ME589/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
  – 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 120 minutes
• Remaining time spent on field trips or in occasional extra discussion sessions (SME meetings, other presentations, guest speakers)
• 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
Class Details

• Exams: Midterm and Final—both are take home exams that will emphasize short answer and essay questions.
• Presentation before Feb 17 (SME talk/poster, paper, other)
• 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 exercises 5%
- Presentation 5%
- Term project 20%
- Field trip reports 10%
- Class Participation 5%
Sources of data

- Internet
- http://www.minerals.com/
- Societies (SME, others)

- Some slides from Jon Price, State Geologist Emeritus, Nevada Bureau of Mines and Geology
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?

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.

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.

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.

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.

Don’t forget the mineral fuels needed to generate the electricity to light up the bulb. In the U.S., these are the sources of our fuels:

<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>Source</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](http://www.mii.org)

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

Geography: Research & ID the states and countries producing these minerals.
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.
Another definition
Definition of Minerals

In industry, minerals refer to any rock, mineral, or other naturally occurring material of economic value, including metals, industrial minerals, energy minerals, gemstones, aggregates, and synthetic materials sold as commodities.
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
A mineral occurrence is any locality where a useful mineral or material is found.
A mineral prospect is any occurrence that has been developed by underground or by above ground techniques, or by subsurface drilling to determine the extent of mineralization.
The terms **mineral occurrence** and **mineral prospect** do not have any resource or economic implications.
Definition of mine

any opening or excavation in the ground for extracting minerals, even if no actual production occurred, mine feature
A mineral deposit is any occurrence of a valuable commodity or mineral that is of sufficient size and grade (concentration) that has potential for economic development under past, present, or future favorable conditions.
An ore deposit is a well-defined mineral deposit that has been tested and found to be of sufficient size, grade, and accessibility to be extracted (i.e. mined) and processed at a profit at a specific time. Thus, the size and grade of an ore deposit changes as the economic conditions change. Ore refers to industrial minerals as well as metals.
Mineral Deposits versus Ore Bodies

mineral deposit $\neq$ ore body

ore body $=$ reserves

mineral deposit $=$ $\pm$ reserves
+ unmineable
+ uneconomic
+ mined
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
CLASSIFICATION OF MINERAL RESOURCES ON U.S. FEDERAL LAND
Locatable Minerals are whatever is recognized as a valuable mineral by standard authorities, whether metallic or other substance, when found on public land open to mineral entry in quality and quantity sufficient to render a claim valuable on account of the mineral content, under the United States Mining Law of 1872. Specifically excluded from location are the leasable minerals, common varieties, and salable minerals.
Leasable Minerals  The passage of the Mineral Leasing Act of 1920, as amended from time to time, places the following minerals under the leasing law: oil, gas, coal, oil shale, sodium, potassium, phosphate, native asphalt, solid or semisolid bitumen, bituminous rock, oil-impregnated rock or sand, and sulfur in Louisiana and New Mexico.
Salable Minerals The Materials Act of 1947, as amended, removes petrified wood, common varieties of sand, stone, gravel, pumice, pumicite, cinders, and some clay from location and leasing. These materials may be acquired by purchase only.
Other terms
Canadian Instrument 43-101

- Set of rules and guidelines for reporting information relating to a mineral property in order to present these results to the Candian stock exchange
  - created after the Bre-X scandal to protect investors from unsubstantiated mineral project disclosures
  - gold reserves at (Bre-X's) Busang were alleged to be 200 million ounces (6,200 t), or up to 8% of the entire world's gold reserves FRAUD

- Similar to JORC (joint ore reserves committee code, Australia)

- South African Code for the Reporting of Mineral Resources and Mineral Reserves (SAMREC)
Other terms

• Adjacent property
  – Company has no interest
  – Boundary close to project
  – Geologic characteristics similar to project

• Advanced property
  – Mineral reserves
  – Minerals resources with a PEA or feasibility study

• Early stage exploration property
Qualified person (43-101)

- engineer/geoscientist with a university degree, or equivalent accreditation, in an area of geoscience, or engineering, relating to mineral exploration or mining
- has at least five years of experience
- has experience relevant to the subject matter of the mineral project and the technical report
- is in good standing with a professional association
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
Presidential Executive Order No. 13817

“a mineral (1) identified to be a nonfuel mineral or mineral material essential to the economic and national security of the United States, (2) from a supply chain that is vulnerable to disruption, and (3) that serves an essential function in the manufacturing of a product, the absence of which would have substantial consequences for the U.S. economy or national security”
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.

What are the differences between critical and strategic?
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 limestone, clay, and aggregate, over the period of a lifetime.

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

30,190 lbs. Salt
14,337 lbs. Phosphate Rock
75,327 gallons Petroleum
53,071 lbs. Cement
980 lbs. Copper
20,127 lbs. Iron Ore
466 lbs. Zinc
2,066 lbs. Bauxite (Aluminum)
1.54 Troy oz. Gold
1.36 million lbs. Stone, Sand, & Gravel
953 lbs. Lead
330,573 lbs. Coal
plus 62,648 lbs. Other Minerals & Metals

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

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Learn more at www.MineralsEducationCoalition.org

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

© 2011, Mineral Information Institute, SME Foundation

U.S. flow of raw materials by weight 1900-2014. The use of raw materials in the U.S. increased dramatically during the last 100 years (modified from Wagner, 2002).

https://www.usgs.gov/centers/nmic/mineral-commodity-summaries
Elements in Computer Chips
(National Research Council, 2007)

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

Periodic Table:

H, He, Li, Be, B, C, N, O, F, Ne,
Na, Mg, Al, Si, P, S, Cl, Ar,
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 to 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

Iron

Production statistics mostly from USGS/USBM
Copper

- Copper production (thousand tonnes)
- World population (millions)
- Per capita consumption (g/person)

~42X more production than in 1900

4.5X more population than in 1900

9.3X more per capita consumption than in 1900

Data from USGS, USBM, & CIA, to 2018
Global copper production in 2018 (21 million metric tons) exceeded over 100 years of production from the Bingham Canyon mine (~17 million metric tons).
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
Global gold production in 2018 (3,260 metric tons) exceeded the cumulative production from the Carlin trend in Nevada (~3,000 tons), one of world’s top regions.
Gold production, 1835-2018

Current boom = 290 Moz (1981-present)
West = 95 Moz (1897-1920)
49ers = 29 Moz (1849-1859)

We are in the midst of the biggest gold-mining boom in history.
China has been #1 in iron-ore production since 1992.

**Iron**

![Graph showing the percentage of world iron-ore production by country from 1930 to 2008. The graph indicates that China has surpassed the US and the USSR/Russia in iron-ore production.](image-url)

*Production statistics mostly from USGS/USBM*
China has been #1 in coal production since 1985.

Percentage of Annual Coal Production by Country, 1930-2008

Production statistics mostly from DOE/EIA. For 2008, world coal figures estimated to rise at the same percentage as China.
Selected commodities for which China produced >19% of the global total:

- Aluminum*(54%)
- Arsenic* (68%)
- Cadmium* (36%)
- Fluorspar (63%)
- Gypsum (50%)
- Lime* (66%)
- Molybdenum (45%)
- Aluminum ore (23%)
- Barite (39%)
- Cement* (59%)
- Germanium* (>50%)
- Indium* (43%)
- Magnesium (67%)
- Nitrogen (31%)
- Rare Earths (81%)
- Selenium* (28%)
- Steel* (49%)
- Tin (34%)
- Vanadium (54%)
- Antimony (73%)
- Bismuth* (79%)
- Coal (45%)
- Graphite (65%)
- Lead (51%)
- Mercury (80%)
- Phosphate (53%)
- Salt (24%)
- Silicon* (65%)
- Tellurium* (67%)
- Tungsten (83%)
- Zinc (39%)

Data from USGS in 2017, except coal from IEA in 2016.
In production of 44 mineral commodities, China ranks well above all others.

<table>
<thead>
<tr>
<th>Country</th>
<th>Number of commodities for which this country is the #1 producer</th>
<th>Number of commodities for which this country is among the top 3 producers</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>21</td>
<td>28</td>
</tr>
<tr>
<td>USA</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>South Africa</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Australia</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td>Chile</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Congo</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Russia</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>Canada</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Brazil, Mexico, &amp; Indonesia</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

Data for 2017, except coal, oil, and gas (2016)
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 environmentally 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
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
• combustion chambers, turbine blades, and exhaust nozzles of jet engines
• US $4,575 per kg (2011)
• By-product of molybdenum and copper production
• Found in molybdenite
### Salient Statistics—United States:

<table>
<thead>
<tr>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Production^1</td>
<td>8,510</td>
<td>7,900</td>
<td>8,440</td>
<td>8,200</td>
<td>8,300</td>
</tr>
<tr>
<td>Imports for consumption^2</td>
<td>25,000</td>
<td>31,800</td>
<td>31,900</td>
<td>34,500</td>
<td>42,000</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^3</td>
<td>33,500</td>
<td>39,700</td>
<td>40,300</td>
<td>42,700</td>
<td>51,000</td>
</tr>
<tr>
<td>Price, average value, dollars per kilogram, gross weight:^4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metal pellets, 99.99% pure</td>
<td>2,980</td>
<td>2,670</td>
<td>2,030</td>
<td>1,550</td>
<td>1,500</td>
</tr>
<tr>
<td>Ammonium perrhenate</td>
<td>3,080</td>
<td>2,820</td>
<td>2,510</td>
<td>1,530</td>
<td>1,400</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 reliance^5 as a percentage of apparent consumption</td>
<td>75</td>
<td>80</td>
<td>79</td>
<td>81</td>
<td>84</td>
</tr>
</tbody>
</table>

### World Mine Production and Reserves:

The reserves estimate for the United States was revised based on company reports.

<table>
<thead>
<tr>
<th></th>
<th>Mine production^6</th>
<th>2017</th>
<th>2018e</th>
<th>Reserves^7</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td></td>
<td>8,200</td>
<td>8,300</td>
<td>400,000</td>
</tr>
<tr>
<td>Armenia</td>
<td></td>
<td>300</td>
<td>260</td>
<td>95,000</td>
</tr>
<tr>
<td>Canada</td>
<td></td>
<td>—</td>
<td>—</td>
<td>32,000</td>
</tr>
<tr>
<td>Chile^8</td>
<td></td>
<td>27,000</td>
<td>27,000</td>
<td>1,300,000</td>
</tr>
<tr>
<td>China</td>
<td></td>
<td>2,500</td>
<td>2,500</td>
<td>NA</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td></td>
<td>1,000</td>
<td>1,200</td>
<td>190,000</td>
</tr>
<tr>
<td>Peru</td>
<td></td>
<td>—</td>
<td>—</td>
<td>45,000</td>
</tr>
<tr>
<td>Poland</td>
<td></td>
<td>9,300</td>
<td>9,300</td>
<td>NA</td>
</tr>
<tr>
<td>Russia</td>
<td></td>
<td>NA</td>
<td>NA</td>
<td>310,000</td>
</tr>
<tr>
<td>Uzbekistan</td>
<td></td>
<td>460</td>
<td>500</td>
<td>NA</td>
</tr>
<tr>
<td>World total (rounded)</td>
<td></td>
<td>48,800</td>
<td>49,000</td>
<td>2,400,000</td>
</tr>
</tbody>
</table>

https://www.usgs.gov/centers/nmic/mineral-commodity-summaries
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
Critical and strategic minerals will change with time.
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 1.1.1. Chronology of Events Related to Mining

<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>c.40,000 Hematite mined for ritual painting (Africa)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c.20,000</td>
<td></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>End of Ice Age</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></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
Lets look at a 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.

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 Durnnberg
- 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
the salinas basin

SALINAS NATIONAL MONUMENT ® NEW MEXICO
U.S. DEPT. OF THE INTERIOR ® NATIONAL PARK SERVICE

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
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Production</td>
<td>45,300</td>
<td>45,100</td>
<td>41,700</td>
<td></td>
<td>42,000</td>
</tr>
<tr>
<td>Sold or used by producers</td>
<td>46,000</td>
<td>42,800</td>
<td>40,200</td>
<td></td>
<td>41,000</td>
</tr>
<tr>
<td>Imports for consumption</td>
<td>20,200</td>
<td>21,600</td>
<td>12,100</td>
<td></td>
<td>17,000</td>
</tr>
<tr>
<td>Exports</td>
<td>935</td>
<td>830</td>
<td>716</td>
<td>1,120</td>
<td>950</td>
</tr>
<tr>
<td>Consumption:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apparent</td>
<td>65,300</td>
<td>63,600</td>
<td>51,600</td>
<td>49,000</td>
<td>57,000</td>
</tr>
<tr>
<td>Reported</td>
<td>55,600</td>
<td>52,300</td>
<td>48,400</td>
<td>48,000</td>
<td>51,000</td>
</tr>
<tr>
<td>Price, average value of bulk, pellets and packaged salt, dollars per ton, f.o.b. mine and plant:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vacuum and open pan salt</td>
<td>180.61</td>
<td>188.87</td>
<td>197.78</td>
<td>200.00</td>
<td>200.00</td>
</tr>
<tr>
<td>Solar salt</td>
<td>75.35</td>
<td>102.04</td>
<td>99.69</td>
<td>100.00</td>
<td>100.00</td>
</tr>
<tr>
<td>Rock salt</td>
<td>48.11</td>
<td>56.32</td>
<td>56.74</td>
<td>55.00</td>
<td>58.00</td>
</tr>
<tr>
<td>Salt in brine</td>
<td>9.08</td>
<td>10.27</td>
<td>8.29</td>
<td>10.00</td>
<td>10.00</td>
</tr>
<tr>
<td>Employment, mine and plant, number ³</td>
<td>4,200</td>
<td>4,200</td>
<td>4,000</td>
<td>4,100</td>
<td>4,100</td>
</tr>
<tr>
<td>Net import reliance ³ as a percentage of apparent consumption</td>
<td>29</td>
<td>33</td>
<td>22</td>
<td>23</td>
<td>28</td>
</tr>
</tbody>
</table>

**Recycling:** None.

**World Production and Reserves:**

<table>
<thead>
<tr>
<th></th>
<th>Mine Production ³</th>
<th>Reserves ⁴</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2017</td>
<td>2018</td>
</tr>
<tr>
<td>United States ¹</td>
<td>40,000</td>
<td>42,000</td>
</tr>
<tr>
<td>Australia</td>
<td>11,000</td>
<td>12,000</td>
</tr>
<tr>
<td>Austria</td>
<td>4,600</td>
<td>4,600</td>
</tr>
<tr>
<td>Brazil</td>
<td>7,400</td>
<td>7,500</td>
</tr>
<tr>
<td>Canada</td>
<td>12,000</td>
<td>13,000</td>
</tr>
<tr>
<td>Chile</td>
<td>8,500</td>
<td>9,500</td>
</tr>
<tr>
<td>China</td>
<td>67,000</td>
<td>68,000</td>
</tr>
<tr>
<td>France</td>
<td>4,500</td>
<td>4,500</td>
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<tr>
<td>Germany</td>
<td>13,000</td>
<td>13,000</td>
</tr>
<tr>
<td>India</td>
<td>28,000</td>
<td>29,000</td>
</tr>
<tr>
<td>Mexico</td>
<td>9,000</td>
<td>9,000</td>
</tr>
<tr>
<td>Netherlands</td>
<td>6,940</td>
<td>7,000</td>
</tr>
<tr>
<td>Pakistan</td>
<td>3,600</td>
<td>3,600</td>
</tr>
<tr>
<td>Poland</td>
<td>4,450</td>
<td>4,500</td>
</tr>
<tr>
<td>Russia</td>
<td>5,800</td>
<td>5,800</td>
</tr>
<tr>
<td>Spain</td>
<td>4,500</td>
<td>4,500</td>
</tr>
<tr>
<td>Turkey</td>
<td>5,500</td>
<td>5,500</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>5,100</td>
<td>5,100</td>
</tr>
<tr>
<td>Other countries</td>
<td>47,200</td>
<td>47,000</td>
</tr>
<tr>
<td>World total (rounded)</td>
<td>288,000</td>
<td>300,000</td>
</tr>
</tbody>
</table>

https://www.usgs.gov/centers/nmic/mineral-commodity-summaries
Is salt a critical/strategic mineral?
What has changed from Prehistoric times to today?
Need for more commodities

Technology
Global market

Fig. 1. Trade patterns in phosphate rock.
Environmental concerns
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
China has ~19% of the world population.
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
- China: 1,500
- UAE: 710
- Saudi Arabia: 620
- Japan: 320
- Libya: 250
- Malaysia: 40
- India: 10

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!

But it is not on the list

Why?
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
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
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
<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>Indicator1) 2006</th>
<th>Indicator1) 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>
</tr>
<tr>
<td>Palladium (PGM)</td>
<td>267</td>
<td>23</td>
<td>77</td>
<td>0.09</td>
<td>0.29</td>
</tr>
<tr>
<td>Titanium</td>
<td>7,211,000.2</td>
<td>15,397</td>
<td>58,148</td>
<td>0.08</td>
<td>0.29</td>
</tr>
<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>

Critical Minerals 2018

- **Aluminum (bauxite)**, used in almost all sectors of the economy
- **Antimony**, used in batteries and flame retardants
- **Arsenic**, used in lumber preservatives, pesticides, and semi-conductors
- **Barite**, used in cement and petroleum industries
- **Beryllium**, used as an alloying agent in aerospace and defense industries
- **Bismuth**, used in medical and atomic research
- **Cesium**, used in research and development
- **Chromium**, used primarily in stainless steel and other alloys
- **Cobalt**, used in rechargeable batteries and superalloys
- **Fluorspar**, used in the manufacture of aluminum, gasoline, and uranium fuel
- **Gallium**, used for integrated circuits and optical devices like LEDs
- **Germanium**, used for fiber optics and night vision applications
- **Graphite (natural)**, used for lubricants, batteries, and fuel cells
- **Hafnium**, used for nuclear control rods, alloys, and high-temperature ceramics
- **Helium**, used for MRIs, lifting agent, and research
- **Indium**, mostly used in LCD screens
- **Lithium**, used primarily for batteries
Critical Minerals 2018

- **Magnesium**, used in furnace linings for manufacturing steel and ceramics
- **Manganese**, used in steelmaking
- **Niobium**, used mostly in steel alloys
- **Platinum group metals**, used for catalytic agents
- **Potash**, primarily used as a fertilizer
- **Rare earth elements group**, primarily used in batteries and electronics
- **Rhenium**, used for lead-free gasoline and superalloys
- **Rubidium**, used for research and development in electronics
- **Scandium**, used for alloys and fuel cells
- **Strontium**, used for pyrotechnics and ceramic magnets
- **Tantalum**, used in electronic components, mostly capacitors
- **Tellurium**, used in steelmaking and solar cells
- **Tin**, used as protective coatings and alloys for steel
- **Titanium**, overwhelmingly used as a white pigment or metal alloys
- **Tungsten**, primarily used to make wear-resistant metals
- **Uranium**, mostly used for nuclear fuel
- **Vanadium**, primarily used for titanium alloys
- **Zirconium**, used in the high-temperature ceramics industries
Assignment

• The classification of ore deposits (Noble, 1955)