before work is undertaken: to avoid excessive time being spent on trivial material; to avoid loss of perhaps unexpected information; and to avoid endangering the existence or stability of the coin. Such aims require collaboration (section 1.3); it is essential that maximum information concerning the interest of a particular coin in the fields both of numismatics and of archaeology, the expected composition and legend of the coin, and the cleaning techniques are pooled. Skilled mechanical cleaning often assisted by judicial use of chemicals under a microscope to soften hard, overlying copper(II) encrustations may reveal dislodged silvering (plate 5.21a), decayed lacquer, etc., and the original surface within a cuprite layer. Heavy-handed use of brushes, excessively strong chemicals, or lack of numismatic awareness all lead to disaster. This controversial subject is more fully discussed in the proceedings of a *symposium held in 1980.*[71]

5.5.5 Deterioration after excavation

Upon excavation it seems that many patinated and crusted copper/copper alloys are stable, with corrosion of any remaining metal only occurring at an RH greater than 80 per cent. This figure is lower in polluted air, especially if contaminated by chlorides. In marine artefacts, corrosion by chlorides is particularly noticeable locally where these are trapped in calcareous and ferrous concretions. However, if nantokite (CuCl) is present within any patina or crust, an extremely destructive type of decay known as 'bronze disease' can occur at RH as low as 35–50 per cent.[72] Nantokite is stable so long as both oxygen and water are absent and thus it can exist sealed beneath layers of compact corrosion without causing any damage. If water is present, it slowly reacts to give cuprite as shown in section 5.5.2.2. But if there is plentiful oxygen as well as water present, it reacts extremely quickly to give, amongst other products, the basic copper(II) chloride, paratacamite. This appears as small, bulky, loose-fitting, pale-green crystals which are a component of 'bronze disease' (plate 2.6):

$$\underset{\text{nantokite}}{4CuCl} + 4H_2O + O_2 \rightarrow \underset{\text{paratacamite}}{CuCl_2.3Cu(OH)_2} + 2HCl$$

Since nantokite is the deepest of all the corrosion layers, when it forms paratacamite in this fashion, the layers above are physically disrupted as the pressure from the growing bulk of crystals forces them apart. Finally it erupts on the surface. If any metal remains, the released chloride from the above reaction causes renewed corrosion. 'Bronze disease' thus causes, not only disruption of patinas and informative cuprite layers, but also continued corrosion of remaining metal (figure 5.11).

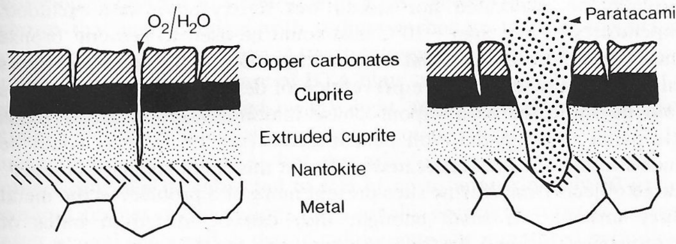

Figure 5.11 Deterioration of a copper alloy caused by 'bronze disease'

Freshly excavated material may develop 'bronze disease' in a matter of hours, as a result of the drying out of a wet or damp crust. As the water recedes and/or the crust shrinks, air, and thus oxygen, enters, and when it penetrates to the nantokite, deterioration ensues. However, even if nantokite is present, a crust, and more especially a compact patina, may remain stable for many years after excavation, since the entry of oxygen and water is blocked by the denseness of the overlying minerals. But if for some reason the crust loses its seal, perhaps as a result of being cracked by handling, cleaning, or continual temperature fluctuation, 'bronze disease' could develop if the ambient relative humidity is over 40 per cent.

Other types of post-excavation deterioration involve the formation of white deposits of lead carbonate on heavily leaded bronzes from corrosion by organic acid vapours (section 5.3.5), and the appearance of brown or black hairy crystals on copper alloys, but these are far less common than 'bronze disease'.

5.5.6 Stabilization

5.5.6.1 Passive

For objects that do not contain chloride but do contain metal, further corrosion may be prevented by maintaining the RH at less than 75 per cent and preventing contamination with chlorides and dust by air-conditioning or tight-fitting containers (section 3.4.1.4). For small objects containing nantokite, 'bronze disease' can be prevented by removing either water or oxygen from the system, and since the latter is difficult to achieve, desiccation of copper alloys is the recommended approach. This must be done within forty-eight hours of excavation, and is easily accomplished using silica gel. Resort to removal of water by solvent storage is only necessary for waterlogged enamels (section 4.4.6.1) and *preserved* textile (i.e. not simply replaced) (section 6.6.5.1); neither of