

This document has been scanned from hard-copy archives for research and study purposes. Please note not all information may be current. We have tried, in preparing this copy, to make the content accessible to the widest possible audience but in some cases we recognise that the automatic text recognition maybe inadequate and we apologise in advance for any inconvenience this may cause.

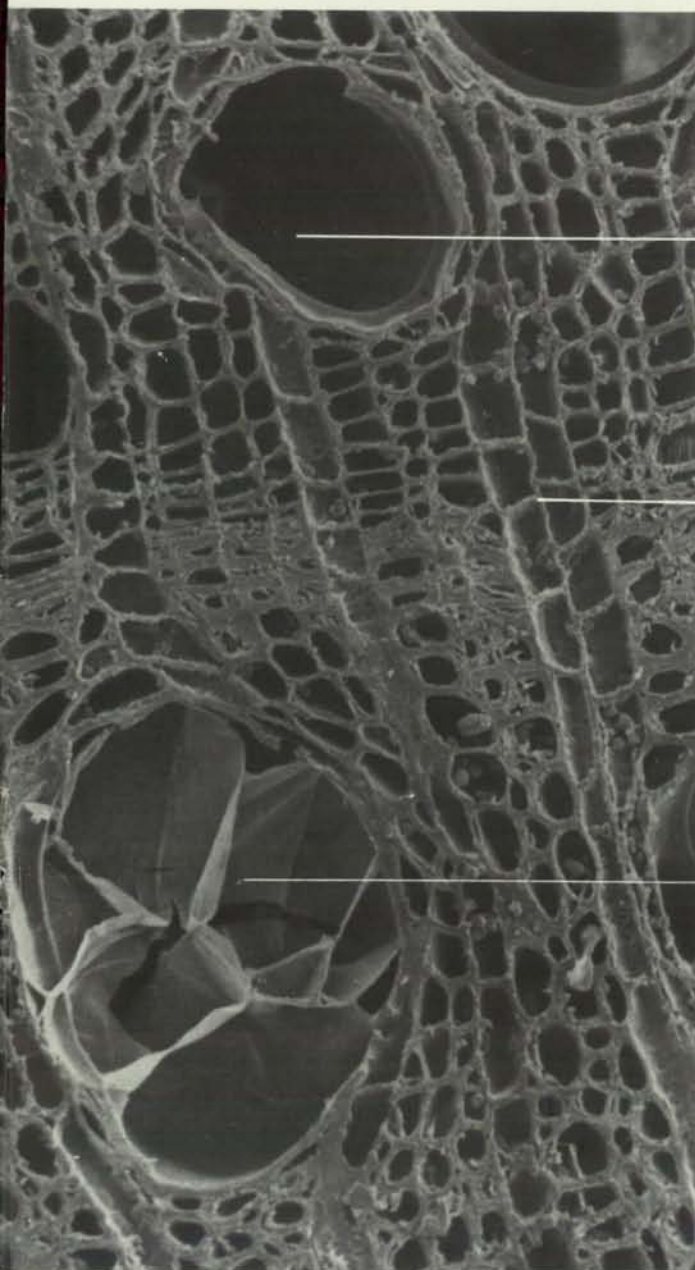


Published 1961 (Bulletin)
Revised 1964 (Technical Publication)
Revised 1974, 1977
Reprinted 1979, 1981, 1983
Revised 1987

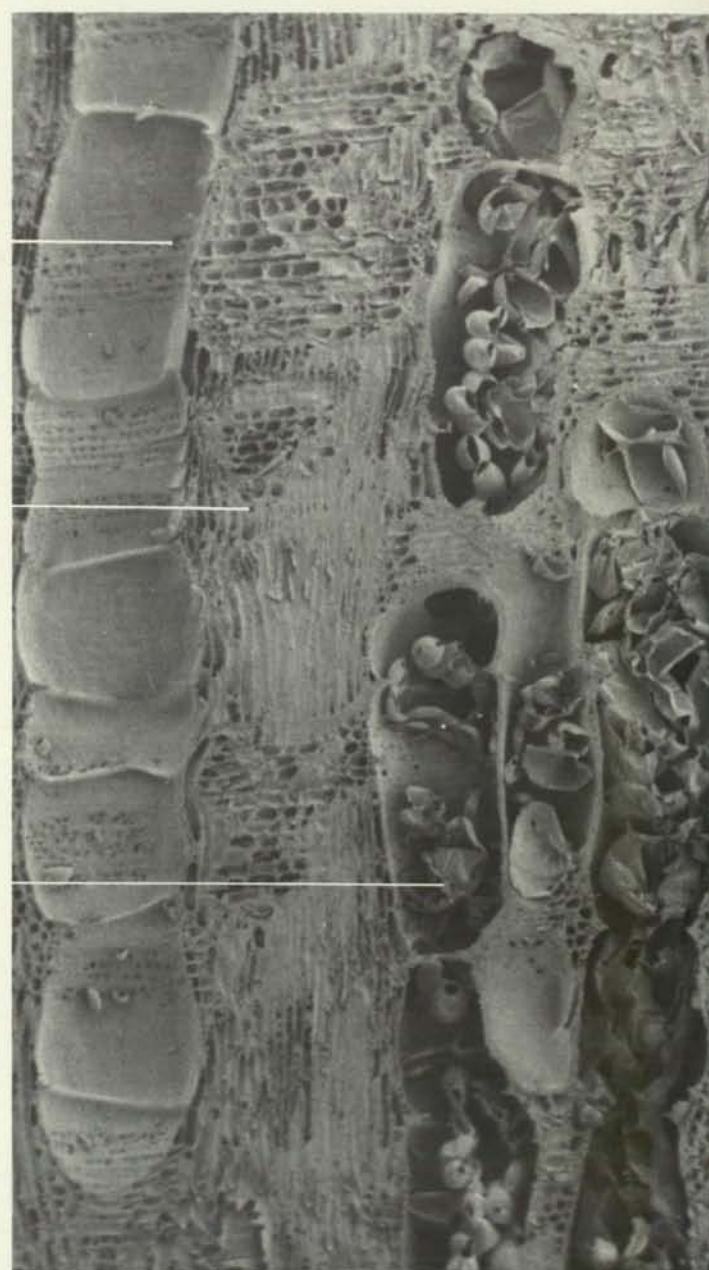
ISBN 0 7240 2067 5
ISSN 0155-7548
ODC 811.5

Sapwood and Heartwood

by
R. K. Bamber



(a)



(b)

Scanning electron micrographs of sapwood/heartwood boundary in *Eucalyptus saligna*. (a) Transverse surface, $\times 400$;
(b) Radial longitudinal surface, $\times 90$

In most trees two types of wood can be recognised, sapwood and heartwood. Sapwood is the outer, pale-coloured wood and heartwood the inner, mostly darker, wood. Because of its susceptibility to fungi and wood destroying insects and lack of colour, sapwood is generally considered inferior to heartwood and is often discarded during conversion.

However, by use of the appropriate preservative treatment, sapwood can be made equal if not superior to heartwood of the same species in durability, thus reducing waste and in addition enabling the marketing of species with little or no heartwood. It is possible, if the properties of sapwood are well understood, to use untreated sapwood of many species in numerous situations with safety.

To assist in the best utilisation of sapwood, the properties of sapwood and heartwood are reviewed, with emphasis being given to the function, determination of sapwood and heartwood, relative strengths, durability and utilisation.

FUNCTION OF SAPWOOD AND HEARTWOOD IN THE LIVING TREE

Sapwood has three main functions in the living tree: support, conduction and storage. Support for the tree is provided by the tracheids in the softwoods (conifers, Figure 1) and by the fibres in the hardwoods (flowering plants, Figure 2). These are the most abundant wood cells and can constitute as much as 95 per cent of the total wood volume. Conduction of water and mineral salts from the roots to the leaves occurs in the sapwood by means of the vessels in hardwoods and tracheids in the softwoods. The sapwood is so well evolved for conduction that sawcuts can be made past the centre of a tree from opposite sides at different levels without halting the flow of water to the leaves. The sapwood serves as a store for food reserves usually in the form of starch. These reserves originate from the sugars produced by the photosynthesis in the leaves, the sugars being translocated down through the phloem tissue and then inwards by the ray parenchyma tissue (Figure 3), and then transformed into starch grains in the axial and ray parenchyma cells (Figure 4). The starch grains may be reconverted back into soluble sugars to satisfy food requirements for growth. The starch reserves are known to be greatly depleted during periods of intense growth of the crown and can be completely resorbed when such growth occurs after fire or insect defoliation. Once the tree is felled and the wood dried, the starch is retained in the wood cells as a permanent deposit. No economic process for removing the starch deposits from wood has been successfully demonstrated. Great variations in the amounts of starch occur both between and within species.

In contrast to the sapwood heartwood has no living cells and neither conducts water or stores reserve materials. Heartwood does not appear to be essential for the growth and survival of trees. While it does provide the main structural support for most trees this role could have been adequately provided if it had remained as sapwood.

It has been suggested that heartwood forms as a repository for waste metabolic products (polyphenolics or tannins) or for surplus photosynthates. It is more likely, however, that heartwood forms to keep the amount of sapwood at an optimum thus conserving the nutritional balance in the living part of the tree as it is well

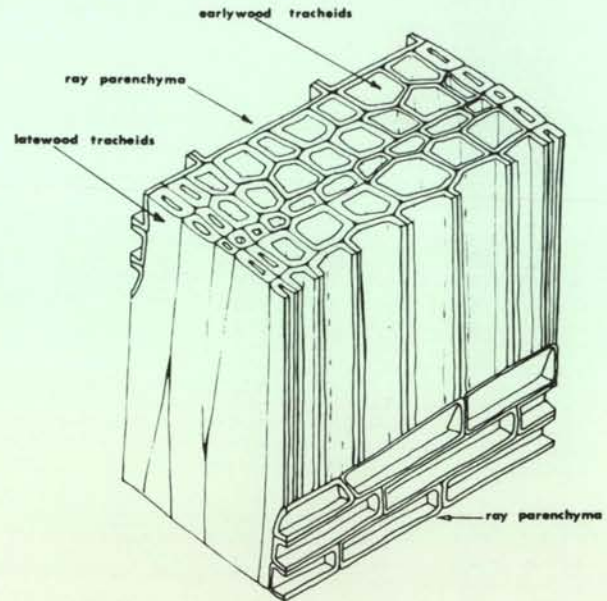


Figure 1. Simplified drawing of a cube of softwood magnified about 250 times. The cell wall pits have been omitted

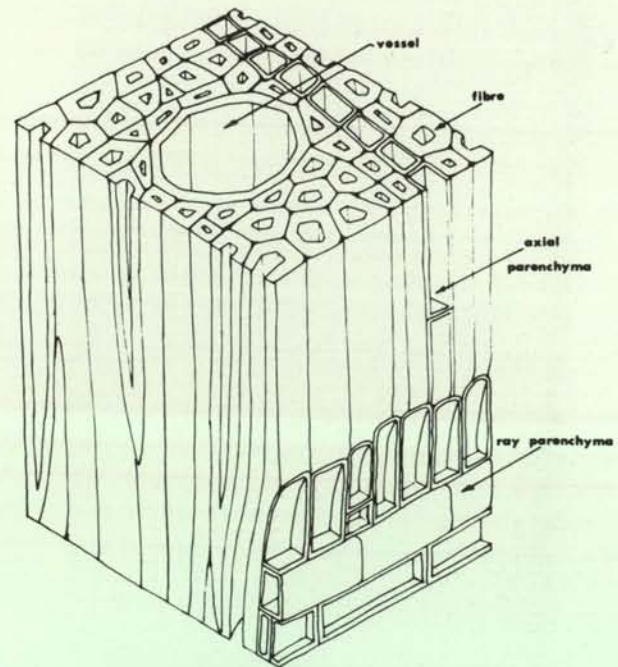


Figure 2. Simplified drawing of a cube of hardwood on the same scale as Figure 1. Cell wall pits again omitted

known that potassium, phosphorus, nitrogen and sulphur are resorbed from the sapwood as it is transformed into heartwood. Elements not resorbed are lost until the tree dies, decays and becomes part of the forest humus. The larger the tree the larger the amount of nutrients which could be locked up in this way.

FORMATION OF SAPWOOD AND HEARTWOOD

Wood cells are produced by a layer of cells between the living bark (phloem) and the wood (Figure 3). This layer is called the cambium and can be seen only with a microscope. Cells which form on the inside of the cambium become wood and those on the outside phloem. Once wood cells are laid down by the cambium, they rapidly differentiate in size and shape until finally a thickened wall is formed, the process being completed within a millimetre or so from the outer wood layers. After the thickened wall is produced, the cells remain largely unaltered in shape for the life of the tree. The wood cells thus produced by the cambium become the sapwood.

The ray and axial parenchyma cells remain alive in the sapwood, while the more specialised wood cells, the fibres, vessels and tracheids, lose their living contents soon after differentiation and thickening of the cells are completed.

Changes in the nature of the sapwood occur with the death of the parenchyma cells and with the completion of these changes heartwood is produced. These changes occur gradually through a layer of cells of variable width known as the transition zone. In this zone increased amounts of so called tannins (polyphenolics) and coloured materials of many types are deposited in the ray and axial parenchyma and these materials diffuse into the surrounding tissue (Figure 5). The development of heartwood colour is due to this deposition.

The development of heartwood colour is the most spectacular change between sapwood and heartwood. While a great number of timbers do not produce coloured heartwood extractives the large majority of species show some evidence of doing so. Heartwood colours range from white to cream as in southern silver ash, alpine ash and European ash, to black in ebony, olive-green in lignum vitae, yellow-orange in osage orange, brown in tallowwood and red in red ironbark. Most of the colours undergo a change with age, becoming darker and more brown. Frequently the heartwood substances are unevenly distributed giving rise to bands of wood of different colour. Such banded or striped effects are evidently related to the growth conditions as they occur concentrically with the growth rings (Figure 6).

In hardwoods, as well as the production of tannins and other materials, changes occur in the vessels which become blocked on heartwood formation. This blocking of the vessels takes place by means of the pits. Pits occur abundantly in all wood cell walls and are well-defined thin regions in the wall through which solutions can readily diffuse from one cell to another (Figure 7). In species with larger pits, blockage of the vessels occurs as a result of the growth of adjacent parenchyma cells through the pit forming balloon-like structures in the vessels. These growths are known as tyloses. In species with small pits, blockage of the vessels occurs due to the secretion by the ray parenchyma of tannin or gum-like materials through the pits. This deposition of materials can also occur in the species with large pits along with tyloses. Tyloses are common in the eucalypts and the merantis whereas tannin-like materials are common in the mahoganies, true Australian red cedar and Queensland maple.

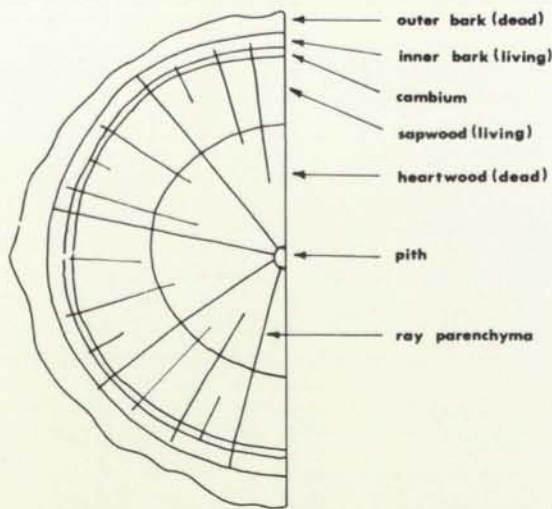


Figure 3. Cross section of tree trunk showing the relationship of the various tissues

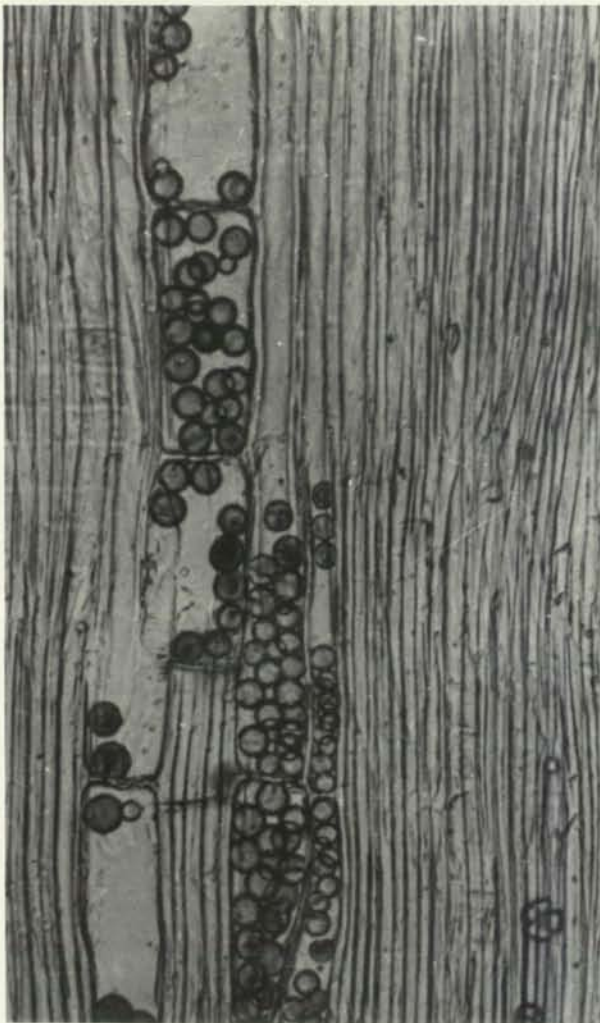


Figure 4. Photomicrograph of radial longitudinal section of *Angophora costata* smooth-barked apple. Magnification $\times 270$. Starch bodies can be seen as spherical bodies in the axial parenchyma

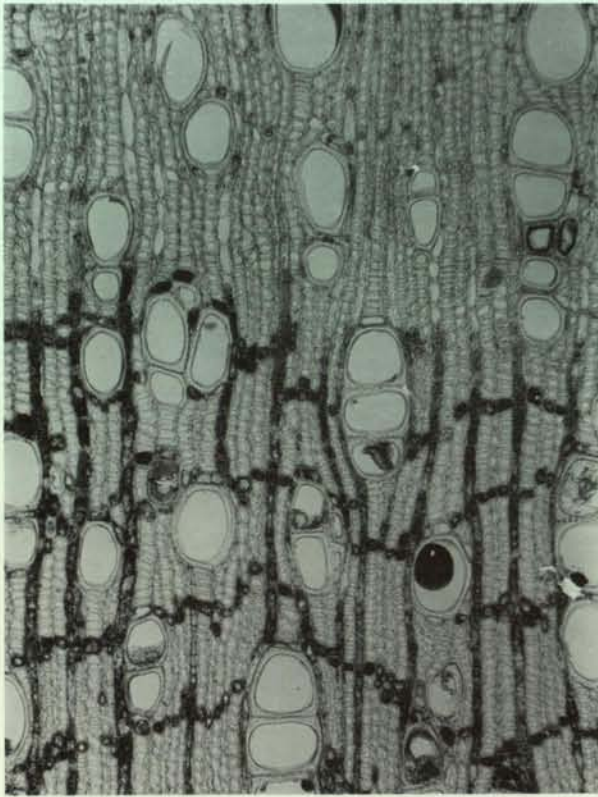


Figure 5. Photomicrograph of a transverse section of *Excoecaria parufolia*. Magnification $\times 150$. The deposition of coloured heartwood material in the parenchyma cells can be seen

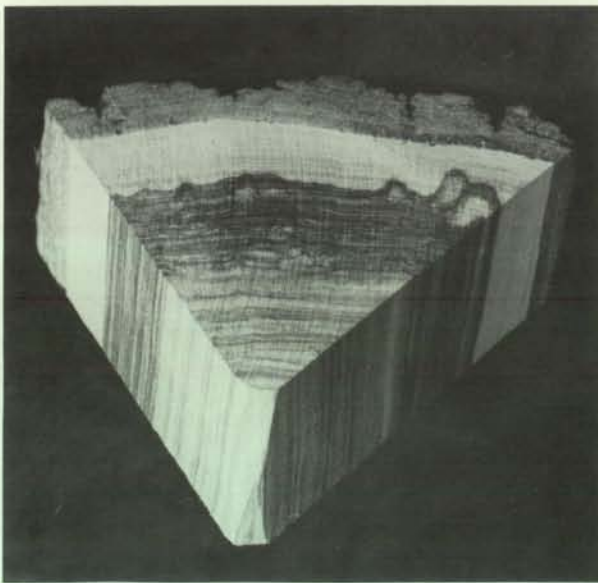


Figure 6. Photograph of tree segment of *Callitris columellaris* white cypress pine. The irregular line of heartwood formation can be seen on the end face

In softwoods, blockage of the tracheids on heartwood formation can occur either by closing of the pits (aspiration) or by the increased deposition of resins and tannins. The pit membrane of a tracheid is a specialised structure consisting of a thickened centre (torus) supported by a cellulose web, the web being flexible and allowing the torus to move and close (aspirate) the pit opening (Figure 7).

Aspiration is confined to the pits of the earlywood tracheids, latewood pits remaining open. Latewood tracheids appear to be specialised structural cells not conducting cells. They have narrow lumens and thick cell walls and are formed near the end of the growing season. Earlywood tracheids have wide lumens and thin cell walls and are formed in the first part of the growing season.

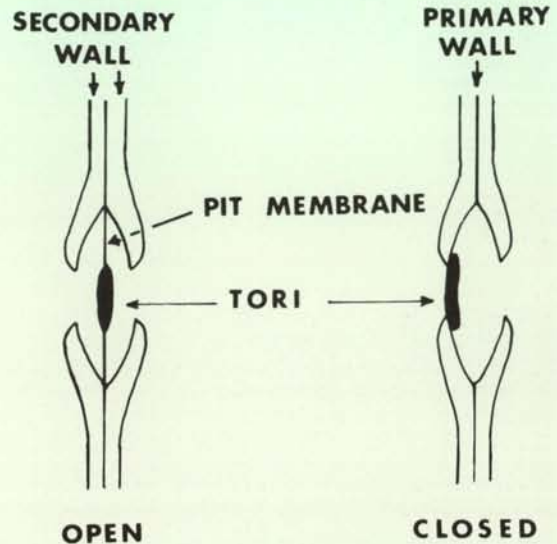


Figure 7. Diagrammatic representation of a pair of pits in the walls of two adjacent tracheids approximately. Magnification $\times 2000$

WIDTH OF SAPWOOD

The width of the sapwood depends primarily on the longevity of the parenchyma cells. It is subject to great variation between species and minor variation between individuals of the one species and even within the individual. While the sapwood width seems regular along the grain, it is apt to show fluctuations around the growth ring (Figure 6). In radiata pine the sapwood may be wider than 200 mm, while in eucalypts it is typically less than 50 mm. Table 1 lists measurements obtained from 14 species.

Some trees, such as flame kurrajong, do not have a coloured heartwood or blocked vessels. The fact that starch is frequently detected well into the heart of these logs indicates that parenchyma cells are able to remain alive for long periods.

Variation in sapwood width within a species has been related to many factors, some of which are:

- *Rate of growth.* It seems fairly evident that the width of sapwood would be wider in dominant than in suppressed trees.
- *Environment.* It also seems fairly evident that the width of sapwood would be wider in the more favourable environment; however, it has been suggested that heartwood formation is encouraged by favourable water relations in radiata pine.

- *Position in tree.* Sapwood widths remain fairly constant with height. It can be seen therefore, due to the natural taper of a tree, that the proportion of sapwood to heartwood increases with height.
- *Age.* Young trees have wider sapwood than old trees.

It is important to note that once the tree has commenced to lay down heartwood the volume of sapwood in proportion to heartwood becomes less as the tree becomes older. Consequently the production of wood with the least amount of heartwood such as required by the paper industry is favoured by rapid growth and early harvesting whereas the production of wood with a minimum volume of sapwood such as required for exterior uses is encouraged by slower growth and later harvesting.

SUSCEPTIBILITY OF TIMBERS TO BORER ATTACK

Infestations by almost all timber borers are either limited to the sapwood or else sapwood is infested in preference to heartwood. This is undoubtedly due to the presence of food materials such as starch and the absence of unpalatable and perhaps toxic heartwood substances.

Two common groups of borers, lyctids and bostrychids, both limit their infestation to the sapwood and are discussed below.

The Lyctid Borer

These borers are members of the family *Lyctidae* which are commonly known in Australia as powder post beetles. They only attack partially or wholly seasoned sapwood of hardwoods. The susceptibility of timbers to attack is governed by several factors. The first factor is the ability of the borer to obtain access into the wood for egg-laying. For example the common lyctid borer of New South Wales, *Lyctus brunneus*, cannot infest the wood if the diameters of the vessels of the timber are too small for the beetle to insert its egg laying organ (ovipositor).

For practical purposes timbers with vessel diameters less than 0.09 mm are considered to be resistant to *L. brunneus* attack. Softwoods do not have vessels and are considered to be immune to lyctids. Attack on softwoods has not been recorded in Australia.

Once access to the timber is made through the vessels then the degree of damage by the lyctids is largely dependent on the concentration of the starch deposits. Where starch is absent infestation does not occur and immunity is assured.

Further information on the lyctid borer is continued in Forestry Commission of New South Wales Technical Publication No. 18 *Timber Borers of Common Occurrence* and Technical Publication No. 19 *Lyctus Susceptibility of the Commercial Timbers used in New South Wales*.

The Bostrychid Borer

These borers may attack timber as soon as it is felled and during seasoning. Seasoned timber and timber of low moisture content are not attacked. However if bostrychid larvae are already present in such timber they may continue to feed and work and adult insects may later emerge. Bostrychid infestation of the sapwood may be followed by lyctid infestation when the timber is seasoned.

In New South Wales attack by bostrychid appears to be confined to the sapwood of hardwoods. In contrast with lyctid infestation it is not limited by the presence in the wood of vessels of a certain size as the bostrychid eggs are laid in tunnels in the sapwood. These tunnels, which are often "L" shaped, are bored by the adult bostrychid.

DURABILITY

The greater durability of heartwood over sapwood is attributed to the presence of extraneous materials (described earlier) which are deposited during the transition from sapwood to heartwood. Extraction of these extraneous heartwood substances with suitable solvents reduces the resistance of heartwood to fungal decay.

Sapwood is also more susceptible to attack by surface moulds than is heartwood. Similar measures to those used for the control of sap stain fungi will prevent the growth of surface moulds.

In the case of untreated poles, it is customary to remove the sapwood from the portion which enters the ground to about 45 cm above ground level as the sapwood may encourage termites or the growth of fungi. Also the loss of the sapwood while the pole is in the ground would allow it to loosen. The sapwood is frequently left on the upper part of the pole and although it may ultimately be lost by insect or fungal attack, it protects the outer heartwood from the weather for such time as it remains. Because sapwood is relatively free of deposits it can be readily impregnated with preservatives by means of pressure methods. This allows the sapwood to be retained over the whole tree.

Cypress pine flooring enjoys great popularity, partly because of the resistance of the heartwood to fungi and termites. However, because of the relatively small diameter of the trees and the fairly wide sapwood it is found in practice that most cypress flooring contains a considerable proportion of sapwood. If correct building practice is followed the presence of sapwood in cypress pine flooring is quite acceptable and because of the colour contrast may enhance the appearance of the floor.

The blocking of the vessels by tyloses or gum-like materials which characterises heartwood appears to restrict the development of many fungi. The blocking of the vessels could mechanically impede the free progress of fungi or restrict the diffusion of gases. Fungal attack on dense timbers appears to be retarded due to the diminished oxygen and accumulated carbon dioxide around the hyphae.

SEASONING

Despite the higher moisture content of the sapwood it is found in practice that it seasons in much the same time as heartwood, the lack of deposits and tyloses allowing a much more rapid loss of moisture than is possible in heartwood. In regard to the relative shrinkage of heartwood and sapwood, there appears to be only a small difference between the two. While checking often appears first on the outside of a log, this may be due to rapid water loss there and by the radial checks becoming larger towards the outside with the increasing circumference.

STRENGTH

In most species there is no significant difference in the strength of sapwood and heartwood. This is because the cell wall becomes fully thickened and lignified very close to the cambium, as noted earlier. While sapwood may exhibit some greater flexibility in the green condition, this will disappear on drying. It is well known, however, that brittleness is associated with older wood near the centre of the tree, and so sapwood would be less liable to brittleness than the heartwood. The outer heartwood and the sapwood are normally free from brittle heart.

In certain uses, requiring high strength, for example, axe handles (hickory *Carya* spp.) and cricket bats (willow *Salix alba*, sapwood is preferred to heartwood. This is largely a "customer" preference for the even white appearance of the sapwood.

In some timbers which have large amounts of extractives deposited during heartwood formation, a small increase in the strength of the heartwood is found (e.g. redwood *Sequois sempervirens*). With redwood removal of the heartwood extractives of this species with solvent results in a loss of strength to values approaching that of the sapwood.

UTILISATION

Provided the sapwood is immune or resistant to lyctid borer and the situation does not require a durable timber then sapwood is structurally equivalent to heartwood.

In situations requiring a pale-coloured timber free of extractives and tainting substances, sapwood is preferred to heartwood; for example, wooden spoons, pulpwood, and food containers. Sapwood is also more desirable where complete impregnation with preservative is required. This allows the utilisation of smaller trees such as thinnings for fence posts, poles and other uses where high durability is a desirable feature.

Being pale in colour sapwood can be readily stained to match coloured heartwood. If the sapwood has been infested with sap stain fungi this will not be successful as the grey colour imparted to the sapwood by the fungi is permanent.

Sapwood is utilised extensively in the manufacture of plywood. It peels and glues as satisfactorily as heartwood and is readily penetrated by preservatives (dip diffusion process).

DETERMINATION OF SAPWOOD AND HEARTWOOD

Sapwood becomes heartwood with the death of the parenchyma. It is difficult however to show, even with the most sophisticated techniques, the precise zone where this takes place. It is possible by using some of the other properties which change from sapwood to heartwood to obtain a fairly reliable estimate of the sapwood/heartwood boundary. Some of these are described below:

- *Colour.* The development of heartwood colour in many species gives a good indication, although in some species the transition zone tends to be wide, merging slowly into heartwood.
- *Starch.* The presence of starch indicates that the wood is sapwood; however, its absence does not indicate heartwood. Starch may be detected by the blue-black colour with iodine/potassium iodide solution. Refer to the Forestry Commission of New South Wales Wood, Technology Leaflet No. 8 *Preparation and Care of Iodine Solution for Starch Tests.*
- *Colour reactions of wood material.* A number of chemicals are known to give quite spectacular colour changes between heartwood and sapwood. Some of these chemicals are listed in Appendix I. Table 2 lists some reactions obtained using six chemicals.
- *Acidity.* In certain eucalypts the acidity increases from pH5 to pH4 from sapwood to heartwood.
- *Penetration of stained solution.* The differential penetration of a stained solution (for example, 0.5 per cent alcoholic safranin) into the end grain of dried timber allows reasonable detection, the stain being absorbed more readily by the sapwood than the heartwood.
- *Tyloses.* The presence of tyloses is easily detected on cleanly cut end grain by examination with a 10x hand lens; however, it is possible for tyloses to form abnormally following certain stimuli such as axe-cuts, or chemical treatment of the tree. Its absence certainly indicates sapwood in the species which normally develop tyloses.

Tests for heartwood such as colour reactions and acidity can only be relied upon where the wood is unaffected by rot, leaching, of some other agency likely to alter the chemical constituents of the wood. It is also important to realise that the measurement of sapwood width may vary somewhat between methods.

Table 1. Sapwood widths of some Australian Timbers

Botanical name	Common name	Approximate width of sapwood in millimetres*
<i>Acacia pendula</i>	Myall	6 average
<i>A. doratoxylon</i>	Lancewood	3 average
<i>Eucalyptus acmenioides</i>	White mahogany	9-16
<i>E. saligna</i>	Sydney blue gum	6-25
<i>E. paniculata</i>	Grey ironbark	16-38
<i>E. obliqua</i>	Messmate stringy bark	22-30
<i>E. microcorys</i>	Tallowwood	12-38
<i>E. gummifera</i>	Red bloodwood	16-38
<i>E. maculata</i>	Spotted gum	25-50
<i>Angophora costata</i>	Smooth barked apple	25-60
<i>Callitris spp.</i>	Cypress pine	25
<i>Schizomeria ovata</i>	White birch	75
<i>Pinus radiata</i>	Monterey pine	100
<i>Brachychiton acerifolium</i>	Flame tree	No heartwood known

*These measurements have been obtained from a limited number of samples.

Table 2. Colour indicators for sapwood and heartwood (See Appendix I for formulations)

Reagent	Species*	Colour	
		Sapwood	Heartwood
Bromcresol blue	<i>E. viminalis</i>	Green	Yellow
Dimethyl yellow	<i>E. maculata</i>	Yellow	Red
Vanillin sulphuric acid (alcoholic)	<i>E. viminalis</i>	Red	Purple-brown
Ferric chloride (aqueous)	<i>Shorea spp.</i>	Red	Purple-brown
Ferric chloride (methanolic)	<i>E. viminalis</i>	Blue	Blue-black
Silver nitrate (ammoniacal)	<i>E. viminalis</i>	Green-blue	Blue-black
	<i>E. viminalis</i>	Brown	Blue-black

*These are timbers with which the reagents have been used with success. The reagents will no doubt be applicable to many other species.

Forestry Commission of New South Wales photofile numbers:

- Figure 1: SB 9608
- Figure 2: SB 9607
- Figure 3: SB 9609
- Figure 4: SA 3734/2
- Figure 5: MP 250
- Figure 6: SA 3739
- Figure 7: SB 9610

APPENDIX I

A number of these formulations are poisonous and it is recommended that they be made up by qualified people and used with care.

Potassium iodide — iodine solution

- 1.0 g potassium iodide
- 0.5 g iodine crystals
- 98.5 ml water

Dissolve the potassium iodide in a little of the water, add the iodine and stir until dissolved and then add the remainder of the water. Additional information about this solution is available in *Preparation and Care of Iodine Solution for Starch Tests*. Wood Technology leaflet, W.T.8 of the Forestry Commission of New South Wales.

Sodium nitrite

- 10 per cent aqueous solution

Ferric chloride (aqueous)

- 10 per cent aqueous solution

Ferric chloride (methanolic)

- 10 per cent ferric chloride in a 50 per cent solution of methanol

Silver nitrate (ammoniacal)

- 14 g silver nitrate
- 100 ml water
- 6N ammonium hydroxide

Dissolve silver nitrate in the water, add ammonium hydroxide until the silver oxide which precipitates out just redissolves.

Vanillin sulphuric acid (alcoholic)

- Solution A
- 250 ml water
- 436 ml conc. sulphuric acid
- 425 ml absolute ethanol

Add the sulphuric acid to the water carefully and cool before adding to the ethanol.

Solution B

- 5 per cent solution of vanillin in 100 per cent ethanol

Mix 4 parts of solution A with 1 part of solution B keeping mixture at 25°C while being made.

Bromcresol blue

- 0.1 per cent solution in 80 per cent ethanol

Dimethyl yellow

- 0.1 per cent solution in 80 per cent ethanol

This publication may be reproduced in full provided acknowledgement is made to the Forestry Commission. Extracts may not be published without prior reference to the Forestry Commission of New South Wales.