CHAPTER 2

COPPER: SOURCES AND SUPPLY

2.1. Physical properties and chemistry

Copper has atomic number 29, belongs to the same group (1B) as silver and gold, and shares some of their properties, including color, high electrical and thermal conductivity, high ductility (making it easy to draw into wire) and high malleability. Copper is second only to silver in electrical and thermal conductivity, and is significantly better than the third and fourth highest metals in both categories (gold and aluminum, respectively). Copper is also relatively corrosion resistant, although it does oxidize slowly in air. It has a high melting point (1083°C), with specific heat of 0.39 kJ/kg per degree C, and its melting heat is 343 kJ/kg, whence the theoretical heat requirement for melting pure copper is less than for competing metals such as iron and aluminum. It has a very high boiling point (2595°C) and has a very low tendency to fume, as compared to other non-ferrous metals such as arsenic, cadmium, lead, and zinc.

Pure copper is very ductile, as mentioned, and consequently it is easy to draw into wire. However the wire from pure copper is not very strong. Unfortunately, most alloying elements significantly reduce conductivity. Adding 10 percent aluminum doubles the strength but cuts electrical conductivity by over 80 percent. On the other hand, adding 0.8 percent cadmium significantly increases the strength and hardness of copper, while cutting conductivity only 10 percent (Henstock undated). This use accounts for 1–2 percent of cadmium consumption at present (See also the section on cadmium in Chapter 4).

Copper has several valence states, ranging from 0 to +3. Pure copper Cu(0) is very stable. It oxidizes at first to Cu(1)O (cuprite), which is black and unstable. On heating, the cuprite oxidizes to normal cupric oxide, Cu(II)O which is quite stable and insoluble. Some other salts of Cu(II), notably the sulfate, CuSO₄, are extremely soluble (See Table 1.1 for a list of copper ores).

The attractive blue-green patina on exposed copper surfaces consists of several compounds, depending on the surroundings. For example in coastal and marine environments where there is salt in the air, the chloride Cu₃(OH)₂Cl is likely to be formed. Where there is sulfur in the air, on the other hand, the sulfate Cu₅(OH)₆SO₄·H₂O (posnjakite) will be formed after some years the latter tends to evolve to Cu₅(OH)₆SO₄ (brochantite). The latter compounds are relatively insoluble, but not totally so. Also, they can be washed off an exposed surface, over time, by wind or flowing water.
Copper is quite biologically active. This is due to its tendency to form strong complexes in water or soil with organic ligands containing nitrogen or sulfur. It also forms complexes with some large macromolecules (proteins, nucleotides, etc.) The tendency of divalent copper ions to form complexes with organic substances accounts for the fact that in natural waters only a very small fraction (typically less than 1 percent) of the copper is found in free ionic or hydrated form (Landner and Lindeström 1999, p. 19). The rest is normally complexed with hydroxyl (OH) ions or carbonate (CO$_3^{2-}$) ions. The distribution of copper in fresh water depends on the pH and alkalinity of the water. Other inorganic ligands such as hydrogen sulfide (HS$^-$), phosphate (PO$_4^{3-}$), chloride (Cl$^-$) and ammonia (NH$_3$) can also play a role. However organic ligands such as humic acids, amino acids, polysaccharides and polyphenols tend to dominate in both freshwater and marine environments, with 75–99 percent of all copper bound in organic complexes (Flemming and Trevors 1989). Humic acid-copper complexes, in particular, tend to be very stable.

Another important chemical mechanism governing the fate of copper in natural systems is precipitation, primarily as hydroxides or sulfides. (Two of the major copper ores, malachite and azurite, are precipitated hydroxides; the rest are primarily precipitated sulfides.) Conditions for precipitation depend on dissolved oxygen level, pH, and alkalinity.

The final chemical mechanism involved in determining the fate of copper in the environment is sorption. Copper is adsorbed on both inorganic particles (such as clays) and organic colloidal materials, including living or dead cells. Again, the organic materials tend to be preferred. Moreover, copper tends to out-compete most other divalent metal ions in finding absorption sites on humic particulates (Flemming and Trevors 1989). In soils it has been shown that up to 98 percent of the copper is bound to the organic fraction (Thornton 1983).

Trace levels of copper are essential to all living organisms. However, copper is also quite toxic at high exposure levels. An important consideration is that only soluble copper is bio-available. Copper complexed with organic matter, or copper oxides and other insoluble compounds are not accessible to living organisms. For this reason, the total amount of copper in a water body is not a measure of potential hazard to biological organisms. Even the soluble fraction is only bio-available under restricted conditions as to pH, dissolved organic carbon (DOC), dissolved carbon dioxide, hardness and salinity. A more detailed discussion of this issue can be found in Appendix B.

### 2.2. Copper production

By 1950 global output of primary copper had reached 2.7 million metric tons (MMT). In 1998 it was 12.3 MMT, up from 8.96 MMT in 1990. Trends in