Motor, wheels- Aluminum
Body- Iron + Chromium (steel)
Windows, lights- Silica glass
Battery- Lead
Wiring- Copper
Tires, plastic parts- Petroleum
Paint- Various minerals
Fuel- Petroleum

Where does this material come from?

- Geologic Resources
  - Metals
  - Nonmetals
  - Energy

- These are all Nonrenewable!
Resources
- Total amount of geologic material in all deposits known and unknown
- Difficult to estimate
- fixed amount from year to year

Reserves
- Subset of resources
- Discovered deposits extracted economically and legally
- Constantly changing amounts
  - Economic changes
  - Changes in laws: trade, protected land, etc.

Metals and Ores
- Average continental crust
  - Si + O + minor amts of others
  - Concentrations of lead, iron, copper, etc. very low

- Natural processes concentrate metals into ore
  - Rock that contains sufficient concentration of a metal to make extraction economically feasible
### Table 21.2 Common Ore Minerals

<table>
<thead>
<tr>
<th>Metal</th>
<th>Ore Mineral</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>Bauxite (a mineral mixture)</td>
<td>Al₂O₃·nH₂O</td>
</tr>
<tr>
<td>Chromium</td>
<td>Chromite</td>
<td>FeCr₂O₄</td>
</tr>
<tr>
<td>Copper</td>
<td>Native copper</td>
<td>Cu</td>
</tr>
<tr>
<td></td>
<td>Chalcolite</td>
<td>Cu₂S</td>
</tr>
<tr>
<td>Gold</td>
<td>Native gold</td>
<td>Au</td>
</tr>
<tr>
<td>Iron</td>
<td>Hematite</td>
<td>Fe₃O₄</td>
</tr>
<tr>
<td></td>
<td>Magnetite</td>
<td>Fe₃O₄</td>
</tr>
<tr>
<td>Lead</td>
<td>Galena</td>
<td>PbS</td>
</tr>
<tr>
<td>Manganese</td>
<td>Pyrolusite</td>
<td>MnO₂</td>
</tr>
<tr>
<td>Mercury</td>
<td>Cinnabar</td>
<td>HgS</td>
</tr>
<tr>
<td>Nickel</td>
<td>Pentlandite</td>
<td>(Fe, Ni)S</td>
</tr>
<tr>
<td>Silver</td>
<td>Native silver</td>
<td>Ag</td>
</tr>
<tr>
<td></td>
<td>Argentite</td>
<td>Ag₃S</td>
</tr>
<tr>
<td>Tin</td>
<td>Cassiterite</td>
<td>SnO₂</td>
</tr>
<tr>
<td>Uranium</td>
<td>Pitchblende</td>
<td>U₃O₈</td>
</tr>
<tr>
<td>Zinc</td>
<td>Sphalerite</td>
<td>K(UO₂)₃(VO₄)₂·3H₂O</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ZnS</td>
</tr>
</tbody>
</table>

### Table 21.3 Some Ways Ore Deposits Form

<table>
<thead>
<tr>
<th>Type of Ore Deposit</th>
<th>Some Metals Found in This Type of Ore Deposit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crystal settling within cooling magma</td>
<td>Chromium, platinum, iron</td>
</tr>
<tr>
<td>Hydrothermal deposits (contact metamorphism, hydrothermal veins, disseminated deposits, hot-spring deposits)</td>
<td>Copper, lead, zinc, gold, silver, iron, molybdenum, tungsten, tin, mercury, cobalt</td>
</tr>
<tr>
<td>Pegmatites</td>
<td>Lithium, rare metals iron, manganese, copper</td>
</tr>
<tr>
<td>Chemical precipitation as sediment</td>
<td>Gold, tin, platinum, titanium</td>
</tr>
<tr>
<td>Placer deposits</td>
<td>Aluminum, nickel, copper, silver, uranium, iron, manganese, lead, tin, mercury</td>
</tr>
<tr>
<td>Concentration by weathering and ground water</td>
<td></td>
</tr>
</tbody>
</table>

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Origin of Metallic Ore Deposits

- **Hydrothermal Processes**
  - Porphyry Copper deposits
  - Mississippi Valley Type lead-zinc deposits

- **Surface Processes**
  - Iron ore in banded iron formations (BIFs)
  - Aluminum ore in bauxite deposits
  - Supergene copper deposits
- **Disseminated porphyry copper ore**
  - Associated with granitic plutons formed along a convergent margin
  - Open pit mining, smelting, electrolysis to produce Cu (Ag and Au)
  - Example: Chuquicamata, Chile. World's largest open-pit mine
- Pluton intrusion with hydrothermal alteration 32 Ma
- Ore grade 1.2% Cu
- 2,700,000,000 tons of Cu reserves
- 650,000 tons fine Cu produced/year
- 30% of Chile’s Cu output
- 6% of entire world Cu production
Mississippi Valley-Type lead-zinc ores

- Lead-Zinc ore minerals deposited within limestone and dolomite
- Important to Wisconsin's growth & history
  - French explorers learned of Pb from natives by 1650
  - SW Wisconsin attracted many Europeans 1820-1840
  - “Badger” holes to underground workings give us a mascot
  - 16 steamboats shipped ore & goods on Mississippi
  - Pb for Civil War bullets
  - Mining peaked during WWI
  - State mineral: Galena (PbS)
- **Formation of MVT lead zinc deposits**
  - Long thought to be magmatic-hydrothermal
    - But, no intrusive rocks were ever found associated with these deposits
  - Current model:
    - Deposition of galena (PbS), sphalerite (ZnS), and other ore minerals from salt-rich groundwater called brine that migrated hundreds of km
    - Brine heated to 200 °C as it passed through deeply buried strata and dissolved metallic elements from them
    - Maquoketa shale formed impermeable "lid" trapping fluid in Ordovician dolomite of the Galena and Platteville formations
    - As brine rose to shallow depths, it cooled, became over saturated in metals and precipitated the ores at ca. 150 °C in cavities
    - Brine migration 245 Ma in response to mountain building in Arkansas

- **Banded iron formations (BIF)**
  - Formed from sediments in shallow basins on all continents
  - Unique to Precambrian 2.0 to 1.5 Ga
  - No modern analogs
    - Reflects different surface conditions in Precambrian than today
    - *Iron rich solutions prior to rise of atmospheric oxygen to levels needed to oxidize iron into relatively insoluble hematite and magnetite?*
    - *Iron-reducing microbial activity prevents formation since 1.5 Ga?*
    - Exact process of formation still mysterious

- BIFs in Minnesota, Wisconsin, Michigan
  - One of greatest iron ore districts in world
- Concentration by weathering
  - Bauxite ore form main reserves of aluminum
  - Deep lateritic weathering of igneous rock
    - Iron, silica removed under wet hot tropical conditions leaving $\text{Al}_2\text{O}_3 \cdot n\text{H}_2\text{O}$ as a residue
Laterite Soil Develops in Wet Climates

*Think: Amazon River Basin!*

- Concentration by weathering
  - **Supergene** enrichment of disseminated copper ore
    - Copper leached to depth of water table
    - Leaves iron rich cap called “gossan”
    - Concentrated lens of chalcocite rich ore

![Diagram of laterite soil development](image)

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- Former grains of chalcopyrite weathered by ground water
- Iron-rich gossan
- Chalcocite grains
- Chalcopyrite grains
- Disseminated ore deposit
- Country rock
- Pluton

1 Kilometer