Biodeterioration of Wood

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Introduction

A huge proportion of the cultural collections housed in Australian museums is composed of wood and other cellulosic material. Every state and territory in Australia supports a large natural history collection of which ethnographic objects, composed almost entirely of wood and vegetable products, form a major part. In addition, wooden items are common in historical collections and are found, to a lesser extent, in archaeological collections.

This paper is intended to provide general background information about the characteristics of wood, and the processes associated with its deterioration, with the aim of furnishing a practical and logical basis for the conservation of wooden artefacts. It is also intended to emphasize that there is a vast amount of available technical and scientific literature relating to the study and preservation of wood, and that there are many research institutions in Australia and the Pacific which can provide practical advice and information on the subject. Wood as a major economic resource has been the subject of considerable research and much of the data is of practical value to the conservator.

Characteristics of Materials

Wood. Wood is the hard tissue of trees which, when living, translocates food between roots and leaves, and when dead contributes to the structural rigidity of the stem. This region of active transport is called sapwood, and there is usually a clear junction between it and non-living heartwood. It is laid down in the form of cells of various shapes composed of cellulose and lignin. The arrangement of these cells, their shape, and fine detail, are the basis of timber identification and their chemical and physical properties may have profound effects on the life span of artefacts made from them.

Wood is usually divided into two groups on an anatomical basis; the softwoods in which vessels are

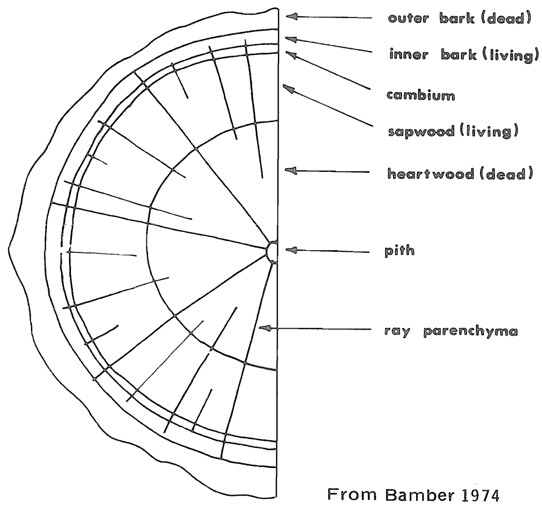
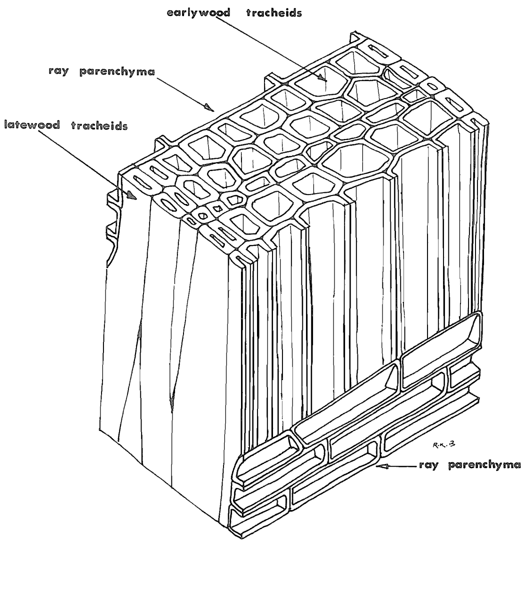


Figure 1. Cross section of tree trunk

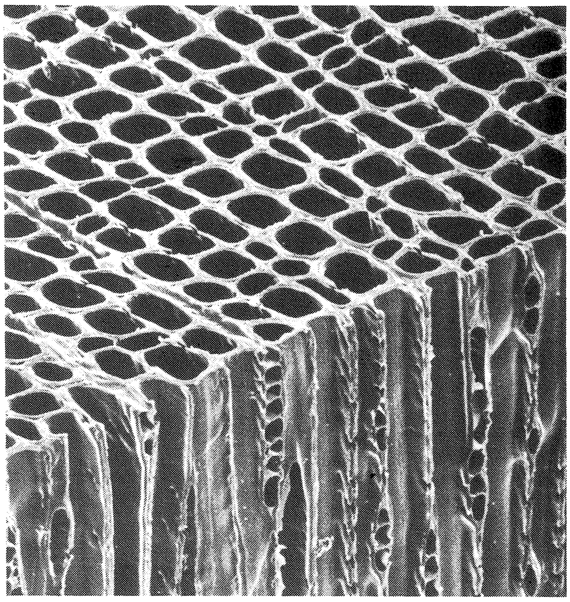
absent, and the hardwoods or pored timbers. In softwoods the conducting elements are the tracheids and ray parenchyma of the sapwood. In hardwoods this function is taken over by vessels and ray parenchyma, again in the sapwood. The heartwood of both types does not act as a conductive tissue as it has undergone anatomical and chemical changes as it is formed which affect such characteristics as permeability and durability.

It is important when dealing with artefacts to be able to distinguish sapwood from heartwood because of the different properties of the two types of wood. The sapwood of many species is different in colour to the heartwood, and is usually much paler. There are exceptions to this general rule, and other tests may be necessary. Sapwood does not differ significantly in strength from heartwood, but is usually more porous. In softwood heartwood this is due either to the tracheids of softwoods being



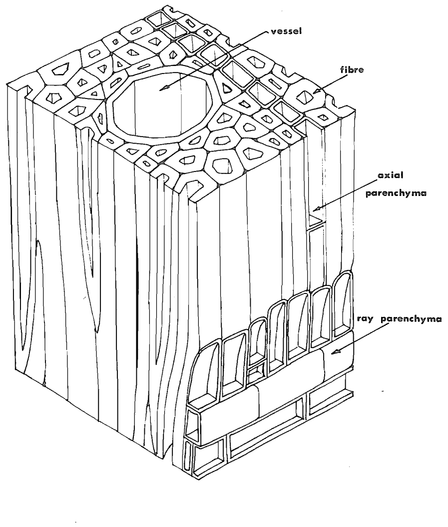
From Bamber 1974

Figure 2. Enlarged view of softwood block



Courtesey of Dr. B. Meylan

Figure 3. Scanning electron micrograph



From Bamber 1974

Figure 4. Enlarged view of hardwood block

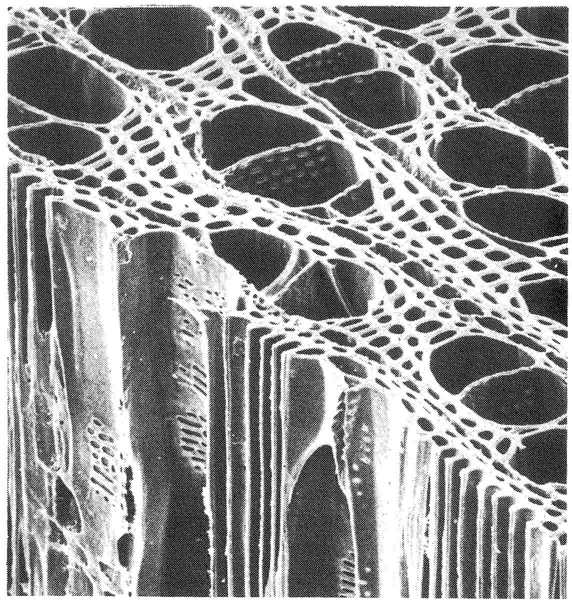


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Figure 5. Scanning electron micrograph

blocked by resin infiltration or to closure of the openings between adjoining cells (pits). In hardwoods the vessels become blocked by tyloses, and there may be heavy deposition of polyphenolic compounds which further restrict water movement. These obstructions can be seen under the microscope.

In hardwoods the sapwood may contain starch which may be detected by the iodine/potassium iodide test described by Bamber (1974). This test is widely used to determine if timber is susceptible to attack by the powder post beetle, (*Lyctus brunneus* Steph.). In more difficult cases, staining reactions, or microscopic examination, may be required.

The structure of wood has many other bearings on conservation.

1. The occurrence of abnormal features, e.g., reaction wood, spiral grain, knots, included phloem tissues, and defects due to insects, fungi, fire, frost

or mechanical damage determine the mode of conservation to be used.
2. Because of its structure timber is an anisotropic material. i.e., its properties are not the same in all directions. This applies especially to strength characteristics, and to shrinkage.
3. The width of the lumen, (interior diameter), of the vessels of hardwood determines whether certain forms of insect attack can take place.

An understanding of wood chemistry is helpful if the overall pattern of wood deterioration is to be understood. The processes of chemical degrade of cellulose products are covered in depth by Watson (1976) earlier in these proceedings. Further information is given by Browning *et al* (1963), whilst wood extractives are treated in depth by Hillis (1962).

Thermal expansion is another property of wood which must be considered where other materials have been applied to, or incorporated into, timber artefacts. For example, the coefficient of expansion of wood is between 1/10 and 1/3 the values for common metals, concrete and glass. Whilst this ratio of linear expansion may not be important from a builder's point of view, it may well be a problem where brittle materials have been incorporated into wooden artefacts. It is necessary to ensure that such objects are not subjected to excessive heat.

For those interested in the general properties of wood, its strength characteristics, defects, plasticity, dielectric properties, etc., Bootle (1971) and Brown *et al* (1949) are good introductory texts. These should be supplemented as required by publications of the Forest Services and C.S.I.R.O.

Bark. Bark has been defined as the tissues of the stem, branch and root outside the cambium layer. Like wood, bark has a definite arrangement of cells which in some cases may be used to identify the tree species concerned. Its anatomy has not been studied to the same extent as wood anatomy, however, and such identifications may be very tentative. Bark and wood contain many substances in common, cellulose, flavonoids, fats, phenolic compounds, polysaccarides, and terpenes. In bark the majority of these undergo extensive modifications on being laid down to provide considerable protection against fungi and bacteria. The outer bark is very resistant to biological attack, conversely the inner bark is very susceptible.

Physical and Chemical Causes of Wood Degrade

Water. Water affects the integrity of artefacts in a number of ways, e.g., by causing wood to shrink and swell, by removing substances which give wood its durability, by physical erosion, by hydrolysis, or by providing moisture necessary for insects or fungi.

Water is held in wood in two forms, free moisture which is water filling the cell cavities, and bound water which saturates the cell walls. Free water is the first water to leave wood as it dries, but whilst this causes loss of weight it does not cause the wood to distort. The loss of bound water on the other hand is accompanied by major changes in wood properties, such as cracking and warping.

When all free moisture has been lost from the cell cavities but the cell walls are still saturated, *fibre saturation point* is reached. Below this point wood begins to shrink and this process is continued until the *equilibrium moisture content* is reached. At this point the wood moisture content is in equilibrium with the surrounding air moisture content and the wood is said to be seasoned. Thereafter wood will swell and shrink usually to a minor degree with changes in relative humidity. However, if wooden artefacts are taken from an area where the relative humidity is very low to a humid situation big changes in moisture content and hence in swelling will occur, and vice versa. As an example, timber in equilibrium with an R.H. of 10% has a moisture content about 3% but at 90% R.H. the moisture content will rise to 22%. Such samples will swell, causing fractures in surface ornamentation, may distort slightly in shape, and will be capable of supporting fungal growth.

A similar situation but with different effects occurs when artefacts are removed without proper precautions from tropical environments to dry areas, or to air conditioned buildings without humidity control. In fact, air-conditioned buildings may have an R.H. as low as 10% which will result in wood moisture contents as low as 3%. If wooden artefacts from totally different climatic environments are to be imported they should be specially packed to prevent sudden changes in moisture content and then gradually allowed to come into equilibrium with their new environment. All these changes can take place on a micro-scale in uncontrolled storage areas over many years, or centuries, contributing to a very slow deterioration of the artefact.

The main facts for conservators to remember are that when wood is dried below fibre saturation point:—

1. It shrinks in three different directions relative to its initial orientation within the tree. In a direction tangentially or radially orientated to the long axis of the tree shrinkage can be considerable (2 to 9%), but along its length shrinkage is only about 0.1%.

The moisture content of wood is determined either by the oven dry weight method which is not suited to artefact conservation, or by use of electrical moisture meters. It is expressed as

$$MC = \frac{\text{Weight of water}}{\text{Weight of wood substance}} \times 100\%$$

Tables of shrinkage of various species can be obtained from most Forest Services.

2. Timber that is dried incorrectly checks or cracks because the difference between the drying rates at the centre and surface of a piece of wood may be considerable, creating severe physical stresses within the artefact.

This process may be repeated many times in objects exposed to weather, but is also important when artefacts are removed from water and taken into collections.

3. Timber which contains sloping, cross, or curly grain e.g., around knots may also warp when being dried, but this can be prevented in some cases by use of mechanical restraints.

Good general accounts of wood moisture content are given by Marshall (1969) and Brown et al (1949).

Weathering. The rate of wood degrade may be accelerated when artefacts are continuously exposed to the atmosphere. Objects that are frequently wet by rain, develop a chequered surface as a result of differential expansion and contraction of the wood. Frost may cause the same effect, and long periods of exposure result in a finely broken surface that is readily eroded by wind. These situations are complicated by the action of radiation chiefly in the ultra-violet region, and by the presence of fungi and bacteria suited to such conditions. Ultra-violet radiation does not penetrate more than a few mm into wood, but it causes the surface of most woods to turn a silvery grey colour because of photochemical changes in the cellulose. Little is known as to the long term effects of museum lighting in this regard.

Heat. Timber will burn when its temperature exceeds approximately 200^{o}C, but thermal degrade occurs at much lower temperatures particularly if wood decay has been present in the timber. It is important to realise that although these changes may be gradual, they are cumulative in so far as wood loss and lowering of ignition temperatures are concerned, and, if continued over many years will eventually change the nature of wooden artefacts significantly.

Low temperature processes are very slow, but MacLean (1951) reported average weight losses per year of 11 species of wood as 2% at 93^{o}C, 28.6% in 470 days at 121^{o}C and 21.4% in 102 hours at 167^{o}C. Surface charring was said to be pronounced even at 93^{o}C. These reactions could possibly take place at lower temperature if wood decay had been present. Slow thermal degrade is also associated with the darkening of wood.

Chemical. There are many forms of chemical degrade of wood and other cellulosic materials.

Timber items in continual contact with salt water may show electro-chemical degrade if two dissimilar metals are in contact with the wood. A similar situation may occur around nails in wooden floors due to inadequate subfloor ventilation. Such damage is caused by the interaction of the metal corrosion products with the wood cellulose. Any metal used in repairing such objects should be non-reactive e.g., monel metal, and the wood must be carefully dried, and be kept dry.

Strong acids, and mild to strong alkaline solutions, attack wood lignin causing defibration or woolly brown surface degrade. A common example of this damage occurs where wood is exposed for long periods to sulphur dioxide fumes. Another type of degrade occurs when wood containing metal fastenings, for example, is wet. If the particular timber species has a high tannin content and iron nails are used, blue-black streaks may occur along the surface of the wood. A similar reaction, this time reddish-brown, occurs when copper or copper alloy fastenings react with wood tannins.

Some stains in wood, usually black, yellow, red or brown, occur as a result of the oxidation of wood components. Mostly these occur in sapwood whilst it is still wet, and they do not extend further when the wood is dried. Wood when wet may have a pH of 4.5 or less, and may give off corrosive vapours, e.g., acetic acid. Artefacts which contain metals or other substances corroded or etched by such vapours should not be shipped in cases made from green timber. This is especially so when long sea voyages under conditions of high humidity are involved. Dry timber, proper packing, and the use of desiccants will greatly mitigate such problems.

Most cases of chemical degrade are far advanced or have run their course by the time the artefact is received by a museum. What is needed is the ability to recognise the damage both as a basis for treatment and to avoid any situation that may cause its recurrence.

Biodegradation

Fungi, and other micro-organisms. The fungi are a large and complex group of organisms usually placed in the plant kingdom and numbering at a conservative estimate 100,000 species. All fungi lack chlorophyll and so must live either as saprophytes feeding on dead organic matter, or as parasites on other organisms including plants, animals and other fungi. It is the former group with which we are concerned.

Useful references on the fungi of interest to conservators include Alexopolous (1962), Hudson (1972), and Ingold (1961).

The fungi are divided on the basis of anatomical and other characters into four classes.

The Phycomycetes. This class contains some familiar moulds such as *Mucor* and *Rhizopus* which may colonise wet wood or other organic materials with astonishing rapidity to give a thick furry coating of mould. This class is distinguished by a lack of cross walls (septa) in the cells (hyphae) and by the type of spores produced.

The Ascomycetes. These include the yeasts, the perfect stages of mould groups such as *Aspergillus* and *Penicillium* spp. and many of the soft rot fungi. They also include some wood rotting agents and many diseases of flowers, trees and food plants. Ascomycetes have septa, and bear their sexual spores in a structure called an ascus. There are usually but not always eight spores in each ascus.

The Basidiomycetes. These include most decay fungi, as well as mushrooms, toadstools, and many diseases of trees and other plants. Many of the decay fungi are familiar to us as bracket fungi growing out of diseased trees or decaying logs. Basidiomycete sexual spores are borne on a structure called a basidium and the septa are sometimes modified to give structures called clamps.

The Fungi Imperfecti. This is a Form Class for a wide range of fungi which are known only from their vegetative stages and so cannot be assigned to other Classes. They include the vegetative stages of *Aspergillus,* and *Penicillium,* as well as other surface moulds such as *Stachybotrys* and *Trichoderma.*

The conservator is likely to meet with all four Classes of fungi in biodeterioration situations, and some working knowledge of them is therefore essential.

Surface Moulds. Among the more persistent agents of deterioration of wood and other organic materials in museums are the surface moulds. These include a great array of fungi such as *Aspergillus, Cladosporium, Penicillium, Stachybotrys,* belonging to the Class Ascomycetes, the form Class Fungi Imperfecti and the Phycomycetes. Descriptions of the more common types may be found in Smith (1969) who gives numerous photographs and much information of value to conservators. Additional useful information is given in Cartwright and Findlay (1958) Nicholas (1973) and Hudson (1972). These fungi may cause slight surface breakdown of the wood, many produce brightly coloured, red, pink, orange, green or yellow surface discolouration and some may penetrate quite deeply into the wood. Pigments, paints, glues, feathers, horn and other surface ornaments may be attacked and a musty smell is frquently present.

Most surface mould fungi require wood surface moisture contents of 18% or above but this limit may be lower on cotton or similar textiles. Some fungi are considered by Hudson (1972) to be very xerophytic. The usual sequence of events is for large numbers of spores to be produced during, or just after, warm humid weather. These spores will germinate only when the microclimate at the artefact surface is favourable, but many can remain dormant and resist desiccation for long periods after their production.

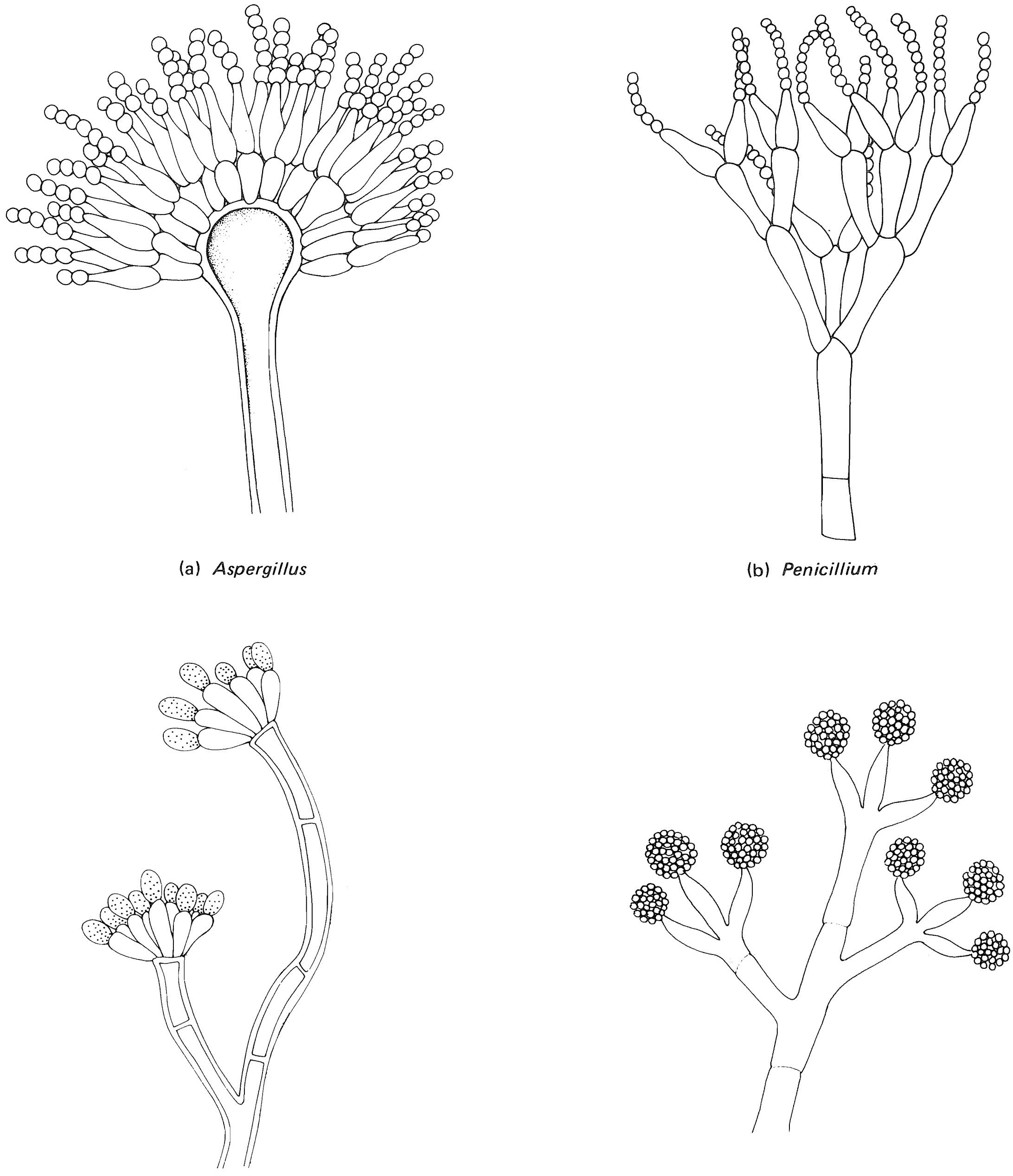
When dealing with mould infestations several things need to be kept in mind.

1. Dry, well ventilated storage is essential, and the artefacts themselves must be carefully dried. A safe relative humidity is 68% or less.
2. Consideration must be given to both the wood and to any ornamental glues, etc. since most of these fungi colonise a wide range of substrates.
3. Care must be taken to avoid spreading clouds of spores to other parts of the museum during cleaning operations, e.g. through air conditioning systems.
4. Many fungal species produce highly resistant spores, and unless fumigation or surface sterilization is carried out, considerable amounts of infective material may be transferred from place to place in the museum. The life of such mould spores is variable but some may survive dry conditions for many years. The remedy, if surface sterilization or fumigation is not practicable, is to control storage conditions on a long term basis, after careful removal of visible signs of the moulds.
5. Persons dealing with such mould infestations must wear suitable respirators because of the risk of serious respiratory mycoses.

As a typical example of what one might expect in museum situations, a survey in Sydney, N.S.W. of the Australian Museum air spora during 1974 showed the widespread presence of the fungal genera *Aspergillus, Penicillium, Rhodotorula, Scopulariopsis, Stachybotrys* and *Trichoderma,* with occasional *Alternaria, Epicoccum, Mucor, Nigrospora,* and *Stemphylium* spp., plus unidentified yeasts and bacteria.

This list may be compared with that of Upsher (1968) for Innisfail, Queensland in 1966 and 1967. At that location, using different techniques to the Sydney survey, he found the dominant species to be *Cladosporium, Leptosphaerulina* and sterile fungi with lesser amounts of *Curvularia, Epicoccum, Geotrichum, Monilia,* and *Penicillum* spp.

Decay. Decay fungi occupy a most important ecological niche because they can use wood cellulose and/or lignin for food, thus assisting its return to the cycle of living organisms. They are the subject of a vast literature but good general accounts are



(a) *Aspergillus* (b) *Penicillium*

(c) *Stachybotrys* (d) *Trichoderma*

S. Walston

Figure 6. Typical fungal sporophores found on timber artifacts

given by Cartwright and Findlay (1958), Hicken (1972b), and Nicholas (1973). Wood decay, dry rot, wet rot, brown rot, white rot, doze and many other terms are used to denote variations in the patterns of decay.

The chief features of interest are:

1. For decay to occur the wood moisture content must be above 20-24%.
2. The wood must be non-durable, i.e., low in fungitoxic components.
3. Decayed wood air dried below 20%, but not heat sterilized, may harbour a decay fungus for many years. When rewetted the fungus may resume its growth.

The general sequence of infection is as follows. Spores are freely produced from decay sporophores (fruiting bodies). Sometimes as many as 10 million spores per day can be produced by a moderate sized fruiting body. These become airborne, and are almost universally present in the air of museums and storage rooms. If by chance a spore falls on to a wet wood surface it may germinate to produce a tiny thread (hyphae) which penetrates the wood cells. If the timber is not durable and is not completely saturated with water, the hyphae spread rapidly, feeding on the wood cells causing their decay. Many fungi also spread by contact between sound and decayed wood. Fragments of hyphae may also cause infection.

Some fungi attack only wood cellulose and not the lignin. These are called brown rots and the timber often appears degraded into small brown cubes (brown cubical rot). Other fungi attack both cellulose and lignin, leaving behind a white residue (white rots).

Many fungi cause decays only in standing trees. Some such decays are accompanied by black or brown zone lines, and specialist knowledge is needed to determine whether the rot occurred before or after felling the tree.

Precise identification of wood decay fungi is most difficult unless fruiting bodies are present, and demands much time and effort plus access to large culture collections. Even with these facilities many decays cannot be assigned to known species of fungi, but the identity of the fungus is seldom important in museum situations.

When examining artefacts for decay and when applying remedial measures it is important to remember that:

Decayed wood is often very brittle even when the decay can just be detected. This decayed area may extend beyond the visible signs of decay into apparently sound wood –

Decayed wood is more absorbent than sound wood, and shrinks more –

Decayed wood is more easily affected by thermal degrade, and has a lower ignition temperature --

There is usually no satisfactory way of determining exactly how long decay has been in progress in an artefact –

Some wood decay fungi also attack other cellulose based materials i.e., bamboo, paper and cotton. Bark is very resistant to destruction by most fungi.

Decay found in museum artefacts may have occurred before acquisition, and necessary remedial treatments should take into account the changed properties of the wood, and the conditions under which it is to be stored. Decay may also occur in the museum because of poor storage conditions i.e. in damp basements, leaking sheds, or unventilated areas where very high moisture contents may be reached, often in as short a time as twelve weeks. The latter situation must be corrected whenever it occurs since decay is quite inevitable once the wood moisture rises above 20-24% for any lengthy period.

Wooden objects under snow may also be attacked by a variety of fungi, but wood encased in, or under ice does not deteriorate.

The durability of wood is based largely on the deposition of toxic substances in cells, and cell walls. Durability tables listing the likely performance of various timber species in ground contact for periods up to 30+ years are available. Information on these may be obtained from State Forest Services and C.S.I.R.O.

As a general rule the sapwood and pith of most timbers are non-durable, but the heartwood may range from highly durable to non-durable. There are exceptions to this rule, and not all trees of a species conform to the life expectancy suggested by such durability ratings.

Soft Rots. Soft rots are sometimes encountered in artefacts which have been in contact with the soil, or immersed in fresh or salt water. These are caused by a heterogeneous collection of Ascomycetes and Fungi Imperfecti. The damage appears as a softening of the wood inwards from the surface. Although the object retains its shape it becomes darkened. Small objects may become very brittle and the surface may appear somewhat fibrous. Degrade is usually slow, and less extensive than that caused by decay fungi.

Soft rot fungi require a good supply of oxygen, and do best in warm, wet tropical soils or where there are continuous films of warm water passing over the wood surface. Timber fully immersed in water is attacked also, but more slowly, and the position may be complicated by the presence of marine borers and other organisms attracted to the soft-rotted wood.

When wood containing soft rot is dried the soft, decayed portion sometimes becomes quite hard, giving a false impression of strength. However, as mentioned above the decayed portion is usually very brittle and great care is needed in handling small carvings and similar objects when soft rot is suspected.

Confirmation of soft rot attack usually depends on a microscopic examination of thin sections of the affected material. Transverse sections of timber containing soft rot when mounted in lactophenol cotton blue mountant and examined at 300-600 X by transmitted light usually reveal the presence of 'bore holes' in the wood cell walls.

Both hardwoods and softwoods are attacked by soft rots, and in Australia some hardwoods appear to be particularly susceptible. Heartwood can be damaged as well as sapwood. Soft rot attack ceases when the source of moisture is removed and the object is maintained at an equilibrium moisture content of below 20%.

Whilst the presence of soft rot gives some clues as to the past history of an artefact there is no accurate way for determining how long it has been active.

Bacteria. Bacterial attack on wood is of little importance in relation to museum specimens. Where it has occurred, usually in wood submerged in fresh or stagnant water, or in mud, the main effect is increased porosity. In the case of small objects there may sometimes be a severe loss of strength, and sapwood of logs stored under water may become discoloured on exposure to air.

Bacterial damage to adhesives, organic pigments and decorative materials used in artefacts is also likely to be encountered. However the conditions which favour such attack also favour surface mould fungi and decay, and similar remedial measures are required. Further information on bacteria in wood is given by Greaves (1971), and on the mechanisms of microbial corrosion of metals by Iverson (1968).

Lichens. These are symbiotic associations of algae and fungi which occur on rocks, wood, bark and other materials especially under wet, cold conditions. They cause superficial surface damage to artefacts and their removal leaves discoloured patches on the surface of the wood. There are no known wood decays associated with this group.

Insects. Artefacts may be infested by wood destroying insects before they are acquired by a museum, and may spread to other materials within the museum. Conservators should be able to recognise active and inactive damage, and either know how to treat it or where to seek advice. Storage of artefacts also presents problems, and requires a clear appreciation of how insects can gain access to collections and how to control them. Among the useful reference books on wood destroying insects and similar pests are those of Hadlington and Cooney (1971), Hicken (1963), (1971), (1972a) and Nicholas (1973). These should be supplemented by bulletins from the Forest Services, and other government bodies, and where possible the museum should obtain typical examples of termite, lyctid, anobiid, bostrychid and other types of insect damage.

Termites. Termites (sometimes misnamed white ants) belong to the Order Isoptera. They are primitive, highly successful social insects of wide distribution, chiefly in the tropics and warm temperate zones. A few groups are also found in the cold temperate regions.

Termites attack a large range of cellulosic materials including wood, paper, bamboo, vegetable fibres, etc. To reach food sources termites will damage a wide variety of materials; some species will also damage inorganic building materials such as lead flashing and plastics. The damage caused by termites has led to the establishment of a large pest control industry, both here and abroad, and much research into their biology and control has been undertaken.

Termites may live in subterranean nests or in above-ground colonies in trees and buildings. The most common termites of economic importance in southern Australia are *Coptotermes acinaciformis* and *Nasutitermes exitiosus* both of which construct subterranean nests. Termite attack becomes progressively less important as one goes further south. Conversely the termite species of northern Australia such as *Mastotermes* can cause serious damage to buildings in a very short time.

From their subterranean nests foraging galleries are built, often up to 30 m in length, in search of wood. These galleries may penetrate through cracks in the walls and foundations of buildings or pass up the outside of water pipes and inside or outside foundation walls, until access is gained to sources of cellulose. Such galleries are necessary because termites rapidly desiccate when outside the nest system and its connecting tunnels, in which a close control is maintained by the insects over the air humidity.

The termite colony is divided into various castes. The queen is the central feature of the nest, devoting her entire existence after fertilization to egg production. She is attended by a large worker caste, and the nest is protected by a soldier caste. New nests are founded after emergence and mating of winged reproductives and once established may persist and grow in size for many years.

There are two Australian Standards (1966), (1968) for the termite protection of new buildings which should be specified when museum storerooms are being built. However, whatever method is used it is still important to make regular inspections of all stored material at least each six months.

The second group of termites which may be encountered are the drywood termites which nest in wood, but do not need connecting tunnels to a subterranean nest. These may be introduced into museums in large objects and are sometimes difficult to detect. Again careful examination of all new collections is essential.

Termites in artefacts can be killed by fumigation with methyl bromide or similar toxic gases, but this method should not be attempted by persons untrained in its use. Australian Health Departments have very strict regulations requiring the registration of commercial fumigators because of the serious health hazards involved.

It is most important that termite infestations found in artefacts coming from outside Australia be referred promptly to the Australian Plant Quarantine Service since there are a number of potentially very destructive termite species found in Asia and elsewhere which have not so far become established here.

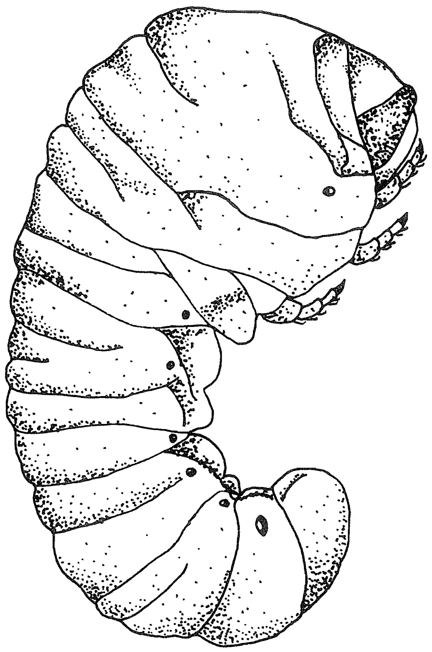
Lyctids. One of the most important groups of insect pests of hardwood timbers is the lyctids of which *Lyctus brunneus* Steph. the powder post beetle is perhaps the most familiar to conservators.

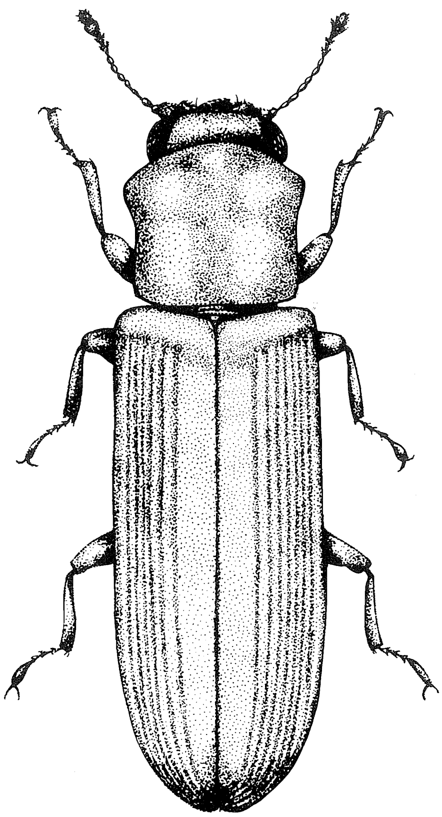
Lyctus attack is confined to the sapwood and two conditions must be present for it to develop. The wood must contain a suitable amount of starch to provide food for the larva, and the vessels must be more than about 90μ in internal diameter before the female can lay her eggs within the wood.

The female beetle 'tastes' the wood surface before egg laying to determine if starch is present. If it is, she lays two to three eggs in each vessel (pore) sometimes to a depth of 7 mm. Incubation time varies with temperature, and may range from 6 to 20 days. The larvae are creamy-white in colour, and when young are about 6 mm long. This is the destructive stage, and usually an infestation once established continues until all susceptible sapwood has been eaten. A wood moisture content of between 8% and 30% is needed for such attack by *L. brunneus.* Finally, after sufficient development has taken place the larvae turn into whitish pupae and finally become adults which then emerge to begin a new cycle.

The length of the life cycle depends on temperature, wood moisture content and other factors. In Australia it may vary from 6 months to one year, but may be longer if conditions are unfavourable.

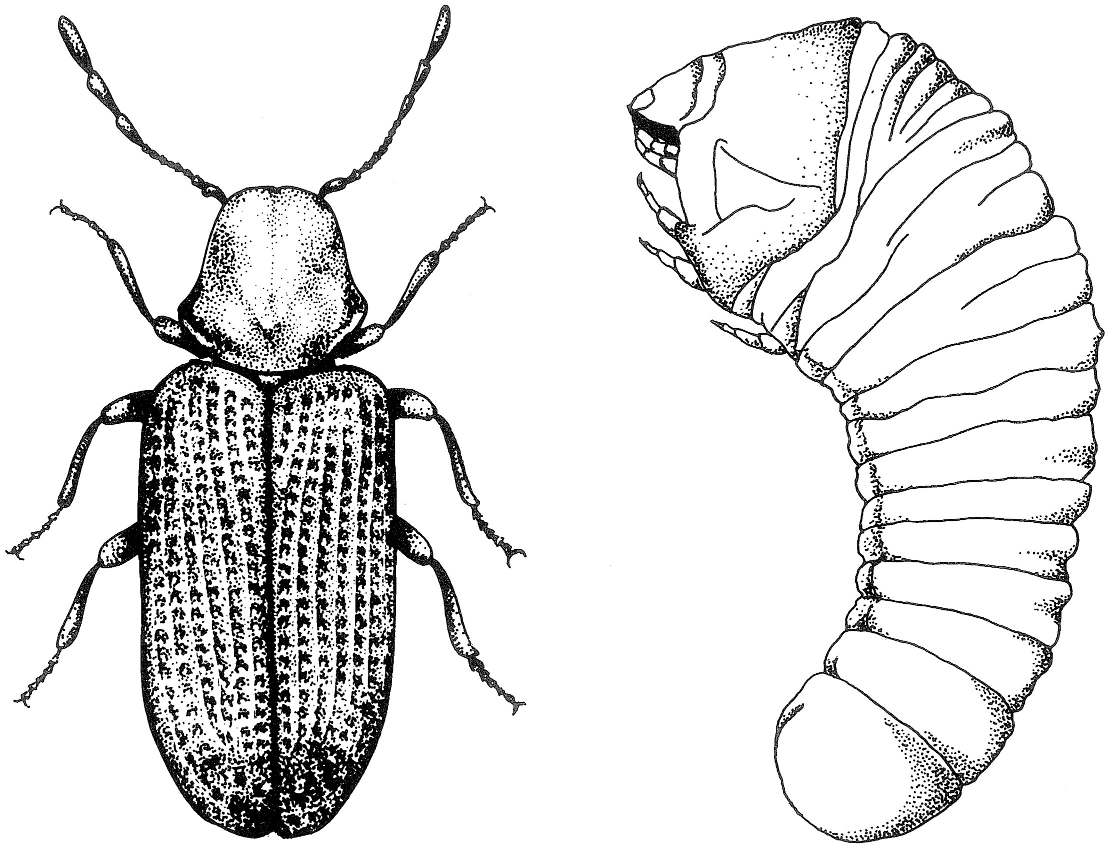
Lyctus attack causes serious economic losses of timber in Australia, and in two States, N.S.W. and Queensland there is legislation which deals with the sale, and preservation, of *Lyctus* susceptible sapwood. A comprehensive list of *Lyctus* susceptible timber species has been prepared by Fairey (1975), and publications on the beetle and its control may be obtained from the State Forest Services, or C.S.I.R.O.





M. Kolotas after illustration supplied by the Forestry Commission of N.S.W.

Figure 7. *Lyctus brunneus*



M. Kolotas

Figure 8. *Anobium punctatum*

The custodian of artefacts should be familiar with *Lyctus* attack, know how to test for starch, and be familiar with suitable control measures. In this regard it must be emphasised that whilst effective fumigation or heat sterilization will kill existing infections it does not confer protection against future attack.

Other species and genera in the lyctid group which may be encountered in wood artefacts are *Lyctus planicollis* in timber from North America, *L. sinensis* from Japan, and an unnamed *Lyctus* from north eastern Australia. *Minthea* spp. including *M. rugicollis* and *Tristaria* spp., are also found occasionally, and the former species often occurs in materials from Asia.

Anobiids. Of this group the most important from a wood conservation viewpoint is *Anobium punctatum*, de Geer, the common furniture beetle. Hicken (1963) has described these insects in detail and there has been much research on their biology and control.

The life cycle is similar to that of *Lyctus.* The whitish eggs are laid in cracks or depressions on the surface of wood, especially on the end grain. The incubation time is about two to five weeks, but may vary, depending on local conditions, being shorter in humid weather. The larvae which emerge are white and about 6 mm long. These larvae bore directly into the wood, and in severe infestations may reduce the timber to a finely honeycombed appearance.

When the larvae have reached a sufficient size, and conditions are favourable, they tunnel very close to the surface, then turn back and enter the pupal stage. This may last from two to eight weeks, after which the adult beetle emerges. These immediately break through the thin surface layer already partly prepared by the larvae. The exit hole is circular in shape and may be about 2 mm in diameter. Although the number of exit holes does not give any indication of the extent of internal damage the arrangement of these holes does give some indication of the parts affected.

In Australia emergence usually takes place over a short period in November, and in the Northern Hemisphere between May and August. The adults then mate and the female lays her eggs, completing the cycle.

Infestations are favoured by high wood moisture content, the presence of decay, high starch content and cool to moderate temperature conditions. Lists of susceptible timbers may be obtained from the State Forest Services. *Anobium* is a weak flyer and in Australia nearly all infections are introduced into houses by medium of old infected furniture, packing cases, etc.

Other Insects

1. Bostrychids. This is a large family of wood-boring beetles which include 'shot-hole beetles' and some 'powder post' beetles other than the lyctids.

The general life cycle of bostrychids resembles that of the lyctids but the important difference is that these species bore into freshly felled logs to lay their eggs and no further infestation occurs once the timber is dried. Thus it is unlikely that active infestations would be encountered in a museum. The size of the surface holes made by this group varies from 2 mm to 5 mm and may be circular to oval in shape. One fact which conservators should remember is that emerging adult bostrychids tunnel to the outside of the wood, and thence straight through any reasonably soft obstructions in their way, such as plaster board, to reach the outdoors.

2. Pinhole Borers. These beetles bore in trees or logs to make tunnel systems of various stages of elaboration for egg laying, and the rearing of the larva. They belong to the families Lymexylidae, Platypodidae and Scolytidae, and are abundant in the tropics although some representatives are found in southern Australia. The adult females of most wood-boring members of this group carry spores of certain fungi which are called ambrosia fungi, which they use to infect their tunnel walls. The fungi serve as food for both adults and larvae, but there are many variations on this theme to suit particular host/insect situations. This group does not attack seasoned wood, even if it becomes wet, and existing infestations will not survive in timber with a moisture content below 30%.

Attack by some of these insects, because of the arrangement of the tunnels, and probably because of enzymatic degrade of the wood by the ambrosia fungi, render wood very brittle in horizontal planes across a tree. Such wood if incorporated into artefacts will also be very weak in thin planes parallel to each other at various distances apart. The edges of such tunnels are usually surrounded by a black halo of stained wood but this stain does not extend more than a few mm from the hole.

There are many other wood-attacking insects which occur from time to time in artefacts on which specialist advice should be sought, e.g. *Ernobius mollis, Hylotrupes bajulus, Sirex* spp. and the wood boring weevils.

Marine Borers. Damage due to marine borers may be found in artefacts which have been immersed in sea water. Visible damage does not necessarily indicate the extent of internal attack and where doubt exists the object should be X-rayed.

Marine borers fall into two main groups, the molluscs, which include teredinids and pholads, and the crustaceans which include *Limnoria* and *Sphaeroma.* Information on both groups is given in Nicholas (1973). Keirle (1975) and Gareth Jones and Eltringham (1968).

Molluscs burrow beneath the surface of the wood to produce a honeycomb effect; the extent of the damage cannot be estimated by the numbers of surface holes. The crustaceans attack wood from the surface inwards; as the outer layers of timber become eroded, they burrow more deeply thus progressively weakening the wood.

1. The Molluscs. Teredinids are also known as shipworms, or 'cobra'. Internal and external damage caused by these molluscs can be severe, but the intensity of attack cannot be used to date the time of immersion in sea water with any precision. The two main genera involved in Australian waters are *Teredo* and *Bankia.*

Teredinids begin life in the sea as free swimming larvae, which in the case of *Teredo* quickly settle on wood surfaces. *Bankia* larvae however may retain a free swimming habit for some time. These organisms produce long tunnels in the wood which are lined with a calcareous material. In these tunnels they undergo a change to a long worm like appearance and gather their food by a siphon system. At the same time the bivalve shell hardens to form a plug which can be used to close the burrows. The end result of this tunnelling is a honeycomb of burrows whose extent cannot be determined from the numbers of surface holes.

Pholads such as *Martesia* are widespread and destructive but do not actually feed on the wood. They are common in shallow water especially in areas where summer temperature are high. Unlike Teredinids this group retains a typical bivalve appearance, and its burrows are wider and shorter then those of *Teredo.*

2. The Crustaceans. Limnoria are crustaceans which attack wood from the surface inwards and as the outer layers of the timber are eroded they burrow more deeply thus progressively weakening the wood. *Sphaeroma* or pillbugs not only attack wooden objects but can bore into soft rock, and are more important as pests of timber in tropical waters.

When encountered in artefacts the problem is to determine whether some form of support or infiltration is required. In addition those artefacts taken freshly from the sea will contain much animal material which will continue to decompose until drying under carefully controlled conditions is carried out. Such artefacts must be kept dry at all times since they are good sources of food for mould fungi. An expert may be able to tell from an examination of the artefact something as to the likely area of exposure, e.g. in a warm, shallow tropical bay, cold temperate estuary, or brackish water. However, it should be recognised that many marine borers are of wide distribution and such conclusions need to be treated with great caution.

Institutions Carrying Out Extensive Research Into The Properties Of Wood

Wide Spectrum Research

1. Biodegradation, preservation, identification, effects of fire, utilisation, chemistry and physics of wood, engineering aspects of wood use, surface finishes.

Division of Building Research, C.S.I.R.O., Graham Road, Highett, Victoria, 3190.

Wood Technology and Forest Research Division, Forestry Commission of N.S.W., Oratava Avenue, West Pennant Hills, N.S.W.

Forest Products Research Branch, Queensland Department of Forestry, 388-400 Ann Street, Brisbane, Queensland.

The Forest Products Research & Development Centre, Department of Forests, P.O. Box 1358, Boroko, Papua/New Guinea.

Forest Research Institute, N.Z. Forest Service, Private Bag, Rotorua, New Zealand.

2. Specialist aspects of wood use and deterioration – Partial list only.

Division of Entomology, C.S.I.R.O., Black Mountain Laboratories, Clunies Ross Street, Acton, A.C.T., 2601. Termite biology and identification.

Department of Health, Plant Quarantine Branch, Canberra, A.C.T. For information on all aspects of plant quarantine. Reporting centre when living insects are found in imported wooden artefacts.

Division of Chemical Technology, C.S.I.R.O., 69 Yarra Bank Road, South Melbourne, Victoria, 3205. Pulp and paper.

Australian Museum, College Street, Sydney, N.S.W. 2000. Identification of marine borers.

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