Mineral Resources

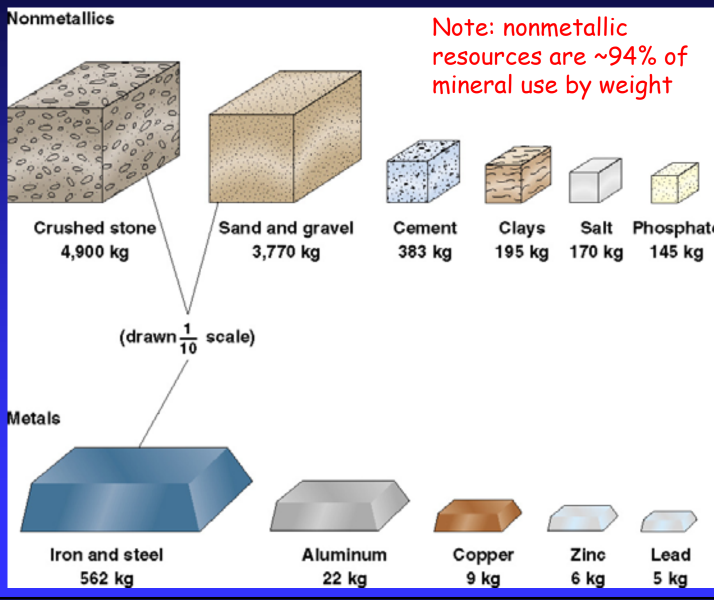
- We depend upon mineral resources
- Every American born this year will need 3.6 million pounds of metals, minerals and fuels in their lifetime
  - 31,000 lbs of salt
  - 21,500 lbs clay
  - 1.71 million lbs of stone, sand & gravel
  - 83,000 lbs of petroleum
  - 850 lbs of lead
  - 775 lbs of zinc
  - 1,300 lbs of copper
  - 5.8 million cubic feet of natural gas
  - 73,000 lbs of cement…

TABLE 14.1 A Few of the Mineral Products in a Typical American Home

Building materials	Sand, gravel, stone, brick (clay), cement, steel, aluminum, asphalt, glass
Plumbing and wiring materials	Iron and steel, copper, brass, lead, cement, asbestos, glass, tile, plastic
Insulating materials	Rock, wool, fiberglass, gypsum (plaster and wallboard)
Paint and wallpaper	Mineral pigments (such as iron, zinc, and titanium) and fillers (such as talc and asbestos)
Plastic floor tiles, other plastics	Mineral fillers and pigments, petroleum products
Appliances	Iron, copper, and many rare metals
Computers, phones, videos	Petroleum products, and many minerals
Furniture	Synthetic fibers made from minerals (principally coal and petroleum products); steel springs; wood finished with mineral varnish
Clothing	Natural fibers grown with mineral fertilizers; synthetic fibers made from minerals (principally coal and petroleum products)
Food	Grown with mineral fertilizers; processed and packaged by machines made of metals
Drugs and cosmetics	Mineral chemicals
Other items	Windows, screens, light bulbs, porcelain fixtures, china, utensils, jewelry: all made from mineral products

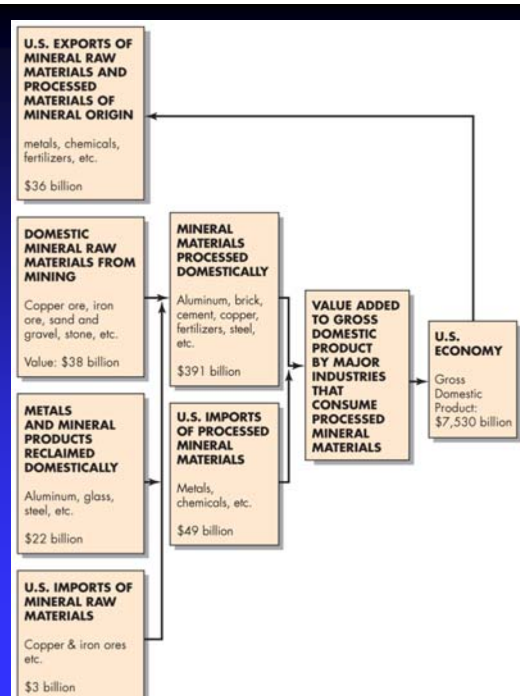
Source: U.S. Geological Survey Professional Paper 940, 1975.

Approximate annual per captia consumption of non-fuel mineral resources in the US in 2004



Minerals and Human Use

- *The role of minerals in the U.S. economy*
- Processed materials from minerals have an annual value of several hundred billion dollars, which is about 5% of the U.S. GDP
- The value of <u>reclaimed</u> *metals and mineral products* is ~25% of the value of domestic mineral raw materials
- NONRENEWABLE
  - Processes too slow



Mineral deposits

- If deposited in concentrated volume, we get veins or lodes.
- If deposited in large volume, we get disseminated deposit.
- *grade*: The relative quantity of ore in an ore body (gold ≈0.05 oz/ton)

Mineral deposits

- *Hydrothermal deposits*: minerals deposited from hot waters usually associated with igneous intrusions
- These fluids carry "low temperature ions"; when the fluids cool off (near surface) the solubility goes down and minerals with Pb, Fe, Hg, Cu, Zn, Ag, Au, etc. are precipitated.

Table 22.1 Economical Concentration Factors of Some Commercially Important Elements

Element	Crustal Abundance (Percent by Weight)	Economical Concentration Factor[1]
Aluminum	8.00	3–4
Iron	5.8	5–10
Copper	0.0058	80–100
Nickel	0.0072	150
Zinc	0.0082	300
Uranium	0.00016	1,200
Lead	0.00010	2,000
Gold	0.0000002	4,000
Mercury	0.000002	100,000

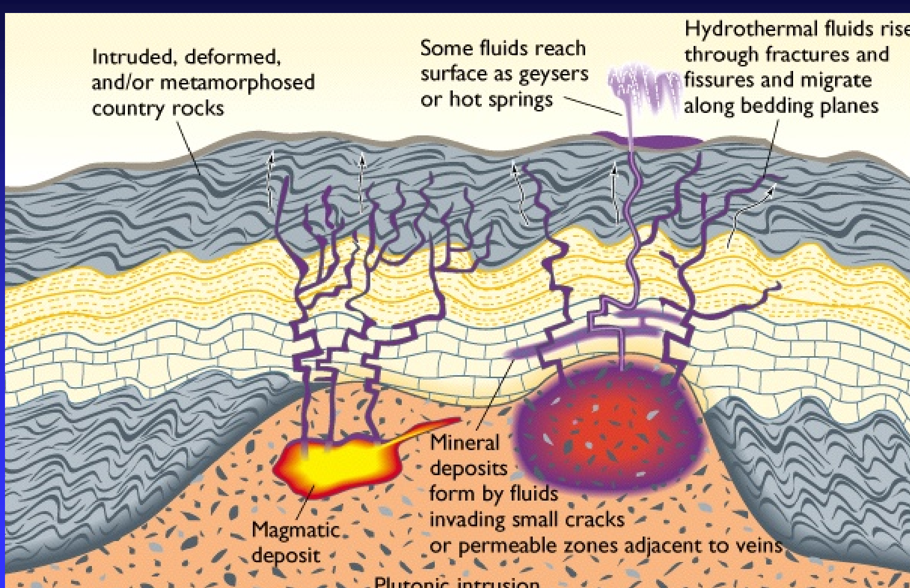
[1]Concentration factor = abundance in deposit divided by crustal abundance.

SOURCES: Data from B. J. Skinner, *Earth Resources,* Prentice Hall, 1969; and D. A. Brobst and W. P. Pratt, *Mineral Resources of the U.S.,* USGS Professional Paper 820, 1973.

Iron Ores

Native Gold on a Quartz Crystal

Hydrothermal Ore Deposits



Vein Deposit of Gold and Silver

Metal Sulfide Ores

Galena Cinnabar Pyrite Sphalerite

Copper Ores

Resource Example: Canadian Diamonds

- Ekati Diamond mine, Canada's Northwest Territory
  - Yield from one pit 7 or 8 million carats (~$100/carat is $700 or $800 million)
  - Prospect discovered in 1991
  - Opened in 1998, one pit produces 10,000 carats/day
- ~30 years ago, this was a speculative resource
  - 1991 Canadian diamonds became hypothetical resource
- Alternative to "conflict" or "blood" diamonds from Angola, Congo and Sierra Leone

Mineral resource reserves

- **Mineral Reserve** - quantities of **ores** that we are confident can be extracted **profitably** in the foreseeable future
  - The reserve amount is dependent on
    - Economics – market value
    - Exploration – are new sources found
  - Mineral reserves are always smaller than mineral resources
- **Ore** - any rock that can be mined *for profit*
- **Ore deposit** - an accumulation of valuable minerals whose extraction is economically feasible

How is value of a mineral reserve determined?

- market price (unit price now: gold = high, copper = low, *well not as high*)
- weight for transportation
- location of mine
- number of uses (specialized or broad)
- energy required to extract
- concentration of desired mineral(s)
- quality standards

Availability and Use of Mineral Resources

- Types of Mineral Resources
  - Earth's mineral resources can be divided into several broad categories based on how we use them
    - Elements for metal production and technology
      - Are classified according to their abundance
        - Abundant metals – iron, aluminum, chromium, manganese
        - Scarce metals – gold, silver, platinum

- Building materials
  - Aggregates
    - Sand
    - Gravel
    - Crushed stone
  - Clay
  - Volcanic ash
- Materials for the chemical industry
  - Minerals used in the production of petrochemicals
- Minerals for agriculture
  - Fertilizers using
    - Phosphate, Nitrogen
    - Sulfur, Calcium & Potassium

- When we think of mineral resources, we usually think of metals used in structural materials
- With the exception of iron, the predominant mineral resources are not metals
- The annual world consumption rate of some elements:
  - Sodium and iron - ~0.1 to 1.0 billion tons per year
  - Nitrogen, sulfur, potassium, calcium – 10 to 100 million tons per year
  - Zinc, copper, aluminum, and lead - ~3 to 10 million tons per year
  - Gold and silver – 10,000 tons per year or less

- Nonmetallic mineral resources, with the exception of iron, are consumed at much greater rates than elements used for their metallic properties
- Of the metallic minerals, iron makes up 95% of all the metals consumed
  - Other common metals such as chromium, cobalt, nickel, and manganese are used mainly in alloys of iron, like stainless steel

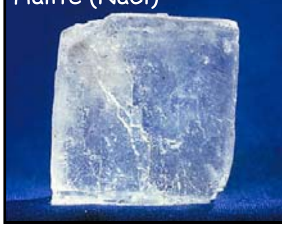
TYPES of MINERAL RESOURCES

Bauxite (Al ore)

Based on how we use them:

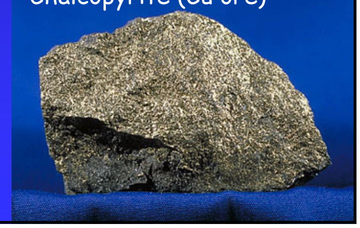
- Materials for metal production and technology (iron, aluminum, etc.)
- Construction materials (gravel, sand, crushed stone, clay, etc.)
- Agricultural industry (fertilizers: N, S, K, Ca)
- Mineral resources for chemical industry (petrochemicals)
- Others (precious gem stones, cosmetics, food, etc.)
- Energy mineral resources (fossil fuels, geothermal, nuclear)

Halite (NaCl)



Coal

Chalcopyrite (Cu ore)

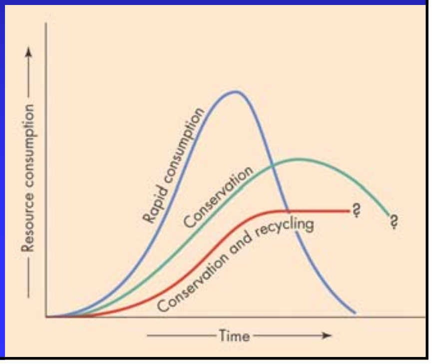


- **Mineral Resources Problems**
  - Nonrenewable resources
  - Finite amount of mineral resources and growing demands for the resources
  - Supply shortage due to growing global industrialization
    - With more developed countries consuming disproportionate share of mineral resources
  - The erratic distribution of the resources and uneven consumption of the resources.
    - Highly developed countries use most of the resources

- Responses to Limited Availability
  - The fundamental problem associated with the availability of mineral resources is not actual exhaustion or extinction
  - Rather, it is the cost of maintaining an adequate reserve within an economy through mining and recycling
    - At some point, the costs of mining exceed the worth of the material

- When the availability of a particular mineral becomes a limitation, several solutions are possible
  - Find more sources
  - Find a substitute
  - Recycle what has already been obtained
  - Use less and make more efficient use of what we have
  - Do without

- A particular mineral resource can be used in several ways
  - Rapid consumption
  - Consumption with conservation
  - Consumption and conservation with recycling
- The option selected depends in part on
  - Social criteria
  - Economic criteria
  - Political criteria



- Historically, resources have been consumed rapidly
  - With the exception of precious metals
- As more resources become limited, increased conservation and recycling are expected
  - The trend toward recycling is well established for metals such as copper, lead, and aluminum

Sustainable resources vs. Non-sustainable resources:

- "Sustainable" - with careful management, *can* last indefinitely
  - Examples of sustainable resources:
    - Water, food and fiber crops, timber, fisheries, livestock
- Are minerals sustainable resources?
  - No
    - Limited quantities
    - Rapid extraction rate (when compared to renewal rate)
      - Minerals take millions of years to form

Options for sustainability

- Recycling
  - Can it be collected?
  - What is the cost to re-use? How much energy is required?
- Exploration - Constantly search for **new deposits**
  - Keep one step ahead (oil companies)
- Find a substitute - different or alternative sources

- Examples of recycling and the advantages and disadvantages:
  - Aluminum
    - Chemically inert - will not corrode or dissolve
    - Light, easy and cheap to transport
    - Easy to recycle because it is usually used in pure form, meaning there are no other metals to separate
    - 95% savings in energy compared to mining of ore
  - Gold - estimated that 90% of all gold ever mined is still in circulation

- but...
  - Zinc
    - Too often combined with other metals when made into products
    - Too difficult and expensive to recover
  - Limestone and clay - too altered to re-use

TABLE 14.2 U.S. Import Reliance (by Percentage) for Selected Nonfuel Mineral Resources, 2001

Mineral	U.S. Reliance on Import From (%)	Major Sources (1996–1999)[1]
Arsenic trioxide	100	China, Chile, Mexico
Asbestos	100	Canada
Bauxite and alumina	100	Australia, Guinea, Jamaica, Brazil
Columbium (niobium)	100	Brazil, Canada, Germany, Russia
Fluorspar	100	China, South Africa, Mexico
Graphite (natural)	100	China, Mexico, Canada
Manganese	100	South Africa, Gabon, Australia, France
Mica, sheet (natural)	100	India, Belgium, Germany, China
Quartz crystal	100	Brazil, Germany, Madagascar
Strontium	100	Mexico, Germany
Thallium	100	Belgium, Canada, Germany, United Kingdom
Thorium	100	France
Yttrium	100	China, Hong Kong, France, United Kingdom
Gemstones	99	Israel, India, Belgium
Bismuth	95	Belgium, Mexico, United Kingdom, China
Antimony	94	China, Mexico, South Africa, Bolivia
Tin	86	China, Brazil, Peru, Bolivia
Platinum	83	South Africa, United Kingdom, Russia, Germany
Stone (dimension)	80	Italy, Canada, Spain, India
Tantalum	80	Australia, China, Thailand, Japan
Chromium	78	South Africa, Kazakhstan, Russia, Zimbabwe
Titanium concentrates	76	South Africa, Australia, Canada, India
Cobalt	74	Norway, Finland, Zambia, Canada
Rare earths	72	China, France, Japan, United Kingdom
Barite	71	China, India, Mexico, Morocco
Potash	70	Canada, Russia, Belarus
Iodine	69	Chile, Japan, Russia
Tungsten	68	China, Russia, Bolivia
Titanium (sponge)	62	Russia, Japan, Kazakhstan, China
Zinc	60	Canada, Mexico, Peru
Nickel	58	Canada, Norway, Russia, Australia
Peat	52	Canada
Silver	52	Canada, Mexico, Peru
Silicon	48	Norway, South Africa, Russia, Canada
Diamond (dust, grit, and powder)	47	Ireland, China, Russia
Magnesium compounds	45	China, Canada, Austria, Australia
Magnesium metal	40	Canada, Russia, China, Israel
Copper	37	Canada, Chile, Mexico
Beryllium	35	Russia, Canada, Kazakhstan, Germany
Aluminum	33	Canada, Russia, Venezuela, Mexico
Pumice	33	Greece, Turkey, Ecuador, Italy
Lead	24	Canada, Mexico, Peru, Australia
Gypsum	22	Canada, Mexico, Spain
Sulfur	22	Canada, Mexico, Venezuela
Nitrogen (fixed), Ammonia	21	Trinidad and Tobago, Canada, Mexico, Venezuela
Cement	20	Canada, China, Spain, Venezuela
Iron ore	19	Canada, Brazil, Venezuela, Australia
Iron and steel	17	European Union, Canada, Japan, Mexico
Mica, scrap and flake (natural)	17	Canada, India, Finland, Japan
Perlite	15	Greece
Salt	15	Canada, Chile, Mexico, The Bahamas
Talc	12	China, Canada, France, Japan
Cadmium	6	Canada, Belgium, Australia
Phosphate rock	1	Morocco

[1] In descending order of import share.

Source: U.S. Geological Survey, Minerals Information, 2001, Mineral Commodity Summaries 2001.

LIMITED AVAILABILITY of MINERAL RESOURCES

Domestic supplies are insufficient for current use and must be imported

The concern is that supplies may be interrupted by political, economic or military instability

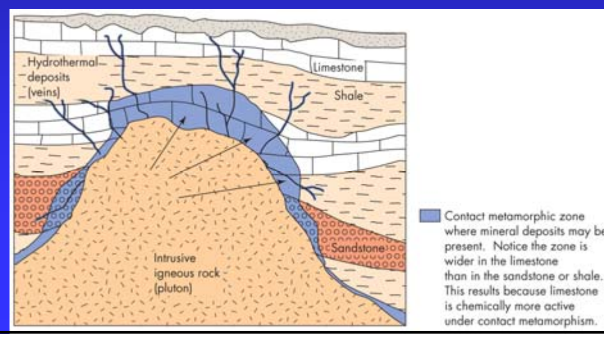
Geology of Mineral Resources

- ORE: Useful metallic minerals that can be mined for a profit
  - Varies depending upon technology, economics, and politics; emphasis on profitability, technological feasibility, and political demands
- CONCENTRATION FACTOR: Concentration necessary for profitable mining
  - Variable with types of metals
  - Variable over time

- Genesis of Some Common Mineral Resources
  - Most deposits of economic minerals can be related to the various parts of the rock cycle under the influence of
    - Tectonic cycles
    - Geochemical cycles
    - Hydrologic cycles
  - Mineral resources with commercial value can be subdivided into several categories based on the type of process that formed them
    - Igneous processes
    - Metamorphic processes
    - Sedimentary processes
    - Biological processes
    - Weathering processes

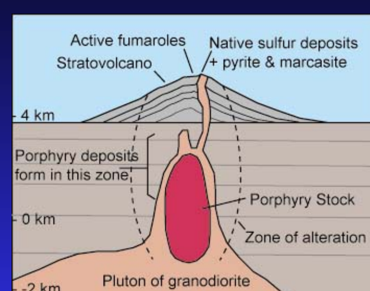
- Igneous Processes
  - Most of the world's ore deposits result from igneous rock-forming and enrichment processes that concentrate economically desirable metals
    - Like copper, nickel, or gold
  - Sometimes, the entire mass of igneous rock may contain ***disseminated*** crystals
    - Diamonds
      - Found in a coarse-grained igneous rock called kimberlite
      - The diamonds are scattered or disseminated within the rock

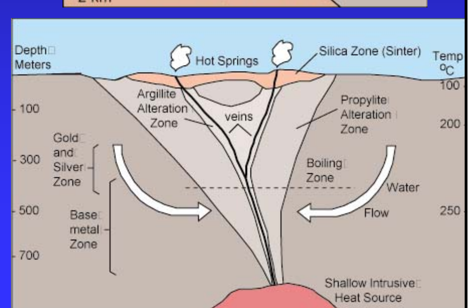
- The most common type of ore deposits associated with igneous processes are ***hydrothermal deposits***
  - Hydrothermal activity involves
    - Hot, chemically active fluid associated with magma
    - That gives rise to a variety of minerals, including gold, silver, copper, mercury, lead, and zinc
  - The hydrothermal solutions that form ore deposits are mineral-rich fluids that migrate through a host rock
  - They then recrystallize the ore minerals as veins or small intrusions known as dikes



Geologic Processes Producing Ore

- Hydrothermal fluids: H_2O, CO_2
- Catalysts that promote recrystallization by enhancing ion migration
- Increases the rate of chemical reactions
- Removes or adds ions, thereby changing bulk composition of rock
- Metasomatism

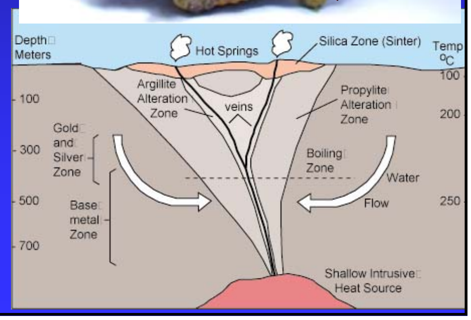


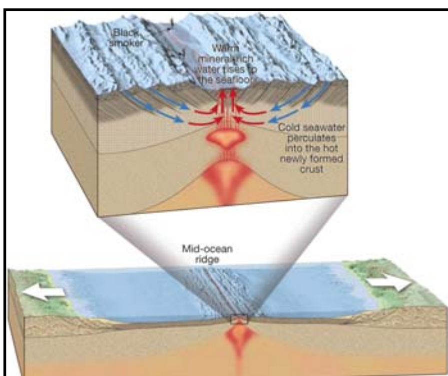


Geologic Processes Producing Ore

- *Fluid Sources:*
  - Water trapped in the pore spaces of sedimentary rocks
  - Volatile magmatic fluids
  - Dehydration of water-bearing minerals (clays, micas, amphiboles)

Andradite garnet on Epidote, Miracle Mountain Mine, Garnet Hill (Calaveras County, CA)





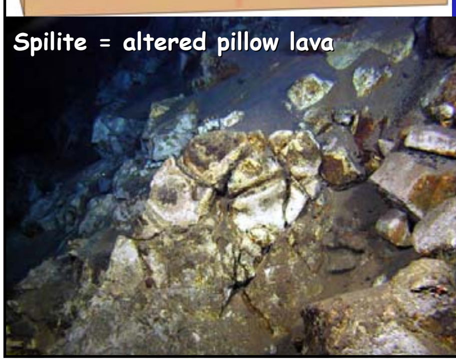
Chemical alteration caused when hot, ion-rich fluids, called hydrothermal solutions, circulate through fissures and cracks that develop in rock

Widespread along the axis of the mid-ocean ridge system, but also associated contact metamorphism around igneous intrusions at subduction zones

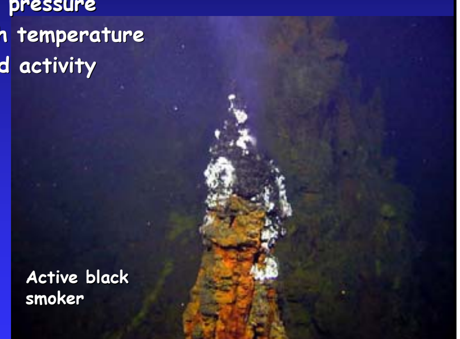
Low pressure

High temperature

Fluid activity

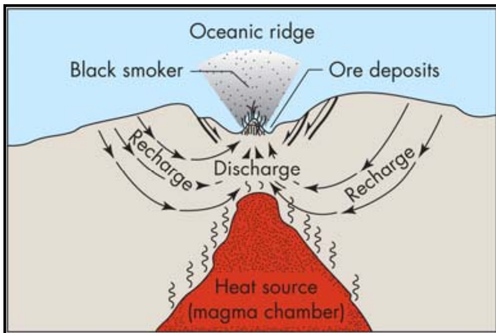


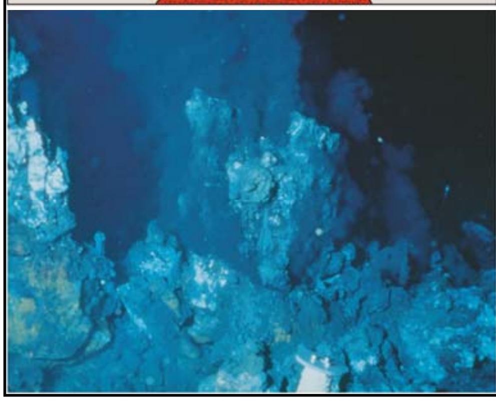
Spilite = altered pillow lava

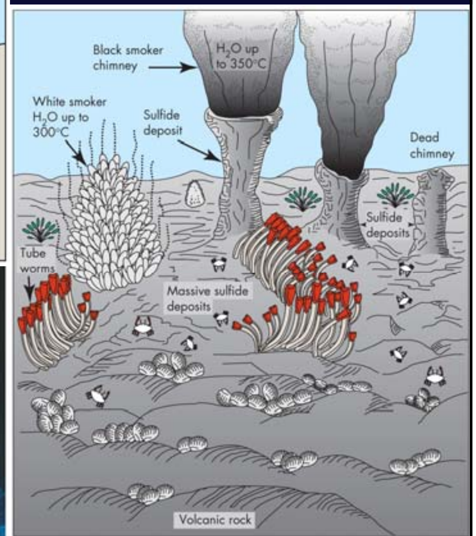


Active black smoker

Rocks that have been totally altered by hot (hydrothermal) fluids. Their original minerals are now completely replaced by other, different minerals



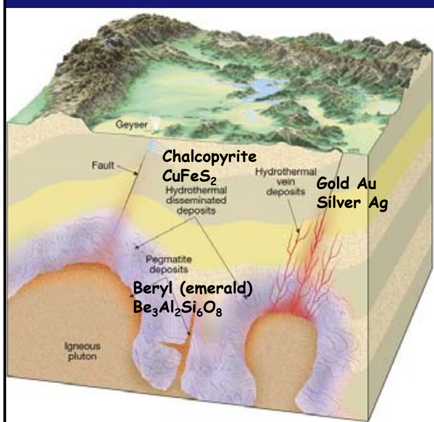




- Metamorphic Processes
  - Metamorphism creates environments of increased heat and pressure, either locally or regionally
  - Metamorphism also produces chemically active fluids
  - The metamorphic process causes changes in the rock, including the concentration and formation of minerals
  - These minerals include both metallic deposits and nonmetallic deposits, such as asbestos and talc

Igneous and Metamorphic Processes

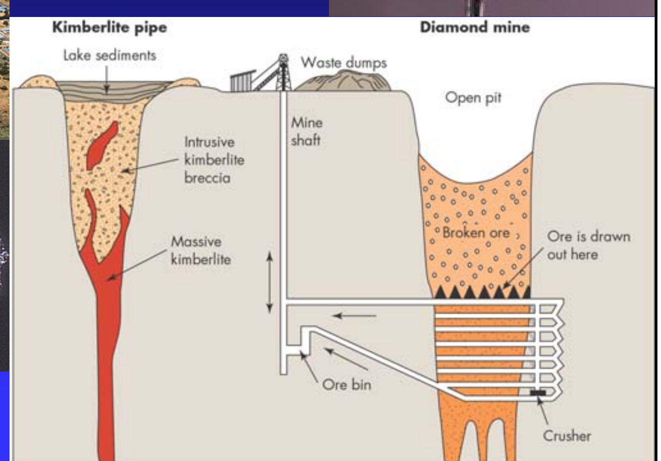
PEGMATITE DEPOSITS
VEIN DEPOSITS
DISSEMINATED DEPOSITS
KIMBERLITE PIPES (diamonds)



- Many important accumulations of metals are produced by igneous processes CONCENTRATION
  - Hydrothermal solutions - Originate from hot, metal-rich fluids that are remnants of the late-stage magmatic process (gold, silver, copper, mercury, lead, zinc)
- Igneous mineral resources can form from:
  - Magmatic segregation – separation of heavy minerals in a magma chamber

    CHROMITE, MAGNETITE, PLATINUM

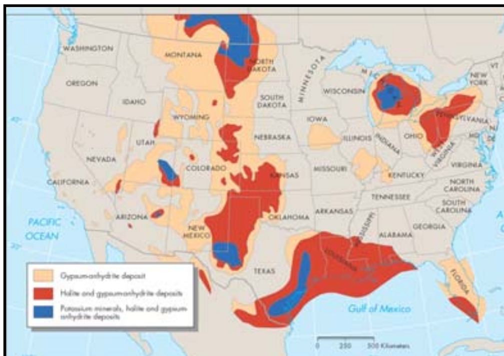
Igneous Processes



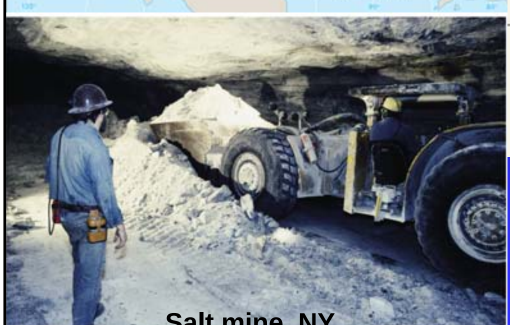
Diamond Mine, Kimberly, South Africa – this is one of the largest hand-dug excavations in the world

- Sedimentary Processes
  - Sediment deposits resulting from physical or chemical weathering processes produce a variety of important mineral resource
  - Sand and gravel produced by stream processes constitute a multibillion-dollar industry
    - Most sand and gravel is obtained from
      - River deposits
      - Water-worked glacial deposits

- Evaporite deposits
  - Result when shallow marine basins or lakes dry up
  - Through evaporation the dissolved minerals in the ocean or lake precipitate (become solid)
  - This forms a wide variety of compounds and minerals that have important economic value
  - Evaporite deposits include
    - Halite – common salt (NaCl)
    - Gypsum ($CaSO_4 \bullet 2\ H_2O$) – used for industrial purposes
    - Potassium minerals – used for a variety of industrial and agricultural activities



Mineral Name	Chemical Formula	Economic Use
Calcite	$CaCO_3$	Portland cement, lime
Dolomite	$CaMg(CO_3)_2$	Portland cement, lime
Halite	NaCl	Common salt
Fluorite	CaF_2	Used in steel making
Sylvite	KCl	Fertilizer
Hematite	Fe_2O_3	Ore of iron, pigment
Magnetite	Fe_3O_4	Ore of iron
Corundum	Al_2O_3	Gemstone, abrasive
Ice	H_2O	Solid form of water
Galena	PbS	Ore of lead
Sphalerite	ZnS	Ore of zinc
Pyrite	FeS_2	Sulfuric acid production
Chalcopyrite	$CuFeS_2$	Ore of copper
Cinnabar	HgS	Ore of mercury
Gypsum	$CaSO_4 \cdot 2H_2O$	Plaster
Anhydrite	$CaSO_4$	Plaster
Barite	$BaSO_4$	Drilling mud
Gold	Au	Trade, jewelry
Copper	Cu	Electrical conductor
Diamond	C	Gemstone, abrasive
Sulfur	S	Sulfa drugs, chemicals
Graphite	C	Pencil lead, dry lubricant
Silver	Ag	Jewelry, photography
Platinum	Pt	Catalyst

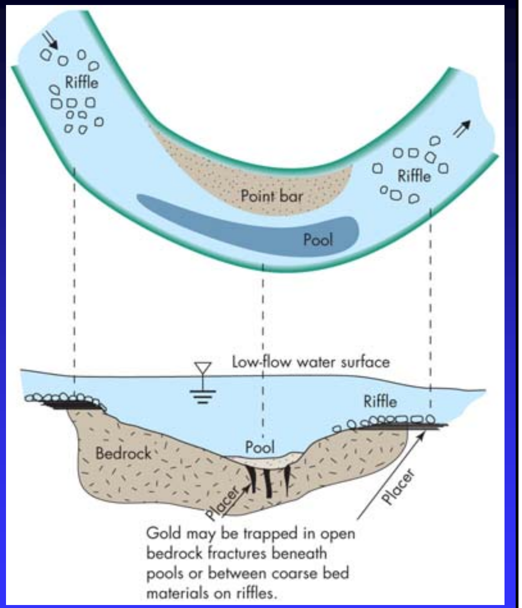


Salt mine, NY

Evaporites

Halite, Gypsum

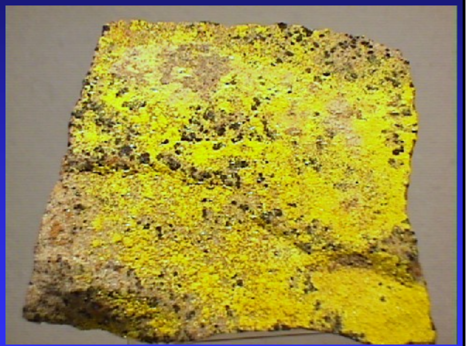
- Stream processes may concentrate a variety of heavy metals weathered from rocks
- These are placer deposits
  - Gold is a common placer deposit
    - May be trapped in open bedrock fractures beneath pools
    - May be trapped between coarse bed materials on riffles



SEDIMENTARY PROCESSES

Uranium

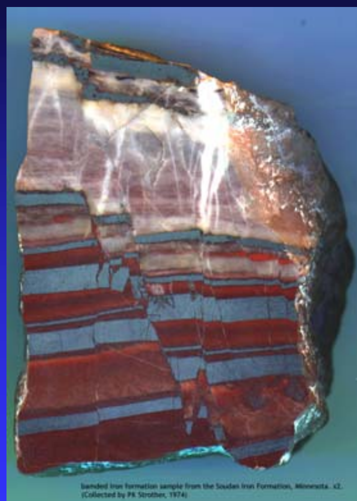
Most uranium used in North American nuclear reactors comes from carnotite, a mineral found in sedimentary rocks



$K_2(UO_2)_2(VO_4)_2$- 1-3H_2O Hydrated Potassium Uranyl Vanadate.

An important ore of uranium and vanadium and as mineral specimens.

SEDIMENTARY PROCESSES



Banded Iron Formation

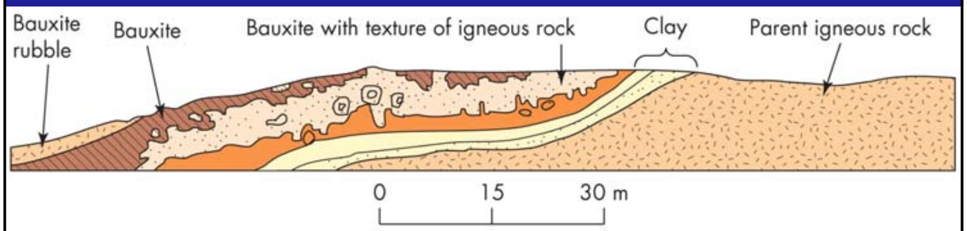
Layers of chert with iron oxide (hematite)

All over ~2 b.y.

- Biological Processes
  - Organisms are able to form many types of useful minerals
    - Calcium carbonate and magnesium carbonate for shells
    - Calcium phosphate in the bones of fish and other organisms
  - Accumulations of phosphate-rich fish bones and teeth form some of the world's richest phosphate deposits
    - Fish and other marine organisms extract the phosphate from seawater
    - The mineral deposits result from sedimentary accumulation of phosphate-rich fish remains that are deposited with other sediments at the bottom of the ocean
    - These sediments eventually form sedimentary rocks from which phosphate deposits are mined

- Weathering Processes
  - Physical, chemical, and biochemical weathering processes may concentrate some materials to the point at which they can be extracted at a profit
  - These processes can produce **residual ore deposits** in weathered material
    - **Residual ore deposits** result from intense weathering of rocks and soils that leaves behind the less soluble material with economic value
  - Intensive weathering of some rocks in a tropical climate forms a particular type of soil known as **laterite**
    - Laterite is often derived from aluminum and iron-rich igneous rocks

- The weathering process concentrates oxides of aluminum and iron
- The residual aluminum oxide forms an ore of aluminum known as **bauxite**



- Weathering can also cause secondary enrichment processes that increase the concentration of a metal – such as copper – in an ***enriched zone***

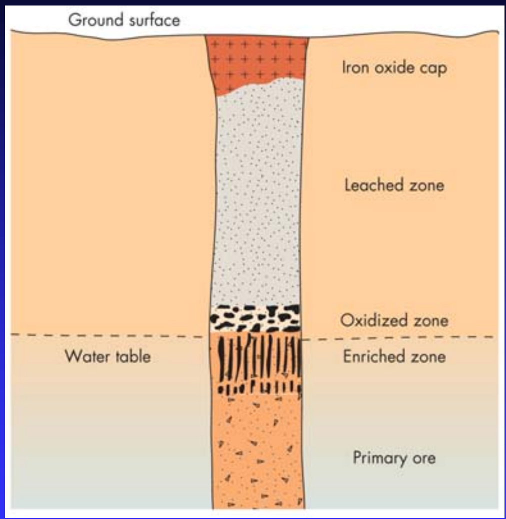


Table 3.1 Occurrences of metallic minerals

Metal	Principal Ores	Geological Occurrences
Aluminum	Bauxite	Residual product of weathering
Chromium	Chromite	Magmatic segregation
Copper	Chalcopyrite Bornite Chalcocite	Hydrothermal deposits; contact metamorphism; enrichment by weathering processes
Gold	Native gold	Hydrothermal deposits; placers
Iron	Hematite Magnetite Limonite	Banded sedimentary formations; magmatic segregation
Lead	Galena	Hydrothermal deposits
Magnesium	Magnesite Dolomite	Hydrothermal deposits
Manganese	Pyrolusite	Residual product of weathering
Mercury	Cinnabar	Hydrothermal deposits
Molybdenum	Molybdenite	Hydrothermal deposits
Nickel	Pentlandite	Magmatic segregation
Platinum	Native platinum	Magmatic segregation; placers
Silver	Native silver Argentite	Hydrothermal deposits; enrichment by weathering processes
Tin	Cassiterite	Hydrothermal deposits; placers
Titanium	Ilmenite Rutile	Magmatic segregation; placers
Tungsten	Wolframite Scheelite	Pegmatites; contact metamorphic deposits; placers
Uranium	Uraninite (pitchblende)	Pegmatites; sedimentary deposits
Zinc	Sphalerite	Hydrothermal deposits

TABLE 14.3 Types of Mineral Resources

Type	Example	Location
Igneous		
Disseminated	Diamonds	South Africa
Crystal settling[1]	Chromite	Stillwater, Montana
Late magmatic	Magnetite	Adirondack Mountains, New York
Pegmatite[2]	Beryl and lithium	Black Hills, South Dakota
Hydrothermal	Copper	Butte, Montana
Metamorphic		
Contact metamorphism	Lead and silver	Leadville, Colorado
Regional metamorphism	Asbestos	Quebec, Canada
Sedimentary		
Evaporite (lake or ocean)	Potassium	Carlsbad, New Mexico
Placer (stream)	Gold	Sierra Nevada foothills, California
Glacial	Sand and gravel	Northern Indiana
Deep ocean	Manganese oxide nodules	Central and southern Pacific Ocean
Biological	Phosphorus	Florida
Weathering		
Residual soil	Bauxite	Arkansas
Secondary enrichment	Copper	Utah

[1]Heavier crystals sink to bottom of magma.
[2]Very coarse-grained igneous rock.

Source: Modified from Foster, R. J. 1983. *General geology*. 4th ed. Columbus, OH: Charles E. Merrill

Environmental Impact of Mineral Development

- The environmental impact comes from
  - mineral exploration and testing
  - mineral mining
  - mineral resources refining
  - mining waste disposal

- The environmental impact depends on many factors:
  - Mining procedures
  - Hydrologic conditions
  - Climate factors
  - Types of rocks and soils
  - Topography

- Impact of Mineral Exploration and Testing
  - Types of exploration and testing activities
    - Surface mapping
    - Geochemical data collection
    - Geophysical data collection
    - Remote-sensing data collection
    - Test drilling
  - Impact
    - Generally minimal impact
    - More planning and care needed for sensitive areas
      - Arid areas
      - Wetlands
      - And permafrost areas

- Impact of Mineral Extraction and Processing
  - General impact
    - Direct impact on land, water, air, and biological environment
    - Indirect impact on the environment
      - Topographic effect, transportation of materials, etc.
    - Impact on social environment
      - Increased demands for housing and services

- Impact from mining operations
  - Land disturbances from access, surface mining
  - Waste from mines:
    - 40% of the mining area for waste disposal
    - mining waste 40% of all solid wastes
  - Special mining, e.g., chemical leaching from gold mining
  - Mining acid drainage, during mining and post-mining
  - Water pollution, such as smelting emissions of SO_2
  - Biological environment

Bingham Canyon Copper Mine near Salt Lake City, UT

Runoff from mine tailings

The white streaks are mineral deposits leached from the tailings

- Water Pollution
  - Trace elements leaching out into water
    - Such as
      - Cadmium (Cd)
      - Cobalt (Co)
      - Copper (Cu)
      - Lead (Pb)
      - Molybendium (Mo)
      - Zinc (Zn)
  - Flooding of abandoned mines
  - Acid mine drainage from tailings
  - Acidic and toxic mining wastewater

Berkley Pit, Butte, MT - Lake formed in abandoned copper mine – water is acidic and toxic – kills birds that land on it and drink the water

Regional Management Issues

Nuclear Waste down the Colorado River? Moab Utah's Atlas Mill tailings pile

Moab, Utah

- The Colorado River is undoubtedly one of the West's greatest "natural" treasures
- Its beauty and environmental value are supplemented by its value as a water resource
  - Provides water for over 20 million people, hydroelectricity, and endless recreational uses
- Turning the Colorado River into a radioactive dump would be unthinkable, or is it?

Why Moab, Utah?

- In 1952 in a remote corner of southeastern Utah, an out of work geologist by the name of Charlie Steen struck the largest deposit of high-grade uranium ore that had ever been found in the United States
- His discovery came at a time when America was frantic for a domestic source of uranium and Steen's strike set off a "uranium rush"

Moab cira. 1950-1975

- Carson City had silver, San Francisco boomed with gold at Moab it was all about uranium
- After World War II, as the nation built its arsenal of cold war weapons and nuclear energy plants, the rich radioactive deposits that snake through southeast Utah made Moab the nation's Geiger counter capital
- At its height, there were 40 to 50 publically-traded uranium companies listed in Utah, and most were in Moab

What Happened?

- The accident at the Three Mile Island plant in Pennsylvania in 1979 stalled the nuclear industry
- The Soviet Union fell so less need for cold war weapons development
  - Moab's go-go uranium economy was gone
- An economic revival in the 1980's was led by young health-conscious mountain bikers who discovered the area's back roads and sandstone trails
- Now coffee bars, bike shops and back-country tour operators dominate Main Street

Atlas Uranium Mill

- Atlas Uranium Mill stood outside of Moab limits on the shore of the Colorado River in the 1950s
- What remains are 13 million tons of mine tailings on a floodplain just 750 feet from the Colorado River
- Officials, politicians and some scientists debated in 2001-2002 whether radioactive waste leaching into the Colorado River is really that big a deal
  - *Dilution is the solution to pollution*
- Cost - $200-300 million to relocate the tailing pile
- Alternative - $15-20 million (+ an optional $77 million for water treatment) cap the tailings pile and leave it where it is

Leakage from the tailings pond contains uranium levels 590 times what federal regulations allow for uranium mines and mills

This causes a 1,660% increase in uranium levels in the river, which is 31 times the levels allowed under EPA standards

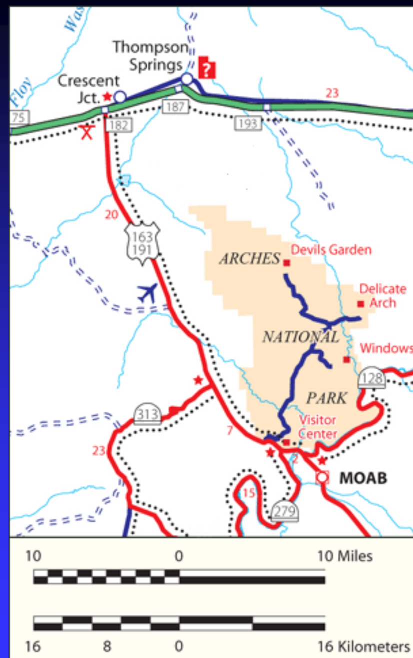
Background

- In 1956 the Atlas Uranium Mill was commissioned by the Atomic Energy Commission to produce uranium for Cold War weapons and reactor programs
- It was bought in 1961 by Atlas Corporation and continued to operate until 1984
- Operation the mill accumulated 13 million tons of radioactive waste and other hazardous material (tailings), all of which were slurried into an unlined pond 750 feet from the Colorado River
- The pond has been leaking

Controversy

- Removing the tailings pile has widespread support
  - Paying for removal has been an unpleasant issue
  - The Bush Administration has been reluctant to provide any funding
- In 2001 the DOE asked Congress and the Bush Administration for $10 million for a National Academy of the Sciences study
  - They received $1.4 million
- NAS recommended that 16 million tons of tailings be moved from the banks of the Colorado River
  - On Oct. 22, 2010, the U.S. Department of Energy reached another milestone on the Moab, Utah, Uranium Mill Tailings Remedial
    - 2.5 million tons of tailings shipped by rail from the Moab site to the Crescent Junction, Utah, site for permanent disposal
      - 3 million tons expected in Jan 2011
    - Funding under the American Recovery and Reinvestment Act supported nearly 60 percent of the total shipments.

http://www.moabtailings.org/ & http://www.gjem.energy.gov/moab/



Thompson Springs
Crescent Jct.
23
75
182
187
193
20
163
191
ARCHES
Devils Garden
Delicate Arch
NATIONAL
Windows
128
PARK
313
Visitor Center
23
7
MOAB
15
279
10 0 10 Miles
16 8 0 16 Kilometers

- Minimizing the Impact of Mineral Development
  - Knowledge and technology transfer: developed countries to developing countries
  - Environmental Regulations:
    - Forbid bad mining practices
    - Clean Air Act
    - On- and offsite treatment of wastes
  - Land reclamation: About 50% of land used in mining industry reclaimed
  - Use of new biotechnology in mining:
    - Bio-oxidation
    - Bioleaching
    - Biosorption
    - Genetic engineering

Significant Sources of Global Mercury Emissions

- Fuel combustion – especially coal
- Artisanal gold mining – deliberate use of mercury to assist in gold recovery
- Metal smelting (from trace mercury in ore)
- Cement production (trace mercury in limestone)
- Waste disposal (from mercury in products)
- Chlor-alkali plants (production catalyst)

Hg in Au Mines

- Today, Hg not added to industrial scale gold mining
  - By-product of gold mining
- Mercury was added to gold mining to extract Au
  - Hg served as an amalgam
    - Causes gold particles to stick to the mercury
  - Mercury and gold would be heated up and the mercury volatilizes into the air
- Process still used by small scale, "artisanal" miners in the Amazon, in Mongolia, and in parts of Africa
  - Serious health risk for those doing it
  - Practice contributes a lot of mercury pollution to the environment

US Mercury Emissions

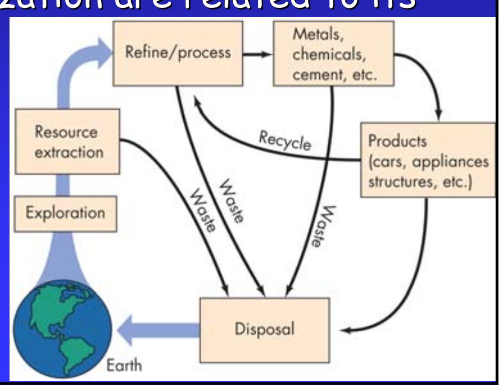
- Significant reductions (best estimate–more than 50% reduction since 1990)
- Major factor–controls on medical and municipal incinerators
- Also: reductions in mercury use–batteries, medical equipment, fungicides in paint
- Biggest remaining source: coal combustion and gold mining

Gold Mining

- Primarily in northeastern Nevada (Elko, NV)
  - High mercury concentrations in gold ores
- Biggest individual sources in U.S.
- Voluntary program has led to roughly 75% emissions reduction since 2000 (process changes, control devices)
  - Mining companies self-test and self-report
  - Typically one stack test per year
- Mandatory measurements since 2006
  - Regulated by Nevada DEP

Recycling Mineral Resources

- Why recycle?
  - A diagram of the mineral resources cycle reveals that many components of the cycle are connected to waste disposal
  - In fact, the primary environmental impacts of mineral resource utilization are related to its waste products



- Consider the impact of the wastes
  - Toxic to humans
  - Dangerous to natural ecosystems
  - Degradation of air, water, and soil
  - Use of land for disposal
  - Aesthetically undesirable

- More reasons to recycle…
  - Waste contains recyclable materials
  - Saves energy, money, land, raw mineral resources from more mining
  - Saves energy and money when recycling instead of refining raw ore materials
  - Recycling has been proven to be profitable and workable

- What can we recycle?
  - Most-recycled metals: Iron and steel, 90% by weight
    - One-third as much energy needed to produce steel from recycled scrap as from original ore
  - More than $7.9 billion produced from recycled metals in 2005 in the United States
  - Other recycled metals:
    - Lead (63%)
    - Aluminum (38%)
    - Copper (36%)

Minerals and Sustainability

- Sustainability: long-term strategy for consuming the resources
- Find an alternative material for the metal
  - e.g., glass fiber cable for copper wires
- Use raw materials more efficiently
- More R&D on innovative substitutes