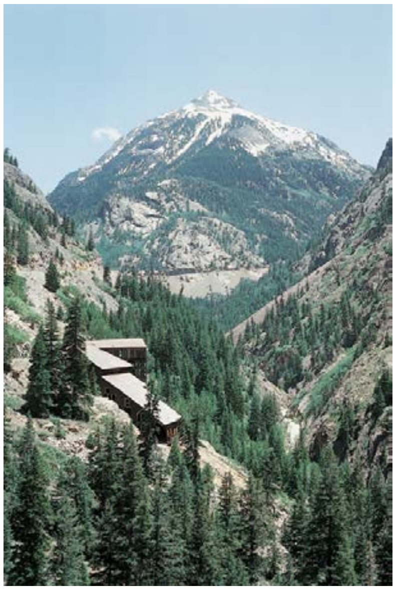
CE/SC 10110-20110

Mineral Resources



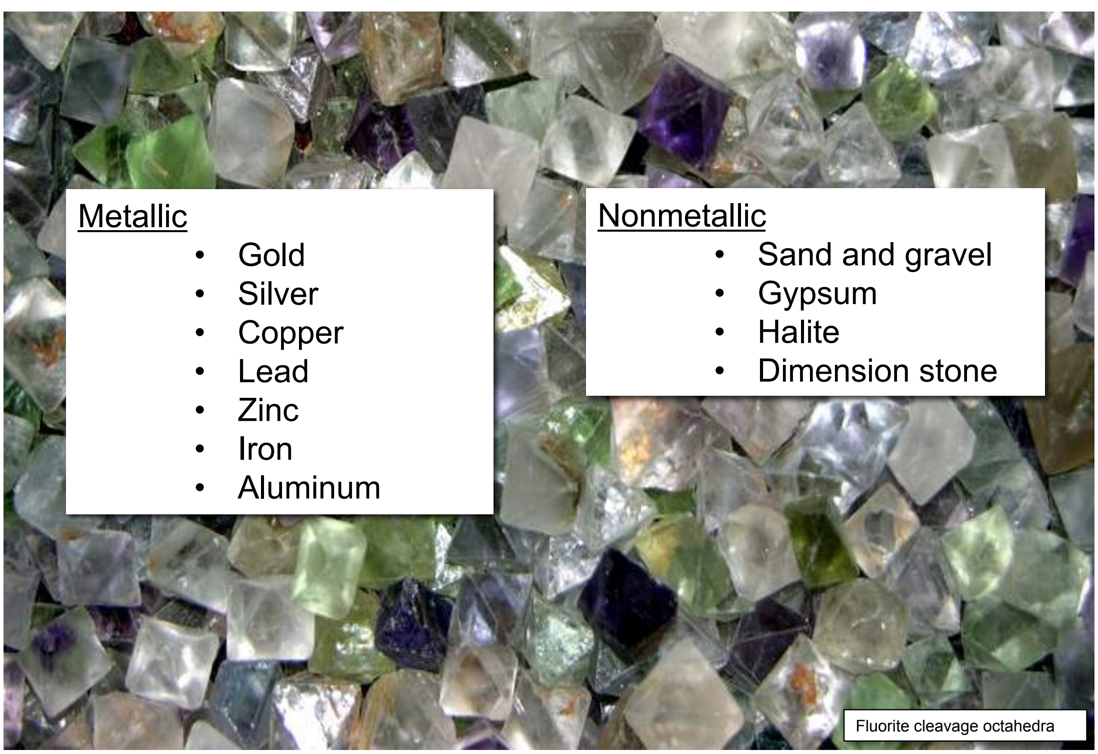
Earth

Portrait of a Planet

Fifth Edition

Chapter 15

Major Categories of Mineral Resources



Metallic

- Gold
- Silver
- Copper
- Lead
- Zinc
- Iron
- Aluminum

Nonmetallic

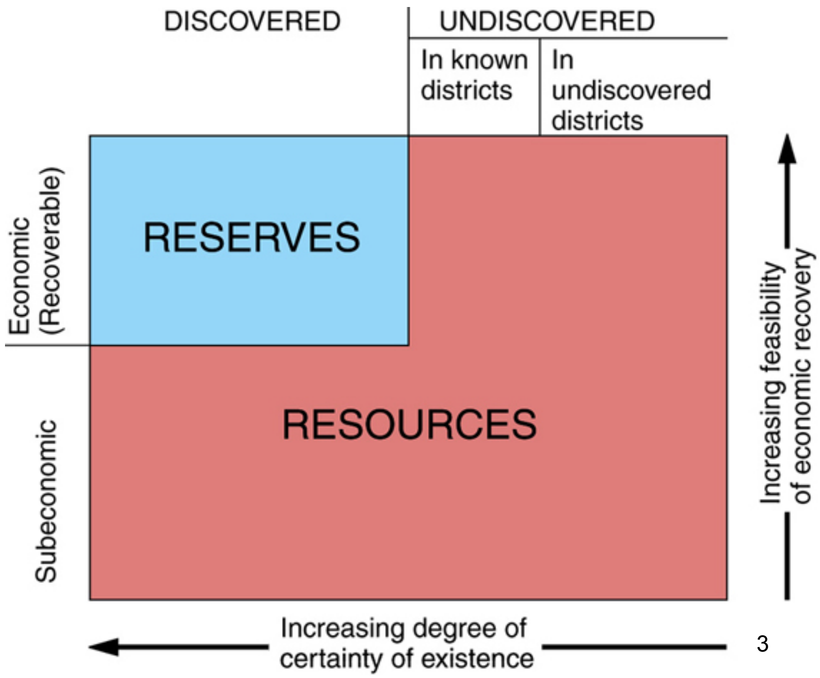
- Sand and gravel
- Gypsum
- Halite
- Dimension stone

Fluorite cleavage octahedra

Resources and Reserves

Resources: Total discovered and undiscovered.

Reserves: Discovered, surveyed, and economically recoverable.



3

Mineral Deposits

Main Subdivisions: Metallic Resources:

- Gold, Silver, Copper, Lead, Zinc, Iron, Aluminium

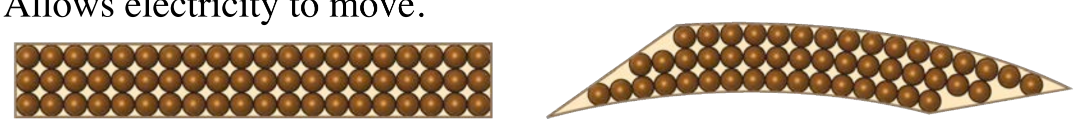
Non-metallic Resources:

- Sand, Gravel, Gypsum, Halite, Dimension stone

Native Metals

Metals are found in nature: Cu, Au, Ag. Also mixtures/blends of metals or **alloys** - Copper + Tin = Bronze.

Metallic: outer shells of atoms move easily from one to another. Allows electricity to move.



Economic deposits require concentration by geologic processes.

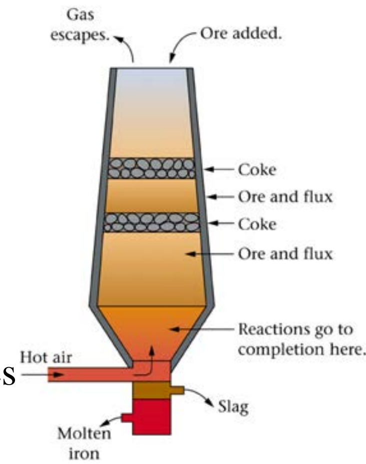
Metallic Deposits

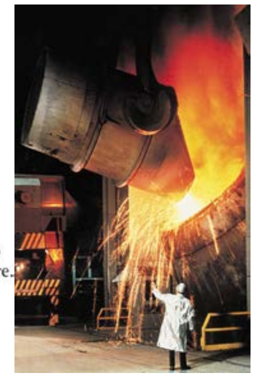
Native metals liberated from rock by heating it: **Smelting**.
Metal runs off and leaves behind a non-metallic residue: **Slag**.

Metals divided into:
Precious Metals: Au, Ag, Pt;
Base Metals: Fe, Cu, Zn, Sn.

Iron is liberated as follows:

$$Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$$





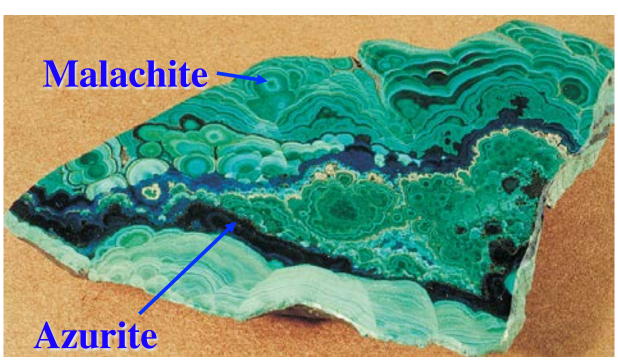
Smelting is a process that releases metals from ore minerals. Different minerals require different smelting techniques at different temperatures.

Smelting

Metallic Deposits

Ore: deposit that can be mined economically. Depends upon, political, economic, social factors. The concentration determines the ***grade*** of the deposit.

Ore is mined that contains native metals or a concentrated accumulation of **ore minerals**. Uneconomic minerals found with native metals/ore minerals is called **Gangue**.



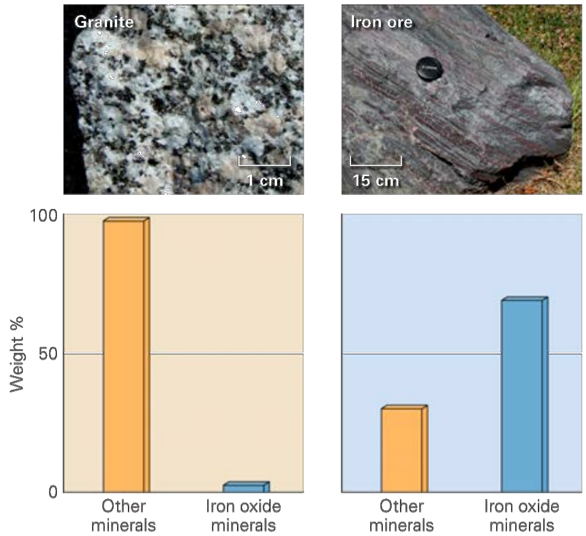
Common Ore Minerals

Metal	Ore Mineral	Composition
Aluminum	Bauxite (a mineral mixture) ure)	$Al_2O_3 \cdot nH_2O$
Chromium	Chromite	$FeCr_2O_4$
Copper	Native copper	Cu
	Chalcocite	Cu_2S
	Chalcopyrite	$CuFeS_2$
Gold	Native gold	Au
Iron	Hematite	Fe_2O_3
	Magnetite	Fe_3O_4
Lead	Galena	PbS
Manganese	Pyrolusite	MnO_2
Mercury	Cinnabar	HgS
Nickel	Pentlandite	(Fe, Ni)S
Silver	Native silver	Ag
	Argentite	Ag_2S
Tin	Cassiterite	SnO_2
Uranium	Pitchblende	U_3O_8
	Carnotite	$K(UO_2)_2(VO_4)_2 \cdot 3H_2O$
Zinc	Sphalerite	ZnS

What is an Ore?

TABLE 15.1 Some Common Ore Minerals

Metal	Mineral Name	Chemical Formula
Copper	Chalcocite	Cu_2S
	Chalcopyrite	$CuFeS_2$
	Bornite	Cu_5FeS_4
	Azurite	$Cu_3(CO_3)2(OH)_2$
	Malachite	$Cu_2(CO_3)(OH)_2$
Iron	Hematite	Fe_2O_3
	Magnetite	Fe_3O_4
Tin	Cassiterite	SnO_2
Lead	Galena	PbS
Mercury	Cinnabar	HgS
Zinc	Sphalerite	ZnS
Aluminum	Kaolinite	$Al_2Si_2O_5(OH)_4$
	Corundum	Al_2O_3
Chrome	Chromite	$(Fe,Mg)(Cr,Al,Fe)2O_4$
Nickel	Pentlandite	$(Ni,Fe)_9S_8$
Titanium	Rutile	TiO_2
	Ilmenite	$FeTiO_3$
Tungsten	Sheelite	$CaWO_4$
Molybdenum	Molybdenite	MoS_2
Magnesium	Magnesite	$MgCO_3$
	Dolomite	$CaMg(CO_3)_2$
Manganese	Pyrolusite	MnO_2
	Rhodochrosite	$MnCO_3$

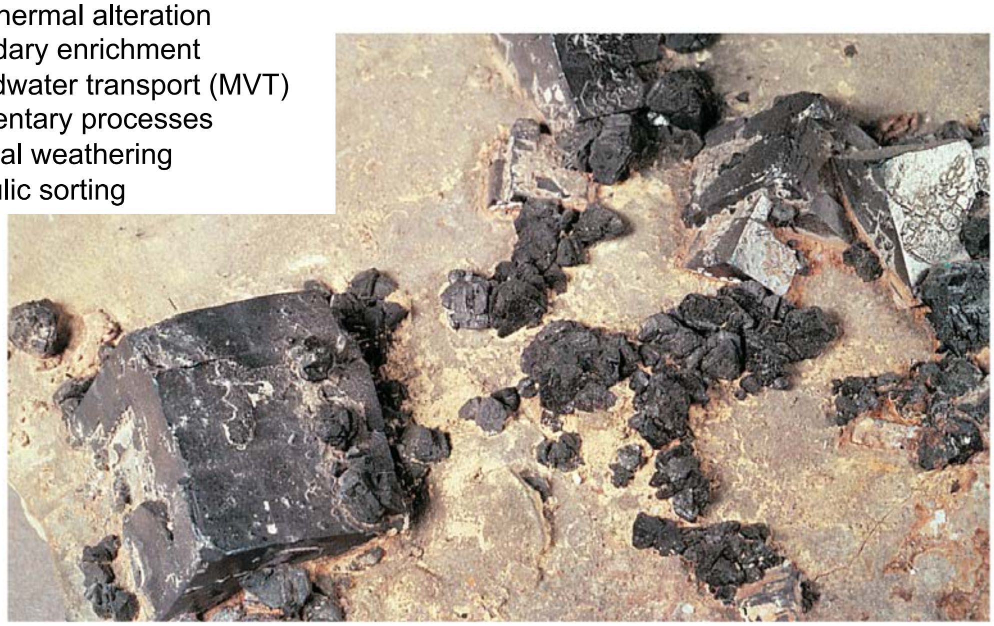


The difference between an ore and other rock is that metals are concentrated in the ore.

How do Ore Deposits Form?

Ore-forming geologic processes:

- Magmatic activity
- Hydrothermal alteration
- Secondary enrichment
- Groundwater transport (MVT)
- Sedimentary processes
- Residual weathering
- Hydraulic sorting

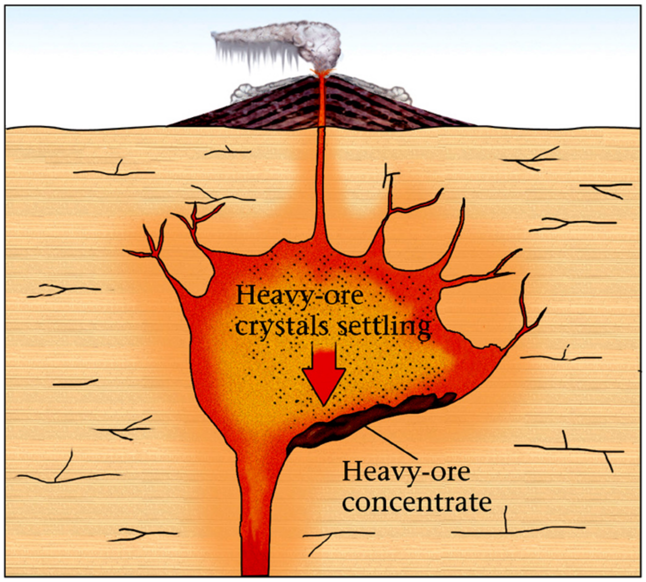


Ore Deposits

Magmatic Deposits

Crystal Settling from magma: Cr (chromite), Bushveld, South Africa

Sulfide (Sudbury, Ontario) - "Massive Sulfide Deposit".



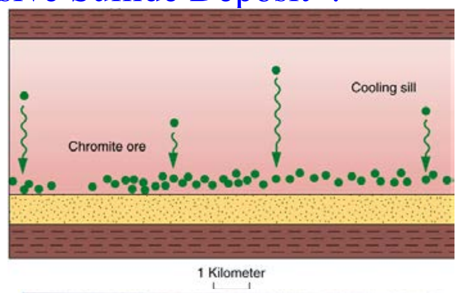


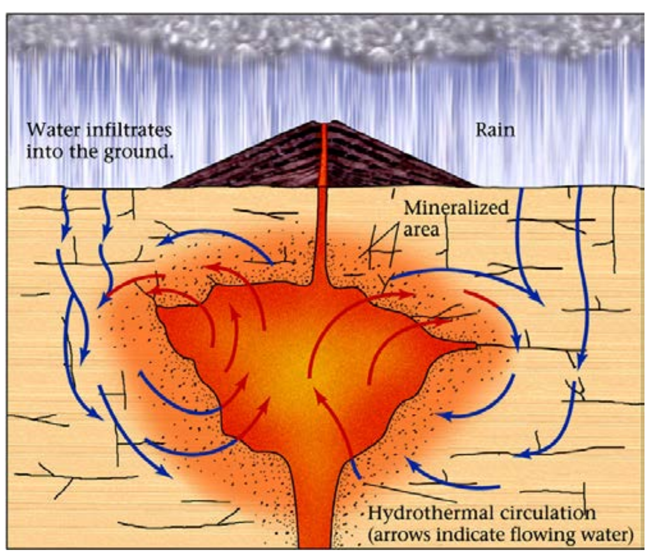
FIGURE 13.5 Layered mineral deposit; Red Mountain, Alaska. The black layers are chromite ($FeCr_2O_4$); the light layers are granitic rocks.

Ore Deposits

Hydrothermal Deposits

Circulation of reactive hot water solutions through a magma or rocks surrounding an igneous intrusion.

Metallic ions are dissolved. They are re-deposited when the fluids enter a region of lower temperature / lower pressure / different acidity /different oxygen availability.
This creates a hydrothermal deposit.

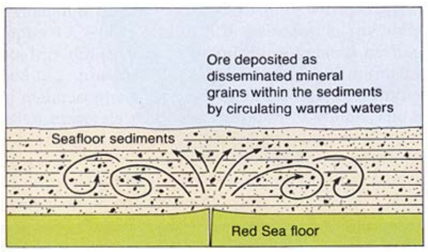


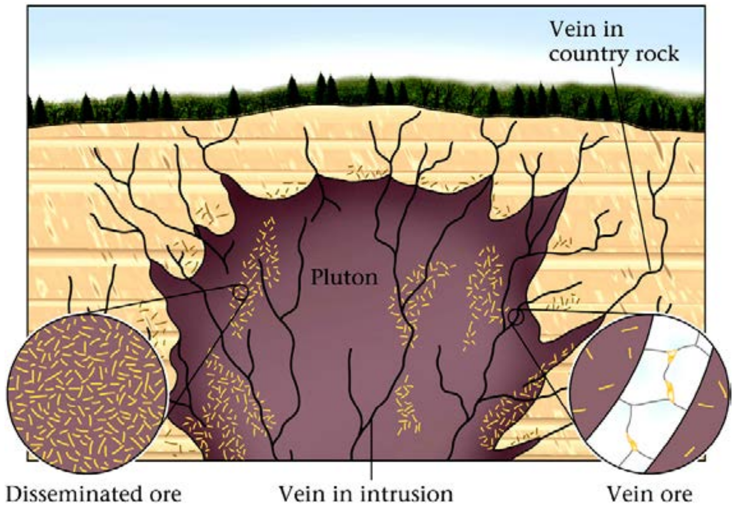
Ore Deposits

Hydrothermal Deposits

Disseminated Deposit: ore minerals are dispersed throughout the intrusion/country rock - often called "**Massive Sulfide Deposits**".
Vein Deposit: ore minerals fill joints with in the pre-existing rock.

Hydrothermal copper deposits are often found in porphyritic igneous rocks; these are **Porphyry Copper Deposits**.

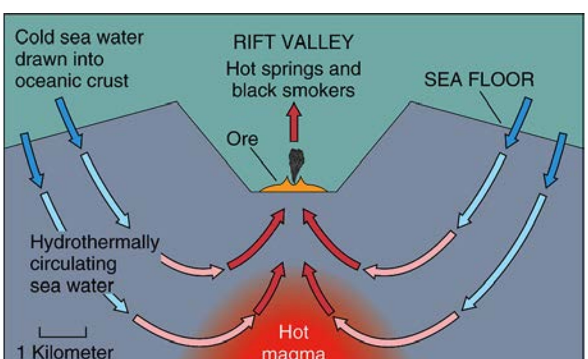


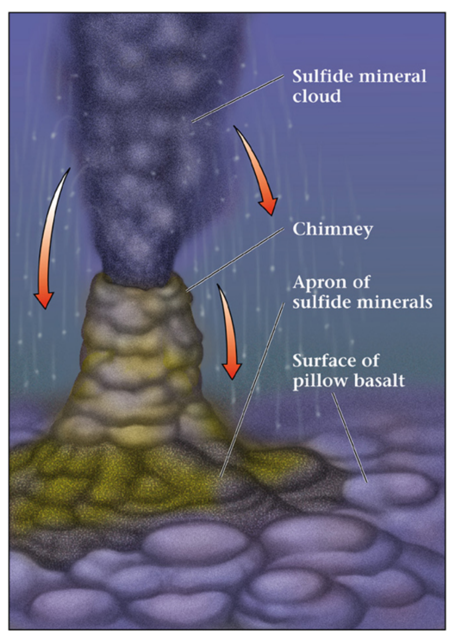


Ore Deposits

Hydrothermal Deposits

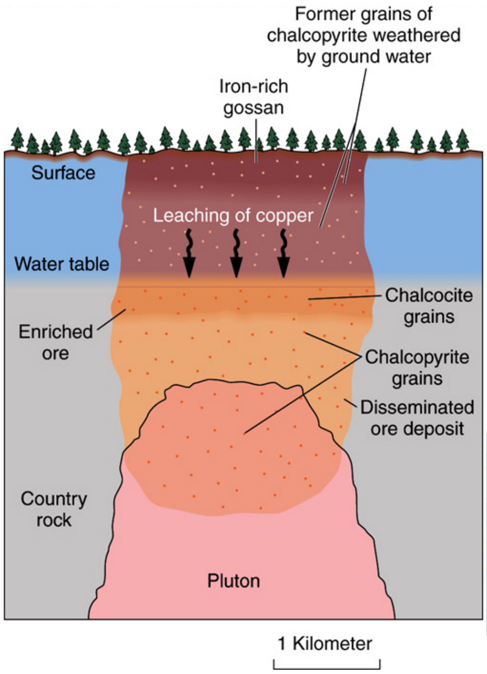
Black Smokers are forming massive sulfide deposits around mid-ocean ridges present day.



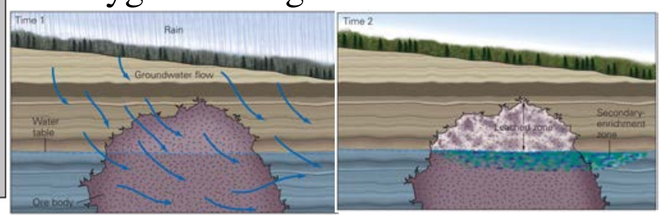


Ore Deposits

Secondary-Enrichment Deposits



Original deposit is sub-economic. Secondary enrichment processes allow concentration of the ore minerals to economic levels. This is also called **Supergene Enrichment**. These deposits can form when dissolution occurs in oxygenated waters and the water moves to a deoxygenated region.

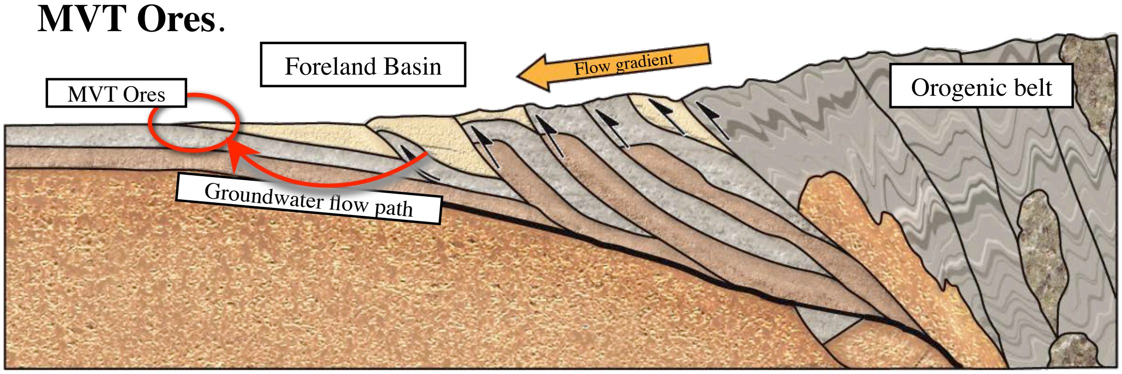


Ore Deposits

Mississippi-Valley-Type Deposits

Groundwater beneath mountain belts sinks several kilometers and comes back to the surface up to several hundred kilometers away. After sinking, the water heats up and dissolves metals. When it rises into cool rocks, the metals precipitate.

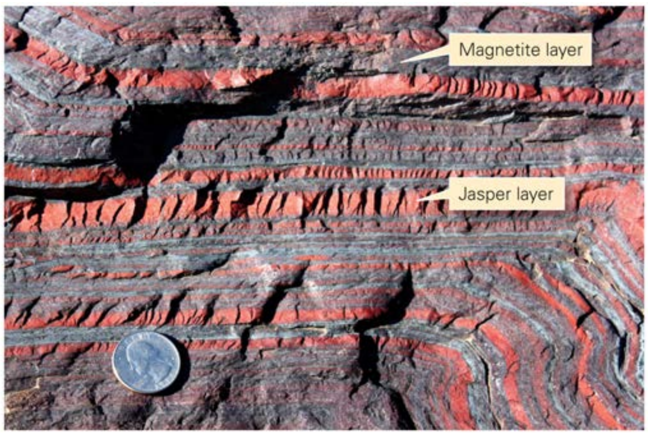
Lead- and zinc-bearing veins are formed in this way - known as **MVT Ores**.



Ore Deposits

Sedimentary Deposits

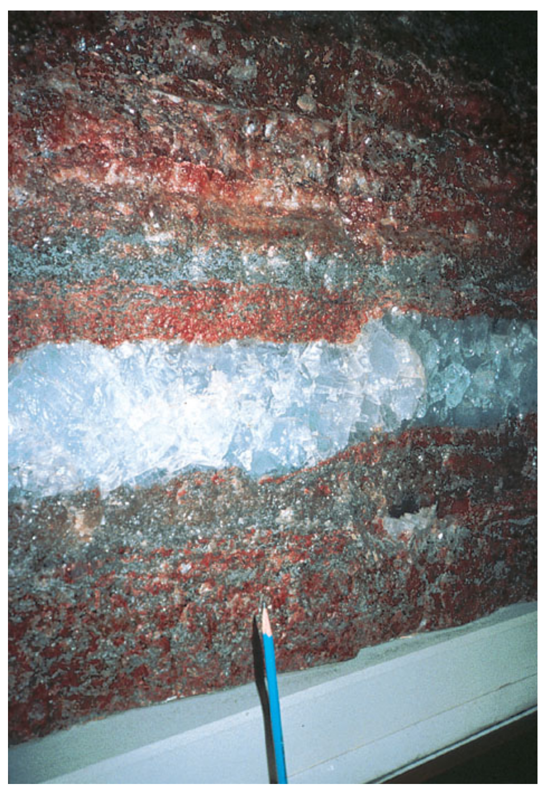
Banded Iron Formations (BIFs): Fe^{2+} is soluble in water, but Fe^{3+} is not. These are found in the Proterozoic, contain Hematite (Fe_2O_3) and Magnetite (Fe_3O_4) in layers that alternate with Fe-rich chert (jasper). They present evidence for an oxygenated atmosphere.



Distribution of Mineral Resources

Sedimentary Deposits

Surficial Precipitation:
Evaporite deposits – two types – marine evaporites (salts of Na, K, Ca – halite, sylvite, anhydrite, gypsum and bedded phosphates); non-marine evaporites (Ca & Na carbonates, nitrate, sulfate, and borate minerals).



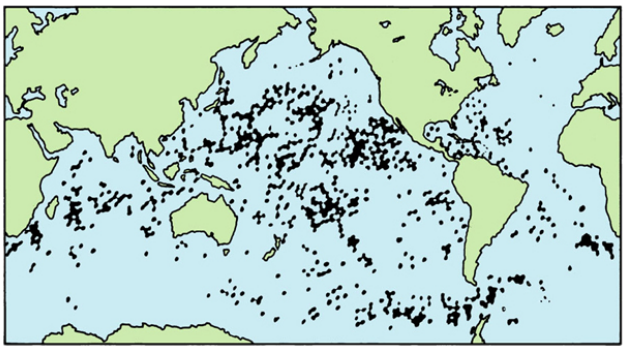
Ore Deposits

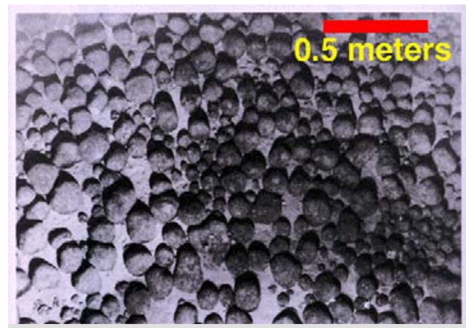
Sedimentary Deposits

Manganese Nodules: potato-size (25% Manganese, 15% Iron, 2% Nickel, 2% Copper).

Chemistry of seawater in some places promotes the deposition of Mn-oxide nodules.

Mining companies have begun to explore technologies to exploit these deposits as they 720 years worth of Cu and 60,000 years of Mn (at current rates of composition).





Manganese nodules grow slowly on the sea floor and are rich in MnO_2 and trace elements.

Distribution of Mineral Resources

Residual Mineral Deposits

Deep chemical weathering of rock in hot, humid, tropical climates promotes mineral enrichment through leaching – insoluble residue left behind.

Lateritic soils = rich in iron. If iron is low, the mineral **Bauxite** forms, the principle Al mineral.

Secondary enrichment can occur by water moving through, for example, a disseminated sulfide deposit – moves a submarginal grade deposit to an economic one.

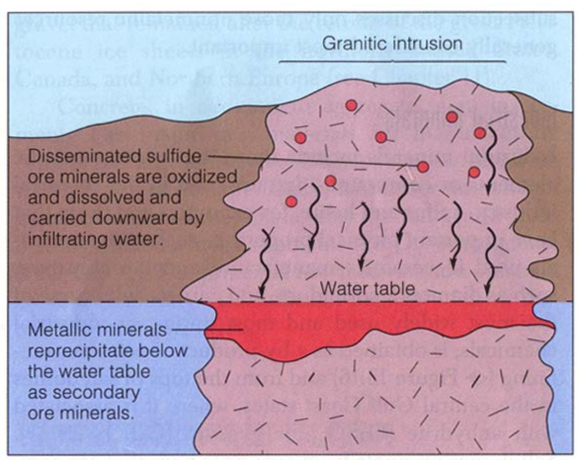
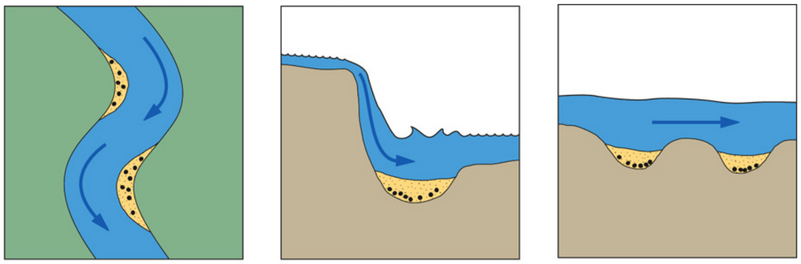


FIGURE 13.14 The development of ores by secondary enrichment. Descending ground water oxidizes and dissolves soluble sulfide minerals, carrying them downward and leaving a brightly colored residue of limonite and hematite. Below the water table new metallic minerals are precipitated as secondary ore minerals.

Ore Deposits

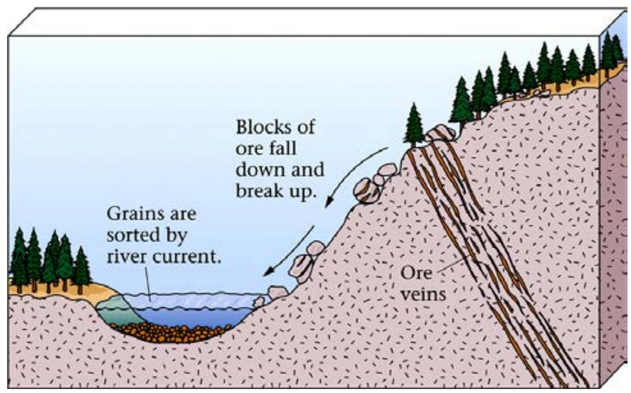
Placer Deposits (Hydraulic Sorting)



A Map view B Side view C Side view

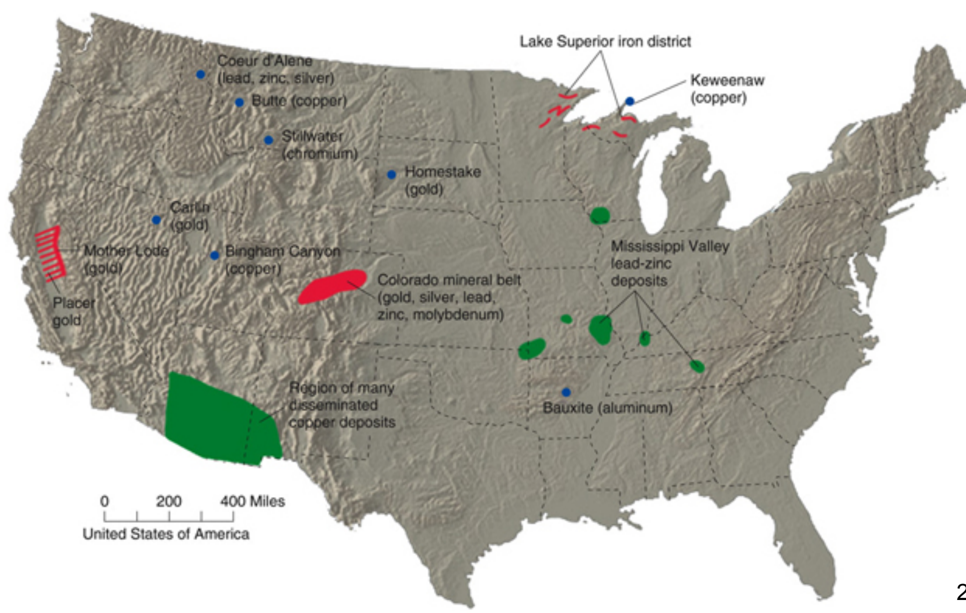
Concentration of heavy minerals in regions of low flow.

Gold panners are looking for placer gold.



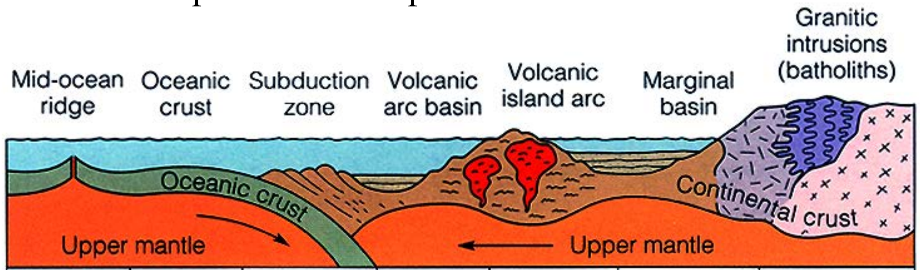
Ore Deposits

Sedimentary & residual deposits are found in shield areas of continents. Bauxite forms on granite that has experienced major leaching in tropical areas.



Distribution of Mineral Resources

Ore deposits associated with igneous rocks are associated with plate boundaries or hot spots – tectonic processes are the dominant control.



	Mid-ocean ridge	Oceanic crust	Subduction zone	Volcanic arc basin	Volcanic island arc	Marginal basin	Granitic intrusions (batholiths)
Metals	Copper and zinc as metallic oxides and sulfides	Manganese, cobalt, nickel	Chromium	Copper, lead, zinc	Copper, molybdenum, gold, silver, lead, mercury, tin	Copper, zinc, gold, chromium (petroleum)	Copper, tungsten, tin, iron (Kiruna type), gold, silver, molybdenum
Deposit type	Volcanogenic massive sulfide	Sea-floor nodules	Chromite in serpentine rock (high-pressure, low-temp., metamorphic)	Stratabound	Porphyry copper; hydrothermal veins	Volcanogenic massive sulfide; evaporites	Contact-metamorphic; hydrothermal veins

Igneous and hydrothermal activity occur at tectonic plate boundaries, along rifts, and at hot spots. These are the places where most mineral resources form. Tectonic effects are then overprinted by the influence of the hydrologic cycle.

Methods of Mineral Exploration

Copper Staining

Originally, exploration entailed looking for a "***show***" of minerals in a hillside, cliff-face, etc. This "show" would include quartz veins or oxidative staining that included the element(s) of interest.

The rock was then ***assayed*** (analyzed) to see what the concentration of the element of interest was.

A claim could be "***staked***" by simply staking off the area.

These days, laws are more stringent and exploration techniques are more sophisticated.

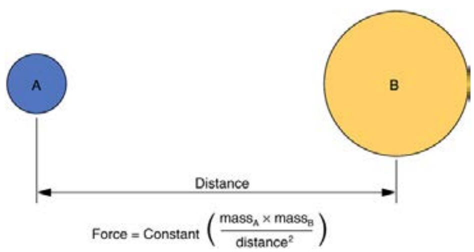
Methods of Mineral Exploration

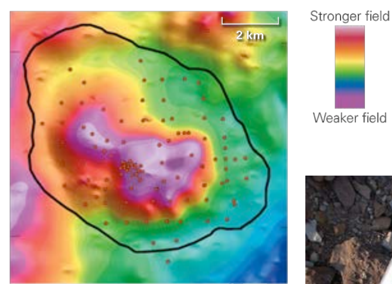
Geophysics: gravity, magnetism. Also radioactivity.

GRAVITY

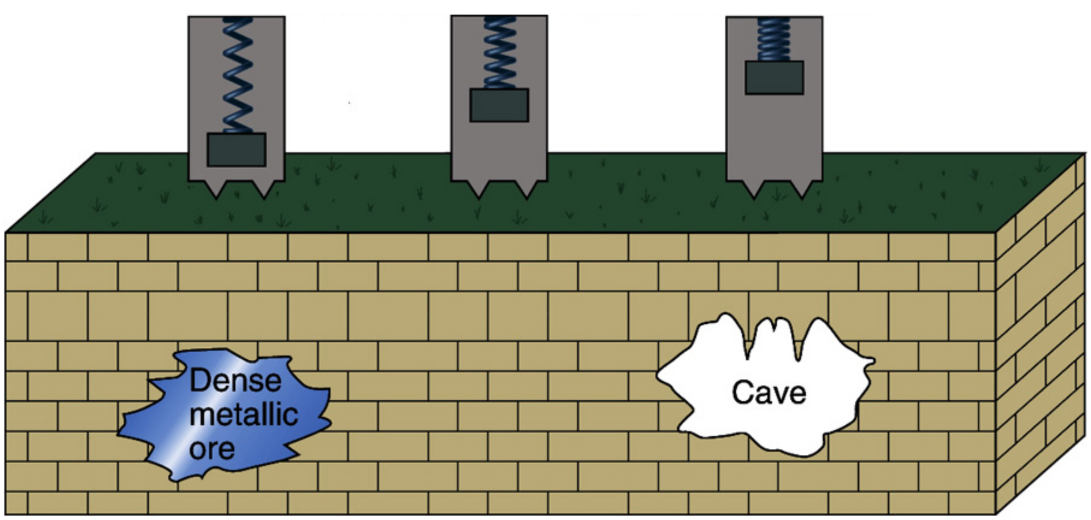
Force of gravity increases between 2 objects with an increase in mass of either one.

Use a gravity meter to explore local variations in rock density: (mass = density x volume).





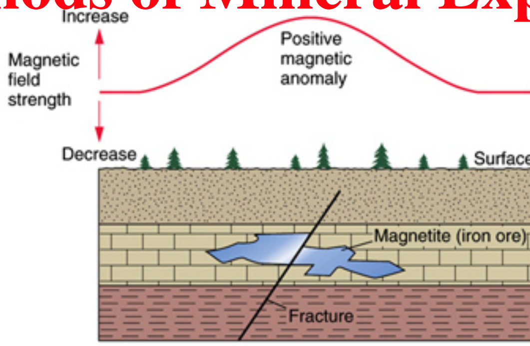
Methods of Mineral Exploration



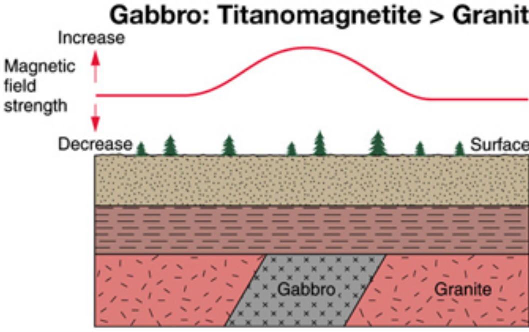
Dense rock = metal ores – used in exploration.

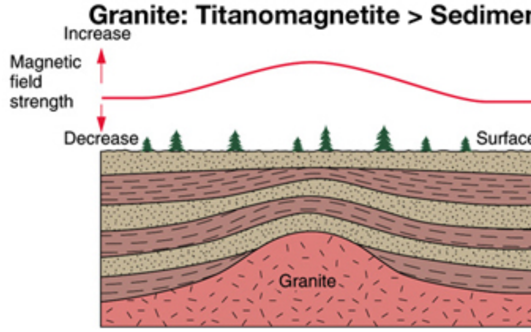
Less dense = cavities or sediment (i.e., salt domes) – used in oil exploration.

Methods of Mineral Exploration



Magnetic Field

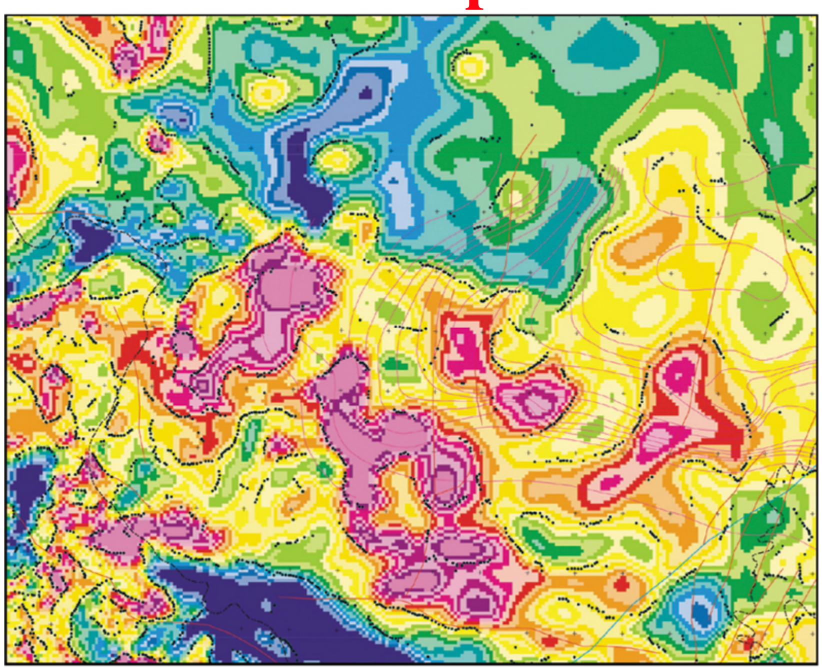




Positive Magnetic Anomaly: magnetic field strength above the average – vice versa for a negative anomaly.

Methods of Mineral Exploration

Reddish areas are positive anomalies; Bluish areas are negative anomalies.



Magnetic Anomaly Map

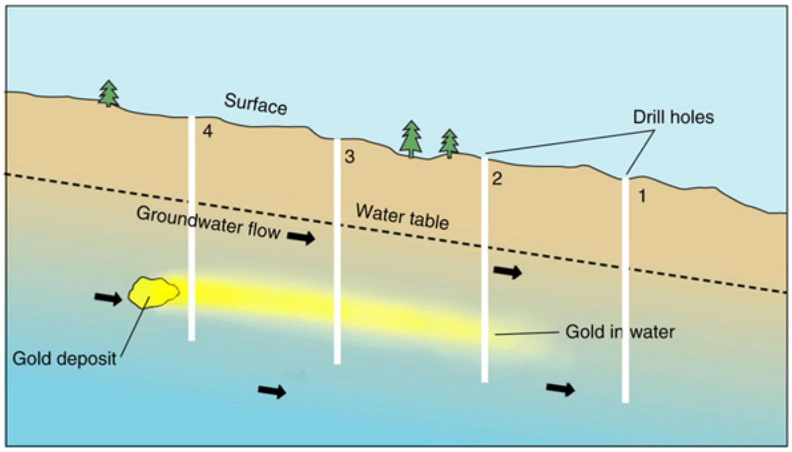
Methods of Mineral Exploration

Geochemical prospecting – looking at concentrations of metals in the weathered rock (soil) over a wide area.

Plants can also be analyzed.

Even soil gases and groundwater can be used.

Groundwater Sampling for Mineral Exploration



Ore Exploration and Production

Core drilling helps determine the extent of an ore deposit.

Mining

The type of mining depends on the proximity of the ore body to the surface.

Surface Mining

Most suitable for large ore bodies and for low grade, disseminated ore bodies.

Usually ore bodies are mined by a combination of surface and underground methods.

Initial mining is by surface methods, but as mining deepens, the amount of waste to be removed increases - soon economical to go underground.

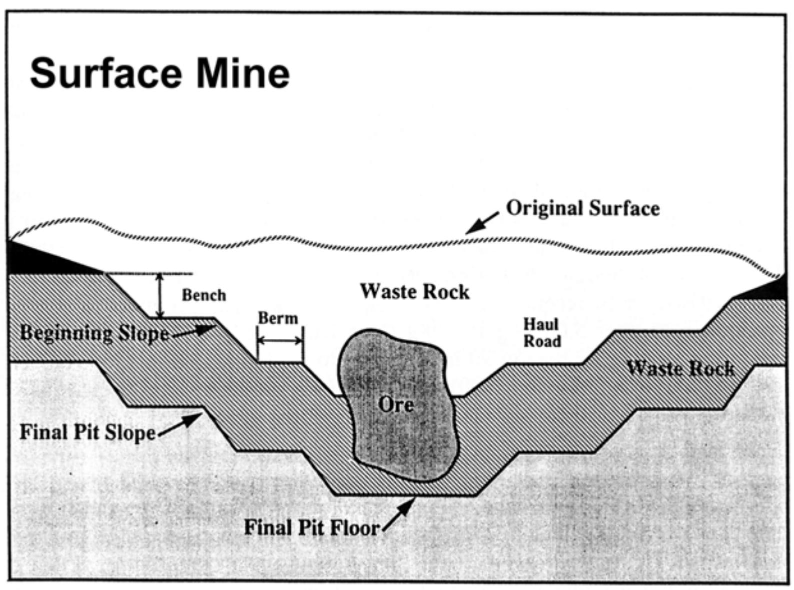
Surface mining requires huge amounts of material to be removed – highly mechanized.

Mining

Surface Mining (cont.)

Two types: ***open pit*** (massive ore bodies) & ***strip mining*** (bedded ore bodies).

Open Pit – waste continues to be stripped off during operation. Widen the area to ensure slope stability as pit deepens.

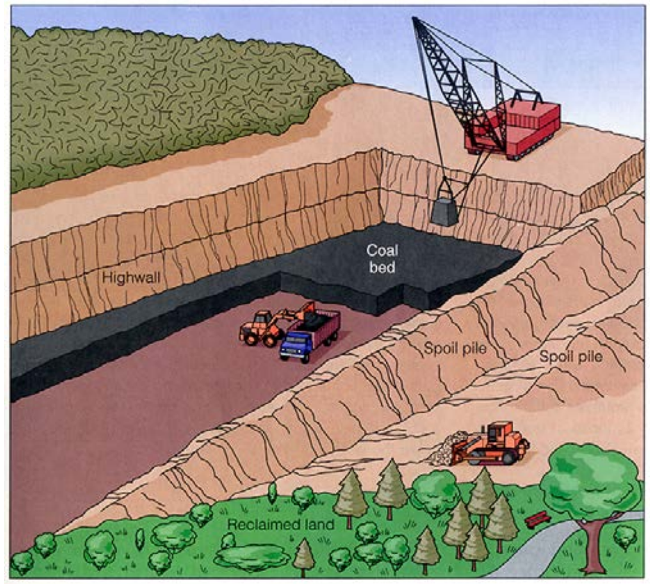


Mining

Surface Mining (cont.)

Strip Mining – overburden is stripped off (dumped as **spoil banks** or **spoil piles**), the ore removed, and waste replaces it in a cyclic manner.

The waste fraction is almost constant throughout mine operation.

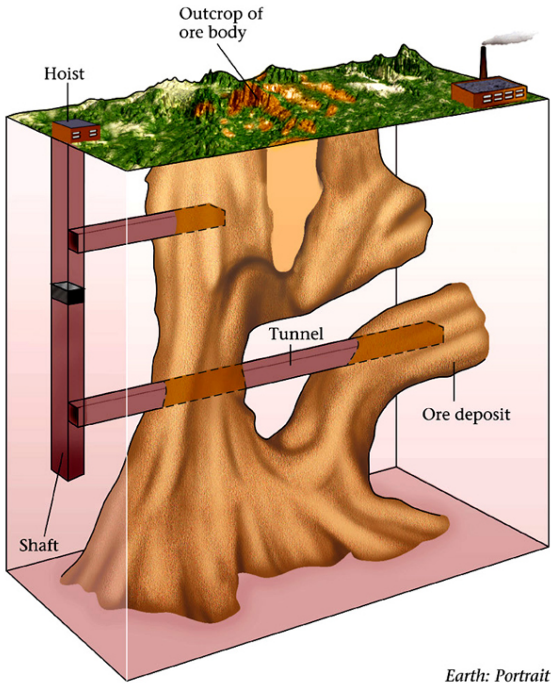


Bingham Canyon, Utah Open-Pit Mine

Surface Mining

Mining

Underground Mining



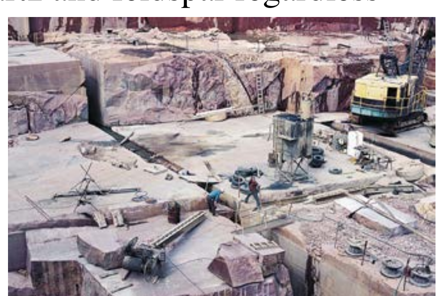
Earth: Portrait

Adit = horizontal entry;
Shaft = vertical entry.

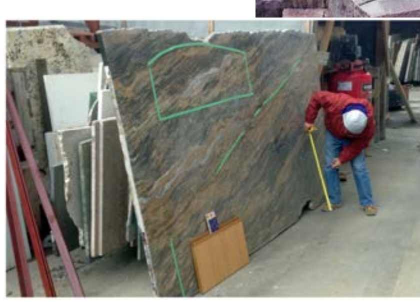
Deepest mine = 3.5 km;
Temp. ~55˚C!
Columns of material left for roof support.
Rock bursts = rock falls due to pressure.

Nonmetallic Mineral Resources

Architects and Geologists have a similar, but different language:
Architects "Stone" = Geologists "Rock";
Architects "Marble": Any polished carbonate rock;
Architects "Granite": Any rock containing quartz and feldspar regardless of whether it is igneous or metamorphic.



Dimension Stone: intact slabs/blocks of rock.
A "Quarry" provides "stone", whereas a "Mine" provides "ore".
Split vertically with wedges, split horizontally with wireline saw, thermal lance (blow torch), or high pressure water jet.



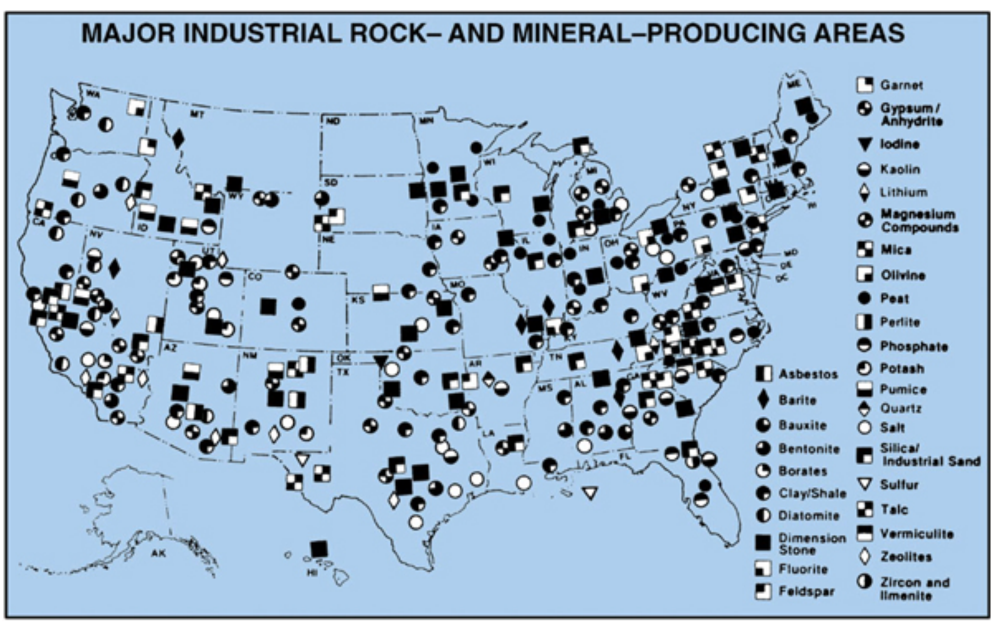
Nonmetallic Rock and Mineral Resources

TABLE 15.2 Common Nonmetallic Resources

Limestone	Sedimentary rock made of calcite; used for gravel or cement
Crushed stone	Any variety of coherent rock (limestone, quartzite, granite, gneiss)
Siltstone	Beds of sedimentary rock; used to make flagstone
Granite	Coarse igneous rock; used for dimension stone
Marble	Metamorphosed limestone; used for dimension stone
Slate	Metamorphosed shale; used for roofing shingles
Gypsum	A sulfate salt precipitated from salt water; used for wallboard
Phosphate	From the mineral apatite; used for fertilizer
Pumice	Frothy volcanic rock; used to decorate gardens and paths
Clay	Very fine mica-like mineral in sediment; used to make bricks or pottery
Sand	From sandstone, beaches, or riverbeds; quartz sand is used for construction and for making glass
Salt	From the mineral halite, formed by evaporating saltwater; used for food seasoning, and for melting ice on roads
Sulfur	Occurs either as native sulfur, typically above salt domes, or in sulfide minerals; used for fertilizer and chemicals

Nonmetallic Mineral Resources

Activities in the U.S.



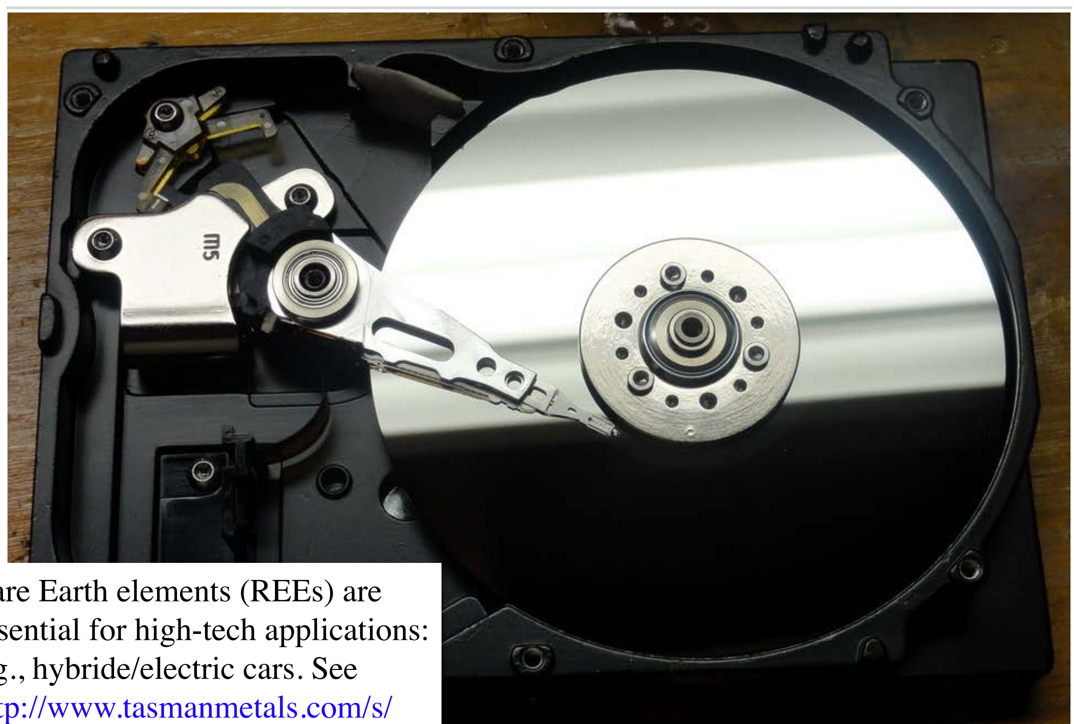
Nonmetallic Mineral Resources

Crushed Stone & Concrete

Crushed Stone: substrate for roads and railways, raw material for manufacturing cement, asphalt, etc.
Quarried by blasting and crushing.

Mortar: substance that holds bricks together.
Concrete: substance used for roads, walls, etc.
Both contain **Cement**: ~66% lime (CaO); ~25% silica (SiO_2), ~9% Al_2O_3 and Fe_2O_3 **(from clay or shale)**.
The ideal limestone contains these elements in those proportions. This is from the Jurassic Portland Limestone from England. Cement is now predominantly made by mixing limestone, clay, and quartz **(sand)** in the right proportions.
These are then heated in a kiln to ~1,450˚C, which releases CO_2 and produces “clinker”. This is crushed to give cement.

Nonmetallic Mineral Resources



Rare Earth elements (REEs) are essential for high-tech applications: e.g., hybride/electric cars. See http://www.tasmanmetals.com/s/Applications.asp

In the Home

Bricks (clay);
Cement;
Porcelain;
Crockery;
Glass (silica);
Drywall (gypsum);
Salt;
Cutlery (steel);
Cookware;
Countertops;
Electrical Wire;
Appliances….

What Else???

Per Capita Annual Usage

4,100 kg	Stone
3,860 kg	Sand & Gravel
3,050 kg	Petroleum
2,650 kg	Coal
1,900 kg	Natural Gas
550 kg	Iron & Steel
360 kg	Cement
220 kg	Clay
200 kg	Salt
140 kg	Phosphate
25 kg	Aluminium
10 kg	Copper
6 kg	Lead
5 kg	Zinc

Mineral/Rock Resources are Finite

Lifetime (years) of Known Ore Resources

Metal	**World Resource**	**U.S. Resources**
Iron	120	40
Aluminium	330	2
Copper	65	40
Lead	20	40
Zinc	30	25
Gold	30	20
Platinum	45	1
Nickel	75	<1
Cobalt	50	<1
Manganese	70	0
Chromium	75	0

Strategic Metals: Mn (100%); Pt (92%); Cr (73%); Co (95%).

Percentages = amount needed to be imported annually.

Needed for national security but not produced by host country.

Environmental Effects

1) Waste dumps - leaching and landslides

2) Subsidence/Earthquakes

3) Acid mine drainage

4) Pollution

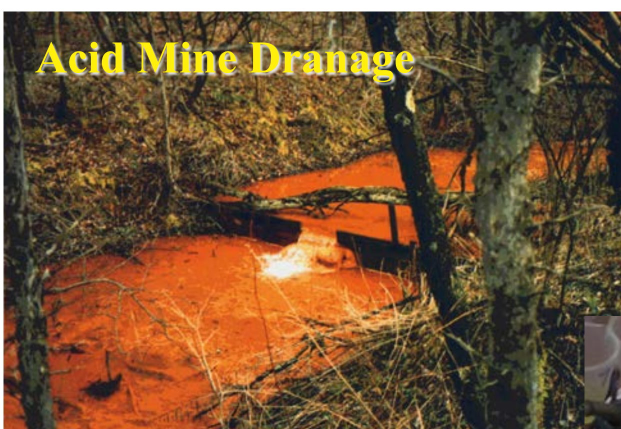
Mining & The Environment

Environmental Impacts of Mining

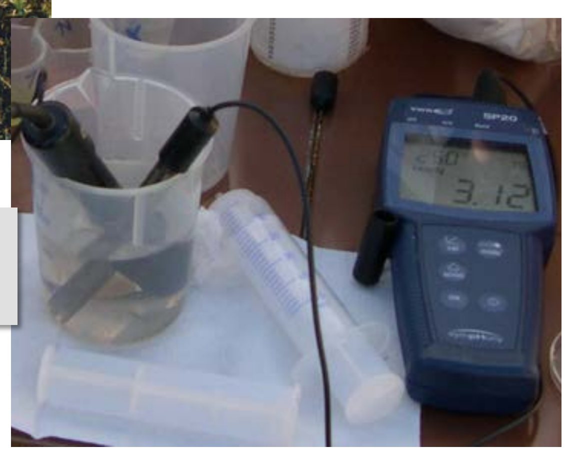
Mining creates huge volumes of waste tailings.

Copper mine spoil, Bisbee, Arizona.

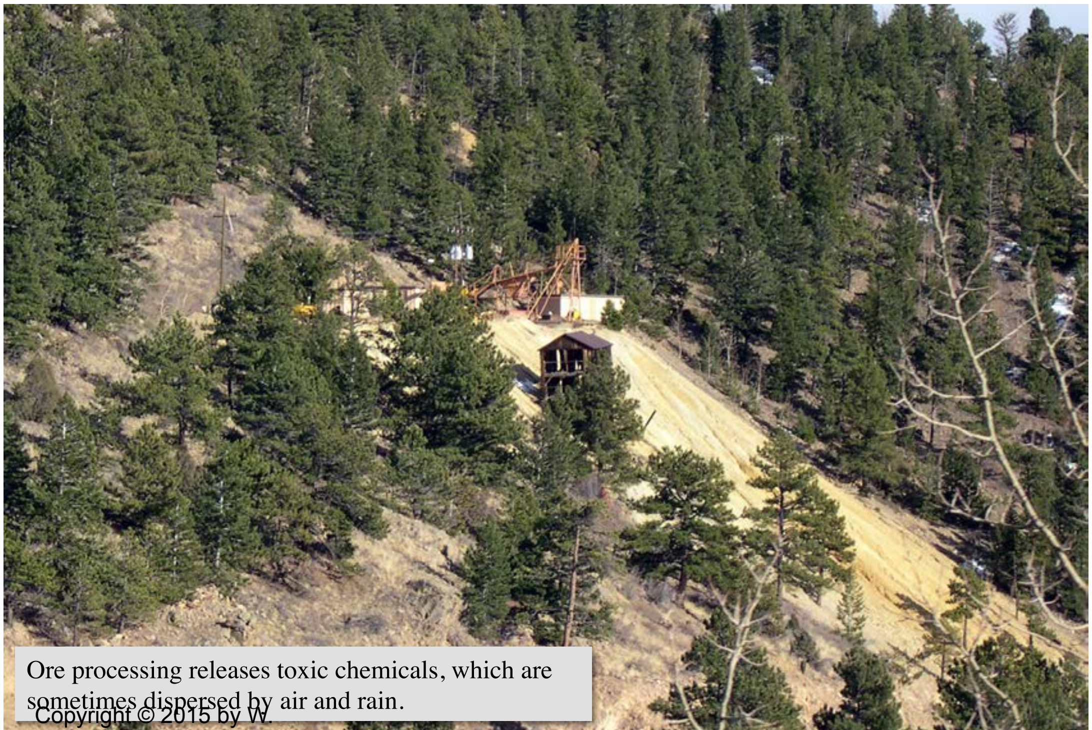
Environmental Impacts of Mining



Sulfides react with water and O_2 to form sulfuric acid (H_2SO_4).



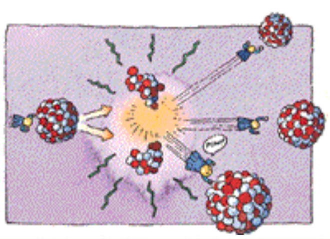
Environmental Impacts of Mining

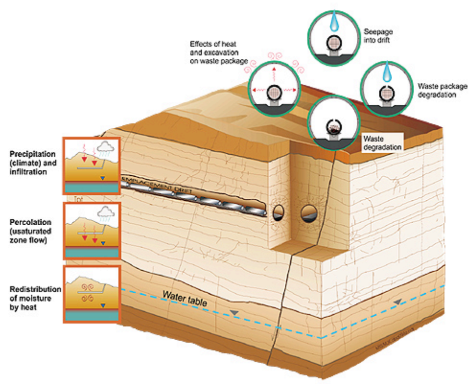


Ore processing releases toxic chemicals, which are sometimes dispersed by air and rain.

Environmental Effects

Nuclear Waste





Schematic cross-section of Yucca Mountain and depiction of processes that are important to repository performance

Cutaway showing artist's concept of the complex of underground tunnels into which waste would be emplaced. A repository at Yucca Mountain would rely on the semiarid climate, natural barriers, and engineered barriers to contain and isolate waste for thousands of years.

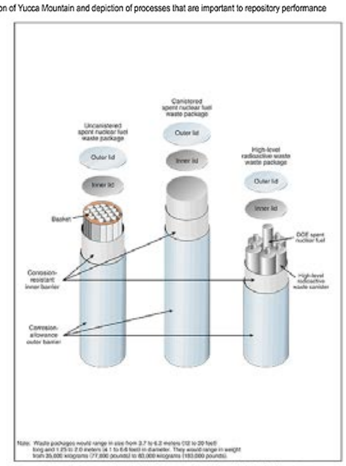
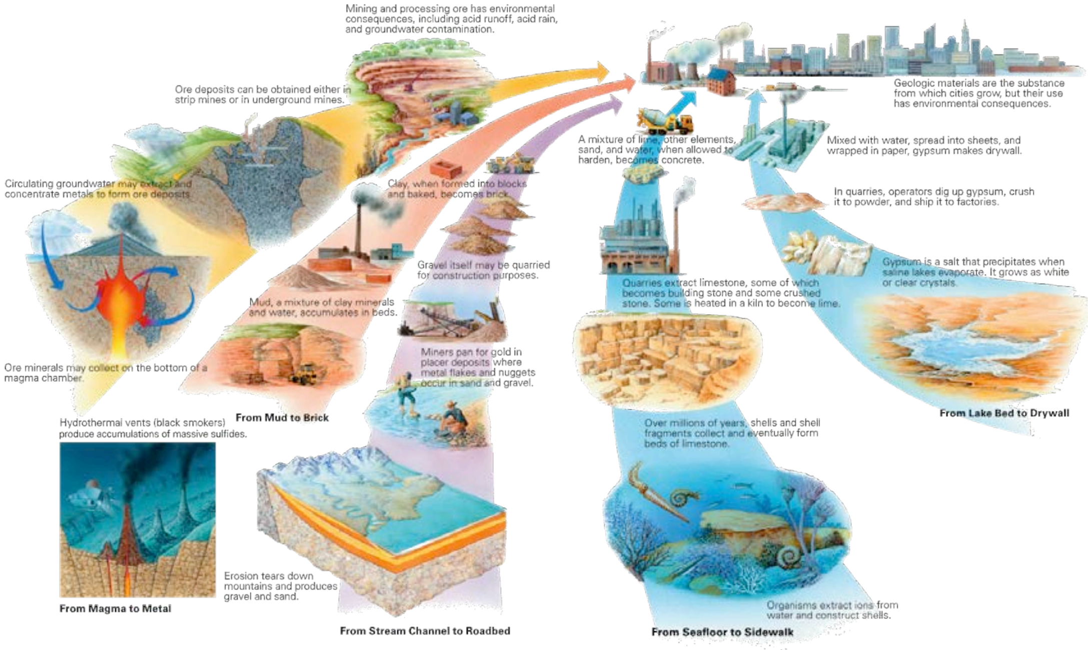


Figure 5-5. Potential waste package designs for spent nuclear fuel and high-level radioactive waste.

Summary



Summary

Resources & Reserves.

Mineral Deposits: Metallic, Nonmetallic.

Metallic Deposits: Native Metals; Smelting; Slag.

Ore Deposits: Ore; Grade; Gangue; Magmatic Deposits; Hydrothermal Deposits (Massive Sulfide, Vein, Porphyry Copper, Disseminated, Black Smoker); Secondary (Supergene) Enrichment Deposits; Mississippi-Valley-Type Deposits; Sedimentary Deposits (BIFs, Evaporite, Mn-Nodules); Residual Mineral Deposits; Placer Deposits.

Distribution of Ore Deposits.

Mineral Exploration: Show, Staining, Veins; Gravity; Magnetism; Groundwater.

Mining: Open Pit, Strip, Underground (adit, shaft).

NonMetallic Resources: Architects vs. Geologists; Dimension Stone; Crushed Stone; Concrete (Mortar, Cement).

Mining and The Environment: Subsidence; Waste Dumps; Acid Mine Drainage; Nuclear Waste.