Major Categories of Mineral Resources

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

**Nonmetallic**
- Sand and gravel
- Gypsum
- Halite
- Dimension stone
Resources and Reserves

**Resources**: Total discovered and undiscovered.

**Reserves**: Discovered, surveyed, and economically recoverable.

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**Main Subdivisions**

**Metallic Resources**:
- Gold, Silver, Copper, Lead, Zinc, Iron, Aluminium

**Non-metallic Resources**:
- Sand, Gravel, Gypsum, Halite, Dimension stone

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**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.

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.
What is an Ore?

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”.

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 within the pre-existing rock.

Hydrothermal copper deposits are often found in porphyritic igneous rocks; these are Porphyry Copper 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): $\text{Fe}^{2+}$ is soluble in water, but $\text{Fe}^{3+}$ is not. These are found in the Proterozoic, contain Hematite ($\text{Fe}_2\text{O}_3$) and Magnetite ($\text{Fe}_3\text{O}_4$) 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).

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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.
Ore Deposits

Placer Deposits (Hydraulic Sorting)

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.

Methods of Mineral Exploration

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 \times volume).

Dense rock = metal ores – used in exploration.

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

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.

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**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.

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**Surface Mine**

- Original Surface
- Waste Rock
- Ores
- Haul Road
- Final Pit Floor
- Final Pit Slope
- Beginning Slope
- Bench

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**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.

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**Bingham Canyon, Utah Open-Pit Mine**

**Surface Mining**

**Tailings Around Bingham Canyon**

*Spoil piles*
Mining

Underground Mining

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

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

**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 (SiO₂), ~9% Al₂O₃ and Fe₂O₃ (*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 CO₂ 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](http://www.tasmanmetals.com/s/Applications.asp)
In the Home

<table>
<thead>
<tr>
<th>Material</th>
<th>Per Capita Annual Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bricks</td>
<td>4,100 kg Stone</td>
</tr>
<tr>
<td>Cement</td>
<td>3,860 kg Sand &amp; Gravel</td>
</tr>
<tr>
<td>Porcelain</td>
<td>3,050 kg Petroleum</td>
</tr>
<tr>
<td>Crockery</td>
<td>2,650 kg Coal</td>
</tr>
<tr>
<td>Glass</td>
<td>1,900 kg Natural Gas</td>
</tr>
<tr>
<td>Drywall</td>
<td>550 kg Iron &amp; Steel</td>
</tr>
<tr>
<td>Salt</td>
<td>360 kg Cement</td>
</tr>
<tr>
<td>Cutlery</td>
<td>220 kg Clay</td>
</tr>
<tr>
<td>Cookware</td>
<td>200 kg Salt</td>
</tr>
<tr>
<td>Countertops</td>
<td>140 kg Phosphate</td>
</tr>
<tr>
<td>Electrical Wire</td>
<td>25 kg Aluminium</td>
</tr>
<tr>
<td>Appliances</td>
<td>10 kg Copper</td>
</tr>
<tr>
<td></td>
<td>6 kg Lead</td>
</tr>
<tr>
<td></td>
<td>5 kg Zinc</td>
</tr>
</tbody>
</table>

What Else???

Mineral/Rock Resources are Finite

Lifetime (years) of Known Ore Resources

<table>
<thead>
<tr>
<th>Metal</th>
<th>World Resource</th>
<th>U.S. Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron</td>
<td>120</td>
<td>40</td>
</tr>
<tr>
<td>Aluminium</td>
<td>330</td>
<td>2</td>
</tr>
<tr>
<td>Copper</td>
<td>65</td>
<td>40</td>
</tr>
<tr>
<td>Lead</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>Zinc</td>
<td>30</td>
<td>25</td>
</tr>
<tr>
<td>Gold</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>Platinum</td>
<td>45</td>
<td>1</td>
</tr>
<tr>
<td>Nickel</td>
<td>75</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Cobalt</td>
<td>50</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Manganese</td>
<td>70</td>
<td>0</td>
</tr>
<tr>
<td>Chromium</td>
<td>75</td>
<td>0</td>
</tr>
</tbody>
</table>

**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 spoils, Bisbee, Arizona.

Environmental Impacts of Mining

Acid Mine Drainage

Sulfides react with water and O₂ to form sulfuric acid (H₂SO₄).
Ore processing releases toxic chemicals, which are sometimes dispersed by air and rain.

Environmental Effects

Nuclear Waste

Yucca Mtn

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