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Conservation of waterlogged timbers from the Batavia 1629

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Introduction

The problems associated with determination of longitude in the seventeenth century have led to the recovery of a fine collection of artefacts from the wrecks of the Dutch East Indiamen *Batavia* 1629 and the *Vergulde Draeck* 1656. From the analysis of materials recovered from the wrecks, an insight into the industrial technology of seventeenth century metal and woodworking industries has been obtained (MacLeod, 1987; Baker and Green, 1977 and Green, 1989). Since records of construction techniques are essentially non-existent for the period in question, the structure that is being revealed in the rebuilding of the *Batavia* at the Western Australian Maritime Museum is providing a real insight into the 'state-of-the-art' technique used in Dutch yards in the 1620s (Hundley, 1983 and Green and Parthesius, 1989).

Much of this report on the conservation of the ship's timbers and other wooden objects recovered from wreck sites is based on the work of colleagues who have come and gone during the twelve year treatment programme (Pang, 1982 and Tilbrooke, 1977). Latter-day direct involvement with the programme has enabled a different perspective to be given, particularly to the problems of degradation in display conditions (MacLeod, 1990).

The warm tropical to sub-tropical waters of Western Australia mean that significant amounts of ship's timbers will only be found when parts of the site have become essentially anaerobic, i.e. when the timbers are buried under layers of sand or coral debris. An excellent example of preservation is seen in the largely intact hull of the *James Matthews* 1841 which is buried under 2 m of sand in Cockburn Sound (Henderson and Stanbury, 1983). The warm waters promote a high level of biological activity and wood-boring organisms such as ship worms (Teredinidae) and *Limnoria* normally reduce ships structures to the level of the sea-bed over many decades. When the *Batavia* site was excavated approximately twenty tonnes of waterlogged timber, mainly European oak, was recovered in what appeared to be very good condition. The mound of ballast, cannon balls and a prefabricated stone archway helped to cover the timber and protect it from the worst ravages of the wood-boring organisms. Encrusting coralline algae and other calcareous colonizing organisms interacted with iron corrosion products to form a concreted mass on the sea-bed (North, 1976). The effects of interaction of the micro-environment with the timbers are only now beginning to be understood.

Excavation and on-site recording

Owing to limited resources of field equipment and storage on Beacon Island it was necessary to cut through sections of the large timbers so that they could be handled in the often dangerous conditions. Strong surges and heavy surf can easily reduce a four week expedition to only a few days of diving, as Morning Reef in the Wallabi Group of the Houtman Abrolhos is fully exposed to Indian Ocean swells. With the benefit of hindsight such procedures should be avoided if at all possible since they can lead to cosmetic problems in the reconstruction, viz., all the natural breaks in the planking are scarf joints and so a line of butt joints down the side of the ship spoils the historical perspective. The largest single timber was raised intact and as such the fashion piece weighs over one tonne and was cut from solid oak. It forms the key piece in the reconstruction, and details of its conservation have previously been reported (Pang, 1981), see Figure 1. All the transom beams were also raised as single sections of massive proportions.

Underwater photography was used to record the undisturbed timbers once they had been exposed (Baker and Green, 1976) and detailed recording of individually tagged items was achieved both on-site and at the base camp. Owing to the lack of facilities on the remote coral island, large shallow holding tanks were dug out of the ground, lined with plastic and filled with sea-water. The timbers were partly cleaned of gross concretion and tracings were made using a plastic film and marker pens. Six years later it was shown that for many of the conserved timbers the apparent dimensional changes were due to distortion of the clear polyethylene sheeting itself since its temperature response was found to be anisotropic! The sensitivity of extensively waterlogged wood to osmotic and thermal shock should not be underestimated. The cycling of conditions for the wood as it was removed for drawing, cleaning, etc. and then replaced in the storage dams would have stressed the timber and may have contributed to some distortion and cracking. An alternative approach to full-scale excavation and recovery has been demonstrated in the management of a sixteenth century Basque whaler at Red Bay in Labrador, Canada. Full scale mouldings in polysulphide rubber were taken of the timbers and the loose pieces were then replaced on the site. From the mouldings, a $^{1}/_{10}$ scale model of the remains of the vessel is being constructed for historical, display and didactic purposes (S Stevens, 1982). It should be noted, however, that nothing compares with the majesty of the artefacts themselves.

Although the problems associated with preventing marine borers attacking the replaced timbers prior to the previous conditions being re-established have not been

Figure 1. The Batavia fashion piece being recovered from the sea-bed. Photo: Pat Baker.

overcome, recent developments on the use of synthetic sea grass mats to prevent scouring on submerged oil pipelines show much promise. Each approach has its drawbacks and individual assessments are essential if we are to maximise the preservation of such heritage.

Transportation, desalination and impregnation

For the journey from the Abrolhos Islands to Fremantle the *Batavia* timbers were packed in large clear plastic bags up to four metres in length. These were then sealed in heavy duty black plastic bags containing sea-water and a biocide. This procedure ensured that the timbers remained wet or at least in a 100% RH environment so that any drying was avoided. Periodic spraying of the storage bags with seawater minimized the thermal shock; black plastic on a sunny open deck makes for crude but effective solar hot water storage systems! Because of the sensitivity of timber to strongly acid environments the concretion could not be removed by chemical means but was cleaned with geopicks, bolsters, water spray, etc. Some timbers exposed to HCl fumes during an experiment were shown to be subject to post-impregnation degradation. Because the timbers had been excavated from a mass of corroded iron, the surface was often covered with red-brown iron corrosion products. The desalination in fibreglass-lined, reinforced concrete storage tanks removed a lot of iron and more of the aerobic iron corrosion products were mobilized during the early stages of impregnation as witnessed by a thick red-brown iron-PEG scum that would float on the surface of the tanks. The 'poor quality' of Perth scheme water chloride levels 140-240 ppm tended to minimize osmotic shock when the wet timbers were initially placed in holding tanks - although the conductivity of the tanks was not monitored most of the timbers would have been desalinated in the period prior to commencement of impregnation with aqueous solutions of polyethylene glycol 1500 PEG 1500. Experiments on other timbers showed that most of the seawater salts are removed at ambient temperatures in two years (MacLeod, 1985).

Analysis of the water content of some of the more extensively degraded timbers showed they had up to 250% by weight water based on the oven-dried weight of the samples. With such delicate materials it is essential not to give them undue osmotic or thermal shock when beginning the impregnation. Timbers were placed on a series of Jarrah shelves that were assembled by lying boards across the tank while they in turn were supported at the sides by an internal timber frame. The dimensions of the four mild steel impregnation tanks were typically 5 m x 1.3 m x 1 m deep and the timbers took up between 30% and 60% of the 6.5 m^3 capacity of the vessels. To minimize thermal shock the temperature was slowly increased over a period of one week from ambient values 20±3°C to a thermostated value of 60±3°C- timbers that are 40 cm thick need plenty of time to adjust to an increasing temperature. The tanks were lagged with rolls of glass wool insulation sandwiched between aluminium foil and attached to the side of the tank with a series of studs that had previously been spot welded to the outside of the uncoated metal. Exterior cladding of the insulation with chicken wire protected the insulation from accidental damage from the forklift, etc. The initial level of PEG was generally chosen to be approximately 5-10% by weight the contents of one to two 200*l* drums. If the initial level of impregnate is much higher the movement of water from within the

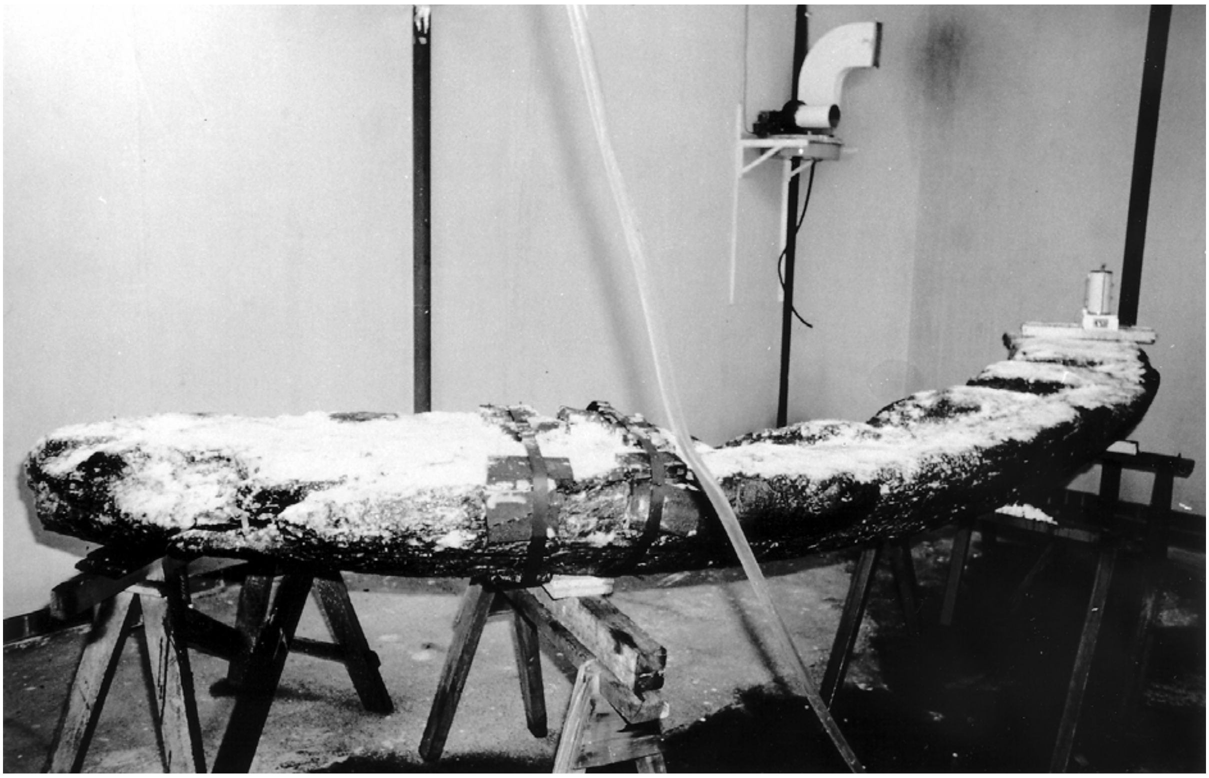

Figure 2. Second generation dehumidification chambers with the fashion piece undergoing drying. Photo: Jon Carpenter.

timber will be too rapid and the stress will result in osmotic cracking. Recent work (MacLeod, *et al*., 1989) has indicated that the optimum level of PEG 1500 for removal of residual iron and chloride salts is in the range 5-10 wt% so it is a happy circumstance that these concentrations were achieved in the early stages of impregnation. The effectiveness of these solutions in removing iron Ill compounds has already been noted in the formation of red-brown scums during the first three to six months of impregnation. The major iron mineral in the scum is the oxyhydroxide, lepidocrocite FeOH.OH (MacLeod, *et al.*, 1989).

The PEG content was periodically determined by taking samples of the solutions, recording the weight and evaporating them to dryness on a hotplate. The tanks were 'stirred' once a month by sparging with nitrogen that was released through holes in PVC irrigation tubing placed at the bottom of the tank prior to loading the timbers. Heating was achieved by conduction from hot water circulating through copper or stainless steel tubing. Despite using stainless steel 316 the high molybdenum content of the alloy 17% Cr - 12% Ni - 2.5% Mo failed to prevent stress corrosion cracking at the heat rejecting surface. Despite corrosion problems found in the lower range of PEG concentrations, the copper ½" tubing gave generally excellent performance. Since the PEG solutions are reused extensively 200 litres of PEG 1500 is currently $854 they contain reasonably high levels of wood extractives which appear to be partly passivating for copper as well as for iron metal (North, 1984). The water temperature of 60°C was regarded as the optimum compromise between minimizing osmotic/thermal shock, increasing inward diffusion rate of the PEG and minimizing biological activity. When the heating system fails it takes only a few days before extensive moulds grow on the surface of the solution. This problem is more marked when the PEG content is less than approximately 10 wt%.

Additions of PEG were made at irregular intervals over a period of two to three years with average equilibration times of two to four months at a particular concentration. Apart from the final batch of timbers that were removed after six months at 65wt% PEG, all the other batches were taken from solutions that analysed at 90-95wt% PEG. To date there appear to be no systematic differences in the amount of shrinkage or cracking in the timbers removed at the two levels of impregnate. We must reserve our judgement on the ultimate fate of the wood for several years since the drying process for massive oak beams is a very slow procedure.

Detailed chemical analysis of the wood from the *Batavia* has not been undertaken but the degradation of the timbers almost certainly mimics that on other sites. Under waterlogged conditions most of the lignin content remains intact but the cellulose materials are more extensively degraded (Hoffmann, 1982). However, recent work has shown that iron corrosion products degrade not only the cellulose fraction but also the lignin component in timbers such as European larch (Richards, 1990).

With an annual mean on-site temperature of 24.5± 4.0°C (North, 1976), the extent of biodegradation of oak over 350 years is apparently much greater than that found for the Bremen Cog recovered at Bremerhaven Germany after almost five hundred years (Hoffmann, 1985) and this has resulted in much greater penetration of the timbers by the stabilizing PEG. Another reason for the relatively rapid treatment of the *Batavia* is due to the fact that inward

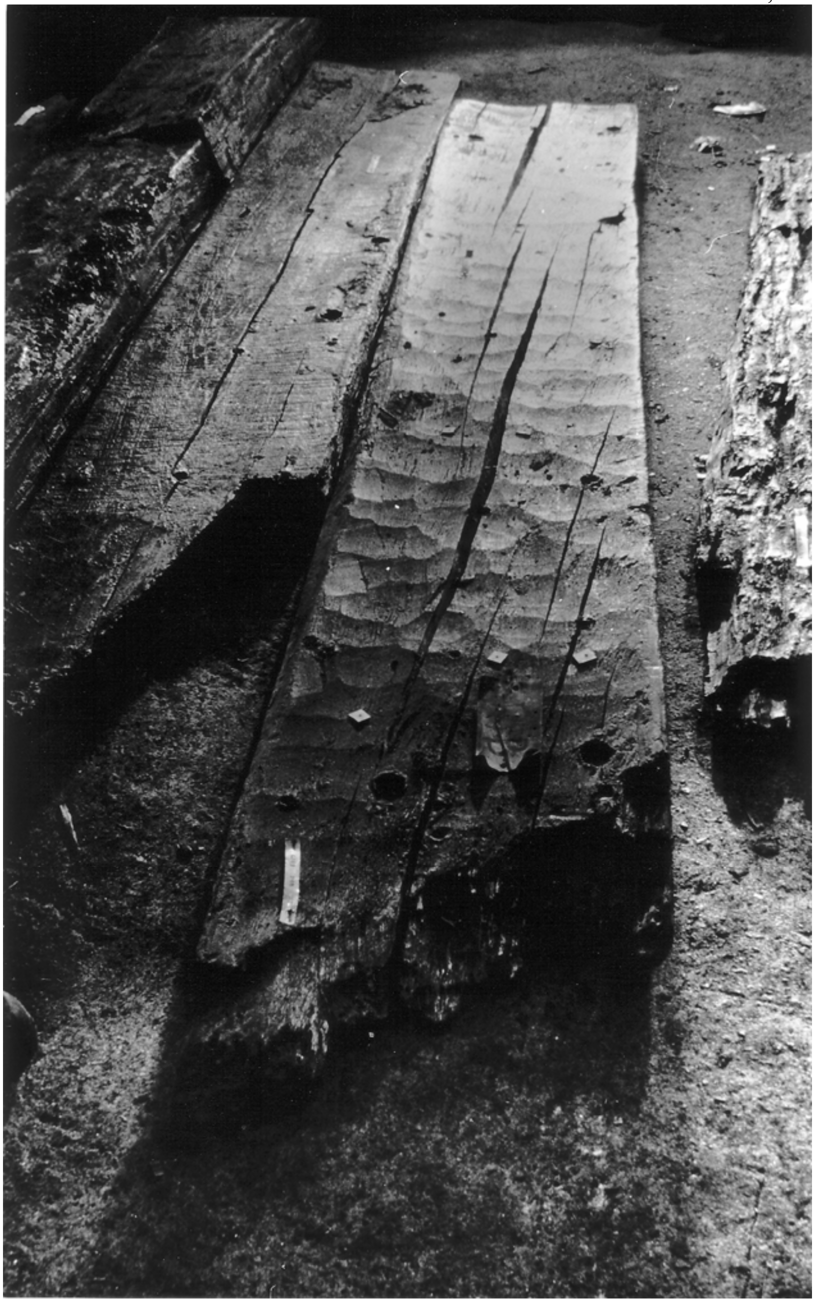

Figure 3. Adze marks on a piece of external planking. Photo: Brian Richards.

diffusion of PEG was not hindered by successive layers of timber because the site management strategy had brought back hundreds of disassembled pieces of wood. Since curatorial requests or plant breakdown resulted in each tank being drained a few times in the course of treatment, it is unlikely that the areas of the timbers lying on the wooden supports within the tank would not have been sufficiently exposed to the PEG solutions to allow adequate impregnation. The lack of rotation of a cast iron cannon from HMB *Endeavour* during electrolysis treatment resulted in post-conservation problems. Areas of original surface cracked because the cradle and insulating supports had minimized the outward diffusion of chloride ions (North, 1984).

Drying and storage

Small sections of timber were freeze-dried (Pang, 1982), but all the ship's timbers were prepared through controlled dehumidification in a series of three different chambers. The first model was temporarily established in the rear of the old Commissariat building in Fremantle while the front section was being restored at the Western Australian Maritime Museum. The aluminium tubing framework was covered with high density clear polyethylene sheeting to form two chambers and the timber was stored on heavy-duty steel racks. Two dehumidification units were balanced by two humidifying plants and control of relative humidity and temperature was achieved to within ±4% and ±3°C respectively. At relative humidities above 85% the PEG treated timbers tended to sweat but this helped

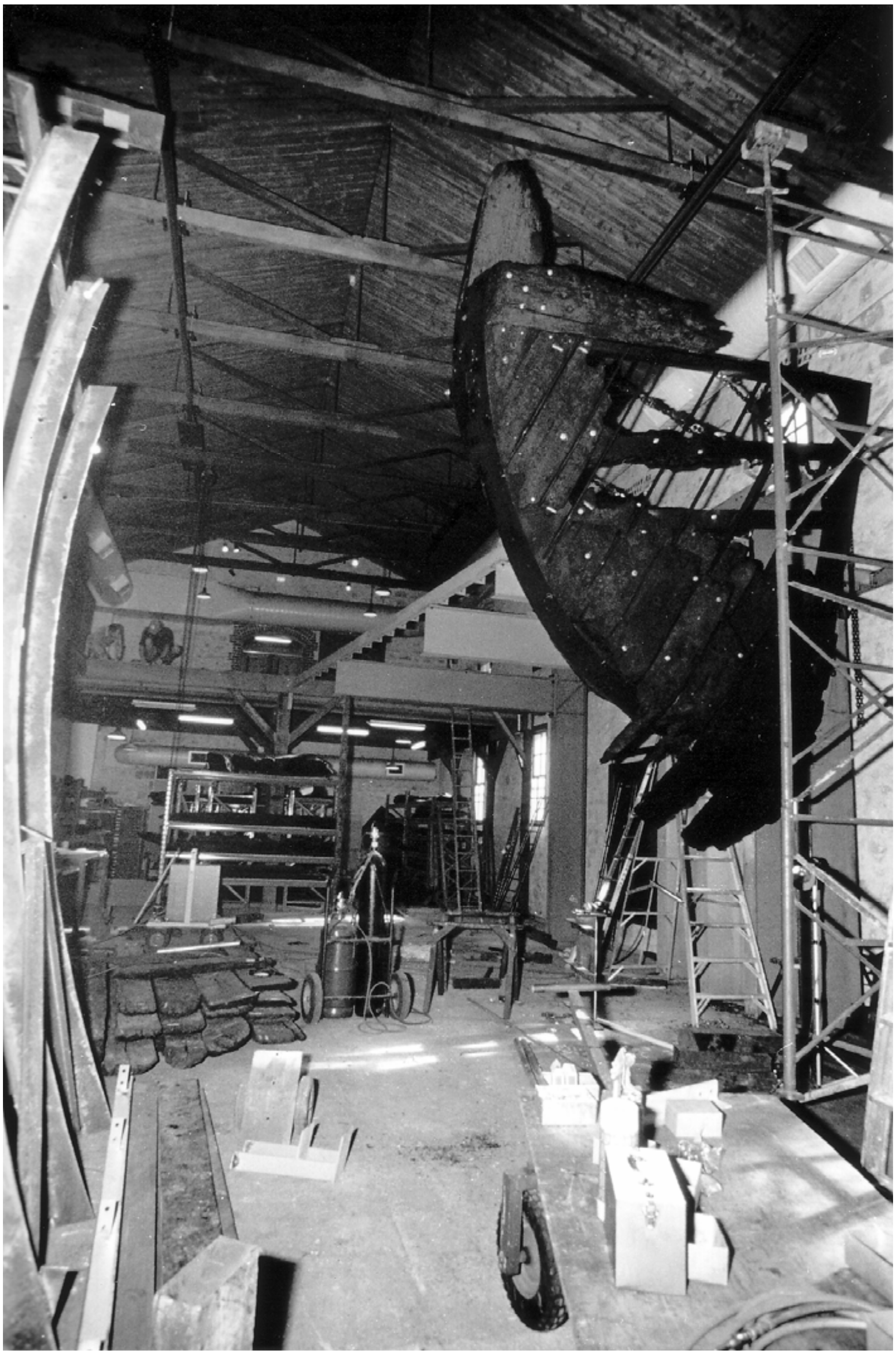

Figure 4. The transom with steel supporting structure being raised into position. Photo: Jon Carpenter.

remove excess surface material. The surfaces were brushed with a 70% PEG 6000 solution; since PEG 6000 is less hygroscopic than PEG 1500 and it was thought that such a coating would help to guard the treated timbers from the worst effects of exposure to high humidities. Problems such as earth tremors upsetting the mercury-switching gear on the dehumidifiers led to temporary rehydration of the timbers and so the process of drying each batch took nine to ten months. The second generation of drying chambers comprised two fibrocement-lined, corrugated iron sheds with the same operational plant as before. Whilst this arrangement worked well for humidity control in the 90-70% RH range, it became progressively more difficult to dehumidify as the 60% RH level of the ultimate display condition was approached (see Figure 2). Problems of insufficient thermal insulation in the walls, inadequate air flow over the compressor units and corroded heat exchanger vanes within the chambers resulted in many ‘restarts' to the drying process.

During the dehumidification process regular monitoring of dimensional changes in selected timbers took place and the results were generally within the 'accepted' values of 1-2% shrinkage in longitudinal measurements (Pang, 1981). Although cracks did appear, particularly in the radial 2% and tangential sections 3-4% the overall length, breadth and depth of the timbers changed by only 2.0±1.5 %. Surface details of original working, such as adze marks, are often found on the treated timber surfaces as seen in Figure 3.

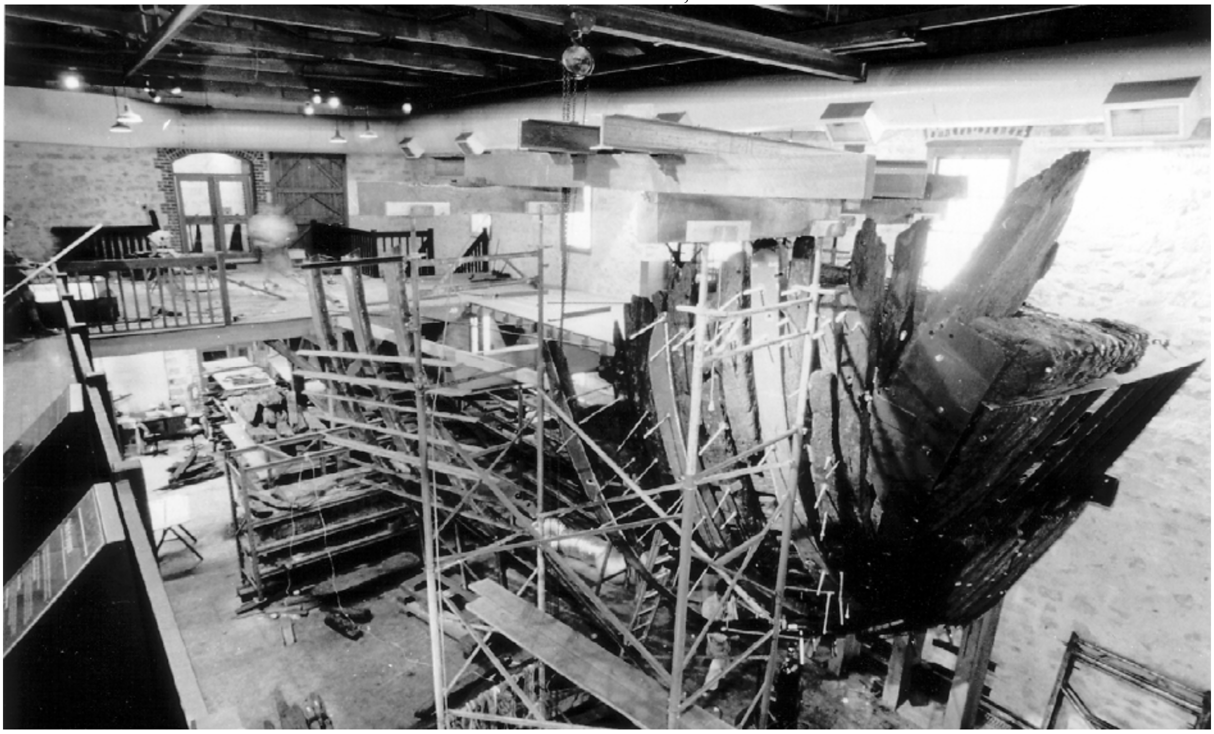

Figure 5. *Batavia* reconstruction as at November 1986. Photo: Brian Richards.

The last two batches of timber were dehumidified in a new purpose-built facility which has total back-up of controls and humidification-dehumidification units. The 6.1 x 4.6 x 3 m high chamber was erected as a commercial cool room and is 'demountable' - the walls are clad in a 'Colorbond' sandwich 10 cm of polyurethane insulation. Electronic temperature and humidity sensors provide a temperature control of ±1°C and RH to ±1% - cheaper humidity sensors based on multistrand hair systems failed to give the desired level of control. Because there were no plant breakdowns, each drying cycle was generally completed in six months with fortnightly incremental drops in the RH controls - the temperature was constant at 11± 1°C despite summer shade temperature of 43°C.

Analysis of the treated timbers for moisture content and PEG penetration involves coring and there are many factors such as compression of the samples that can give rise to error. Core samples taken from some of the massive transom beams and 15 cm thick ribs gave a range of moisture and PEG contents depending on the extent of degradation. For heavily degraded timber, water contents after dehumidification were 15.8±1.9wt% and PEG values were 36±3wt%. The major structural timbers were generally much less degraded and core analyses showed similar water contents of 11± 1wt% water but the PEG content was markedly less at 3.4±1.9wt%. Although much less PEG had penetrated deep 15 cm into the wood it was sufficient to stabilize the timber. Some of the problems associated with analysis of the samples have recently been reported (Mills Reid, *et al.,* 1984).

All the treated timbers are now stored in the Batavia gallery in the Western Australian Maritime Museum where conditions of 22°C and 55.4% RH are maintained throughout the year - apart from the normal crises associated with plant breakdown. The design of the air-conditioning plant for a porous, salt-damaged, sandstone, rubble filled structure is a separate issue, but it is worth noting that a doubling of the estimated demand on the plant, based on modern buildings, has resulted in the system being able to cope. The reconstruction is progressing at a steady rate and the erection of the steelwork by Geoff Kimpton is a major feat in itself (see Figures 4 and 5).

Minerals and timber

When metal objects are placed in sea-water they will corrode at a rate that is dependent on the interaction of salinity, temperature, dissolved oxygen levels and the nature of adventitious materials such as wood. Copper corrosion products diffuse through wood and tend to preserve it from biological attack. For example, analysis of some preserved larch from the *Rapid* 1811 showed a copper content of 32wt% and the chloride level was 3.5wt% the main corrosion product was the biologically toxic mineral Cu_2O. Interaction of copper I corrosion products with wood extractives results in the deposition of metallic copper at sites remote from the parent metal (MacLeod, 1981). Chlorides existed mainly as copper II hydroxy chlorides on the seaward surface of the wood- these are less toxic than Cu_2O.

When the iron corrodes, the metal ions that diffuse into the wood are known to accelerate the hydrolysis of cellulose materials and to affect the overall degradation process (Duncan, 1986). The problems associated with iron corrosion products inhibiting the ingress of PEG have already been discussed (MacLeod, et al., 1989). We report here an unusual example of where iron corrosion products have been used as the 'bulking agent' for the treatment of some billet boxes from the wreck of the *Vergulde Draeck.* The European larch boxes were 2 m x 15 cm x 15 cm and contained strips of iron that were largely corroded away after 325 years in seawater. Because of the more open structure of softwoods, iron corrosion products had diffused right through the wood. Once the bulk of corroded iron was excavated from the cavity, the billet boxes were treated by a six month controlled dehumidification. The wood showed only superficial cracking. Using the same procedure with iron impregnated oak from the same site was utterly disastrous, in accordance with expectations. For native hardwoods such as Jarrah and for material such as *Banksia* cones recovered from the *Star* 1880, freeze-drying or dehumidification after desalination generally gives as good a result as doing the same treatments after some PEG impregnation has taken place.

The problems of iron corrosion and *Batavia* timbers have recently received extensive local press coverage. It was noted that many of the timbers had salty encrustations on them after storage for several years in the gallery. After protracted discussions and analysis of many samples taken from the timbers, the problem appears to be fundamentally a thermodynamic one. The initial iron corrosion products are iron II chlorides which are subject to further oxidation on aerobic sites to the characteristic red-brown iron III oxy-hydroxides. Under the covering of marine concretion on the wreck site, anaerobic conditions (North, 1976) can develop and precipitate corrosion products such as FeS pyrrhotite and FeS_2 pyrite within the wood structure. Oxidation of pyrite and other iron sulphides produces a range of sulphide oxidation products including elemental sulphur and a number of sulphur-oxygen species such as $S_2O_3^{2-}$ and SO_4^{2-} the latter in the form of H_2SO_4 or sulphuric acid! Surface pH measurements on affected timbers gave readings as low as 2.0±0.1 and as such, these values indicate a grave situation for the timbers. Current research (Ralph, 1980) shows that oxidation of pyrite really begins to 'take off' at relative humidities of ≥60%. The previously accepted value of 60±4% RH for display conditions was obviously too high and so the oxidation of pyrite resulted in more than two tonnes of timber being acid-affected. Once the nature of the problem had been identified the display conditions were altered.

Several deacidification techniques were investigated and the most promising one was to use ammonia vapour (Gilberg and Seeley, 1982) to convert the acidic iron sulphates to goethite αFeO.OH and a range of iron-hydroxy-sulphate-hydrates. After small scale experiments, two tonnes of timber were exposed to ammonia gas under a gas-proof membrane for 48 hours, then degassed in the open air for a further two days before being returned to the gallery. Within three weeks the surface pH values had fallen from 9.8 residual ammonia to mean values of 6.5±0.5. The ammonia treatment showed up red-brown patches where the surfaces had been acidic and neutralized iron sulphide oxidation products were removed by dry brushing which resulted in a small weight loss e.g. 2.85 kg of iron minerals were removed from 169 kg of acid-affected wood. Detailed discussions of these problems will be given in subsequent publications.

The future

The longevity of the *Batavia* timbers is still a matter for some debate as we cannot be certain that we have solved the acidity problems. The structure needs to be regularly monitored to ensure that any changes in the timbers are noted at an early stage. It is essential that all measures are taken to ensure proper control of the relative humidity in the display gallery. The treatment of the *Batavia* timbers was begun in the early 1970s and since then the amount of research published on the problem of waterlogged wood has greatly increased (Grattan, 1982; Waterlogged Wood: Study and Conservation, 1984; and MacLeod, 1989). Much of the work reported herein was experimental and treatments have tended to err on the side of the cautious, owing to the historical nature of the materials. Based on the experience of the Western Australian Museum I believe that projects such as the raising of HMS *Pandora* and conserving it for public display are not just the pipe-dreams of maritime archaeologists.

Acknowledgements

There are many people who have worked on the *Batavia* timbers, but the longest serving member of the time was Nick Sander, without whom the current display could not have been achieved. Museum staff including Dr James Pang, David Tilbrooke, Patricia Moncrieff, Nancy Mills Reid and Jan Davies have also played significant roles. In the last few years Dr Ian Godfrey, Alan Kendrick and Vicki Richards have all been involved in conserving *Batavia* waterlogged wooden objects. Without the financial support of the Western Australian State Government the project would have died at the conceptual stage. Without the teamwork of the Western Australian Museum's Department of Maritime Archaeology and Materials Conservation the project could not have taken its present form. Special thanks go to Geoff Kimpton for his patience with the conservation process and to Jeremy Green who led the excavation.

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