td>100</td>
<td>Canada</td>
</tr>
<tr>
<td>QUARTZ CRYSTAL (industrial)</td>
<td>100</td>
<td>China</td>
</tr>
<tr>
<td>RUBIDIUM</td>
<td>100</td>
<td>China, Germany, China</td>
</tr>
<tr>
<td>SCANDIUM</td>
<td>100</td>
<td>China, Germany, Kazakhstan, Russia</td>
</tr>
<tr>
<td>STRONTIUM</td>
<td>100</td>
<td>Germany, Russia</td>
</tr>
<tr>
<td>TANTALUM</td>
<td>100</td>
<td>India, France</td>
</tr>
<tr>
<td>THALLIUM</td>
<td>100</td>
<td>Canada, Czech Rep., Rep. of Korea, Austria</td>
</tr>
<tr>
<td>THORIUM</td>
<td>100</td>
<td>China, Japan, Austria, France</td>
</tr>
<tr>
<td>VANADIUM</td>
<td>100</td>
<td>China, Germany, United Kingdom, China</td>
</tr>
<tr>
<td>YTTRIUM</td>
<td>100</td>
<td>Israel, India, Belgium, South Africa</td>
</tr>
<tr>
<td>GALLIUM</td>
<td>99</td>
<td>China, Belgium, United Kingdom</td>
</tr>
<tr>
<td>GEMSTONES</td>
<td>99</td>
<td>Chile, Japan</td>
</tr>
<tr>
<td>BISMUTH</td>
<td>91</td>
<td>China, Belgium, United Kingdom</td>
</tr>
<tr>
<td>IODINE</td>
<td>91</td>
<td>Chile</td>
</tr>
<tr>
<td>DIAMOND (dust grit, and powder)</td>
<td>88</td>
<td>China, Ireland, Rep. of Korea, Romania</td>
</tr>
<tr>
<td>ANTIMONY</td>
<td>85</td>
<td>China, Mexico, Belgium, Bolivia</td>
</tr>
<tr>
<td>GERMANIUM</td>
<td>85</td>
<td>China, Belgium, Russia</td>
</tr>
<tr>
<td>POTASH</td>
<td>82</td>
<td>Canada, Russia, Israel, Chile</td>
</tr>
<tr>
<td>RHENIUM</td>
<td>80</td>
<td>Chile, Poland, Germany</td>
</tr>
</tbody>
</table>

• Rhenium changes the phase structure in complex alloys, allowing turbine blades to operate longer at higher temperatures (>1600°C) and pressures without deformation.

• General Electric discovered that sufficient Re (by-product of molybdenum production) for mass produced turbines might not be available (or extremely expensive).

~25 kg Re per gas turbine
GE launched a two pronged approach in 2005:

- Recycle pre-consumer scrap to forestall shortage (new supply)
- Develop new alloys with low (zero?) Re (substitution)
- Had success over 5 years*

Is there really a shortage of Rhenium?

- Serendipity recently resulted in the discovery of a new type of super high grade moly deposit with a high Re content.

- Merlin, Australia (6.7 Mt @ 1.34% Mo, 23.2 g/t Re)

- Discovery of additional deposits (if we can develop a geological model for the deposits) should ease fears of Re supply.
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>End of Ice Age</td>
<td></td>
</tr>
<tr>
<td>Late Paleolithic</td>
<td>c. 9500 Copper pendant (Iraq)</td>
<td>c. 10,000 Gold ornaments</td>
<td></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 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
Let's look at 1 commodity in more detail
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
SALT

• 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
http://www.nps.gov/sapu/hsr/fig1.jpg
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?
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
- Saudi 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
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
Managing Materials for a Twenty-first Century Military

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
Production concentration of critical raw mineral materials

- Canada: Cobalt
- Russia: Platinum Group Metals
- USA: Beryllium
- Mexico: Fluorspar
- Brazil: Niobium, Tantalum
- South Africa: Platinum Group Metals
- Democratic Republic of Congo: Cobalt, Tantalum
- Rwanda: Tantalum
- India: Graphite
- Japan: Indium
- China: Antimony, Beryllium, Fluorspar, Gallium, Germanium, Indium, Magnesium, Rare earths, Tungsten
<table>
<thead>
<tr>
<th>Raw material</th>
<th>Production 2006 (t)</th>
<th>Demand from emerging technologies 2006 (t)</th>
<th>Demand from emerging technologies 2030 (t)</th>
<th>Indicator 1) 2006</th>
<th>Indicator 1) 2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gallium</td>
<td>152.6</td>
<td>28</td>
<td>603</td>
<td>0,18</td>
<td>3,97</td>
</tr>
<tr>
<td>Indium</td>
<td>581</td>
<td>234</td>
<td>1,911</td>
<td>0,40</td>
<td>3,29</td>
</tr>
<tr>
<td>Germanium</td>
<td>100</td>
<td>28</td>
<td>220</td>
<td>0,28</td>
<td>2,20</td>
</tr>
<tr>
<td>Neodymium (rare earth)</td>
<td>16.800</td>
<td>4.000</td>
<td>27.900</td>
<td>0,23</td>
<td>1,66</td>
</tr>
<tr>
<td>Platinum (PGM)</td>
<td>255</td>
<td>very small</td>
<td>345</td>
<td>0</td>
<td>1,35</td>
</tr>
<tr>
<td>Tantalum</td>
<td>1,384</td>
<td>551</td>
<td>1,410</td>
<td>0,40</td>
<td>1,02</td>
</tr>
<tr>
<td>Silver</td>
<td>19,051</td>
<td>5,342</td>
<td>15,823</td>
<td>0,28</td>
<td>0,83</td>
</tr>
<tr>
<td>Cobalt</td>
<td>62,279</td>
<td>12,820</td>
<td>26,860</td>
<td>0,21</td>
<td>0,43</td>
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<tr>
<td>Palladium (PGM)</td>
<td>267</td>
<td>23</td>
<td>77</td>
<td>0,09</td>
<td>0,29</td>
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<tr>
<td>Titanium</td>
<td>7,211,000</td>
<td>15,397</td>
<td>58,148</td>
<td>0,08</td>
<td>0,29</td>
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<tr>
<td>Copper</td>
<td>15,093,000</td>
<td>1,410,000</td>
<td>3,696,070</td>
<td>0,09</td>
<td>0,24</td>
</tr>
</tbody>
</table>

Assignment

• NATIONAL INSTRUMENT 43-101, STANDARDS OF DISCLOSURE FOR MINERAL PROJECTS (http://web.cim.org/standards/documents/Block484_Doc111.pdf)
• Geology for investors (http://www.geologyforinvestors.com/classification-of-mineral-deposits/)