Issues to keep in mind for metals:

- abundance (multiple forms?), uses, recovery
- energy used to retrieve, environmental impacts, ease of recycling
- geologic processes of formation--insights for exploration & environmental understanding

Cycles: ore formation is just one of many related earth cycles of chemical+physical movement

Initial distribution and re-distribution of elements; elements “reside” in minerals. Minerals are the sources and sinks of all natural elements.

Processes that re-distribute elements: either collect/concentrate or re-disperse

Some ore depositional processes linked directly with formation of rock itself; other ore-forming processes are overprints on pre-existing rocks. Look at “rock cycle.”

Human use of materials (text Fig. 3.1; organizational chart)

Metals are important: uses and economics.

Metals: chemical and physical properties

about 35 metallic elements used widely, mostly as alloys (mixtures with new properties)

**steel** = iron +/- Ni, Cu, V, Cr, Mn, Mo, Co, C; **brass** = Cu+Zn; **bronze** = Cu+Sn; **solder** = Pb+Sn

Abundant metals:

Defined as those that have concentration > 0.1 wt.% in earth’s crust (Table 7.1):

- iron, aluminum, magnesium, manganese, silicon, titanium

Why “divide” metals by abundance: Large size and large # of deposits; form own minerals.

Ease of finding; how they occur (minerals, concentration)

Size of deposit vs. average crustal abundance; association with rock formation

How much concentration needed to mine? Concentration factors necessary.

What factors determine the concentration necessary for (economic) mining?
Ore minerals: “abundant” metal + ? Oxides, hydroxides, carbonates
For the more scarce metals, the ores often are sulfide minerals, rarely silicates

Iron, as an example of an abundant metal
3rd most abundant metal (Si, Al, Fe) in earth’s crust (5 wt.%); dominant metal in earth’s core
Iron >95% by weight of all metals consumed; much of rest are ferrous metals (Ni, Cr, Mo, W, V)

Why is iron the backbone of industry? Construction, transportation, machinery

Which minerals chosen as ores? Why?? Oxides, hydroxides, carbonates (Table 7.2).
Common iron minerals are FeS₂, Fe₃O₄, Fe₂O₃: pyrite, magnetite, hematite

Iron oxides (importance of different oxidation states: ore formation, environmental issues):
ferrous, Fe²⁺, fairly water soluble. Reducing conditions (dead organisms rotting)
ferric, Fe³⁺, relatively insoluble in water. Oxidizing conditions (open to the air)
hydroxide (OH): goethite, related to “rust” = FeO•OH. Other properties.

Igneous iron deposits: magnetite layers from settling out of crystals from cooling magma
Contact zones: very hot, watery (hydrothermal) fluids ooze/leak out from cooling magma

Sedimentary deposits: precipitates and residues.
Banded iron formation—supplies most of world’s iron; Great Lakes area. 2 billion yrs old.
Chemical precipitates. Record rise in oxygen in Earth’s early atm. Microbes?
laterites—strongly leached, tropical soils

Iron processing: smelting, steelmaking. Very long history. Wrought iron...specialty steels.
need 3000°F (1600°C) to melt iron-bearing rock. Slag is melted rock-waste.
steel: specific alloy. US no longer leader; inefficient smelters
need: iron ore, coal/coke (heated in absence of air), limestone

World resources of iron—couple hundred years or more
Heavily recycled--crushed cars, steel beams  
https://www.youtube.com/watch?v=-SFGEqOAGNI

**Aluminum, as an example of an abundant metal**  
20th century metal; 2nd most abundant metal in crust (8.3 wt.%)  
Lots of Al-rich, common minerals: feldspars, clays  
Very difficult (energetically) to free Al from the minerals that contain it. Hydroelectric power.  
Why use it: weighs ~1/3 of Cu or Fe; malleable, ductile, easily machined or cast, corrosion-resistant, excellent electrical conductor. (How is it resistant to corrosion?)  
50 lbs./year used by every American. 150 lbs. Al in average car.  
Packaging & containers, transportation, building, electrical, **durable goods**  
Al compounds: fillers (plastic, paper), fire retardants, *refractories*, grinding & polishing, synthetic rubies and sapphires ($\text{Al}_2\text{O}_3$)  
Al ore deposits are residues--left after almost everything else is leached out (like laterite). Ore rock of aluminum is called bauxite.  
Smelting is chemically complex and requires huge amounts of electricity to make molten bath  
Thus, Al smelters are in Norway, Canada, US, whereas Al deposits in tropics. Typically use hydroelectric power.  
This cost makes recycling very profitable. Only use 5% as much energy as raw ore does. What controls the recyclability of a material: cost benefits, complexity of material,...  
Environmental concerns: open-pit mining (in tropical areas), fluorine release (weakens bones) during the smelting process.  

**Economic and Environmental Concerns for Abundant Metals**  
How much of the element is left to mine? Where are major deposits located--which countries? Are the deposits concentrated in areas that are particularly sensitive ecologically or environmentally? New ideas about pre-mining evaluations.
How much energy does it take to process the raw materials using standard technology?

What kinds of and how much waste are generated by this processing? How disposed of?

What improvements in technology lie on the horizon?

What is the outlook for continued usage of the metal? Are there substitutes? Are there other reasons why the metal’s use could decline (change in industry, environmental concerns)?

**Changes can be made to Respond to Concerns**

Titanium as an example

In the chlorination process, chloride wastes typically were “disposed of.” Now, they are recycled.

There is a new TiO$_2$-producing technology that has been developed, which eliminates the need for harsh chemical treatment.

“De-materialization”: cell phones vs. land lines; low-power energy generation without need for batteries; plastics instead of metals.

How easy (how much energy, how much use of chemicals, how labor-intensive, how hazardous to health) is it to **recycle metals** from the materials/alloys/compounds in which we currently use them?