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# IAWA LIST OF MICROSCOPIC FEATURES FOR HARDWOOD IDENTIFICATION

with an Appendix on non-anatomical information

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## PREFACE

This list of microscopic features for hardwood identification is the successor to the 'Standard List of Characters Suitable For Computerized Hardwood Identification' published in 1981 (IAWA Bulletin n. s. 2: 99–145) with an explanation of the coding procedure by R.B. Miller. The 1981 publication greatly stimulated international exchange of information and experience on characters suitable for hardwood identification, and inspired considerable debate on the most desirable coding procedures and identification programs. Therefore, at the IAWA meeting during the XIV International Botanical Congress in Berlin, July 1987, it was decided to revise the 1981 standard list. Because of the continuing developments in computer technology and programming, it was agreed to limit the scope of the new list to definitions, explanatory commentary, and illustrations of wood anatomical descriptors, rather than concentrate on coding procedures.

A new Committee was appointed by the IAWA Council to work towards the new list, and thanks to a substantial grant from the USDA Competitive Research Grants – Wood Utilization Program (Grant No. 88-33541-4081), a workshop was held by the Committee from October 2–7, 1988, in the Department of Wood & Paper Science, North Carolina State University, Raleigh, NC, USA, under the joint auspices of IAWA and IUFRO Division 5. A preliminary list was prepared during the workshop. IAWA members were invited to comment on this list, and these comments helped with the final preparation of the new list. The list presented here was agreed to after review of subsequent drafts and extensive internal consultation between committee members.

Although this list has 163 anatomical and 58 miscellaneous features, it is not a complete list encompassing all the structural patterns that one can encounter in hardwoods. Instead it is intended to be a concise list of features useful for identification purposes. Also, the numbers assigned to each feature in the present list are not meant to be codes for a computer program, but are intended to serve for easy reference, and to help translate data from one program/database to another.

Wood and wood cells are biological elements, formed in trees, shrubs, and climbers to fulfill a physiological or mechanical function. Although there is more discrete diversity in wood structure than in many other plant parts, there is also much continuous variation, and any attempt to classify this diversity into well-defined features has an artificial element. Yet we are confident that in the feature list presented here ambiguity of descriptors has been limited to a minimum, and we hope that all present and future colleagues engaged in wood identification and descriptive wood anatomy will find this list a valuable guide and reference.

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## EXPLANATORY NOTES

**Quantitative Features** — For quantitative features of general applicability (e.g., vessel frequency, tangential vessel lumen diameter, vessel element length, and fibre length), this list includes broad categories for easy use when identifying unknowns, as well as more precise quantitative descriptors (mean, range, standard deviation). When constructing a database the numbers of samples as well as the number of measurements or counts done per sample should be recorded. Different computer programs allow storage of different amounts of information (e.g., all measurements, or just the means, ranges, and standard deviations), and use different algorithms for matching quantitative features. This publication does not recommend a particular program or a particular method for the storage and retrieval of quantitative data, but provides some guidance on how to obtain these data.

**Variable Features and Relative Abundance** — Because of wood's inherent variability, it is inevitable that some features will be well-defined in some samples while absent or ill-defined in other samples of the same species. Accommodating such variability has always been a problem in key construction, and most keys (computerised or otherwise) have provisions for such situations. Describing relative abundance of some features, e.g., prismatic crystals, is also problematic, and textual comments on relative frequency should be added to a description or database. In this list of descriptors, some features apply only when the characteristic is of common occurrence. For such features, the illustrations and examples are intended to help interpret 'common'. Although many keys have used these same features accompanied by the same qualifier 'common', there have been no extensive systematic analyses to determine what per cent occurrence constitutes 'common'. Therefore no quantitative criteria for 'common' have been offered in this list.



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### Name

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2. Growth ring boundaries indistinct or absent

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25. Small — 4–7  $\mu\text{m}$
26. Medium — 7–10  $\mu\text{m}$
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28. Range of intervessel pit size ( $\mu\text{m}$ )

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29. Vestured pits

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30. Vessel–ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell
31. Vessel–ray pits with much reduced borders to apparently simple: pits rounded or angular
32. Vessel–ray pits with much reduced borders to apparently simple: pits horizontal (scalariform, gash-like) to vertical (palisade)
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Mean tangential diameter of vessel lumina

40.  $\leq 50 \mu\text{m}$
41. 50–100  $\mu\text{m}$
42. 100–200  $\mu\text{m}$
43.  $\geq 200 \mu\text{m}$
44. Mean, +/- Standard Deviation, Range,  $n = x$
45. Vessels of two distinct diameter classes, wood not ring-porous

***Vessels per square millimetre*** — p. 259

46.  $\leq 5$  vessels per square millimetre
47. 5–20 vessels per square millimetre
48. 20–40 vessels per square millimetre
49. 40–100 vessels per square millimetre
50.  $\geq 100$  vessels per square millimetre
51. Mean, +/- Standard Deviation, Range,  $n = x$

***Mean vessel element length*** — p. 259

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53. 350–800  $\mu\text{m}$
54.  $\geq 800 \mu\text{m}$
55. Mean, +/- Standard Deviation, Range,  $n = x$

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56. Tyloses common
57. Tyloses sclerotic
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59. Wood vesselless

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60. Vascular/vasicentric tracheids present

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**Septate fibres and parenchyma-like fibre bands** — p. 266

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- 66. Non-septate fibres present
- 67. Parenchyma-like fibre bands alternating with ordinary fibres

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- 68. Fibres very thin-walled
- 69. Fibres thin- to thick-walled
- 70. Fibres very thick-walled

**Mean fibre lengths** — p. 269

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- 72.  $900\text{--}1600 \mu\text{m}$
- 73.  $\geq 1600 \mu\text{m}$
- 74. Mean,  $\pm$  Standard Deviation, Range,  $n = x$

**Axial parenchyma** — p. 270

75. Axial parenchyma absent or extremely rare

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- 77. Axial parenchyma diffuse-in-aggregates

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  - 81. Axial parenchyma lozenge-aliform
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- 84. Axial parenchyma unilateral paratracheal

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- 87. Axial parenchyma reticulate
- 88. Axial parenchyma scalariform
- 89. Axial parenchyma in marginal or in seemingly marginal bands

**Axial parenchyma cell type/strand length** — p. 280

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- 91. Two cells per parenchyma strand

- 92. Four (3–4) cells per parenchyma strand
- 93. Eight (5–8) cells per parenchyma strand
- 94. Over eight cells per parenchyma strand
- 95. Unlignified parenchyma

**Rays** — p. 282

**Ray width** — p. 282

- 96. Rays exclusively uniseriate
- 97. Ray width 1 to 3 cells
- 98. Larger rays commonly 4- to 10-seriate
- 99. Larger rays commonly > 10-seriate
- 100. Rays with multiseriate portion(s) as wide as uniseriate portions

**Aggregate rays** — p. 284

- 101. Aggregate rays

**Ray height** — p. 284

- 102. Ray height > 1 mm

**Rays of two distinct sizes** — p. 286

- 103. Rays of two distinct sizes

**Rays: cellular composition** — p. 288

- 104. All ray cells procumbent
- 105. All ray cells upright and/or square
- 106. Body ray cells procumbent with one row of upright and/or square marginal cells
- 107. Body ray cells procumbent with mostly 2–4 rows of upright and/or square marginal cells
- 108. Body ray cells procumbent with over 4 rows of upright and/or square marginal cells
- 109. Rays with procumbent, square and upright cells mixed throughout the ray

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- 110. Sheath cells

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- 111. Tile cells

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- 112. Perforated ray cells

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- 113. Disjunctive ray parenchyma cell walls

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**Wood rayless** — p. 297

- 117. Wood rayless

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- 120. Axial parenchyma and/or vessel elements storied
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***Tubes / tubules*** — p. 306

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- 144. Druses present
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**Other crystal types** — p. 313

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- 153. Crystal sand

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- 155. Two distinct sizes of crystals per cell or chamber
- 156. Crystals in enlarged cells
- 157. Crystals in tyloses
- 158. Cystoliths

**Silica** — p. 318

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  - 166. Mediterranean including Northern Africa and Middle East
  - 167. Temperate Asia (China), Japan, USSR
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  - 169. India, Pakistan, Sri Lanka
  - 170. Burma
- 171. Southeast Asia and the Pacific (Brazier and Franklin region 76)
  - 172. Thailand, Laos, Vietnam, Cambodia (Indochina)
  - 173. Indomalaysia: Indonesia, Philippines, Malaysia, Brunei, Papua New Guinea, and Solomon Islands
  - 174. Pacific Islands (including New Caledonia, Samoa, Hawaii, and Fiji)
- 175. Australia and New Zealand (Brazier and Franklin region 77)
  - 176. Australia
  - 177. New Zealand
- 178. Tropical mainland Africa and adjacent islands (Brazier and Franklin region 78)
  - 179. Tropical Africa
  - 180. Madagascar & Mauritius, Réunion & Comores
- 181. Southern Africa (south of the Tropic of Capricorn) (Brazier and Franklin region 79)
- 182. North America, north of Mexico (Brazier and Franklin region 80)
- 183. Neotropics and temperate Brazil (Brazier and Franklin region 81)
  - 184. Mexico and Central America
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  - 186. Tropical South America
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- 188. Temperate South America including Argentina, Chile, Uruguay, and S. Paraguay (Brazier and Franklin region 82)

**Habit** — p. 321

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- 190. Shrub
- 191. Vine/liana

**Wood of commercial importance** — p. 322

- 192. Wood of commercial importance

**Specific gravity** — p. 322

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- 194. Basic specific gravity medium, 0.40–0.75
- 195. Basic specific gravity high,  $\geq 0.75$

**Heartwood colour** — p. 323

- 196. Heartwood colour darker than sapwood colour
- 197. Heartwood basically brown or shades of brown
- 198. Heartwood basically red or shades of red
- 199. Heartwood basically yellow or shades of yellow
- 200. Heartwood basically white to grey
- 201. Heartwood with streaks
- 202. Heartwood not as above

**Odour** — p. 325

- 203. Distinct odour

**Heartwood fluorescence** — p. 325

- 204. Heartwood fluorescent

**Water & ethanol extracts: fluorescence & colour** — p. 326

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- 206. Water extract basically colourless to brown or shades of brown
- 207. Water extract basically red or shades of red
- 208. Water extract basically yellow or shades of yellow
- 209. Water extract not as above
- 210. Ethanol extract fluorescent
- 211. Ethanol extract basically colourless to brown or shades of brown
- 212. Ethanol extract basically red or shades of red
- 213. Ethanol extract basically yellow or shades of yellow
- 214. Ethanol extract not as above

**Froth test** — p. 327

- 215. Froth test positive

**Chrome Azurol-S test** — p. 328

- 216. Chrome Azurol-S test positive

**Burning splinter test** — p. 328

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- 218. Splinter burns to a full ash: Colour of ash bright white
- 219. Splinter burns to a full ash: Colour of ash yellow-brown
- 220. Splinter burns to a full ash: Colour of ash other than above
- 221. Splinter burns to a partial ash

## NAME

### **Family, genus, species, authority**

When creating a database it is essential to record the full taxonomic information on the specimens, i.e., record family, genus, species, authority. For authorities follow commonly used abbreviations (listed in Mabberley 1987). Reference to Willis's Dictionary of Flowering Plants and Ferns (Willis 1973) and Mabberley (1987) is helpful in determining the familial affinities of various genera, and preferred family names. When preparing a database, also indicate which particular classification scheme, with respect to family delimitation, is being used (e. g., Takhtajan 1980, 1987; Cronquist 1981, 1988; Thorne 1976).

It can be useful to retrieve information on the wood anatomy of particular families or to restrict the search for the identity of an unknown wood to a certain family or families. Consequently, it is advisable to record the family as a feature. For the family name it is not critical what method of coding is employed so long as it is clearly explained in notes accompanying the database. For instance, the family can be indicated as 3-letter acronyms (Weber 1982) or as numerical codes (see pp. 127 and 144–145 in Miller 1981).



## ANATOMICAL FEATURES

### GROWTH RINGS

1. Growth ring boundaries distinct
2. Growth ring boundaries indistinct or absent

#### Definitions:

**Growth ring boundaries distinct** = growth rings with an abrupt structural change at the boundaries between them, usually including a change in fibre wall thickness and/or fibre radial diameter, figs. 1, 2.

**Growth ring boundaries indistinct or absent** = growth rings vague and marked by more or less gradual structural changes at their poorly defined boundaries or not visible, fig. 3.

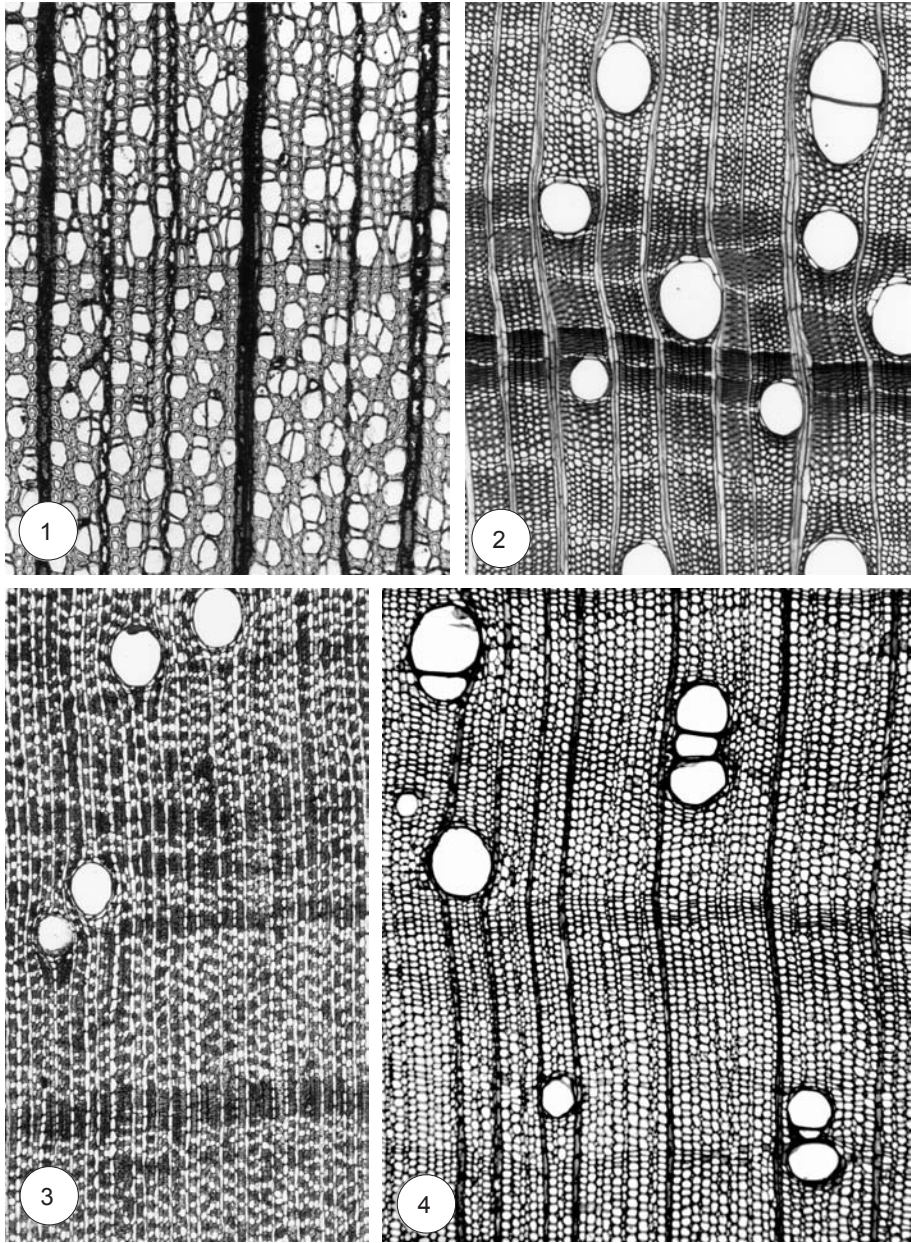
#### Comments:

Growth ring boundaries can be marked by one or more of the following structural changes:

- a. Thick-walled and radially flattened latewood fibres or tracheids versus thin-walled earlywood fibres or tracheids, fig. 1, e.g., *Weinmannia trichosperma* (Cunoniaceae), *Laurus nobilis* (Lauraceae).
- b. Marked differences in vessel diameter between latewood and earlywood of the following ring as in semi-ring-porous and ring-porous woods, figs. 5–8, e.g., *Juglans regia* (Juglandaceae), *Ulmus procera* (Ulmaceae).
- c. Marginal parenchyma (terminal or initial), fig. 2, e.g., *Xylopiia nitida* (Annonaceae), *Brachystegia laurentii* (Caesalpiniaceae), *Juglans regia* (Juglandaceae), *Liriodendron tulipifera* (Magnoliaceae). Irregularly zonate, tangential parenchyma bands without associated abrupt changes in fibre diameter or wall thickness are not considered marginal and do not represent distinct growth ring boundaries, e.g., *Eschweilera subglandulosa* (Lecythidaceae), *Irvingia excelsa* (Simaroubaceae).
- d. Vascular tracheids and very narrow vessel elements very numerous or forming the ground tissue of the latewood, and absent from the earlywood, e.g., *Sambucus nigra* (Caprifoliaceae).
- e. Decreasing frequency of parenchyma bands towards the latewood resulting in distinct fibre zones, e.g., *Lecythis pisonis* (Lecythidaceae), *Donella pruniformis* (Sapotaceae).
- f. Distended rays, e.g., *Fagus* spp. (Fagaceae).
- g. See Carlquist (1980, 1988) for other types of growth ring boundaries and for commonly occurring combinations of several of the above features.

Although absence of growth ring boundaries is a clear enough descriptor, the differences between 'indistinct' and 'distinct' boundaries are somewhat arbitrary, and there are intermediates (fig. 4). Growth rings may appear distinct when observed macroscopically, yet have indistinct boundaries at the light microscopic level; distinctness of the ring boundaries should be judged with a microscope. Indistinct growth ring boundaries are very common in tropical trees (fig. 3, e.g., *Spondias mombin*–Anacardiaceae, *Parkia nitida*–Mimosaceae, *Coelocaryon preussii*–Myristicaceae; *Xanthophyllum philippinense*–Polygalaceae).

Nonperiodical sporadic occurrence of ring boundaries (due to unusual climatic extremes or traumatic events) should be recorded as rings absent or boundaries indistinct.



Figs. 1 & 2. Growth ring boundaries distinct (feature 1). – 1: *Weinmannia trichosperma*, boundary marked by differences in fibre and vessel dimensions,  $\times 80$ . – 2: *Xylopia nitida*, boundary marked by thick-walled latewood fibres and marginal parenchyma band,  $\times 48$ . — Fig. 3. Growth ring boundaries indistinct or absent (feature 2). *Xanthophyllum philippinense*,  $\times 22$ . — Fig. 4. Growth ring boundaries intermediate between distinct and indistinct (features 1 and 2 variable), *Jacaranda copaia*,  $\times 48$ .

## VESSELS

## POROSITY

3. Wood ring-porous
4. Wood semi-ring-porous
5. Wood diffuse-porous

*Definitions:*

**Wood ring-porous** = wood in which the vessels in the earlywood are distinctly larger than those in the latewood of the previous and of the same growth ring, and form a well defined zone or ring, and in which there is an abrupt transition to the latewood of the same growth ring, fig. 5, e.g., *Quercus robur* (Fagaceae), *Fraxinus excelsior* (Oleaceae), *Phellodendron amurense* (Rutaceae), *Bumelia lanuginosa* (Sapotaceae), *Ulmus americana* (Ulmaceae).

**Wood semi-ring-porous** = 1) wood in which the vessels in the earlywood are distinctly larger than those in the latewood of the previous growth ring, but in which there is a gradual change to narrower vessels in the intermediate and latewood of the same growth ring; or 2) wood with a distinct ring of closely spaced earlywood vessels that are not markedly larger than the latewood vessels of the preceding ring or the same growth ring. Alternative definition: intermediate condition between ring-porous and diffuse-porous wood, figs. 6, 7, e.g., *Cordia trichotoma* (Boraginaceae), *Juglans nigra* (Juglandaceae), *Lagerstroemia floribunda* (Lythraceae), *Cedrela odorata* (Meliaceae), *Pterocarpus indicus* (Papilionaceae), *Prunus amygdalus* (Rosaceae), *Paulownia tomentosa* (Scrophulariaceae).

**Wood diffuse-porous** = wood in which the vessels have more or less the same diameter throughout the growth ring, figs. 9, 10, e.g., *Acer* spp. (Aceraceae), *Rhododendron wadanum* (Ericaceae), *Cercidiphyllum japonicum* (Cercidiphyllaceae), *Swietenia* spp. (Meliaceae), *Enterolobium* spp. (Mimosaceae); the vast majority of tropical species and most temperate species.

*Comments:*

The three features for porosity form an intergrading continuum and many species range from diffuse-porous to semi-ring-porous, or from ring-porous to semi-ring-porous. Porosity (features 3–5) is coded independently of vessel arrangement (features 6–8). This implies that woods with a distinct vessel arrangement (features 6–8), as well as those with evenly distributed vessels, may be diffuse-porous.

In some temperate diffuse-porous woods (e.g., *Fagus* spp.–Fagaceae, *Platanus* spp.–Platanaceae) the latest formed vessels in the latewood may be considerably smaller than those of the earlywood of the next ring, but vessel diameter is more or less uniform throughout most of the growth ring (fig. 10).

In a description, characteristics of the earlywood ring of ring-porous woods should be noted, i.e., describe how many vessels wide the ring is. Sudo's (1959) key used the features 'pore ring: 1-seriate' and 'pore ring: multiseriate'. Such characteristics can be useful in distinguishing between species, e.g., *Ulmus americana* typically has an earlywood zone that is one vessel deep, *Ulmus rubra* has an earlywood zone that is more than two vessels deep.

*Caution:* Slow grown ring-porous woods have narrow growth rings with very little latewood (fig. 8). Be careful not to confuse the closely spaced earlywood zones of slow-grown ring-porous woods with a tangential pattern, or to interpret such woods as diffuse-porous.



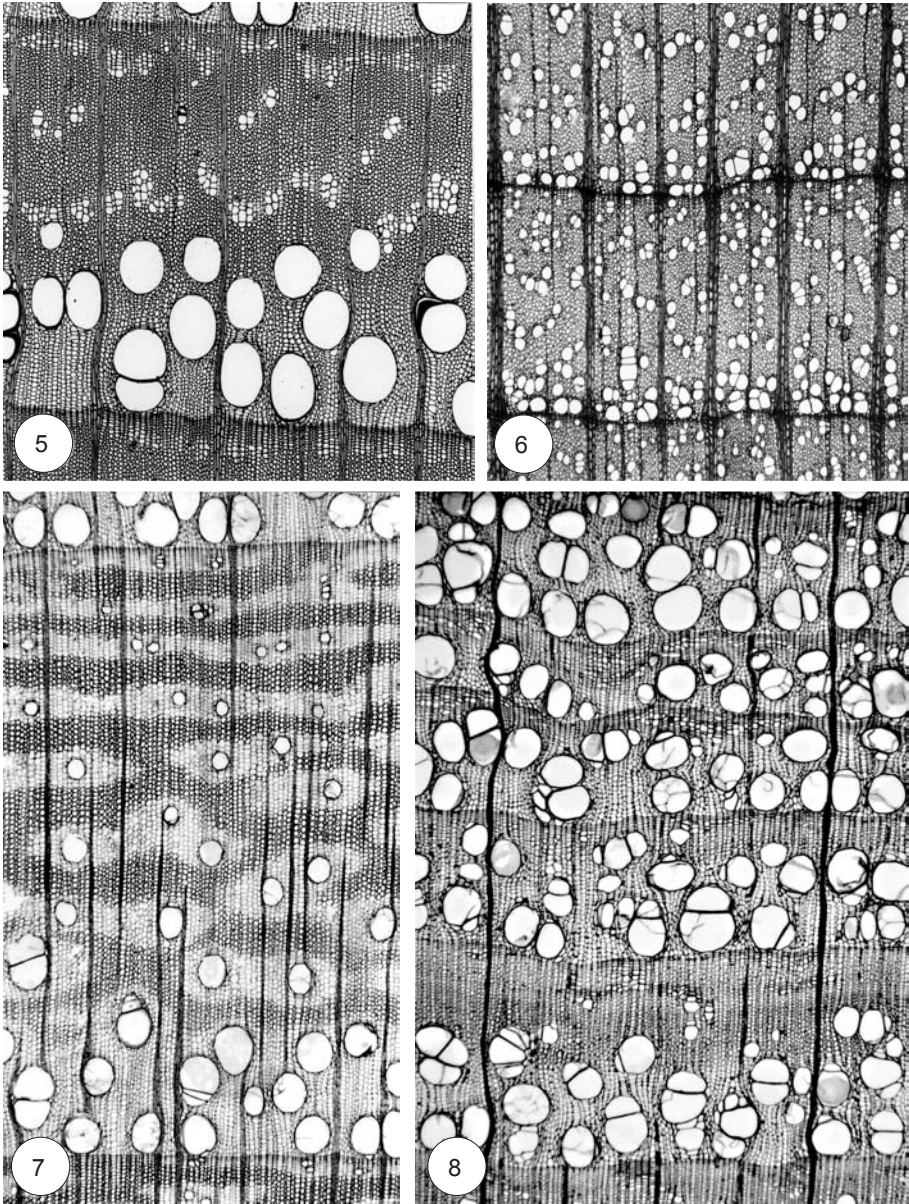


Fig. 5. Wood ring-porous (feature 3), *Phellodendron amurense*,  $\times 28$ . — Figs. 6 & 7. Wood semi-ring-porous (feature 4). — 6: *Prunus* sp.,  $\times 25$ . — 7: *Paulownia tomentosa*,  $\times 18$ . — Fig. 8. Wood ring-porous (feature 3), but with narrow rings giving false impression of diffuse- or semi-ring-porosity, *Catalpa bignonioides*,  $\times 30$ .

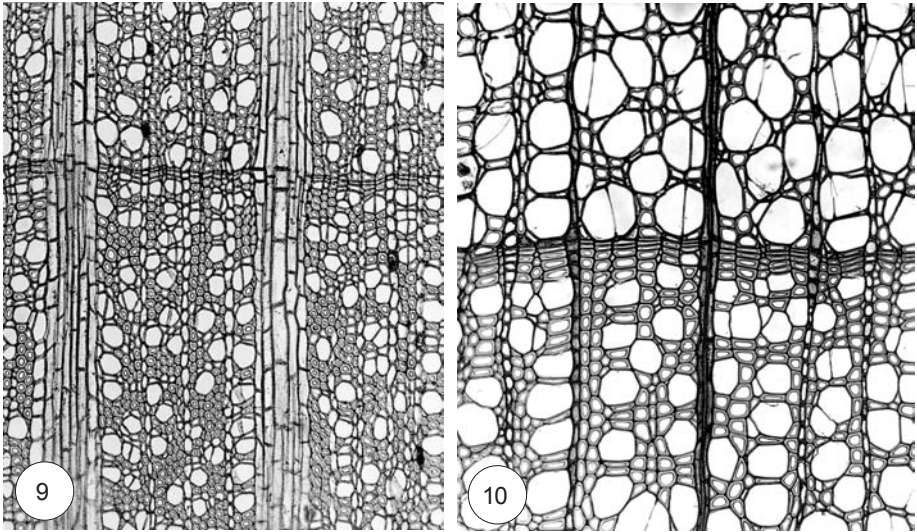


Fig. 9 & 10. Wood diffuse-porous (feature 5). – 9: *Rhododendron wadanum*,  $\times 75$ . – 10: *Cercidiphyllum japonicum*, classified as diffuse-porous despite differences in vessel diameter of latest formed latewood and earlywood,  $\times 30$ .

## VESSEL ARRANGEMENT

### 6. Vessels in tangential bands

### 7. Vessels in diagonal and/or radial pattern

### 8. Vessels in dendritic pattern

#### Definitions:

**Vessels in tangential bands** = vessels arranged perpendicular to the rays and forming short or long tangential bands; these bands can be straight or wavy; includes ulmiform and festooned, figs. 11–13, e.g., *Kalopanax pictus* (Araliaceae), *Patagonula americana* (Boraginaceae), *Enkianthus cornuus* (Ericaceae), *Maclura pomifera* (Moraceae), *Pittosporum tobira* (Pittosporaceae), *Cardwellia sublimis* (Proteaceae).

**Vessels in diagonal and/or radial pattern** = vessels arranged radially or intermediate between tangential and radial (i.e., oblique), figs. 14, 17, 20, e.g., *Lithocarpus edulis* (Fagaceae), *Calophyllum brasiliense*, *C. papuanum*, *Mesua ferrea* (Guttiferae), *Eucalyptus diversicolor*, *E. obliqua* (Myrtaceae), *Amyris sylvatica* (Rutaceae), *Chloroluma gonocarpa* (Sapotaceae). Synonym for diagonal: ‘in echelon’.

**Vessels in dendritic pattern** = vessels arranged in a branching pattern, forming distinct tracts, separated by areas devoid of vessels, figs. 15, 16, e.g., *Rhus aromatica* (Anacardiaceae), *Castanea dentata* (Fagaceae), *Chionanthus retusus* (Oleaceae), *Rhamnus cathartica* (Rhamnaceae), *Bumelia lanuginosa* (Sapotaceae). Synonym: flame-like.



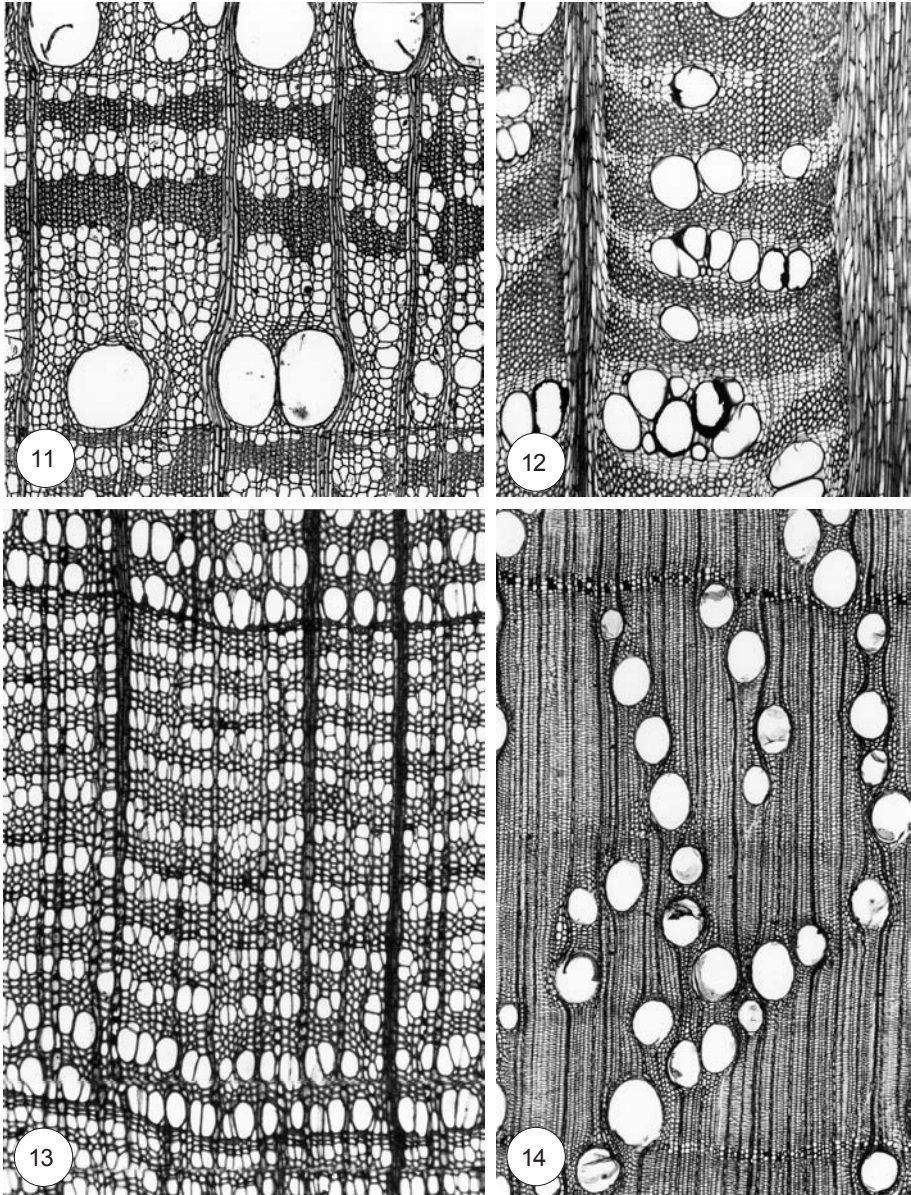


Fig. 11–13. Vessels in tangential bands (feature 6). – 11: Latewood vessels in tangential bands (note also feature 3, wood ring-porous), *Kalopanax pictus*,  $\times 80$ . – 12: Vessels and parenchyma ‘festooned’, *Cardwellia sublimis*,  $\times 30$ . – 13: All vessels in tangential bands, *Enkianthus cornuus*,  $\times 75$ . — Fig. 14. Vessels in a diagonal pattern (feature 7), *Calophyllum papuanum*,  $\times 29$ .



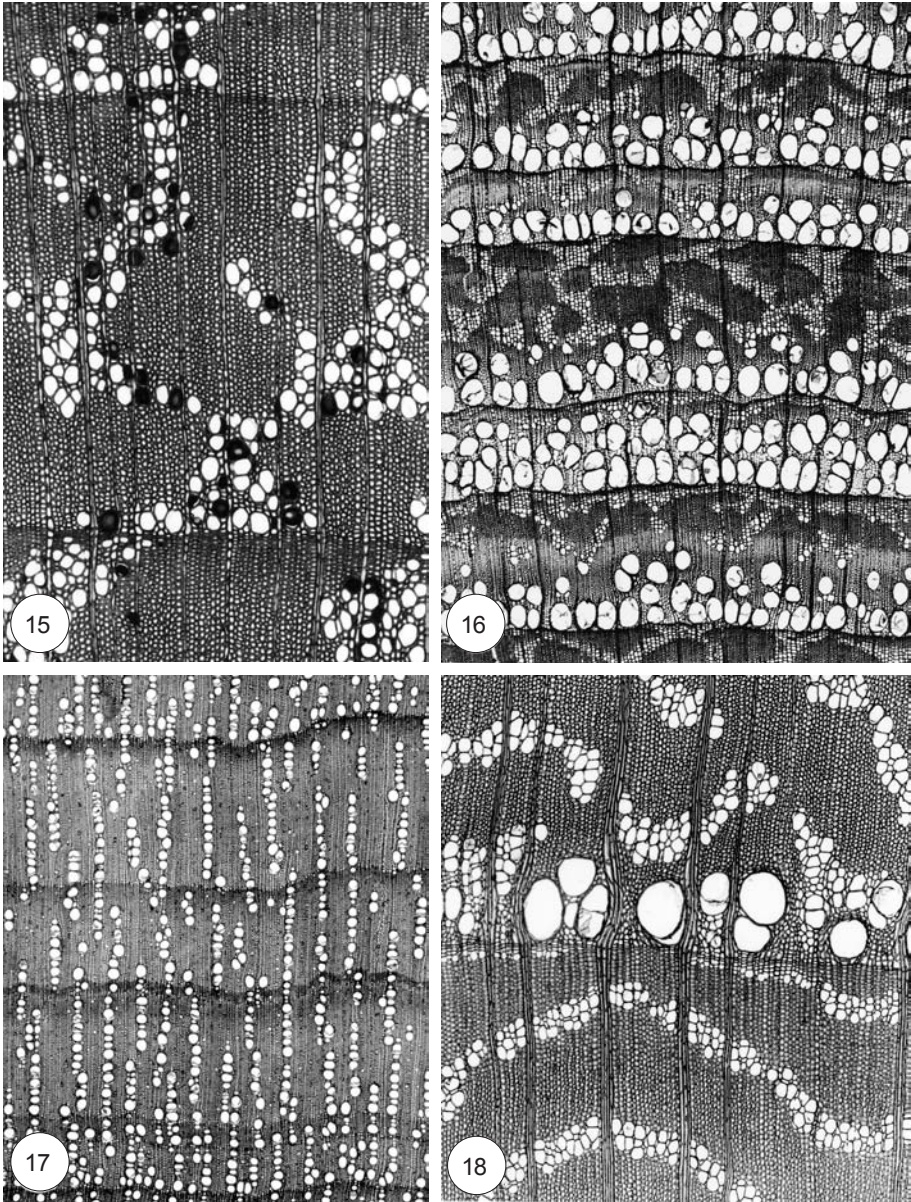


Fig. 15 & 16. Vessels in a dendritic pattern (feature 8). — 15: *Rhamnus cathartica* (note also feature 5, wood diffuse-porous),  $\times 60$ . — 16: *Rhus aromatica*, dendritic pattern restricted to latewood vessels (note also feature 3, wood ring-porous),  $\times 35$ . — Fig. 17. Vessels in a radial pattern (feature 7), *Amyris sylvatica*,  $\times 18$ . — Fig. 18. Narrow vessels in a tangential to diagonal pattern (features 6 and 7), *Kalopanax pictus* (note also feature 3, wood ring-porous),  $\times 80$ .

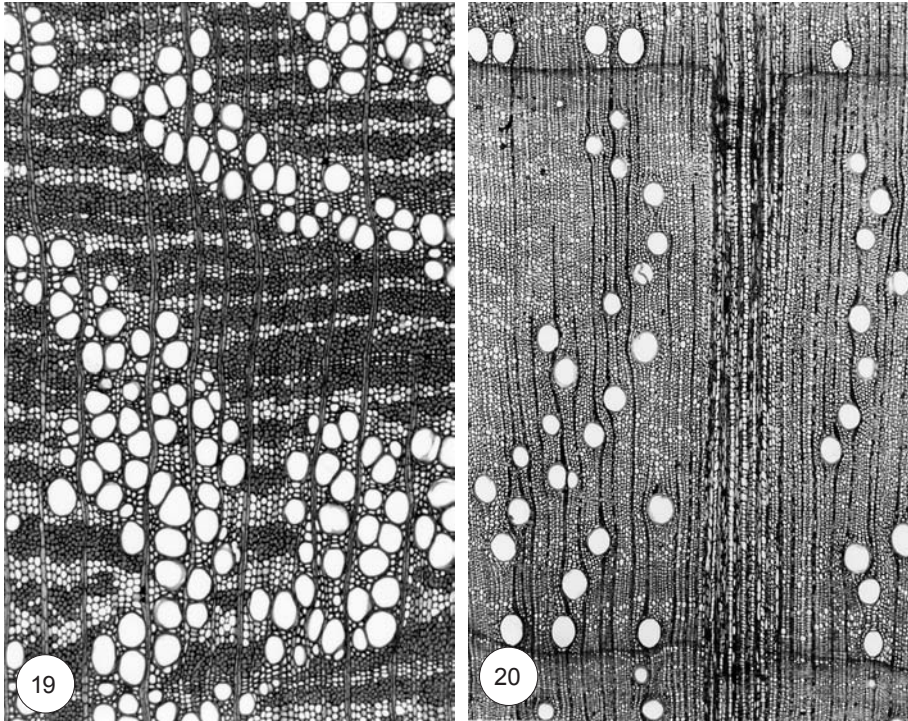


Fig. 19. Vessels in a diagonal to dendritic pattern (features 7 and 8), *Bumelia obtusifolia* (note also feature 5, wood diffuse-porous),  $\times 45$ . — Fig. 20. Vessels in a diagonal to radial pattern (feature 7), *Lithocarpus edulis*,  $\times 29$ .

*Procedure:*

Vessel distribution patterns (tangential, diagonal/radial, dendritic) are determined from the cross section at a low magnification, and are recorded only where there is a distinct pattern. In ring-porous woods, only the intermediate-wood and latewood are examined. The ring of vessels at the beginning of the growth ring of ring-porous woods is not considered when determining vessel distribution patterns.

*Comments:*

These features often occur in combination. Vessel arrangement in some woods intergrades between tangential and diagonal (fig. 18). Diagonal and dendritic often intergrade (fig. 19). All applicable features should be recorded.

The arrangement of pore clusters seen in most species of *Ulmus* (Ulmaceae) has been called ulmiform; this describes woods where the latewood clusters are predominantly in wavy tangential bands (feature 6) and sometimes tend to a diagonal pattern (feature 7). Tangential arcs of vessels, typical of the Proteaceae (fig. 12), have been called festooned.

Since, in ring-porous temperate species, these patterns (features 6–8) may be restricted to the latewood, their expression depends on ring width, and when rings are narrow these patterns are not obvious.



## VESSEL GROUPINGS

**9. Vessels exclusively solitary (90% or more)**

**10. Vessels in radial multiples of 4 or more common**

**11. Vessel clusters common**

*Definitions:*

**Vessels exclusively solitary** = 90% or more of the vessels are completely surrounded by other elements, i.e., 90% or more appear not to contact another vessel, as viewed in cross section, fig. 21, e.g., *Aspidosperma quebracho* (Apocynaceae), *Caraipa* spp. (Bonnetiaceae), *Eucalyptus regnans* (Myrtaceae), *Malus sylvestris* (Rosaceae), *Schima wallichii* (Theaceae).

**Radial multiples of 4 or more common** = radial files of 4 or more adjacent vessels of common occurrence, fig. 22, e.g., *Cerbera floribunda* (Apocynaceae), *Ilex aquifolium* (Aquifoliaceae), *Brachylaena hutchinsii* (Compositae), *Elaeocarpus hookerianus* (Elaeocarpaceae), *Strychnos nux-vomica* (Loganiaceae), *Amyris balsamifera* (Rutaceae), *Gambeya excelsa* (Sapotaceae).

**Clusters common** = groups of 3 or more vessels having both radial and tangential contacts, and of common occurrence, fig. 23, e.g., *Polyscias elegans* (Araliaceae), *Pittosporum ferrugineum* (Pittosporaceae), latewood of *Gleditsia triacanthos*, *Gymnocladus dioica* (Caesalpinaceae), *Morus alba* (Moraceae), and *Ailanthus altissima* (Simaroubaceae).

*Comments:*

Feature 10 'radial multiples of 4 or more common' should be used *only* when radial multiples of 4 or more are an obvious feature of the transverse section. Feature 11 'clusters common' applies only when clusters are frequent enough that they are easily observed during a quick scan of a cross section. Clusters and radial multiples of 4 or more are not mutually exclusive and can occur in combination. Woods with vessels in tangential bands (feature 6) often have clusters.

The most common vessel grouping is radial multiples of 2 to 4 with a variable proportion of solitary vessels (fig. 24). The absence of features 9–11 automatically implies this condition.

When describing a wood, an index of vessel grouping can be calculated in the manner recommended by Carlquist (1988): count the total number of vessels in a minimum of 25 vessel 'groups' (i.e., count both solitary vessels and vessel multiples as a 'group'), divide the total number of vessels by 25 (the number of groups counted). An index of 1.00 indicates exclusively solitary vessels, and the higher the index, the greater the degree of vessel grouping.

*Caution:* Care is needed to recognise the following as not being multiples: (i) solitary vessels composed of vessel elements with oblique overlapping end walls giving the appearance of vessel pairs on the cross section as in *Cercidiphyllum* (Cercidiphyllaceae) and *Illicium* (Illiciaceae), and (ii) closely associated solitary vessels, as in some species of *Eucalyptus* (Myrtaceae) and *Calophyllum* (Guttiferae) (Brazier & Franklin 1961).

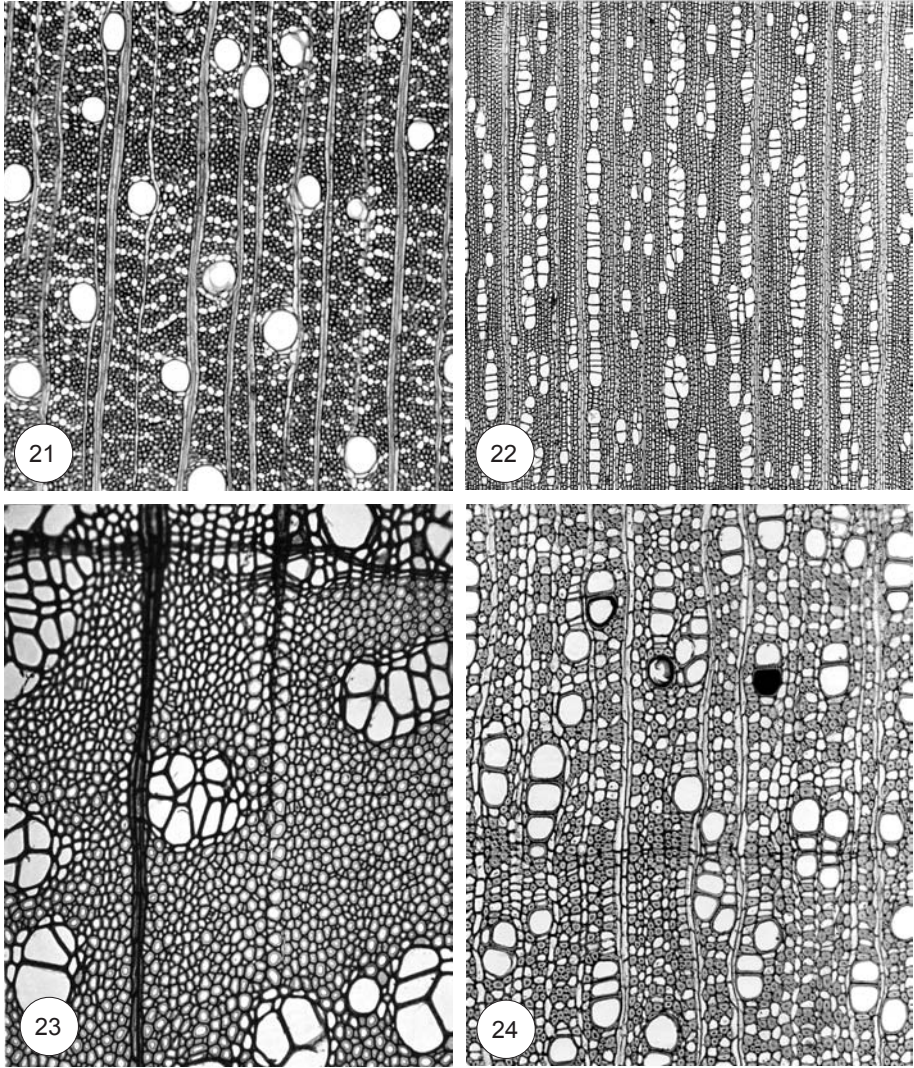


Fig. 21. Vessels 'exclusively solitary' (feature 9), *Aspidosperma quebracho*,  $\times 45$ . — Fig. 22. Radial multiples of 4 or more common (feature 10), *Elaeocarpus hookerianus*,  $\times 29$ . — Fig. 23. Clusters common (feature 11), *Gymnocladus dioica*, latewood,  $\times 140$ . — Fig. 24. Vessels partly solitary, partly in radial multiples of 2–4, or very small clusters (features 9, 10, and 11 absent), *Drypetes gerrardii*,  $\times 75$ .

## SOLITARY VESSEL OUTLINE

**12. Solitary vessel outline angular***Definition:*

**Solitary vessel outline angular** = shape of solitary vessel outline is angular as viewed in cross section, fig. 25, e. g., *Aextoxicum punctatum* (Aextoxicaceae), *Cercidiphyllum japonicum* (Cercidiphyllaceae), latewood vessels of white oaks (e. g., *Quercus alba*, *Q. robur*—Fagaceae), *Stemonurus luzoniensis* (Icacinaeae), *Hortonia* spp. and *Mollinia* spp. (Monimiaceae).

*Procedure:*

In ring-porous woods, examine the latewood because in these woods the earlywood vessels are almost always circular to oval in outline. Use the outline of the solitary vessels because the common walls of vessels in multiples can be flattened giving part of the vessels an angular outline.

*Comments:*

Absence of feature 12 implies that the vessel outline is circular to oval (fig. 26) as in *Banara regia* (Flacourtiaceae) and the latewood of red oaks (e. g., *Quercus falcata*—Fagaceae).

*Caution:* For fossil or archaeological samples, use this feature only when there obviously is no distortion from shrinkage or post-depositional events. Distortion and ‘folding’ of the rays indicates that the wood has been compressed during burial and that vessel outline probably has been altered.

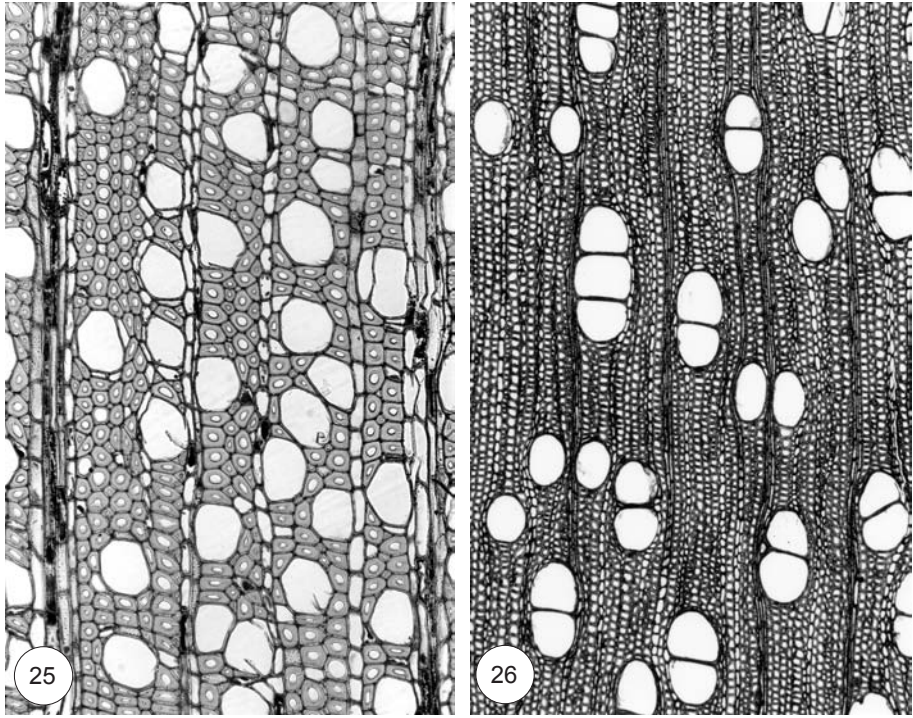


Fig. 25. Solitary vessel outline angular (feature 12), *Stemonurus luzoniensis*,  $\times 75$ . — Fig. 26. Outline of vessels rounded (feature 12 absent), *Banara regia*,  $\times 45$ .



## PERFORATION PLATES

**13. Simple perforation plates****14. Scalariform perforation plates****15. Scalariform perforation plates with  $\leq 10$  bars****16. Scalariform perforation plates with 10–20 bars****17. Scalariform perforation plates with 20–40 bars****18. Scalariform perforation plates with  $\geq 40$  bars****19. Reticulate, foraminate, and/or other types of multiple perforation plates***Definitions:*

**Simple perforation plate** = a perforation plate with a single circular or elliptical opening, fig. 27, e.g., *Aesculus hippocastanum* (Hippocastanaceae), *Entandrophragma* spp. (Meliaceae), *Pterocarpus* spp. (Papilionaceae), *Zelkova* spp. (Ulmaceae).

**Scalariform perforation plate** = a perforation plate with elongated and parallel openings, separated by one to many mainly unbranched bars, fig. 29, examples follow.

**Scalariform perforation plates with  $\leq 10$  bars**, e.g., *Corylus avellana* (Corylaceae) *Goupia* spp. (Goupiaceae), *Liriodendron tulipifera* (Magnoliaceae), *Coula edulis* (Olacaceae), *Rhizophora mangle* (Rhizophoraceae).

**Scalariform perforation plates with 10–20 bars**, e.g., *Betula verrucosa* (Betulaceae), *Altingia excelsa*, *Liquidambar styraciflua* (Hamamelidaceae), *Sacoglottis gabonensis* (Humiriaceae), *Schima wallichii* (Theaceae).

**Scalariform perforation plates with 20–40 bars**, fig. 29, e.g., *Cercidiphyllum japonicum* (Cercidiphyllaceae), *Dicoryphe stipulacea* (Hamamelidaceae), *Nyssa ogeche* (Nyssaceae), *Staphylea pinnata* (Staphyleaceae).

**Scalariform perforation plates with  $\geq 40$  bars**, e.g., *Aextoxicon punctatum* (Aextoxicaceae), *Hedyosmum* spp. (Chloranthaceae), *Dillenia triquetra* (Dilleniaceae).

**Reticulate perforation plate** = a plate with closely spaced openings separated by wall portions that are much narrower than the spaces between them, or with a profuse and irregular branching of wall portions resulting in a netlike appearance, fig. 30, e.g., *Didymopanax morototoni* (Araliaceae), *Iryanthera juruensis* (Myristicaceae).

**Foraminate perforation plate** = a plate with circular or elliptical openings like a sieve, the remaining wall portions can be thicker than in the reticulate type, fig. 31, e.g. *Oroxylum indicum* (Bignoniaceae).

**Other types** = for instance, complex or radiate perforation plates, see comments and figs. 32–35.

*Comments:*

Determine the type(s) of perforation plate from radial sections or macerations, preferably examine at least 25 vessel elements. For scalariform perforation plates, record all the feature categories that encompass the range of the number of bars. Feature 14 ‘scalariform perforation plates’ is a general category included to accommodate information from existing literature that indicates whether scalariform perforation plates are present, but not the number of bars. Feature 14 is to be recorded with other appropriate features for bar number (15–18).

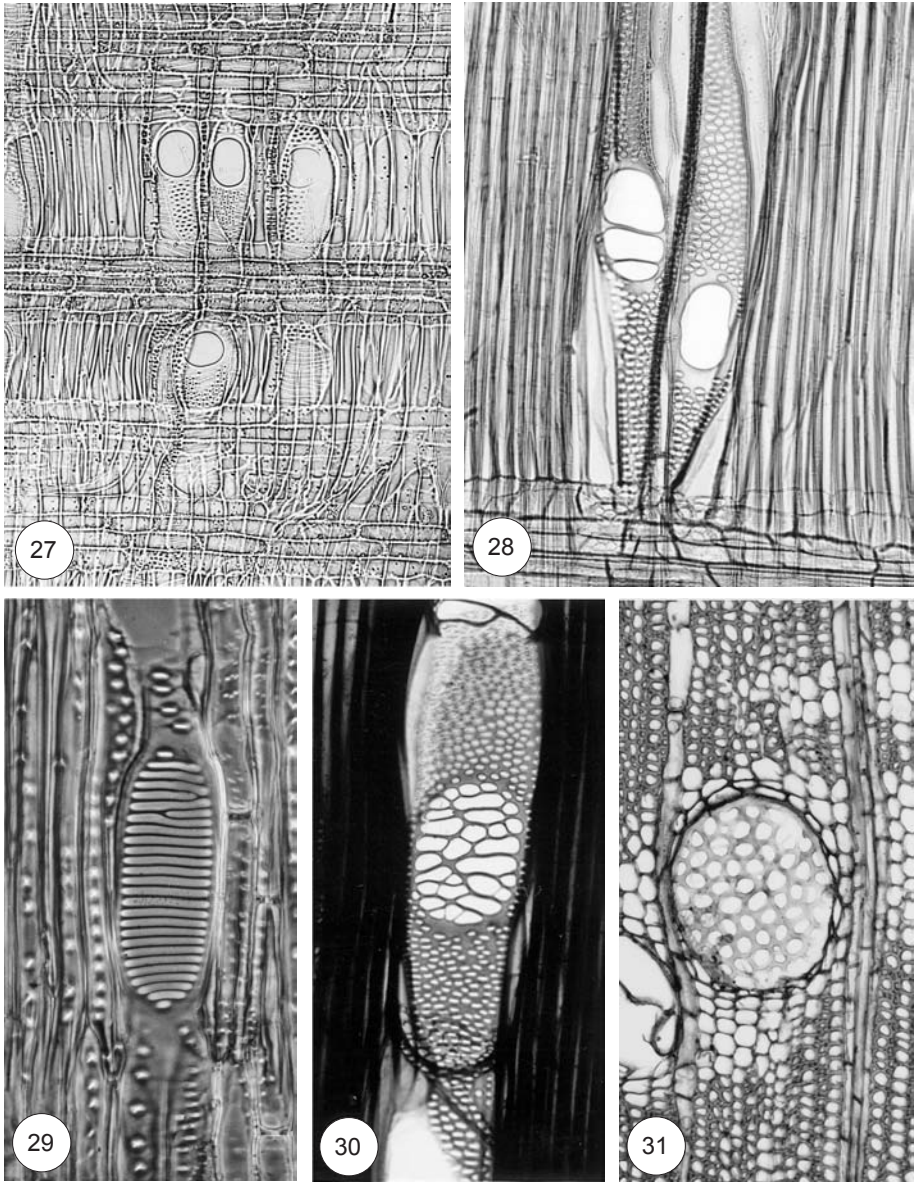


Fig. 27. Simple perforation plates (feature 13), *Aesculus hippocastanum*,  $\times 105$ . — Fig. 28. Simple perforation plate and scalariform perforation plate with 2 bars (features 13, 14, 15), *Didymopanax morototoni*,  $\times 115$ . — Fig. 29. Scalariform perforation plate with 20–40 bars (features 14 and 17), *Staphylea pinnata*,  $\times 220$ . — Fig. 30. Reticulate perforation plate (feature 19), *Didymopanax morototoni*,  $\times 115$ . — Fig. 31. Foraminiate perforation plate (feature 19), *Oroxylum indicum*,  $\times 115$ .

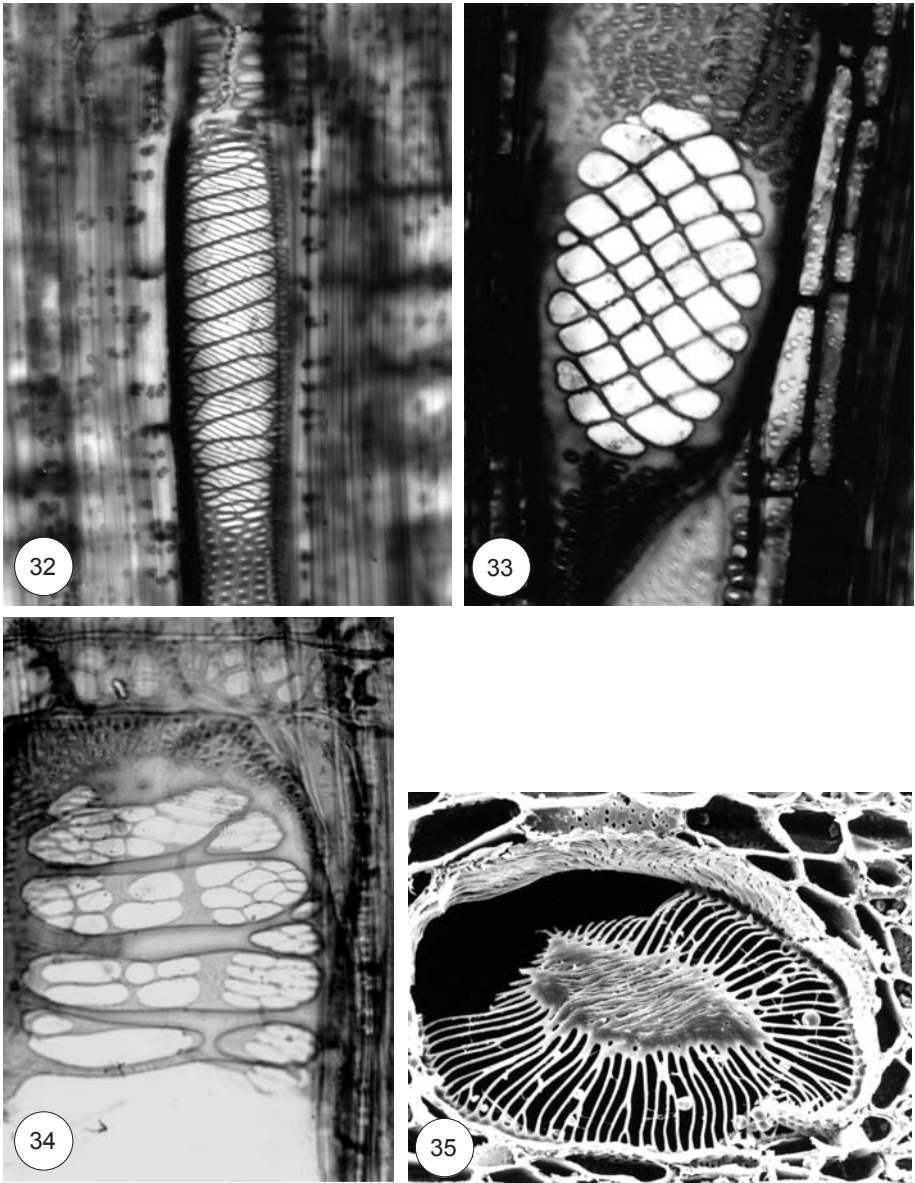


Fig. 32. Perforation plate obliquely compound scalariform with anastomosing bars (feature 14 and 19), *Iryanthera paraensis*,  $\times 209$ . — Fig. 33. Perforation plate regularly reticulate (feature 19, often occurring together with feature 14, scalariform perforation plates), *Iryanthera juruensis*,  $\times 290$ . — Fig. 34. Perforation plate complex scalariform and reticulate (feature 14 and 19), *Iryanthera elliptica*,  $\times 290$ . — Fig. 35. Radiate perforation plate (feature 19), *Cytharexylum myrianthum*,  $\times 300$  (SEM).

Simple perforations are the most common type of perforation plate, and occur in over 80% of the world's woods (Wheeler *et al.* 1986). Most woods have exclusively simple perforations, some have simple perforations together with scalariform and/or other types of multiple perforation plates, and still others have exclusively scalariform perforation plates. When more than one type of perforation plate is present (fig. 28), all types should be recorded and may be used to identify an unknown (e.g., *Didymopanax morototoni*—Araliaceae, *Oxydendron arboreum*—Ericaceae, *Fagus sylvatica*—Fagaceae, and *Platanus occidentalis*—Platanaceae have both simple and scalariform plates). In those woods with both simple and scalariform perforation plates, the narrower vessel elements and the latewood vessel elements are more likely to have scalariform perforation plates.

Scalariform reticulate, and foraminate plates form a continuum, and the latter two are often confused in the literature. Reticulate and foraminate plates are restricted to relatively few taxonomic groups and are combined here. Reticulate perforations frequently occur in combination with scalariform plates and are an elaboration of that type, *Iryanthera* (Myristicaceae), *Dendropanax* and *Didymopanax* (Araliaceae) have scalariform reticulate, and varied intermediates plus simple perforations; *Myrcogenia estrellensis* (Myrtaceae) has simple and multiple plates and the latter can be variously described as irregular-scalariform, foraminate, or even reticulate; *Markhamia* and *Oroxylum* (Bignoniaceae) have simple and foraminate plates.

*Iryanthera* (Myristicaceae) also has compound scalariform plates with few coarse bars with sets of fine secondary bars between them, which are often branched. Similar examples occur in *Didymopanax morototoni* (Araliaceae) and *Ternstroemia serrata* (Theaceae). In these cases, both feature 14 (scalariform perforation plates present) and feature 19 apply. As pointed out by Carlquist (1988), the term 'ephedroid' should not be used for foraminate perforations in dicotyledons.

Radiate perforation plates (also feature 19) with a central wall and radiating simple and branched bars extending to the lateral vessel wall are found in *Cytharexylum myrianthum* (Verbenaceae) (Vidal Gomes *et al.* 1989) and *Caryocar microcarpum* (Caryocaraceae).

Other types of multiple perforations may be found in the future and should be recorded as feature 19, 'reticulate, foraminate, and/or other types of multiple perforations'.



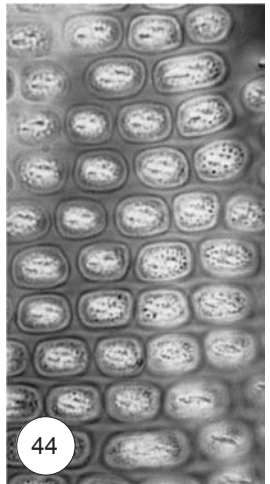
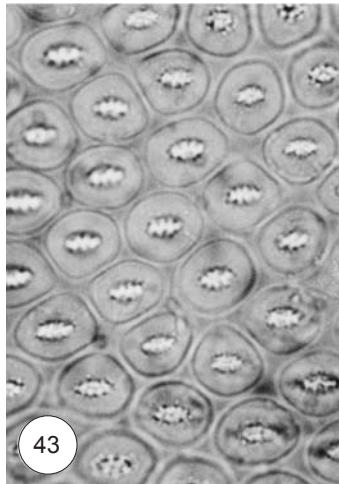
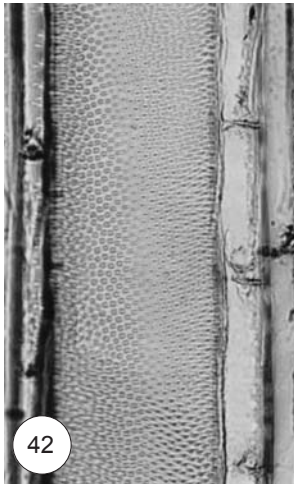
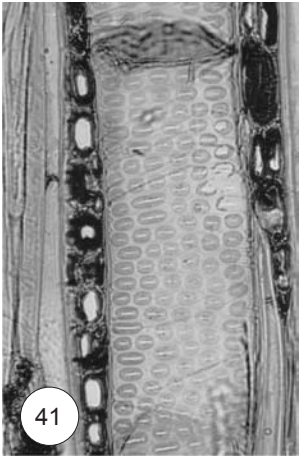
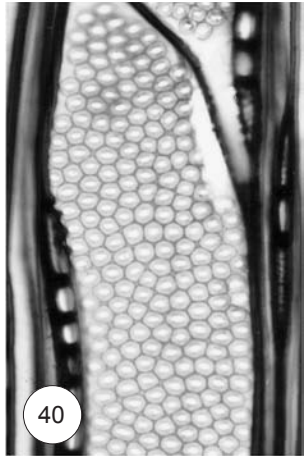
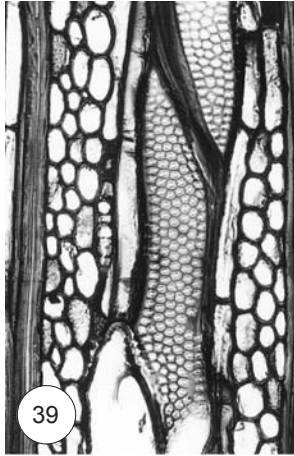
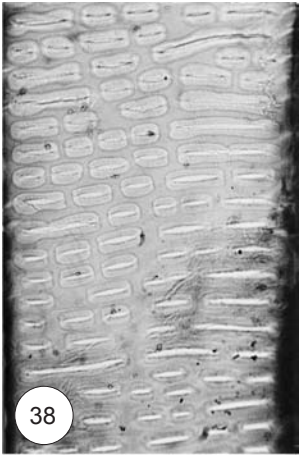
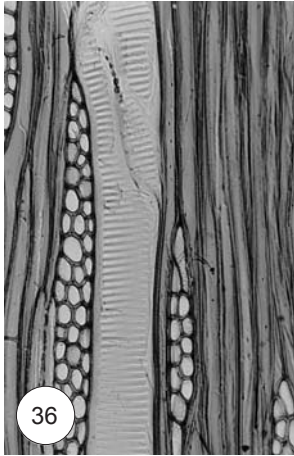
## INTERVESSEL PITS ARRANGEMENT AND SIZE

**20. Intervessel pits scalariform****21. Intervessel pits opposite****22. Intervessel pits alternate****23. Shape of alternate pits polygonal****Intervessel pit size (alternate and opposite)****24. Minute** –  $\leq 4 \mu\text{m}$ **25. Small** –  $4\text{--}7 \mu\text{m}$ **26. Medium** –  $7\text{--}10 \mu\text{m}$ **27. Large** –  $\geq 10 \mu\text{m}$ **28. Range of intervessel pit size ( $\mu\text{m}$ )***Definitions:***Intervessel pits** = pits between vessel elements.**Scalariform intervessel pits** = elongated or linear intervessel pits arranged in a ladder-like series, fig. 36, e.g., *Dillenia reticulata* (Dilleniaceae), *Michelia compressa* (Magnoliaceae), *Laurelia* spp. (Monimiaceae), *Rhizophora* spp. (Rhizophoraceae).**Opposite intervessel pits** = intervessel pits arranged in short to long horizontal rows, i.e., rows orientated transversely across the length of the vessel, figs. 37, 44, e.g., *Liriodendron* spp. (Magnoliaceae), *Nyssa ogeche* (Nyssaceae).**Alternate intervessel pits** = intervessel pits arranged in diagonal rows, figs. 39, 40, 42, 43, e.g., Aceraceae, *Mappia racemosa* (Icacinaeae), Leguminosae, Meliaceae, *Salix* spp. (Salicaceae), Sapindaceae.**Shape of alternate pits polygonal** = outline of intervessel pits, as seen in surface view (longitudinal sections), angular and with more than 4 sides, fig. 40, e.g. Salicaceae, most Leguminosae.**Intervessel pit size (alternate and opposite)** = horizontal diameter of a pit chamber at the broadest point.*Procedure:*

Generally, surface views of intervessel pits are easiest to find in tangential sections because radial multiples are the most frequent type of vessel multiple, and so intervessel pits are most frequent in tangential walls. When vessels are in tangential bands and/or clusters, radial sections also provide surface views of intervessel pits. In woods with (almost) exclusively solitary vessels, intervessel pits will be extremely rare, and often not visible in a single longitudinal

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Fig. 36. Intervessel pits scalariform (feature 20), *Michelia compressa*,  $\times 115$ . — Fig. 37. Intervessel pits opposite (feature 21), *Liriodendron tulipifera*,  $\times 115$ . — Fig. 38. Intervessel pits scalariform to opposite (feature 20 and 21), *Ilex laurina*,  $\times 350$ . — Fig. 39. Intervessel pits alternate (feature 22), *Mappia racemosa*,  $\times 112$ . — Fig. 40. Shape of alternate pits polygonal (feature 23), *Salix* sp. Note also features 22 (pits alternate) and 26, 27 (intervessel pits medium to large);  $\times 290$ . — Fig. 41. Shape of intervessel pits circular to oval (feature 23 absent). Note also pits opposite (feature 21), *Nothofagus moorei*,  $\times 300$ . — Fig. 42. Intervessel pits minute, less than  $4 \mu\text{m}$  (feature 24), *Polyalthia oblongifolia*. Note also pits alternate (feature 22),  $\times 300$ . — Fig. 43. Vestured intervessel pits (feature 29), *Terminalia* sp.,  $\times 825$ . — Fig. 44. Pits seemingly vestured due to presence of soluble deposits (feature 29, vestured pits, absent). Note also pits opposite (feature 21), *Ilex cymosa*,  $\times 800$ .



section. In such woods, intervessel pit shape and size must be observed in overlapping end wall portions of vessel elements in a single vessel. However, in woods with vessel multiples, the pit arrangement, shape, and size is best determined from the middle of the larger vessel elements. Measure ten pits, avoiding exceptionally large or small pits, and record those size classes that encompass the range of pit size.

*Comments:*

Alternate intervessel pitting is the most common, and opposite and scalariform intervessel pitting are found in relatively few groups. When alternate pits are crowded the outlines of the pits tend to be polygonal in surface view; if alternate pits are not crowded then the outlines are usually circular to oval. When opposite intervessel pits are crowded the outlines of the borders tend to be rectangular in surface view. Some species have both polygonal and circular to oval intervessel pit outlines, record feature 23 present for such woods. Combinations of different pitting patterns and/or intergrading types occur (e.g., figs. 38, 41, alternate and opposite in *Buxus*–Buxaceae, opposite and scalariform in *Liquidambar*–Hamamelidaceae) and may be indicated by using combinations of the different pit features.

Pit size can help distinguish between genera within a family and between families, e.g., many Meliaceae have minute pits, while many members of the Anacardiaceae have large pits. The most widely used convention for determining pit size is to measure horizontal pit diameter. To enable use of existing data this parameter is included in this feature list. However, within several taxa, particularly those with some or all opposite to scalariform pits, vertical diameter is a more constant and diagnostic feature, and it is recommended that this dimension be recorded in a description.

*Caution:* Do not mistake vessel-vasicentric tracheid pitting for intervessel pitting.

## VESTURED PITS

### 29. Vestured pits

*Definitions:*

**Vestured pits** = pits with the pit cavity and/or aperture wholly or partly lined with projections from the secondary cell wall, fig. 43, e.g., Combretaceae, Lythraceae, Myrtaceae, Rubiaceae, most Leguminosae.

*Procedure:*

Vestures are best viewed in water or glycerin mounts (or SEM). Bleaching is recommended so as to remove encrusting materials that may be mistaken for vestures (fig. 44 shows pseudo-vestures), i.e., soak sections (or, for SEM observation, wood blocks) in any household bleach until the section or surface has lost its colour, rinse in water, and finish sample preparation.

*Comments:*

Vesturing may occur in intervessel, vessel–ray or vessel–axial parenchyma, intertracheid, or interfibre pits.

Vestures generally are characteristic of entire families, or groups within a family. The number, size, and distribution of vestures varies considerably and these variations may be of diagnostic value (Bailey 1933; Ohtani *et al.* 1984; Van Vliet 1978; Van Vliet & Baas 1984). When intervessel pits are large and the vestures are coarse (e.g., *Terminalia* spp.–Combretaceae), vestures are relatively easy to see with an oil-immersion objective of a good compound microscope. But when the vestured pits are minute (4 µm or less) as in the Apocynaceae or Rubiaceae, the vestures are difficult to see with a compound microscope, and only clearly visible with a scanning electron microscope.

## VESSEL – RAY PITTING

30. Vessel–ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell
31. Vessel–ray pits with much reduced borders to apparently simple: pits rounded or angular
32. Vessel–ray pits with much reduced borders to apparently simple: pits horizontal (scalariform, gash-like) to vertical (palisade)
33. Vessel–ray pits of two distinct sizes or types in the same ray cell
34. Vessel–ray pits unilaterally compound and coarse (over 10  $\mu\text{m}$ )
35. Vessel–ray pits restricted to marginal rows

*Definitions:*

**Vessel–ray pits** = pits between a ray cell and a vessel element.

**Unilaterally compound pits** = pits in which one pit abuts two or more smaller pits in the adjacent cell.

Other features as per descriptors, examples follow.

**Vessel–ray pits with distinct borders; similar to intervessel pits in size and shape throughout the ray cell**, figs. 45, 46, e.g., Aceraceae, Leguminosae, Meliaceae, *Ilex aquifolium* (Aquifoliaceae), *Betula* spp. (Betulaceae), *Camptostemon philippinense* (Bombacaceae), *Couratari* cf. *oblongifolia* (Lecythidaceae).

**Vessel–ray pits with much reduced borders to apparently simple: pits rounded or angular**, figs. 47, 48, e.g., *Elaeocarpus calomala* (Elaeocarpaceae), *Clinostemon* spp. (Lauraceae), *Eucalyptus* spp. (Myrtaceae), *Populus* spp., *Salix* spp. (Salicaceae).

**Vessel–ray pits with much reduced borders to apparently simple: pits horizontal (scalariform, gash-like) to vertical (palisade)**, figs. 49, 50, e.g., *Trigonobalanus verticillata*, *Quercus* spp. (Fagaceae), *Atherosperma moschata*, *Laurella aromatica* (Monimiaceae), *Horsfieldia subglobosa* (Myristicaceae), *Syzygium* spp. (Myrtaceae).

**Vessel–ray pits of two distinct sizes or types in the same ray cell**, figs. 51, 52, e.g., some species of *Erythroxylum* (Erythroxylaceae), *Anacolosa* spp., *Chaunochiton* spp. (Olacaceae), *Santalum* spp. (Santalaceae), *Planchonella* spp. (Sapotaceae).

**Vessel–ray pits unilaterally compound and coarse (over 10  $\mu\text{m}$ )**, fig. 53, e.g., *Michelia champaca* (Magnoliaceae), *Ceriops* spp., *Kandelia* spp., *Rhizophora* spp. (Rhizophoraceae).

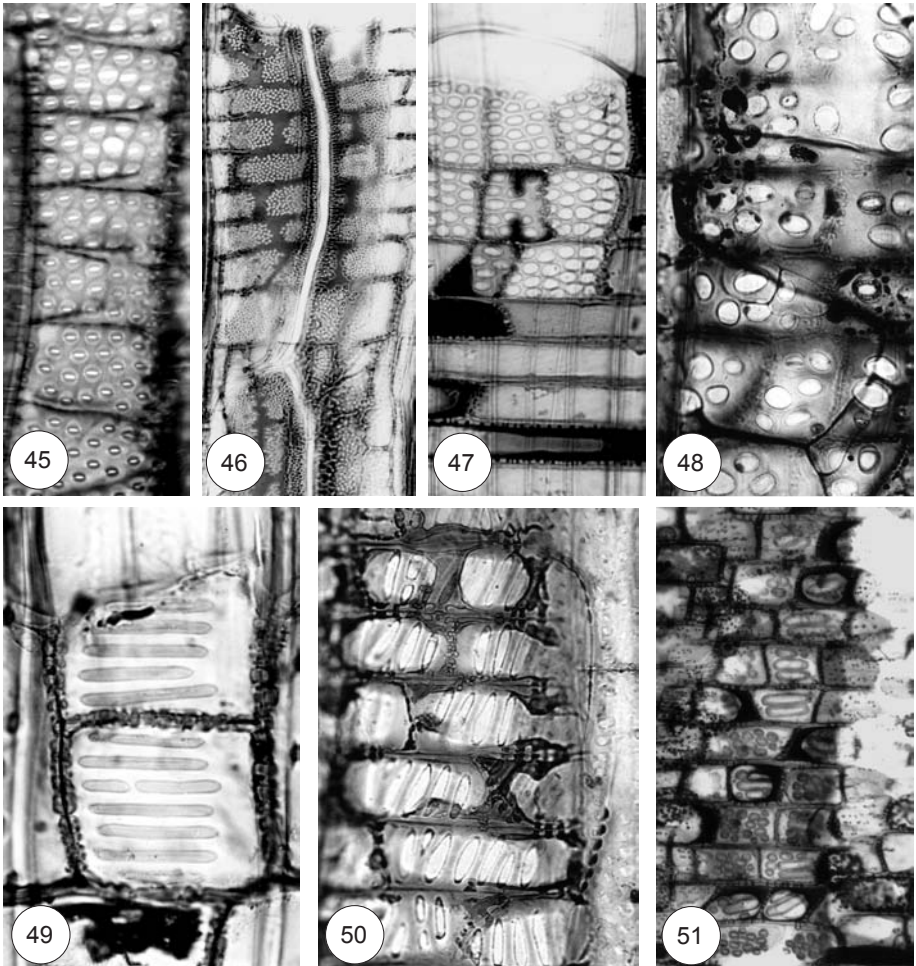
**Vessel–ray pits restricted to marginal rows**, fig. 47, e.g., *Carpinus betulus* (Corylaceae), *Aesculus hippocastanum* (Hippocastanaceae), *Populus* spp., *Salix* spp. (Salicaceae).

*Comments:*

Various combinations of the above features may occur and should be recorded. Vessel–ray pits in the body of the ray may differ from those in the ray margins (e.g., *Palaquium galatoxylum*–Sapotaceae). Record the features for both types of pits.

If a wood has predominantly solitary vessels, comparison of vessel–ray pits with intervessel pits often is not possible. If the vessel–ray parenchyma pits in such woods are uniform in size and shape and have borders, then use feature 30; if not, any of features 31–35 may apply.

Vessel–axial parenchyma pitting usually resembles vessel–ray parenchyma pitting, and is therefore not included as a separate list of almost identical descriptors.



Figs. 45 & 46. Vessel-ray pits with distinct borders, similar to intervessel pits (feature 30). — 45: *Couratari* cf. *oblongifolia*,  $\times 290$ . — 46: *Camptostemon philippinense*,  $\times 75$ . — Figs. 47 & 48: Vessel-ray pits with much reduced borders to apparently simple, pit outline rounded (feature 31). — 47: *Salix* sp. (Salicaceae). Note also feature 35 (vessel-ray pits restricted to marginal rows);  $\times 290$ . — 48: *Elaeocarpus calomala*,  $\times 290$ . — Figs. 49 & 50. Vessel-ray pits with much reduced borders to apparently simple, pits horizontal (gash-like) to vertical (palisade), feature 32. — 49: Pits horizontal, *Atherosperma moschata*,  $\times 450$ . — 50: Pits vertical, *Trigonobalanus verticillata*,  $\times 290$ . — Fig. 51. Part of the vessel-ray pits with much reduced borders, and pits of two distinct sizes or types in the same ray cell (feature 32 and 33), *Horsfieldia subglobosa*,  $\times 115$ .



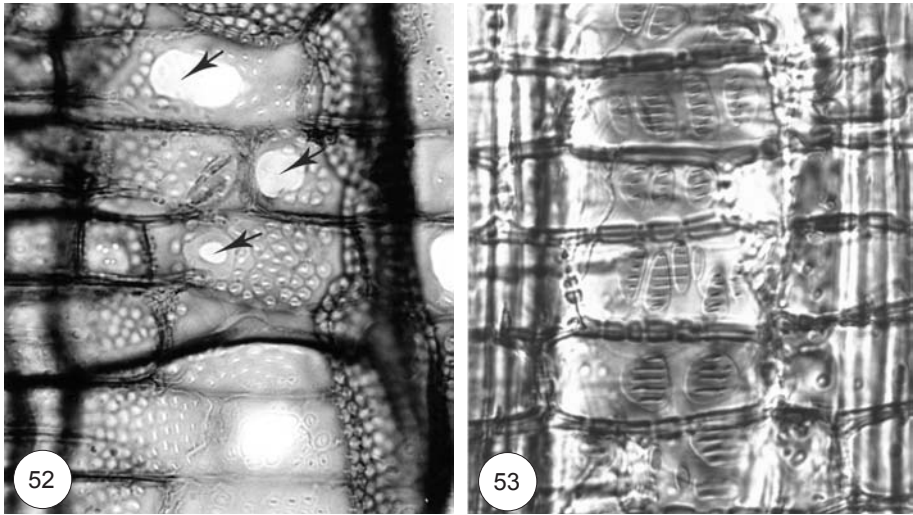


Fig. 52. Vessel-ray pits of two distinct sizes or types in the same ray cell (feature 33); the large pits (arrowed) resemble perforations, *Chaunochiton breviflorum*,  $\times 290$ . — Fig. 53. Vessel-ray pits unilaterally compound and coarse (feature 34), *Ceriops tagal* (differential interference contrast),  $\times 450$ .

## HELICAL THICKENINGS

**36. Helical thickenings in vessel elements present****37. Helical thickenings throughout body of vessel element****38. Helical thickenings only in vessel element tails****39. Helical thickenings only in narrower vessel elements***Definitions:*

**Helical thickenings in vessel elements** = ridges on the inner face of the vessel element wall in a roughly helical pattern. Synonym: spiral thickenings.

Other features as per descriptors, examples follow.

**Helical thickenings throughout body of vessel element**, figs. 54, 55, e.g., *Acer* spp. (Aceraceae), *Aesculus* spp. (Hippocastanaceae), *Cytisus scoparius* (Papilionaceae), *Prunus spinosa* (Rosaceae), *Tilia* spp. (Tiliaceae).

**Helical thickenings only in vessel element tails**, figs. 56, 57, e.g., *Cercidiphyllum japonicum* (Cercidiphyllaceae), *Liquidambar styraciflua* (Hamamelidaceae).

**Helical thickenings only in narrower vessel elements**, e.g., *Robinia pseudoacacia* (Papilionaceae), *Ulmus americana* (Ulmaceae).

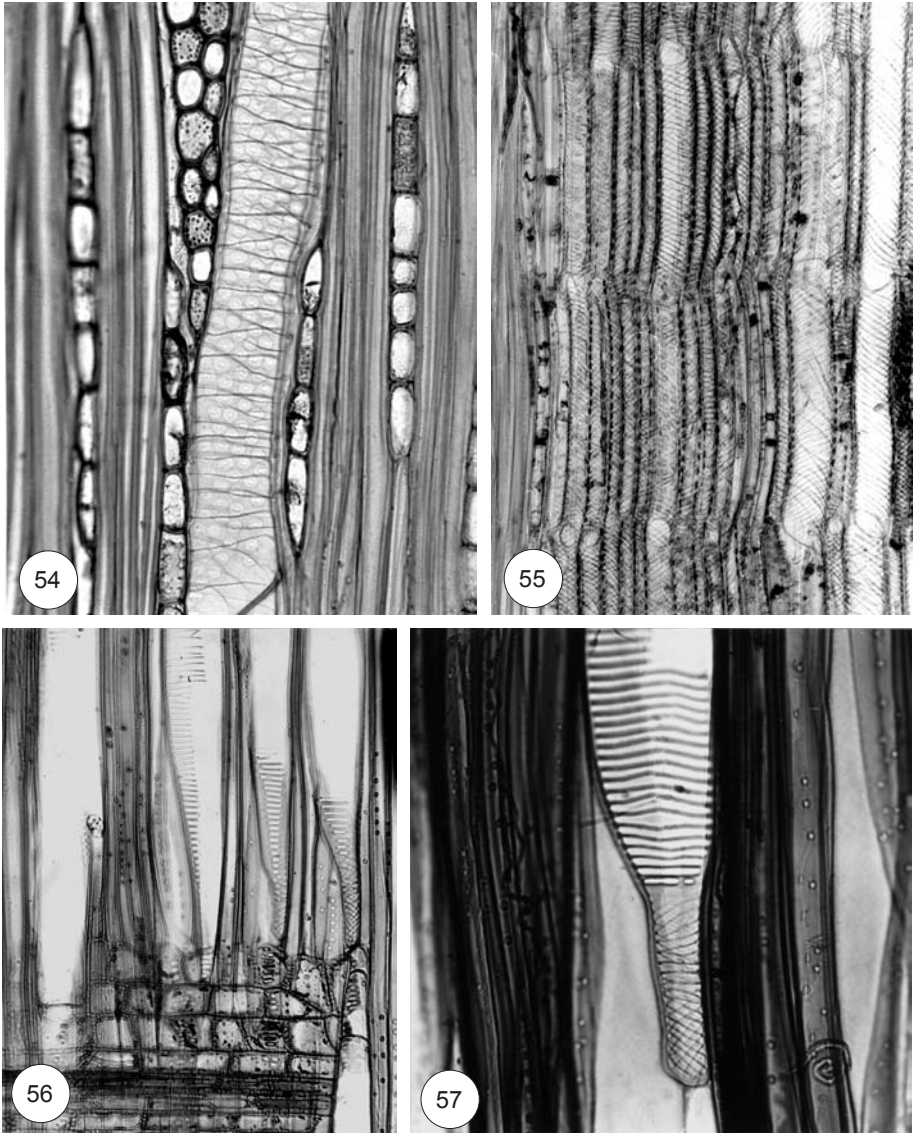
*Comments:*

Helical thickenings are rather variable in terms of thickness (fine to coarse), inclination angle (nearly horizontal to steeply inclined), branching (branched or unbranched), and spacing (close to wide). It is recommended that observations on these features be included in wood descriptions.

Feature 36 'helical thickenings in vessel elements' is included as a general category 1) to accommodate information from existing databases that indicate whether helical thickenings are present, but not their specific location; and 2) to help with the identification of small wood fragments in which vessel elements have helical thickenings, but because of the small sample size it cannot be determined whether the helical thickenings are in all vessel elements, or just in the narrower ones. Feature 36 should be recorded in combination with other appropriate features (feature 37, 38 or 39) for helical thickenings.

Helical thickenings can also occur in vascular/vasicentric tracheids, and in ground tissue fibres (feature 64), and very rarely in axial parenchyma.

*Caution:* Do not confuse coalescent pit apertures with helical thickenings.



Figs. 54 & 55. Helical thickenings throughout body of vessel element (features 36 and 37). – 54: *Prunus spinosa*,  $\times 290$ . – 55: *Cytisus scoparius*,  $\times 220$ . – Figs. 56 & 57. Helical thickenings only in vessel element tails (features 36 and 38), *Cercidiphyllum japonicum*. – 56:  $\times 150$ . – 57:  $\times 240$ .



## TANGENTIAL DIAMETER OF VESSEL LUMINA

**Mean tangential diameter of vessel lumina****40.  $\leq 50 \mu\text{m}$** **41. 50–100  $\mu\text{m}$** **42. 100–200  $\mu\text{m}$** **43.  $\geq 200 \mu\text{m}$** **44. Mean, +/- Standard Deviation, Range, n = x***Procedure:*

Vessel diameter is measured in transverse sections. Vessels are selected for measurement with care not to bias the selection towards the larger or smaller vessels. The *tangential* diameter of the vessel lumina, excluding the wall, is measured at the widest part of the opening. At least 25 vessels should be measured. In ring-porous woods (feature 3) and woods with 'vessels of two distinct diameter classes, wood not ring-porous' (feature 45), only measure and record the larger size class. Information about tangential diameters of the smaller vessels would be useful in a description. In semi-ring-porous woods, measure along a radial transect through a growth ring. For semi-ring-porous woods, it is recommended that more than 25 vessels be measured; a larger standard deviation is expected for such woods. Use the category(ies) in which the mean(s) fall(s).

*Comments:*

In trees, mean tangential diameters of 100–200  $\mu\text{m}$  are more common than mean tangential diameters greater than 200  $\mu\text{m}$  or mean tangential diameters less than 50  $\mu\text{m}$ . In shrubs, mean tangential diameters of less than 50  $\mu\text{m}$  are common.

**44. Vessels of two distinct diameter classes, wood not ring-porous***Definition:*

**Vessels of two distinct diameter classes, wood not ring-porous** = woods with a bimodal distribution of tangential diameters of vessel lumina, fig. 58, e.g., *Actinidia* spp. (Actinidiaceae), *Capparis maroniensis* (Capparidaceae), *Derris hylobia* (Papilionaceae), *Serjania subdentata* (Sapindaceae), *Congea tomentosa* (Verbenaceae).

*Comments:*

Vines and xerophytes often have vessels of two distinct diameter classes (Carlquist 1985; Baas & Schweingruber 1987).

## VESSELS PER SQUARE MILLIMETRE

- 46.  $\leq 5$  vessels per square millimetre**  
**47. 5–20 vessels per square millimetre**  
**48. 20–40 vessels per square millimetre**  
**49. 40–100 vessels per square millimetre**  
**50.  $\geq 100$  vessels per square millimetre**  
**51. Mean, +/- Standard Deviation, Range, n = x**

*Procedure:*

All vessels are counted as individuals, e.g., a radial multiple of four would be counted as four vessels (Wheeler 1986). Count all the vessels in at least five (and preferably ten) fields of appropriate size (depending on vessel diameter and distribution), and convert to number per square millimetre, i.e., for woods with small diameter vessels use fields 1 mm  $\times$  1 mm or less; for woods with large vessels that are widely spaced use whole fields of view at low magnification (e.g., 4  $\times$  objective lens). Of the vessels that are partially in the field of view, only 50% are included in the count. If vessel frequency is very low, examine enough fields to account for local variations, and preferably count at least 100 vessels. Use the categories that include the total range of vessel frequency.

*Comments:*

Vessel frequency is not computed for ring-porous woods, or for woods with their vessels in definite tracts with vascular/vasicentric tracheids, e.g., dendritic pattern as seen in *Rhamnus cathartica* (Rhamnaceae), or tangential bands as seen in *Ulmus* (Ulmaceae).

## MEAN VESSEL ELEMENT LENGTH

- 52.  $\leq 350$   $\mu\text{m}$**   
**53. 350–800  $\mu\text{m}$**   
**54.  $\geq 800$   $\mu\text{m}$**   
**55. Mean, +/- Standard Deviation, Range, n = x**

*Procedure:*

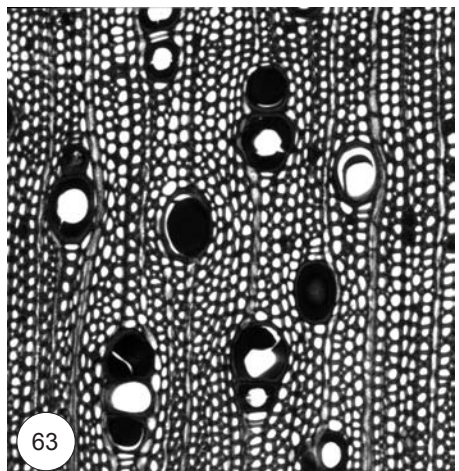
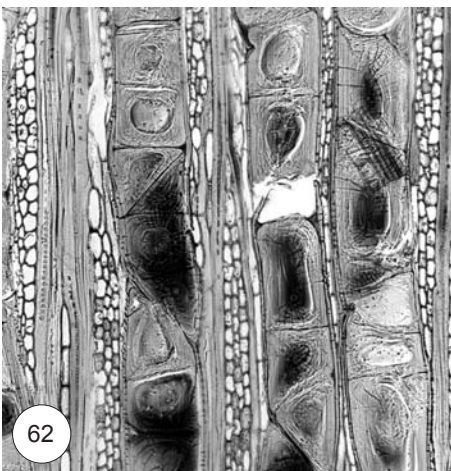
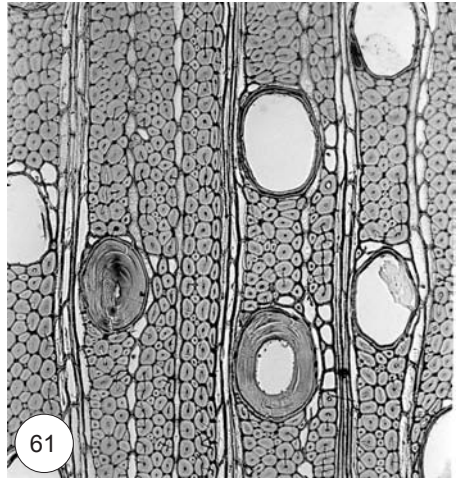
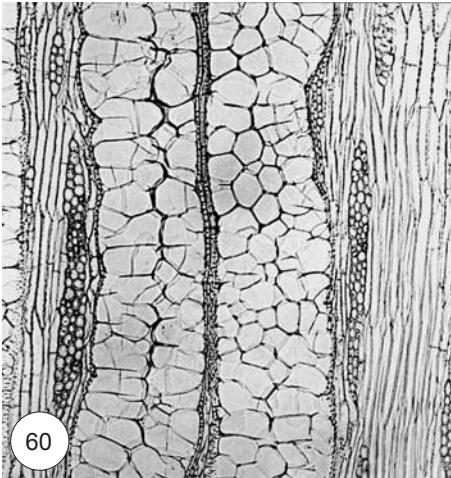
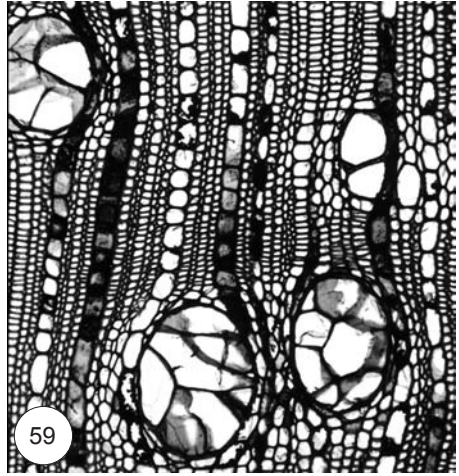
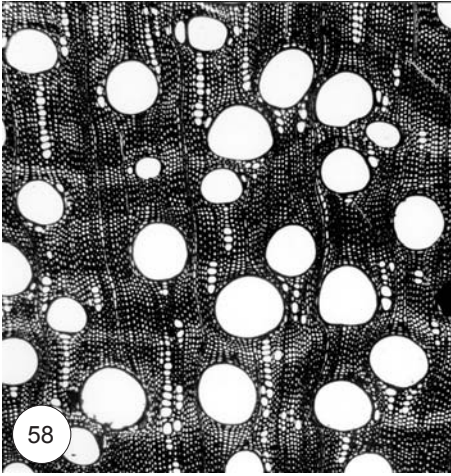
Measure the whole length of each vessel element from one tail end to the other, preferably in a maceration. At least 25 vessel element lengths are measured to derive the mean and range. Use the category(ies) in which the mean(s) fall(s).

## TYLOSES AND DEPOSITS IN VESSELS

- 56. Tyloses common**  
**57. Tyloses sclerotic**

*Definitions:*

**Tyloses common** = outgrowths from an adjacent ray or axial parenchyma cell through a pit in a vessel wall, partially or completely blocking the vessel lumen, and of common occur-



rence (except in outer sapwood), figs. 59, 60, e.g., *Anacardium occidentale* (Anacardiaceae), *Acanthopanax* spp. (Araliaceae), *Cercidiphyllum japonicum* (Cercidiphyllaceae), *Eucalyptus acmenioides* (Myrtaceae), *Strombosia pustulata* (Olacaceae), *Robinia pseudoacacia* (Papilionaceae).

**Sclerotic tyloses** = tyloses with very thick, multilayered, lignified walls, figs. 61, 62, e.g., *Chaetocarpus schomburgkianus*, *Micrandra spruceana* (Euphorbiaceae), *Cantleya corniculata* (Icacinaceae), *Eusideroxylon zwageri* (Lauraceae), *Brosimum guianense* (Moraceae).

*Procedure:*

In ring-porous woods, it is best to examine the earlywood vessels for tyloses because tyloses are often absent from small diameter latewood vessels. Avoid sapwood when determining the presence of tyloses or gums.

*Comments:*

Tyloses may be few or many, ranging from all vessels filled with many tyloses to a few vessels with a few tyloses. Feature 56 applies only when tyloses are not of sporadic occurrence. Tyloses may be thin-walled or thick-walled, pitted or unpitted, with or without starch, crystals, resins, gums, etc. Such information should be recorded in a description.

Woods with sclerotic tyloses usually have thin-walled tyloses as well, and both features 56 and 57 may apply. Some woods may have both tyloses and gum deposits (feature 58), and both features 56 and 58 may apply.

*Caution:* Absence of tyloses is not diagnostic. Do not code traumatic tyloses such as occur in wound heartwood and be careful not to confuse tyloses with foamy deposits, masses of fungi, or other deposits.

## 58. Gums and other deposits in heartwood vessels

*Comments:*

In cross sections, deposits appear to completely fill some vessel lumina (fig. 63); in longitudinal sections, deposits often appear to collect at the end of vessel elements. Deposits often can be seen more clearly by examining the woods with a hand lens; sectioning and mounting techniques may remove some of the deposits.

'Gums and other deposits' includes a wide variety of chemical compounds, which are variously coloured (white, yellow, red, brown, black). In a description it is appropriate to indicate their abundance and colour. See Hillis (1987) for more information on the chemistry of deposits.

*Caution:* Use feature 58 positively only. Do not confuse masses of whitish fungi, which may be packed in a vessel cavity, or sclerotic tyloses with deposits.

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Fig. 58. Vessels of two distinct diameter classes, wood not ring-porous (feature 45), *Serjania subdentata*,  $\times 35$ . — Figs. 59 & 60. Tyloses common (feature 56). — 59: In transverse section, *Anacardium occidentale*,  $\times 220$ . — 60: In tangential section, *Robinia pseudoacacia*,  $\times 140$ . — Figs. 61 & 62. tyloses sclerotic (features 56 and 57), *Cantleya corniculata*. — 61: Transverse section,  $\times 75$ . — 62: Tangential section,  $\times 75$ . — Fig. 63. Gums/deposits in heartwood vessels (feature 58), *Physocalymma scaberrimum*,  $\times 110$ .

## WOOD VESSELLESS

**59. Wood vesselless***Definition:*

**Wood vesselless** = wood without vessel elements, composed only of imperforate tracheary elements and parenchyma, figs. 64, 65, e.g., Amborellaceae, Tetracentraceae, Trochodendraceae, Winteraceae.

*Comments:*

Vesselless dicotyledonous woods are relatively uncommon and are distinguished from coniferous wood by tall multiseriate rays. For vesselless woods, it is not necessary to code for type of imperforate tracheary elements (fibres or vascular/vasicentric tracheids) and impossible to code for vessel features.

**TRACHEIDS AND FIBRES****60. Vascular/vasicentric tracheids present***Definitions:*

**Vascular tracheids** = imperforate cells resembling in size, shape, pitting, and wall ornamentation narrow vessel elements and intergrading with the latter, figs. 66, 67, e.g., *Sambucus nigra* (Caprifoliaceae), *Sophora arizonica* (Papilionaceae), *Phellodendron amurense* (Rutaceae), *Lycium europaeum* (Solanaceae), *Celtis occidentalis* (Ulmaceae).

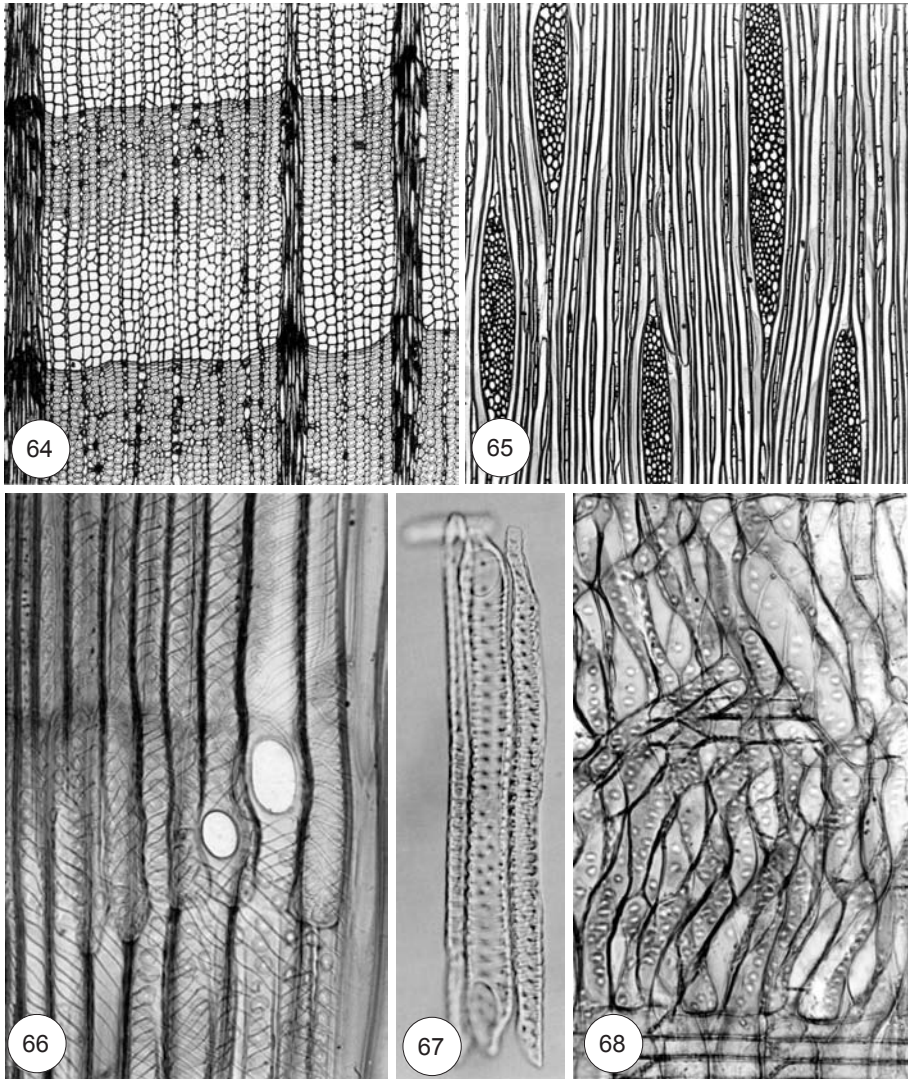
**Vasicentric tracheids** = imperforate cells with numerous distinctly bordered pits in their radial and tangential walls, present around the vessels, and different from ground tissue fibres, often, but not always of irregular shape, fig. 68, e.g., *Castanea* spp., *Quercus* spp. (Fagaceae), many *Shorea* (Dipterocarpaceae) and *Eucalyptus* (Myrtaceae) species.

*Comments:*

Vascular tracheids often occur in association with extensive vessel multiples or clusters, especially in the latewood. A very thorough search of macerations will reveal their presence in many species. However, for wood identification purposes use them only when they are commonly present. The intergradation of vascular tracheids with narrow vessel elements implies that there are some cells with a single, often very small, perforation. Some anatomists would prefer to call such cells vascular tracheids, others would prefer to call them narrow vessel elements, probably terminating a vessel. Because they have a perforation such cells are best referred to as vessel elements; tracheids are imperforate cells.

The IAWA Glossary (1964) includes shortness and irregular form in the definition of vasicentric tracheids, but these criteria do not always apply (e.g., in *Eucalyptus* spp., cf. Ilic 1987). Since vascular tracheids are often intermixed with vessels (i.e., in a vasicentric position) in many taxa, they can also be considered as vasicentric tracheids.





Figs. 64 & 65. Wood vesselless (feature 59), *Trochodendron aralioides*. – 64: Transverse section,  $\times 38$ . – 65: Tangential section,  $\times 38$ . — Figs. 66–68. Vascular/vasicentric tracheids (feature 60). – 66: Radial section, vessel elements surrounded by vascular tracheids (note also helical thickenings in vessel elements, features 36 and 37), *Phellodendron amurense*,  $\times 290$ . – 67: Maceration, vessel element flanked by two vascular tracheids, *Celtis occidentalis*,  $\times 300$ . – 68: Radial section, vasicentric tracheids, *Castanea sativa*,  $\times 170$ .

## GROUND TISSUE FIBRES

**61. Fibres with simple to minutely bordered pits****62. Fibres with distinctly bordered pits****63. Fibre pits common in both radial and tangential walls***Definitions:*

**Fibres with simple to minutely bordered pits** = fibres (libriform fibres) with simple pits or bordered pits with the chambers less than 3  $\mu\text{m}$  in diameter, figs. 71, 72, e.g., *Swietenia* spp. (Meliaceae), *Inga* spp. (Mimosaceae), *Fraxinus* spp. (Oleaceae), *Populus* spp. (Salicaceae).

**Fibres with distinctly bordered pits** = fibres (or fibre-tracheids or ground tissue tracheids) with bordered pits with chambers over 3  $\mu\text{m}$  in diameter, figs. 69, 70, e.g., *Ilex* spp. (Aquifoliaceae), *Dillenia* spp. (Dilleniaceae), *Illicium* spp. (Illiciaceae), *Xanthophyllum* spp. (Polygalaceae), *Camellia* spp. (Theaceae).

**Fibre pits common in both radial and tangential walls** = fibre pits, either bordered or simple, common in radial and tangential walls, e.g., *Ilex* spp. (Aquifoliaceae), *Dillenia* spp. (Dilleniaceae), *Illicium* spp. (Illiciaceae), *Xanthophyllum* spp. (Polygalaceae), *Clematis vitalba* (Ranunculaceae), *Camellia* spp. (Theaceae).

*Procedure:*

Determine the nature and distribution of fibre pits only in longitudinal (radial and tangential) sections, because in cross section many fibre walls are not strictly radial or tangential. Both longitudinal and cross sections are suitable to determine if the pits are bordered or (almost) simple.

*Comments:*

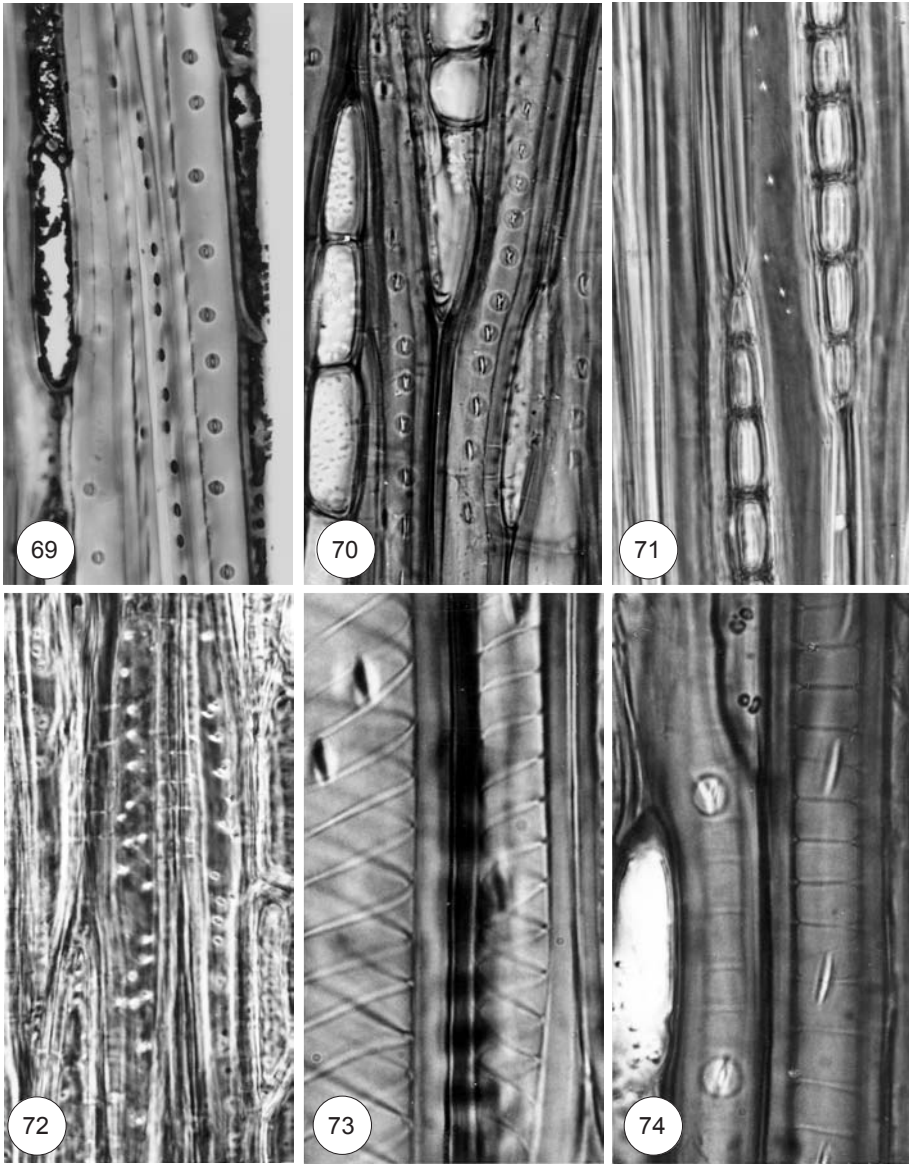
The feature 'fibres with distinctly bordered pits' partly overlaps with the descriptors 'tracheids' sensu Bailey (1936) and Carlquist (1986a, 1986b, 1988) and 'fibre-tracheids' sensu Baas (1986). It usually coincides with 'fibre pits common in both radial and tangential walls' (feature 63).

The following combinations are of very sporadic occurrence: 1) fibre pits not distinctly bordered, i.e., pit chambers less than 3  $\mu\text{m}$  or pits simple, feature 61 present, and pits common in radial and tangential walls, feature 63 present, e.g., *Capparis spinosa* (Capparidaceae), *Nyctanthes arbor-tristis* (Oleaceae), *Vitis vinifera* (Vitaceae); 2) fibres with distinctly bordered pits, feature 62 present, and pits mainly restricted to the radial walls, feature 63 absent, e.g., *Elaeagnus angustifolia* (Elaeagnaceae).

Two types of fibres with respect to wall pitting (both features 61 and 62 present) may occur (e.g., some species of *Vaccinium*–Ericaceae).

Fibres with simple to minutely bordered pits (feature 61 present), mainly confined to the radial walls (feature 63 absent) are libriform fibres in the definition of Baas (1986) or libriform fibres and/or fibre-tracheids in the definition of Carlquist (1986a, 1986b, 1988).

The terms libriform fibres, fibre-tracheids, and 'true tracheids' have been deliberately avoided as descriptors in this list because there is no consensus on their definitions.



Figs. 69 & 70. Fibres with distinctly bordered pits (feature 62), common in both radial and tangential walls (feature 63), tangential sections. – 69: *Illicium cambodianum*,  $\times 230$ . – 70: *Xanthophyllum lanceatum*,  $\times 230$ . — Fig. 71. Fibres with simple to minutely bordered pits (feature 61), tangential section, phase-contrast, *Populus* sp. (Salicaceae). Note also scarcity of pits in tangential walls (feature 63 absent);  $\times 410$ . — Fig. 72. Fibres with simple to minutely bordered pits (feature 61), common in both radial and tangential walls (feature 63). Tangential section, phase-contrast, *Clematis vitalba*,  $\times 410$ . — Figs. 73 & 74. Helical thickenings in ground tissue fibres (feature 64). – 73: *Ilex cinerea*,  $\times 850$ . – 74: *Ilex chinensis*,  $\times 850$ .

#### 64. Helical thickenings in ground tissue fibres

##### Definition:

**Helical thickenings in ground tissue fibres** = as per feature descriptor, see definition of helical thickenings, feature 36, figs. 73, 74, e.g., *Euonymus europaeus* (Celastraceae), *Hamamelis japonica* (Hamamelidaceae), *Cercocarpus ledifolius* (Rosaceae), and temperate species of *Ilex* (Aquifoliaceae) and *Syringa* (Oleaceae).

##### Comments:

Fibres with helical thickenings usually occur in woods that also have helical thickenings in the vessel elements. However, the opposite is not true, i.e., many species with helical thickenings in their vessel elements do not have helical thickenings in the ground tissue fibres. Helical thickenings are much more common in fibres with distinctly bordered pits than in fibres with simple to minutely bordered pits. They also occur more frequently in temperate woods than in tropical woods.

#### SEPTATE FIBRES AND PARENCHYMA-LIKE FIBRE BANDS

##### 65. Septate fibres present

##### 66. Nonseptate fibres present

##### 67. Parenchyma-like fibre bands alternating with ordinary fibres

##### Definitions:

**Septate fibres** = fibres with thin, unpitted, transverse wall(s), figs. 75–78, e.g., *Spondias mombin* (Anacardiaceae), *Aucoumea klaineana* (Burseraeae), *Buchenavia capitata* (Combretaceae), *Elaeocarpus* spp. (Elaeocarpaceae), *Aglaiia* spp. (Meliaceae), *Vitex orinocensis* (Verbenaceae).

**Nonseptate fibres** = fibres without septa.

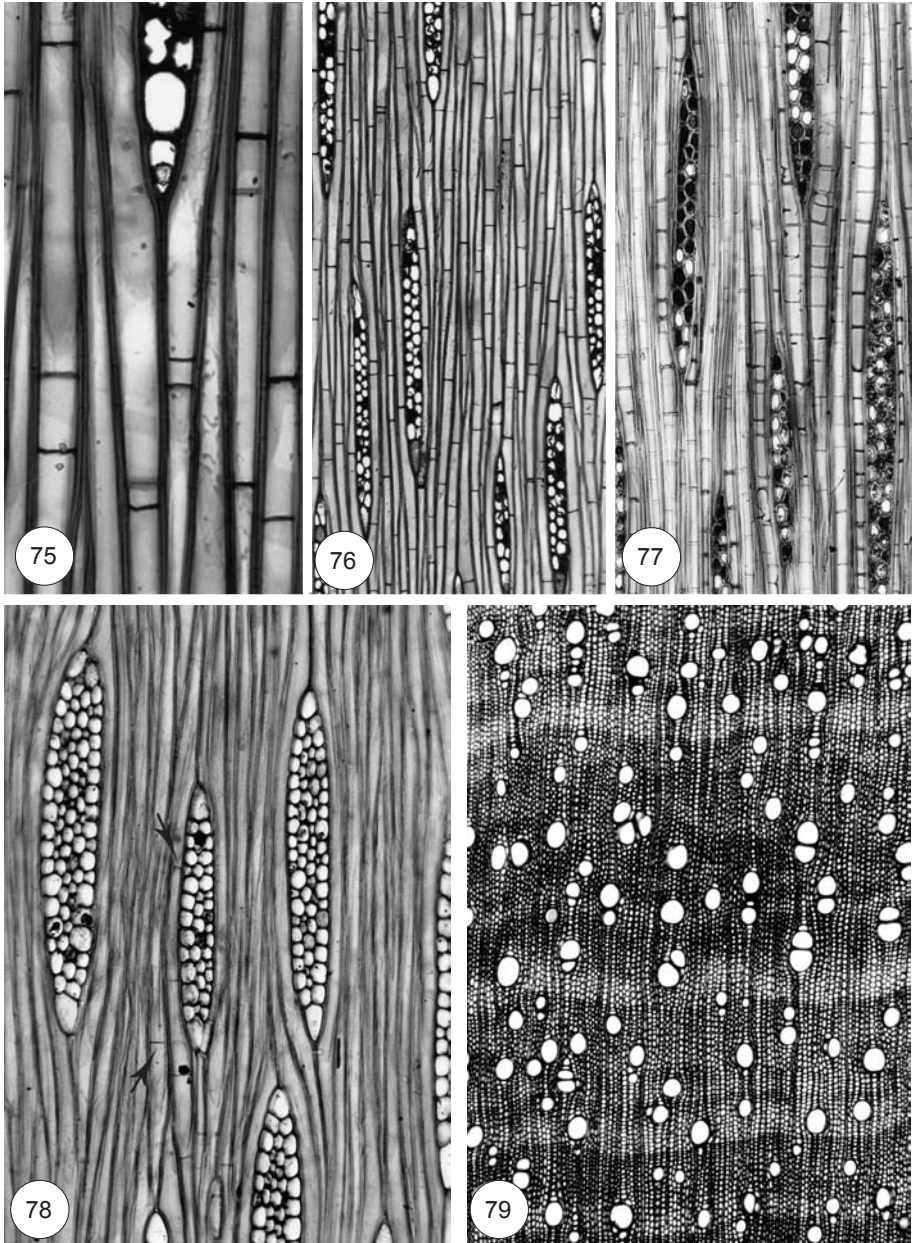
**Parenchyma-like fibre bands alternating with ordinary fibres** = tangential bands of relatively thin-walled fibres alternating with bands of thicker-walled fibres, fig. 79, e.g. *Cassine* spp., *Maytenus obtusifolia* (Celastraceae), *Dubautia* spp. (Compositae), *Lagerstroemia tomentosa*, *Physocalymna* spp. (Lythraceae), *Cupania americana* (Sapindaceae).

##### Comments:

Septa are formed after the secondary fibre walls have been deposited; they therefore do not extend to the compound middle lamellae between adjacent fibres. Septa are usually un lignified and very thin (cf. Parameswaran & Liese 1969).

In some woods, all fibres are septate (feature 65 present, feature 66 absent), e.g., fig. 76, *Lannea welwitschii*, *Spondias mombin* (Anacardiaceae), *Canarium schweinfurthii* (Burseraeae). In other woods, both septate and nonseptate fibres occur together (features 65 and 66 both present), e.g., fig. 78, *Buchenavia capitata* (Combretaceae), *Elaeocarpus* spp. (Elaeocarpaceae), *Swietenia macrophylla* (Meliaceae). The septate fibres may then either be scattered irregularly, situated near the vessels or the rays (feature 67 absent), or arranged in tangential bands (feature 67 present).





Figs. 75–77. Septate fibres present (feature 65). – 75 & 76: All fibres septate, several septa per fibre, *Aucoumea klaineana*. – 75:  $\times 290$ . – 76:  $\times 75$ . – 77: Many septa per fibre, *Aglaia littoralis*,  $\times 150$ . — Fig. 78. Septate (arrows) and nonseptate fibres present in the same sample (features 65 and 66), *Swietenia macrophylla*,  $\times 115$ . — Fig. 79. Parenchyma-like fibre bands (feature 67), *Physocalymna scaberrimum*,  $\times 45$ .



The fibres of parenchyma-like fibre bands (feature 67) are usually septate; the ordinary fibres they alternate with may be nonseptate (feature 66) as in *Cassine maurocenia*, *Maytenus obtusifolia* (Celastraceae), or septate as in *Lagerstroemia tomentosa*, *Physocalymna scaberrimum* (Lythraceae). In the latter case, features 65 and 67 are present, feature 66 is absent.

Fibre septation is coded independently of fibre wall pitting (features 61–63).

The number of septa per fibre can vary from 1 to many. This number can be taxon specific (e.g., Van Vliet 1976b), and so the average number of septa per taxon should be given in a description.

*Cautions:* Do not confuse torn cell wall fragments, cell wall deformations, gum deposits, fungal hyphae, or tyloses in fibres (seen in some Magnoliaceae, Lauraceae) with septa. Sometimes parenchyma strands can also easily be confused with septate fibres.

Avoid tension wood, because gelatinous fibres are nonseptate.

## FIBRE WALL THICKNESS

### 68. Fibres very thin-walled

### 69. Fibres thin- to thick-walled

### 70. Fibres very thick-walled

#### *Defintions:*

**Fibres very thin-walled** = fibre lumina 3 or more times wider than the double wall thickness, fig. 80, e.g., in *Bursera simaruba* (Burseraceae), *Tetrameles nudiflora* (Datiscaceae), *Neubergia corynocarpa* (Loganiaceae), *Tilia japonica* (Tiliaceae).

**Fibres thin- to thick-walled** = fibre lumina less than 3 times the double wall thickness, and distinctly open, fig. 81, e.g., in *Ilex* spp. (Aquifoliaceae), *Michelia compressa* (Magnoliaceae), *Salix alba* (Salicaceae).

**Fibres very thick-walled** = fibre lumina almost completely closed, fig. 82, e.g., in *Goupia glabra* (Celastraceae), *Lophira* spp. (Ochnaceae), *Strombosia pustulata* (Olacaceae), *Krugiodendron ferreum* (Rhamnaceae), *Rhizophora mangle* (Rhizophoraceae).

#### *Comments:*

Measurements of the actual thickness of fibre walls usually involves an amount of work out of all proportion to the limited diagnostic value of the figure obtained. Therefore, the classes for fibre wall thickness are based on the ratio of lumen to wall thickness (Chattaway 1932). The ratio proposed is that of the width of the lumen to the combined thickness of the walls between it and the lumen of the next cell as viewed in cross section. When cells are flattened radially the lumen becomes oval and will give a different ratio with the wall according to whether it is measured radially or tangentially; the radial measurement is suggested.

Chattaway (1932) proposed four categories; three are used here. Feature 68 roughly corresponds to her category 'very thin'-walled; feature 69 includes her two categories 'thin' and 'thick'; feature 70 is identical to her category 'very thick'.

Fibre wall thickness in many species is variable and there may be more than one category of fibre wall thickness in a species.

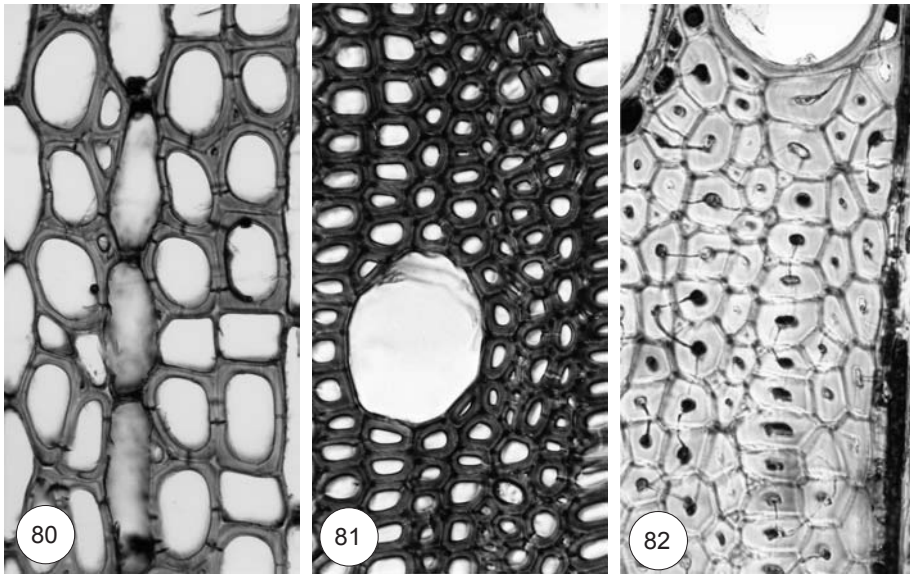


Fig. 80. Fibres very thin-walled (feature 68), *Neuburgia corynocarpa*,  $\times 290$ . — Fig. 81. Fibres thin- to thick-walled (feature 69), *Michelia compressa*,  $\times 290$ . — Fig. 82. Fibres very thick-walled (feature 70), *Rhizophora mangle*,  $\times 290$ .

*Cautions:* In woods with distinct growth rings, fibre wall thickness changes throughout the growth ring, and may be particularly thick at the end of the growth ring. When describing fibre wall thickness, do *not* consider these last latewood fibres.

Also, do not describe gelatinous fibres (~tension wood fibres), which usually have thick walls with an unglified gelatinous layer.

#### MAIN FIBRE LENGTHS

**71.  $\leq 900 \mu\text{m}$**

**72.  $900\text{--}1600 \mu\text{m}$**

**73.  $\geq 1600 \mu\text{m}$**

**74. Mean,  $\pm$  Standard Deviation, Range,  $n = x$**

#### *Procedure:*

Use macerations of mature trunk wood, and measure the length of at least 25 fibres to determine the mean, range, and standard deviation. Use the category(ies) in which the mean(s) fall(s). For woods with distinct growth rings, sample from the middle of the growth ring. Because of the importance of cell length in wood quality studies, a variety of methods have been developed to insure random selection of cells for measurement. It is recommended that one of these methods be used (Dodd 1986; Hart & Swindel 1967). There are very few woods in which fibre length can be measured accurately from sections, so such a method is not recommended.

## AXIAL PARENCHYMA

### *General comments:*

When identifying an unknown, use the most obvious type of parenchyma pattern first and then the less evident type or types. Be sure to use a broad field of view when determining the predominant parenchyma pattern(s) from the transverse section. Various combinations of the three general types (Apotracheal, Paratracheal, and Banded) described below may be present in a given wood.

### **75. Axial parenchyma absent or extremely rare**

#### *Definitions:*

**Axial parenchyma absent or extremely rare** = as per feature descriptor, fig. 83, e.g., *Berberidaceae*, *Punicaceae*, *Violaceae*, *Homalium foetidum*, *Scottellia coriacea* (*Flacourtiaceae*), *Sonneratia* spp. (*Sonneratiaceae*).

#### *Comment:*

It is necessary to study longitudinal sections in combination with transverse sections to be sure axial parenchyma is absent or extremely rare (i.e., very difficult to find; only a few strands per section). This feature may be used in combination with 'axial parenchyma scanty paratracheal' (feature 78) and/or 'axial parenchyma diffuse' (feature 76), if, despite the scarcity of parenchyma strands, the distribution is clear.

## APOTRACHEAL AXIAL PARENCHYMA

### **76. Axial parenchyma diffuse**

### **77. Axial parenchyma diffuse-in-aggregates**

#### *Definitions:*

**Apotracheal axial parenchyma** = axial parenchyma not associated with the vessels.

**Axial parenchyma diffuse** = single parenchyma strands or pairs of strands distributed irregularly among the fibrous elements of the wood, fig. 84, e.g., *Aspidosperma polyneuron* (*Apocynaceae*), *Alnus glutinosa* (*Betulaceae*), *Goupia glabra* (*Celastraceae*), *Cornus mas* (*Cornaceae*), *Apodytes dimidiata* (*Icacinaceae*), *Crataegus* spp. (*Rosaceae*), *Santalum album* (*Santalaceae*).

**Axial parenchyma diffuse-in-aggregates** = parenchyma strands grouped into short discontinuous tangential or oblique lines, fig. 85, e.g., *Durio* spp. (*Bombacaceae*), *Hura crepitans* (*Euphorbiaceae*), *Ongokea gore*, *Strombosia pustulata* (*Olacaceae*), *Agonandra brasiliensis* (*Opiliaceae*), *Dalbergia stevensonii* (*Papilionaceae*), *Pterospermum* spp. (*Sterculiaceae*), *Tilia* spp. (*Tiliaceae*).

#### *Comments:*

Because there is a continuous range from parenchyma extremely rare, diffuse, diffuse-in-aggregates, to parenchyma in narrow bands (feature 86) or scalariform (feature 88), for some taxa it will be necessary to record more than one feature for apotracheal parenchyma. Diffuse

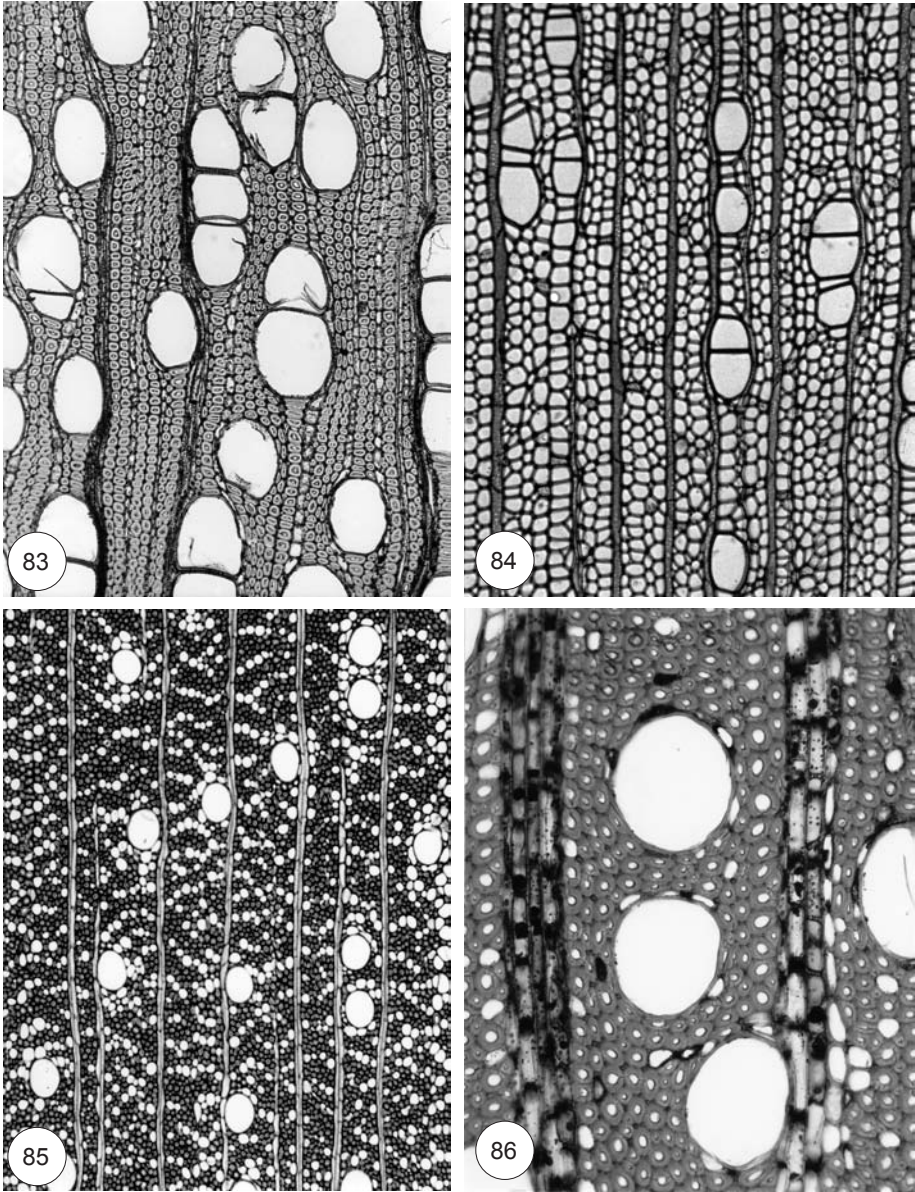


Fig. 83. Axial parenchyma absent or extremely rare (feature 75), *Homalium foetidum*,  $\times 75$ . — Fig. 84. Axial parenchyma diffuse (feature 76), *Alnus glutinosa*,  $\times 115$ . — Fig. 85. Axial parenchyma diffuse-in-aggregates (feature 77), *Agonandra brasiliensis*,  $\times 45$ . — Fig. 86. Axial parenchyma scanty paratracheal (feature 78), and also scanty diffuse (feature 76), *Dillenia pulcherrima*,  $\times 115$ .

and diffuse-in-aggregates frequently occur in combination. Record (1944) referred to diffuse-in-aggregates parenchyma as reticulate. This list does not follow that usage, but uses reticulate to describe a type of banded parenchyma, see feature 87.

*Cautions:* Although by definition apotracheal parenchyma is not associated with vessels, woods with abundant diffuse or diffuse-in-aggregate parenchyma may exhibit several strands touching the vessels. Such random contacts should not be recorded as paratracheal parenchyma.

Apotracheal diffuse parenchyma sometimes occurs primarily near the rays ('ray adjacent parenchyma' of Carlquist 1988), and should *not* be confused with sheath cells in rays (feature 110).

#### PARATRACHEAL AXIAL PARENCHYMA

##### 78. Axial parenchyma scanty paratracheal

##### 79. Axial parenchyma vasicentric

##### 80. Axial parenchyma aliform

##### 81. Axial parenchyma lozenge-aliform

##### 82. Axial parenchyma winged-aliform

##### 83. Axial parenchyma confluent

##### 84. Axial parenchyma unilateral paratracheal

#### *Definitions:*

**Axial parenchyma paratracheal** = axial parenchyma associated with the vessels or vascular tracheids, types of paratracheal parenchyma are scanty paratracheal, vasicentric, aliform (subtypes: lozenge-aliform, winged-aliform), confluent, and unilateral paratracheal.

**Axial parenchyma scanty paratracheal** = occasional parenchyma cells associated with the vessels or an incomplete sheath of parenchyma around the vessels, fig. 86, e.g., *Pistacia vera* (Anacardiaceae), *Sclerobium* spp. (Caesalpiniaceae), *Dillenia pulcherrima* (Dilleniaceae), *Erythroxylum mannii* (Erythroxylaceae), *Laurus nobilis* (Lauraceae).

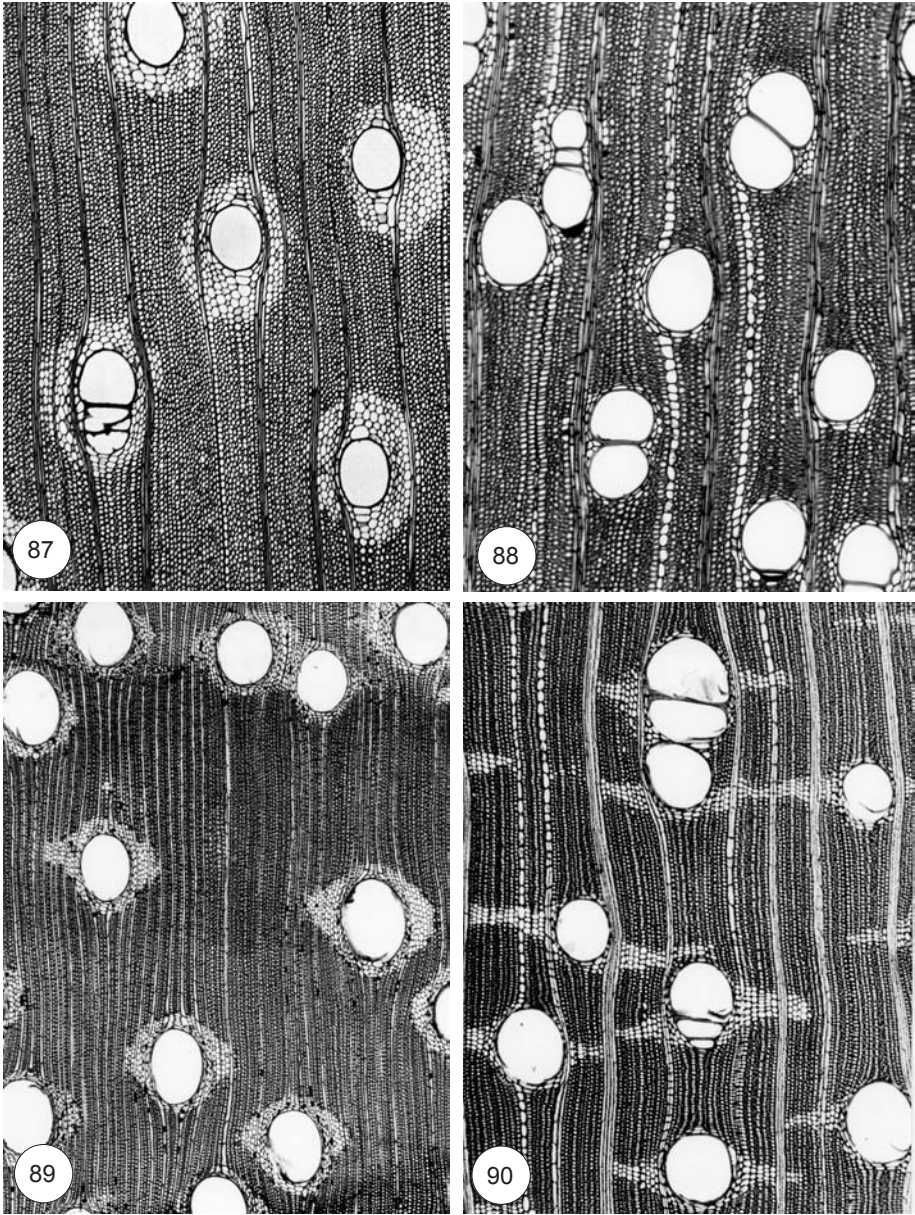
**Axial parenchyma vasicentric** = parenchyma cells forming a complete circular to oval sheath around a solitary vessel or vessel multiple, figs. 87, 88, e.g., *Tachigali myrmecophylla* (Caesalpiniaceae), *Octomeles sumatrana* (Datiaceae), *Phoebe porosa* (Lauraceae), *Khaya grandifoliola* (Meliaceae), *Anadenanthera* spp., *Enterolobium cyclocarpum*, *Piptadeniastrum africanum* (Mimosaceae), *Olea europaea* (Oleaceae)

**Axial parenchyma aliform** = parenchyma surrounding or to one side of the vessel and with lateral extensions. For examples see the two subtypes below.

**Axial parenchyma lozenge-aliform** = parenchyma surrounding or to one side of the vessels with lateral extensions forming a diamond-shaped outline, fig. 89, e.g., *Albizia lebbek*, *Parkia gigantocarpa* (Mimosaceae), *Artocarpus chaplasha* (Moraceae), *Microberlinia brazzavillensis*, *Ormosia flava*, *Vatairea* spp. (Papilionaceae), *Qualea rosea* (Vochysiaceae).

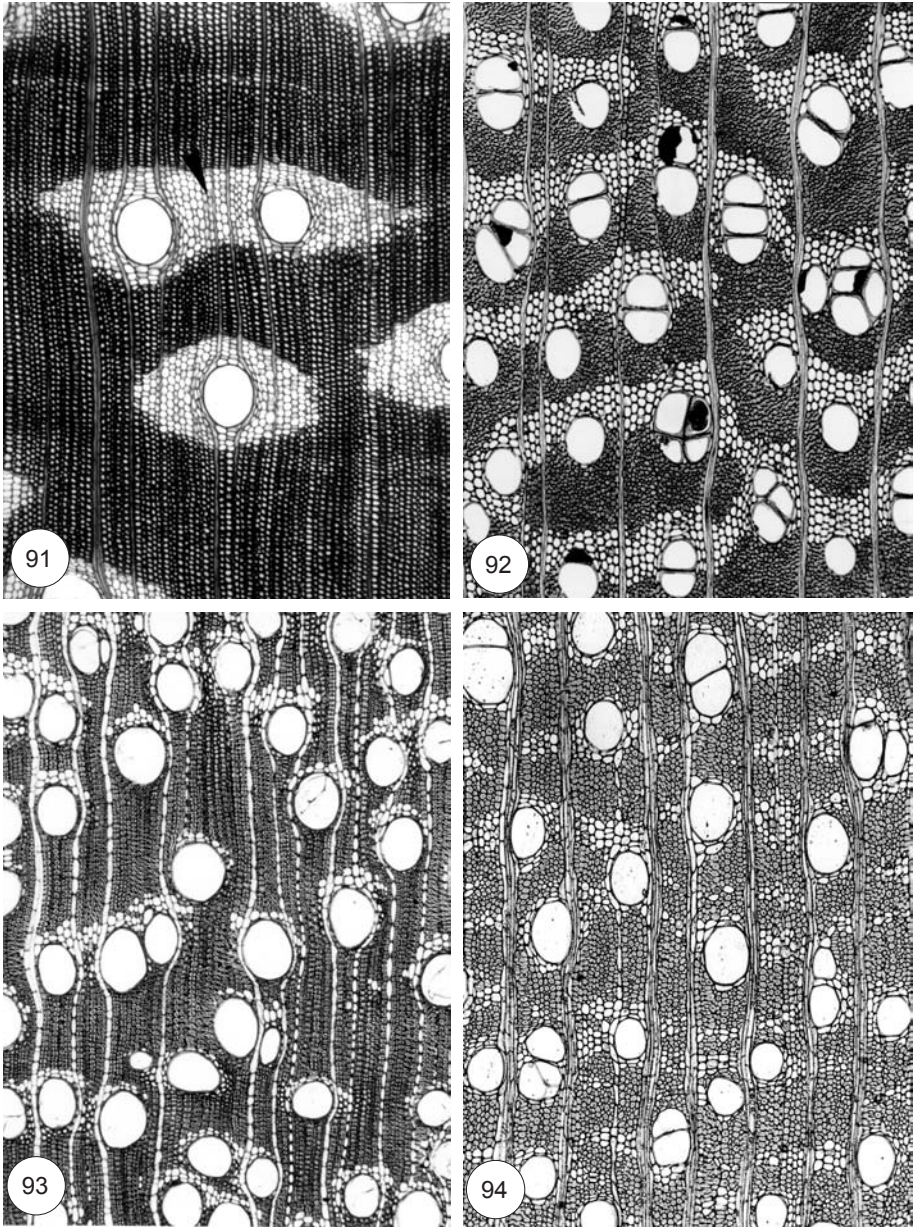
**Axial parenchyma winged-aliform** = parenchyma surrounding or to one side of the vessels with the lateral extensions being elongated and narrow, fig. 90, e.g., *Jacaranda copaia* (Bignoniaceae), *Terminalia superba* (Combretaceae), *Brosimum* spp. (Moraceae), *Quassia amara* (Simaroubaceae), *Gonystylus* spp. (Thymelaeaceae).





Figs. 87 & 88. Axial parenchyma vasicentric (feature 79). – 87: Parenchyma sheath broad, *Piptadeniastrum africanum*,  $\times 26$ . – 88: Parenchyma sheath narrow, *Khaya grandifoliola*,  $\times 45$ . – Fig. 89. Axial parenchyma lozenge-aliform (features 80 and 81), *Microberlinia brazzavillensis*,  $\times 29$ . – Fig. 90. Axial parenchyma winged-aliform (features 80 and 82), *Brosimum rubescens*,  $\times 45$ .





Figs. 91 & 92. Axial parenchyma confluent (feature 83). — 91: *Parkia pendula* (arrowhead, note also features 80 and 81, parenchyma lozenge-aliform),  $\times 36$ . — 92: *Peltogyne confertiflora* (note also feature 84, unilateral parenchyma),  $\times 45$ . — Fig. 93. Axial parenchyma unilateral paratracheal (feature 84), *Caraiipa grandiflora*,  $\times 45$ . — Fig. 94. Axial parenchyma predominantly paratracheal, *Garcinia latissima* (note also features 80, aliform, and 83, confluent),  $\times 45$ .

**Axial parenchyma confluent** = coalescing vasicentric or aliform parenchyma surrounding or to one side of two or more vessels, and often forming irregular bands, figs. 91, 92, e.g., *Kigelia africana* (Bignoniaceae), *Caesalpinia ferrea*, *Peltogyne confertiflora* (Caesalpinaceae), *Marmaroxylon racemosum*, *Parkia pendula* (Mimosaceae), *Chlorophora tinctoria* (Moraceae), *Bowdichia nitida*, *Vatairea guianensis* (Papilionaceae).

**Axial parenchyma unilateral paratracheal** = paratracheal parenchyma forming semi-circular hoods or caps only on one side of the vessels, and which can extend tangentially or obliquely in an aliform or confluent or banded pattern, fig. 93, e.g., *Aspidosperma desmanthum* (Apocynaceae), *Caraipa grandiflora* (Bonnetiaceae), *Peltogyne confertiflora* (Caesalpinaceae), *Mammea bongo* (Guttiferae), *Dilobeia thouarsii* (Proteaceae).

*Comments:*

Scanty paratracheal includes what has been described in the literature as incomplete vasicentric.

Some woods have vasicentric, aliform, and confluent paratracheal parenchyma. Confluent often intergrades with banded and may be recorded or used in combination with features for band width (85 and 86). Feature 80, 'Axial parenchyma aliform', is included as a general category to 1) describe those woods that clearly have aliform parenchyma, but in which it is difficult to decide whether it is lozenge- or winged-aliform, and 2) allow use of information from the literature that does not differentiate between these two types. Features 81 and 82 are used in combination with feature 80.

Feature 84, 'unilateral paratracheal parenchyma', is used in combination with aliform and/or confluent when the unilateral parenchyma extends laterally or obliquely. Unilateral includes both abaxial and adaxial because generally it is not possible to distinguish between the two in a wood fragment.

Woods with several types of paratracheal parenchyma co-occurring and/or intergrading have been assigned the general descriptor 'parenchyma predominantly paratracheal' by several authors (fig. 94).

*Caution:* Vasicentric/vascular tracheids are often thinner-walled than ground tissue fibres, and in cross sections may be confused with axial parenchyma. Examine longitudinal sections to determine whether vasicentric/vascular tracheids or axial parenchyma surrounds the vessels.

## BANDED PARENCHYMA

- 85. Axial parenchyma bands more than three cells wide**  
**86. Axial parenchyma in narrow bands or lines up to three cells wide**  
**87. Axial parenchyma reticulate**  
**88. Axial parenchyma scalariform**  
**89. Axial parenchyma in marginal or in seemingly marginal bands**

*Definitions:*

**Parenchyma bands more than three cells wide** = as per feature descriptor, fig. 95, e.g., *Dicorynia paraensis* (Caesalpinaceae), *Entandrophragma candollei* (Meliaceae), *Ficus retusa* (Moraceae), *Lophira alata* (Ochnaceae), *Basyloxylon brasiliensis* (Sterculiaceae), *Erisma uncinatum* (Vochysiaceae).

**Parenchyma in narrow bands or lines up to three cells wide** = as per feature descriptor, figs. 96, 98, e.g., *Dialium guianensis* (Caesalpinaceae), *Endospermum malaccensis* (Euphorbiaceae), *Bertholletia excelsa* (Lecythidaceae), *Dysoxylum fraseranum* (Meliaceae), *Austranella congolensis* (Sapotaceae), *Hannoa klaineana* (Simaroubaceae).

**Parenchyma reticulate** = parenchyma in continuous tangential lines of approximately the same width as the rays, *regularly* spaced and forming a network with them. The distance between the rays is approximately equal to the distance between the parenchyma bands, fig. 97, e.g., *Cleistopholis* spp. (Annonaceae), *Diospyros discolor* (Ebenaceae), *Bertholletia excelsa*, *Cariniana* spp., *Couratari guianensis*, *Eschweilera* spp. (Lecythidaceae).

**Parenchyma scalariform** = parenchyma in fairly regularly spaced fine lines or bands, arranged horizontally or in arcs, appreciably narrower than the rays and with them producing a ladder-like appearance in cross section. The distance between the rays is greater than the distance between parenchyma bands, figs. 99, 100, e.g., *Anisophyllea* spp. (Anisophylleaceae), *Onychopetalum* sp. and most other Annonaceae, *Cardwellia sublimis*, *Embothrium mucronatum* (Proteaceae), *Rhopalocarpus* spp. (Rhopalocarpaceae).

**Parenchyma in marginal or in seemingly marginal bands** = parenchyma bands which form a more or less continuous layer of variable width at the margins of a growth ring or are irregularly zonate, figs. 101, 102, e.g., *Intsia bijuga* (Caesalpinaceae), *Juglans regia* (Juglandaceae), *Cryptocarya moschata* (Lauraceae), *Liriodendron tulipifera*, *Michelia compressa* (Magnoliaceae), *Cedrela* spp., *Swietenia* spp. (Meliaceae), *Horsfieldia subglobosa* (Myristicaceae).

*Comments:*

Parenchyma bands may be mainly independent of the vessels (apotracheal), definitely associated with the vessels (paratracheal), or both. Bands may be wavy, diagonal, straight, continuous or discontinuous (the latter often intergrading with confluent). The number of bands per mm varies and may be useful as a diagnostic feature in some groups. Bands over three cells wide are visible to the unaided eye. For woods with reticulate, scalariform, or marginal parenchyma the band width (either features 85 or 86) also should be recorded.

In the past, some anatomists (e.g., Record 1944) have used the term reticulate for abundant diffuse-in-aggregates parenchyma with numerous short interrupted lines.

Sometimes marginal parenchyma bands are associated with axial intercellular canals. In some temperate woods there are discontinuous bands/lines of parenchyma at the growth ring margin; this condition also should be described as 'marginal'. Marginal parenchyma includes terminal and initial parenchyma; seemingly marginal includes what has been called irregular zonate bands.

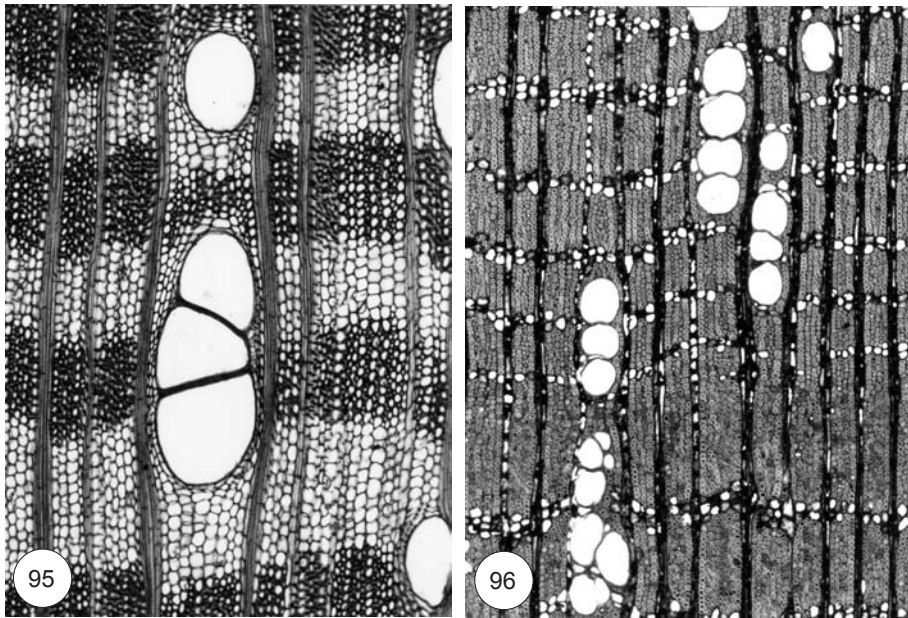


Fig. 95. Axial parenchyma in bands more than three cells wide (feature 85), *Ficus retusa*,  $\times 45$ .  
— Fig. 96. Axial parenchyma in narrow bands or lines up to three cells wide (feature 86),  
*Autranella congolensis*,  $\times 45$ .



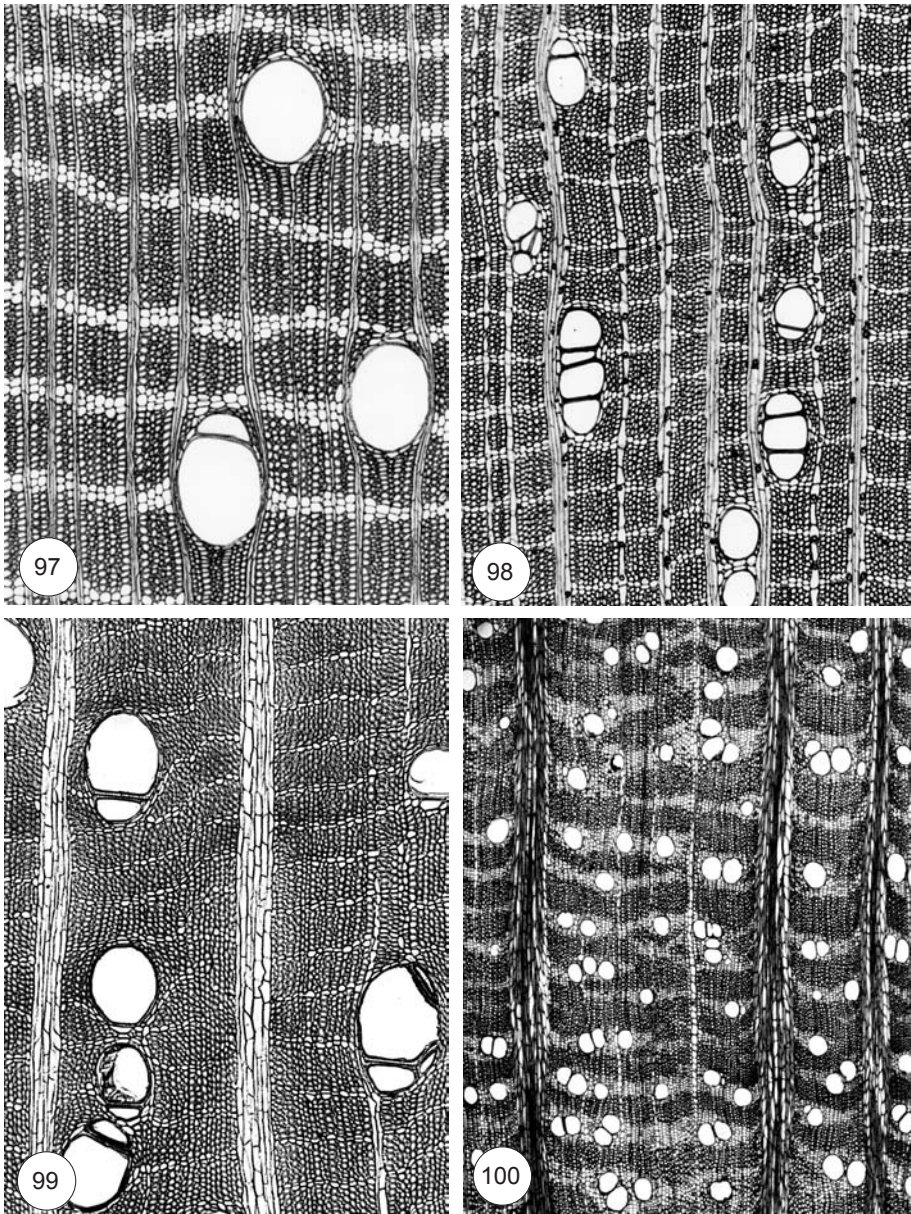
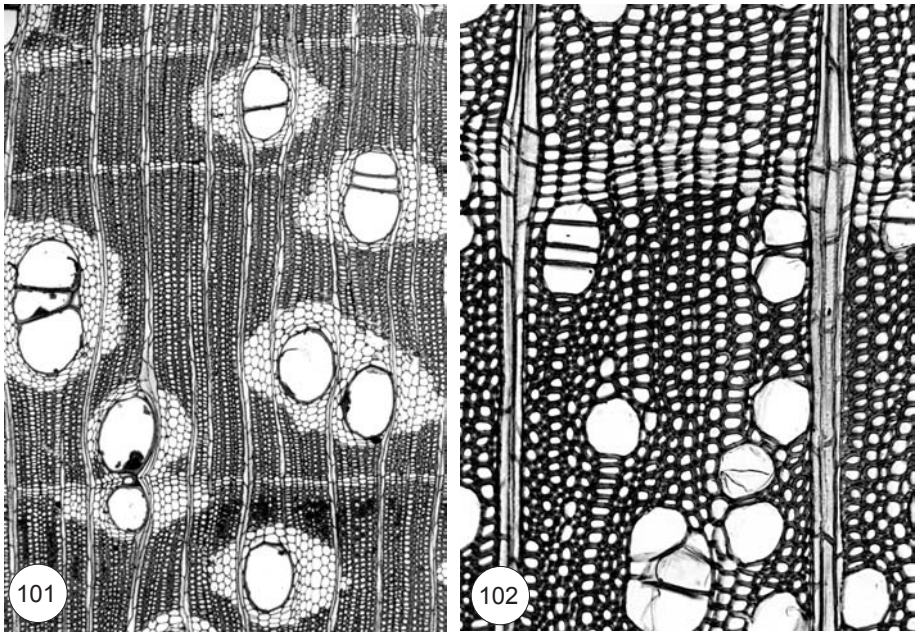


Fig. 97. Axial parenchyma reticulate (feature 87), *Bertholletia excelsa* (note also feature 86, parenchyma in narrow bands),  $\times 45$ . — Fig. 98. Axial parenchyma intermediate between reticulate and scalariform (features 87 and 88 variable), *Couratari guianensis*,  $\times 45$ . — Figs. 99 & 100. Axial parenchyma scalariform (feature 88). — 99: *Onychoptalum* sp.,  $\times 45$ . — 100: Parenchyma bands also 'festooned', *Cardwellia sublimis*,  $\times 15$ .



Figs. 101 & 102. Axial parenchyma in marginal or seemingly marginal bands (feature 89). – 101: *Intsia bijuga*. Note also features 80, 81 (lozenge-aliform parenchyma), 83 (confluent), and 86 (narrow bands);  $\times 29$ . – 102: *Michelia compressa*,  $\times 45$ .

## AXIAL PARENCHYMA CELL TYPE/STRAND LENGTH

**90. Fusiform parenchyma cells****91. Two cells per parenchyma strand****92. Four (3–4) cells per parenchyma strand****93. Eight (5–8) cells per parenchyma strand****94. Over eight cells per parenchyma strand***Definitions:*

**Fusiform parenchyma** = parenchyma cells derived from fusiform cambial initials without subdivisions or tip growth. In shape they resemble a short fibre, fig. 103, e.g., *Capparis* spp. (Capparidaceae), *Aeschynomene elaphroxylon*, *Erythrina* spp., *Lonchocarpus* spp. (Papilionaceae), *Triplochiton scleroxylon* (Sterculiaceae), *Bulnesia* spp., *Guaiacum* spp., *Zygophyllum* spp. (Zygophyllaceae).

**Parenchyma strand** = a series of axial parenchyma cells formed through transverse division(s) of a single fusiform cambial initial cell.

**Two cells per parenchyma strand**, figs. 103, 104, e.g., *Dalbergia* spp., *Lonchocarpus* spp., *Pterocarpus* spp. (Papilionaceae).

**Four (3–4) cells per parenchyma strand**, fig. 104, e.g., *Terminalia* spp. (Combretaceae), *Ligustrum* spp., *Syringa* spp. (Oleaceae), *Nesogordonia* spp. (Sterculiaceae).

**Eight (5–8) cells per parenchyma strand**, fig. 105, e.g., *Nerium oleander* (Apocynaceae), *Macaranga* spp. (Euphorbiaceae), *Fraxinus* spp. (Oleaceae).

**Over eight cells per parenchyma strand**, e.g., *Bhesa* spp. (Celastraceae), *Lophira* spp. (Ochnaceae), *Minquartia* spp., *Tetrastylidium* spp. (Olacaceae).

*Comments:*

Type of parenchyma, fusiform vs. strand, is determined from tangential sections. Fusiform parenchyma cells are relatively uncommon and generally occur in woods with storied structure and short axial elements. In some species, combinations of the above features occur, e.g., ‘fusiform cells’ and ‘two cells per parenchyma strand’, or ‘two cells per parenchyma strand’ and ‘four (3–4) cells per parenchyma strand’. Strand length can differ between earlywood and latewood of the same ring, or between vessel-associated parenchyma and parenchyma which is not in contact with the vessels. Record all commonly occurring strand lengths.

*Caution:* Be careful not to confuse uniseriate rays or septate fibres with strand parenchyma. Do not determine number of cells per strand from chambered crystalliferous strands.

**95. Unlignified parenchyma***Definition:*

**Unlignified parenchyma** = as per feature descriptor, fig. 106, e.g., *Apeiba* spp., *Entelea arborescens*, *Heliocarpus* spp. (Tiliaceae), *Laportea stimulans* (Urticaceae).

*Comment:*

Unlignified parenchyma usually occurs in broad bands, and is restricted to a small number of taxa.



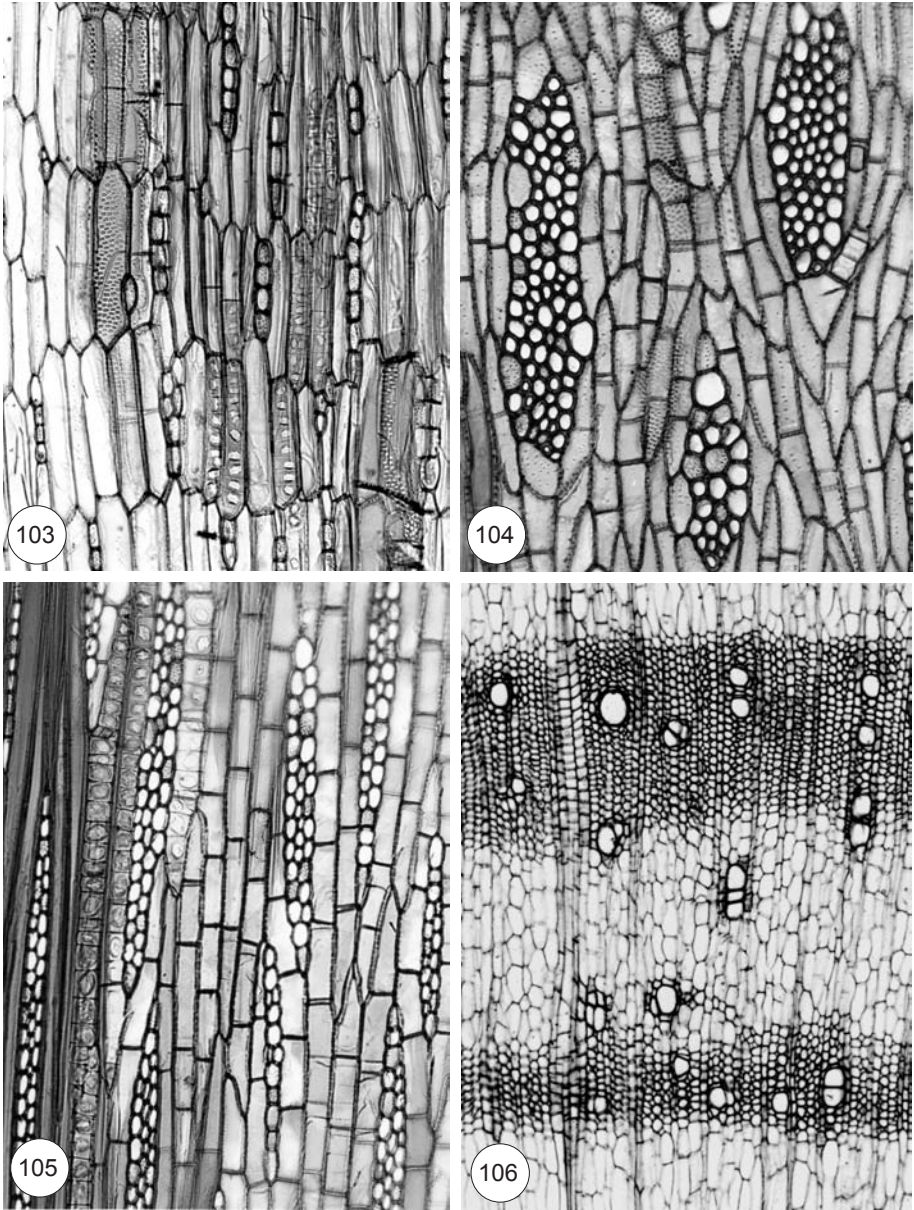


Fig. 103. Fusiform parenchyma cells (feature 90, left and right) and two cells per parenchyma strand (feature 91, left centre). Note also feature 120 (axial parenchyma storied) and feature 142 (crystals in chambered axial parenchyma); *Aeschynomene elaphroxylon*,  $\times 115$ . — Fig. 104. Two (feature 91) to four (feature 92) cells per parenchyma strand, *Cordia abyssinica*,  $\times 115$ . — Fig. 105. Eight (feature 93) or over eight cells (feature 94) per parenchyma strand, *Bertholletia excelsa*,  $\times 115$ . — Fig. 106. Unalignified parenchyma (feature 95), *Entelea arborescens*,  $\times 45$ .

## RAYS

### RAY WIDTH

- 96. Rays exclusively uniseriate**
- 97. Ray width 1 to 3 cells**
- 98. Larger rays commonly 4- to 10-seriate**
- 99. Larger rays commonly >10-seriate**
- 100. Rays with multiseriate portion(s) as wide as uniseriate portions**

#### *Definitions:*

Ray width in cell numbers as per feature descriptors.

**Rays exclusively uniseriate**, fig. 107, e.g., *Lophopetalum beccarianum* (Celastraceae), *Terminalia superba* (Combretaceae), *Hura crepitans* (Euphorbiaceae), *Castanea sativa* (Fagaceae), *Populus* spp. (Salicaceae).

**Ray width 1 to 3 cells**, fig. 108, e.g., *Aucoumea klaineana* (Burseraceae), *Dialium guianense* (Caesalpinaceae), *Alseodaphne costalis* (Lauraceae), *Albizia (Samanea) saman* (Mimosaceae), *Malus communis* (Rosaceae).

**Larger rays commonly 4- to 10-seriate**, fig. 110, e.g., *Acer saccharum* (Aceraceae), *Spondias mombin* (Anacardiaceae), *Anisoperta laevis* (Dipterocarpaceae), *Khaya anthotheca* (Meliaceae), *Celtis sinensis* (Ulmaceae).

**Larger rays commonly >10-seriate**, fig. 110, e.g., *Quercus* spp. (Fagaceae), *Poraqueiba guianensis* (Icacinaceae), *Rapanea* spp. (Myrsinaceae), *Platanus* spp. (Platanaceae), *Cardwellia sublimis*, *Grevillea robusta* (Proteaceae), *Tamarix aphylla* (Tamaricaceae), *Jacquinia revoluta* (Theophrastaceae).

**Rays with multiseriate portion(s) as wide as uniseriate portions**, fig. 111, e.g., *Anthodiscus amazonicus*, *Caryocar costaricense* (Caryocaraceae), *Strombosia pustulata* (Olacaceae), *Adina cordifolia* (Rubiaceae), and many Apocynaceae, Sapotaceae, and Euphorbiaceae.

#### *Procedure:*

Determine ray width on the tangential section by counting the number of cells in the widest part of the rays, perpendicular to the ray axis. When rays are of two distinct sizes (feature 103), record the width of the larger size class in the database.

#### *Comments:*

'Exclusively uniseriate rays' and 'rays >10-seriate' are the least common of the ray width features. The categories for ray width match those of the Clarke (1938) and the Princes Risborough multiple entry keys (Brazier & Franklin 1961). There are some taxa that may be separated by finer distinctions within these categories, and in a description more detailed information than provided by these categories would be desirable.

*Caution:* These features for ray width do not apply to rays containing radial canals (feature 130) or to the rays composing an aggregate ray (feature 101). Thus, for a wood with exclusively uniseriate rays, except for the rays with radial canals, describe the wood by recording feature 96 for exclusively uniseriate rays and feature 130 for radial canals.



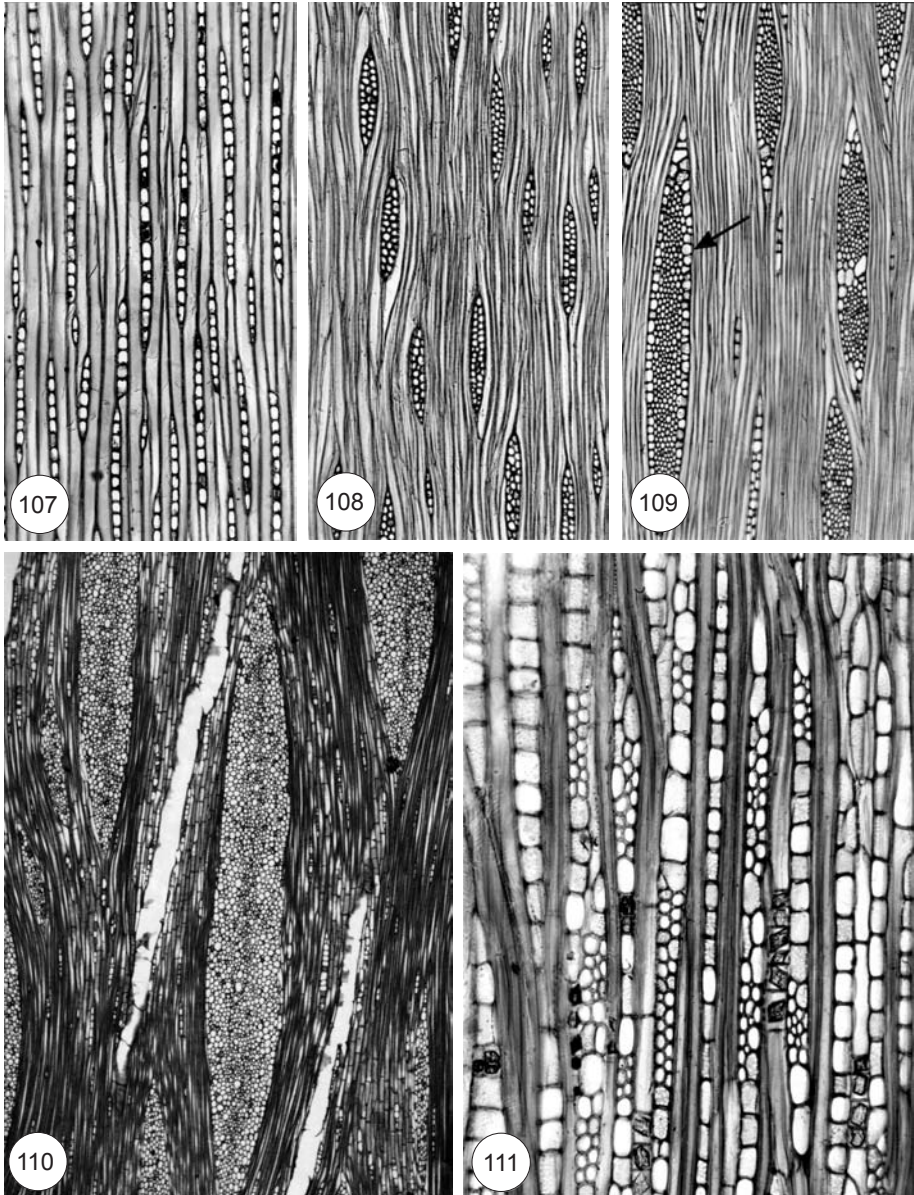


Fig. 107. Rays exclusively uniseriate (feature 96), *Lophopetalum beccarianum*,  $\times 75$ . — Fig. 108. Ray width one to three cells (feature 97), *Albizia (Samanea) saman*,  $\times 29$ . — Fig. 109. Larger rays commonly 4–10-seriate (feature 98). Note also sheath cells (arrow, feature 110); *Celtis sinensis*,  $\times 29$ . — Fig. 110. Larger rays commonly  $>10$ -seriate (feature 99), *Cardwellia sublimis*,  $\times 19$ . — Fig. 111. Rays with multiseriate portion(s) as wide as uniseriate portions (feature 100), *Caryocar costaricense*,  $\times 115$ .

## AGGREGATE RAYS

**101. Aggregate rays***Definition:*

**Aggregate ray** = a number of individual rays so closely associated with one another that they appear macroscopically as a single large ray. The individual rays are separated by axial elements, e.g., many species of *Alnus* (Betulaceae), *Carpinus*, *Corylus* (Corylaceae), *Casuarina* (Casuarinaceae), *Necepsia afzelii* (Euphorbiaceae), *Castanopsis*, *Lithocarpus*, *Quercus*—evergreen species (Fagaceae), *Emmotum orbiculatum* (Icacinaeae), *Cryptocarya densiflora* (Lauraceae).

*Comments:*

There is variation in the size of the individual rays of aggregate rays. In some species the aggregate rays are composed of narrow rays (figs. 112, 113, e.g., *Carpinus* spp.—Corylaceae), while in others they are composed of broad rays (figs. 114, 115, e.g., *Emmotum orbiculatum*—Icacinaeae).

Aggregate rays occur in few taxonomic groups.

*Caution:* Aggregate rays may be relatively infrequent in the taxa in which they occur, so they may be easily overlooked or absent in a small sample; therefore, this feature should preferably be used positively only.

## RAY HEIGHT

**102. Ray height >1 mm***Definition:*

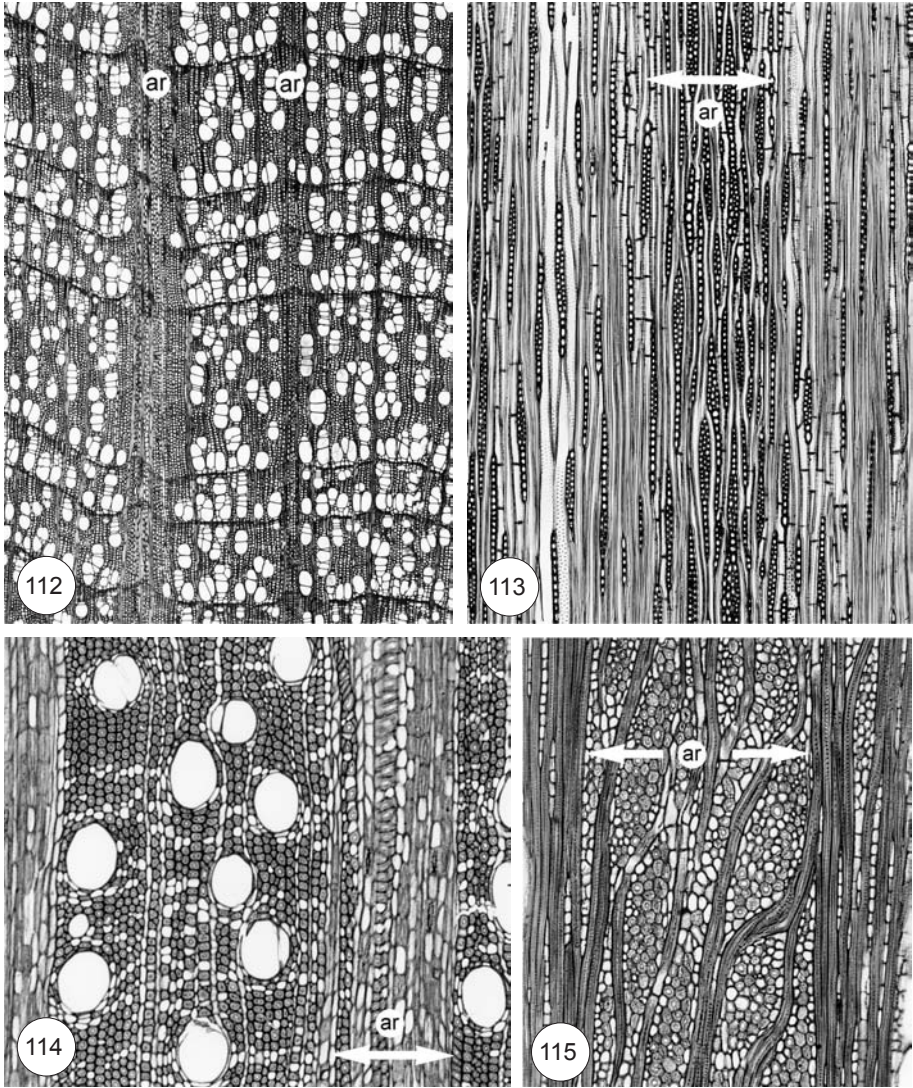
**Ray height >1 mm** = the large rays commonly exceeding 1 mm in height, e.g., *Guatteria schomburgkiana* (Annonaceae), *Anisopera laevis* (Dipterocarpaceae), *Uapaca guineensis* (Euphorbiaceae), *Scottellia coriacea* (Flacourtiaceae), *Barringtonia asiatica* (Lecythidaceae), *Platanus occidentalis* (Platanaceae), *Paypayrola guianensis* (Violaceae).

*Procedure:*

Determine total ray height in tangential section, along the ray axis.

*Comment:*

In this list of features, only one category for total ray height is used as was done in some of the earlier multiple entry keys (Clarke 1938; Brazier & Franklin 1961). More detailed ray height data generally are given in descriptions and may be helpful in distinguishing between taxa in some groups. Ray height is quite variable in some woods (particularly woods with markedly heterocellular rays), but quite uniform in others (particularly woods with storied structure).



Figs. 112–115. Aggregate rays (feature 101). – 112 & 113: *Carpinus betulus*, aggregate rays (ar) composed of narrow rays. – 112: Transverse section,  $\times 20$ . – 113: Tangential section,  $\times 52$ . – 114 & 115: *Emmotum orbiculatum*, aggregate rays (ar) composed of multiserial rays,  $\times 45$ . – 114: Transverse section. – 115: Tangential section.

## RAYS OF TWO DISTINCT SIZES

**103. Rays of two distinct sizes***Definition:*

**Rays of two distinct sizes** = when viewed in tangential section, rays form two distinct populations by their width and usually also by their height, figs. 116, 117, e.g., *Acer saccharum* (Aceraceae), *Poga oleosa* (Anisophylleaceae), *Ilex aquifolium* (Aquifoliaceae), *Dillenia pentagyna* (Dilleniaceae), *Quercus* spp. (Fagaceae), *Dendrobangia boliviana* (Icacinaeae), *Scaphium macropodum* (Sterculiaceae), *Ternstroemia* spp. (Theaceae).

*Comments:*

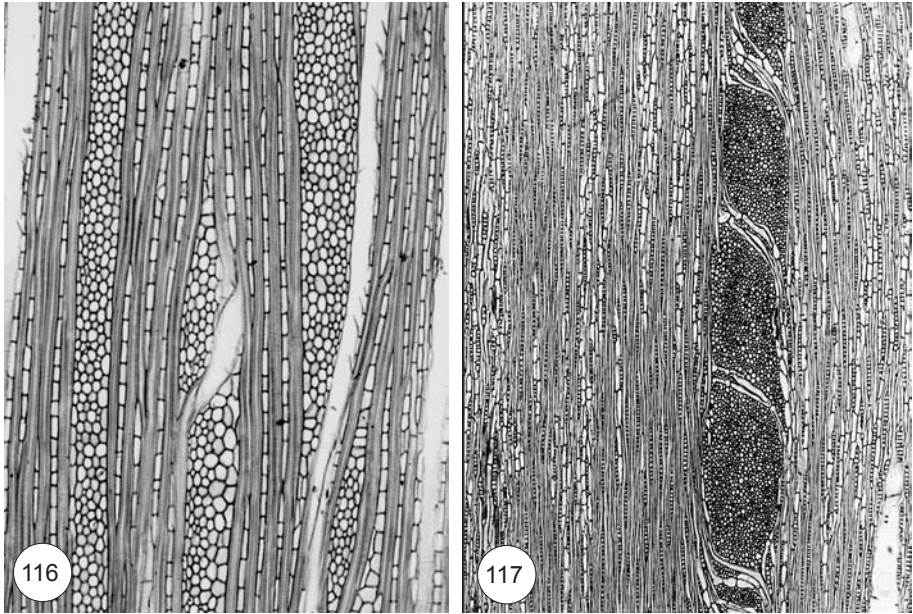
There are no limits for the size classes – the smaller rays may be 1- or 2- or 3-seriate, the larger rays may be less than 5-seriate.

Generally, to fit the feature definition, intermediate rays should not exist between the two populations or be quite rare. Thus, when very large rays occur with a few medium-sized and more numerous small rays (e.g., *Fagus*), feature 103 ‘rays of two distinct sizes’ may still be applied.

*Cautions:* Whether a wood has rays of two distinct widths *cannot* be determined from the cross section because in this view the long uniseriate wings of heterocellular multiseriate rays might be interpreted incorrectly as narrow rays.

Aggregate rays *per se* should not be considered as a separate ray size class. Only in those species where the aggregate rays are composed of much broader rays than the nonaggregate rays does feature 103 apply, e.g., several species of *Casuarina* (Casuarinaceae) and *Quercus* (Fagaceae).





Figs. 116 & 117. Rays of two distinct sizes (feature 103). – 116: *Ternstroemia* sp.,  $\times 45$ . – 117: *Quercus gilva*,  $\times 29$ .

RAYS: CELLULAR COMPOSITION

**104. All ray cells procumbent**

**105. All ray cells upright and/or square**

**106. Body ray cells procumbent with one row of upright and/or square marginal cells**

**107. Body ray cells procumbent with mostly 2–4 rows of upright and/or square marginal cells**

**108. Body ray cells procumbent with over 4 rows of upright and/or square marginal cells**

**109. Rays with procumbent, square and upright cells mixed throughout the ray**

*Definitions:*

**Procumbent ray cell** = a ray parenchyma cell with its longest dimension radial as seen in radial section.

**Square ray cell** = a ray parenchyma cell approximately square as seen in radial section.

**Upright ray cell** = a ray parenchyma cell with its longest dimension axial as seen in radial section.

**All ray cells procumbent**, fig. 118, e.g., *Acer* spp. (Aceraceae), *Tabebuia* spp. (Bignoniaceae), *Albizia* spp. (Mimosaceae), *Hannoa klaineana* (Simaroubaceae).

**All ray cells upright and/or square**, fig. 119, e.g., *Hedyosmum scabrum* (Chloranthaceae), *Aucuba japonica* (Cornaceae).

**Body ray cells procumbent with one row of upright and/or square marginal cells**, fig. 120, e.g., *Kalopanax pictus* (Araliaceae), *Aucoumea klaineana* (Burseraceae), *Pseudocedrela kotschyi* (Meliaceae).

**Body ray cells procumbent with mostly 2–4 rows of upright and/or square marginal cells**, fig. 121, e.g., *Liquidambar styraciflua* (Hamamelidaceae), *Carapa guianensis* (Meliaceae), *Treulia africana* (Moraceae), *Alseis peruviana* (Rubiaceae), *Euscaphis* spp. (Staphyleaceae).

**Body ray cells procumbent with over 4 rows of upright and/or square marginal cells**, fig. 122, e.g., *Weinmannia descendens* (Cunoniaceae), *Quintinia* spp. (Escalloniaceae), *Homalium foetidum* (Flacourtiaceae), *Humiria* spp. (Humiriaceae), *Ottoschulzia* spp. (Icacinaeae), *Coffea* spp. (Rubiaceae), *Turpinia* spp. (Staphyleaceae).

**Rays with procumbent, square and upright cells mixed throughout the ray**, fig. 123, e.g., *Guatteria* spp. (Annonaceae), *Xanthophyllum lanceatum* (Polygalaceae), *Pometia pinnata* (Sapindaceae), *Heliocarpus* spp. (Tiliaceae).

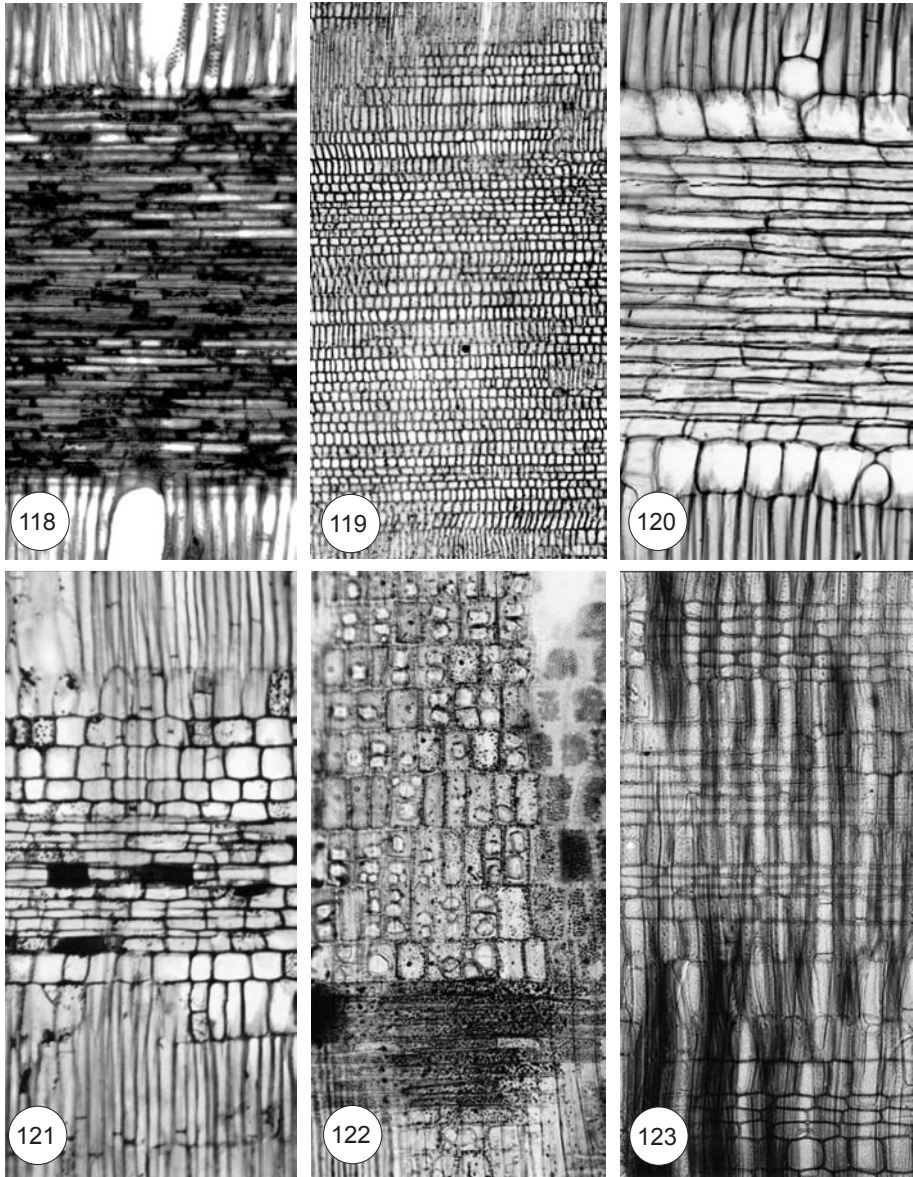


Fig. 118. All ray cells procumbent (feature 104), *Acer campestre*,  $\times 115$ . — Fig. 119. All ray cells upright and/or square (feature 105), *Aucuba japonica*,  $\times 19$ . — Fig. 120. Body ray cells procumbent with one row of upright and/or square marginal cells (feature 106), *Pseudocedrela kotschy*,  $\times 115$ . — Fig. 121. Body ray cells procumbent with mostly two to four rows of upright and/or square marginal cells (feature 107), *Carapa guianensis*,  $\times 114$ . — Fig. 122. Body ray cells procumbent with mostly over 4 rows of upright and/or square marginal cells (feature 108), *Homalium foetidum*,  $\times 115$ . — Fig. 123. Rays with procumbent, square and upright cells mixed throughout the ray (feature 109), *Xanthophyllum lanceatum*,  $\times 90$ .

*Procedure:*

Use radial sections to determine the cellular composition of rays because types of ray cell (procumbent, upright, and square) are defined on the basis of their appearance in radial section. Generally, upright and square cells, if present in combination with procumbent cells, are located in the marginal rows, i.e., those rows at the top and bottom of the ray, and procumbent cells are located in the body (centre) of the ray.

In woods with uniseriate and multiseriate rays – describe the cellular composition of the multiseriate rays, not the uniseriate rays. Some woods have more than one category of ray type with respect to cellular composition, only record the relatively common categories.

*Comments:*

The cellular composition of the multiseriate and uniseriate rays in the same wood is not necessarily the same. In some woods, their uniseriate rays are composed only of upright cells, while their multiseriate rays are composed of both upright and procumbent cells.

Homocellular rays are rays composed of a single cell type; heterocellular rays are composed of two or more cell types.

The terms homogeneous and heterogeneous are used to describe ray tissue as a whole. Designating Kribs types (Kribs 1968) may be useful when describing a wood, but are not used in this list. Roughly speaking, Kribs homogeneous types correspond with feature 104 (all ray cells procumbent), Kribs heterogeneous III with feature 106 (one row of upright and/or square marginal cells), Kribs heterogeneous II with feature 107 (2–4 rows of upright and/or square marginal cells), Kribs heterogeneous I with feature 108 (more than 4 rows of upright and/or square marginal cells). However, feature 108 also may partly overlap with Kribs heterogeneous II if the body of the rays is very high.



*Cautions:*

Ray composition often varies between juvenile and mature wood. In many species, rays near the pith may be composed entirely of upright cells, while rays distant from the pith are composed largely of procumbent cells with only a few rows of upright and/or square cells. When creating a database, only examine mature wood samples or, for shrubs, the peripheral wood of the thickest available stems. When an unknown wood fragment is from a thin branch, do *not* use ray composition.

Although in tangential section, marginal rows of upright and/or square cells often will appear as uniseriate margins, the presence of uniseriate margins alone is not a reliable indicator of heterocellular rays. In some woods (e. g., *Carya* spp.–Juglandaceae), there are uniseriate marginal rows visible in tangential section, and these cells appear larger than the body cells, but when viewed in radial section these cells are procumbent, as are the cells of the multiseriate portion.

Sheath cells (feature 110 or tile cells (feature 111) are not considered when determining ray cellular composition.

Feature 109 only applies if there is a mixture or alteration of different ray cell shapes *throughout* the ray, irrespective of whether it is in uniseriate or multiseriate rays or ray portions. Feature 109 does not apply to woods with vertically fused rays (or ‘rays with alternating uniseriate and multiseriate portions’) where the uniseriate portions may be composed of square and upright cells and the multiseriate portions of procumbent cells. Just the presence of sheath cells (feature 110) or the tile cells (feature 111) also does not qualify a wood for feature 109.

## SHEATH CELLS

**110. Sheath cells***Definition:*

**Sheath cells** = ray cells that are located along the sides of broad rays (>3-seriate) as viewed in tangential section and are larger (generally taller than broad) than the central ray cells, figs 124, 125, e.g., *Ceiba pentandra* (Bombacaceae), *Cordia alliodora* (Boraginaceae), *Sambucus nigra* (Caprifoliaceae), *Dipterocarpus lowii* (Dipterocarpaceae), *Stemonurus luzoniensis* (Icacinaeae), *Ailanthus altissima* (Simaroubaceae), *Sterculia oblonga* (Sterculiaceae).

*Comment:*

Presence of sheath cells should be determined from tangential sections. There is variability in the frequency and distinctiveness of sheath cells. In some species most, if not all, multiseriate rays have sheath cells which are much larger than the other ray cells, while in others sheath cells are not frequent and/or slightly larger than the adjacent cells. When identifying an unknown wood sample, do not use this feature as a first line of approach unless it is well marked.

*Caution:* Do not confuse sheath cells with tile cells (feature 111), which are always found in the body of the ray as well as the edges and are visible in both tangential and radial sections.

## TILE CELLS

**111. Tile cells***Definition:*

**Tile cells** = a special type of apparently empty upright (rarely square) ray cells occurring in intermediate horizontal series usually interspersed among the procumbent cells, figs. 126–129, e.g., *Durio* spp., *Neesia altissima* (Bombacaceae), *Guazuma* spp., *Kleinhovia hospita*, *Pterospermum* spp. (Sterculiaceae), *Desplatsia* spp., *Mollia* spp., and some species of *Grewia* (Tiliaceae).

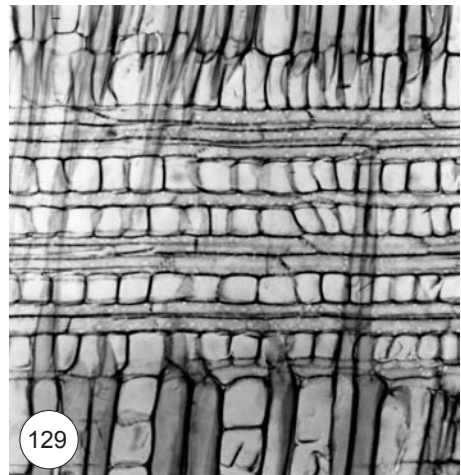
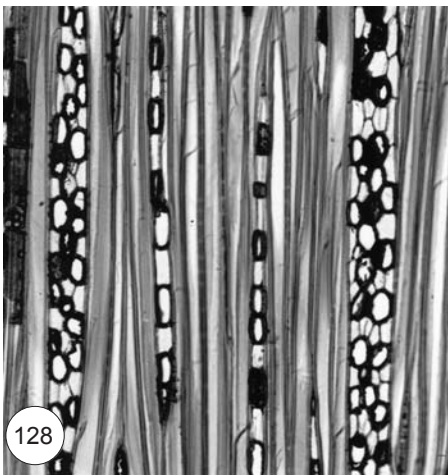
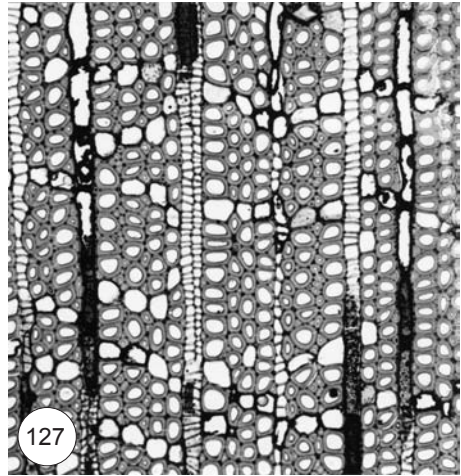
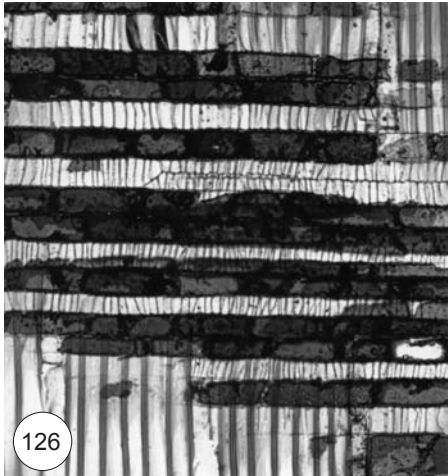
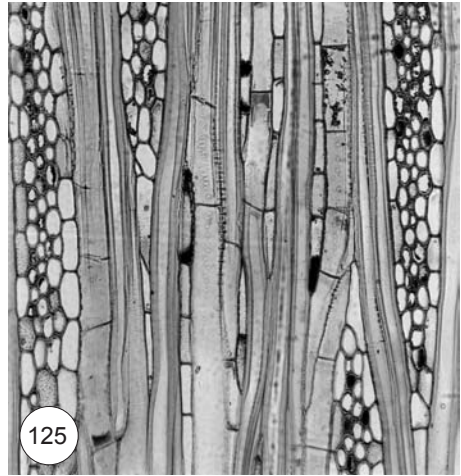
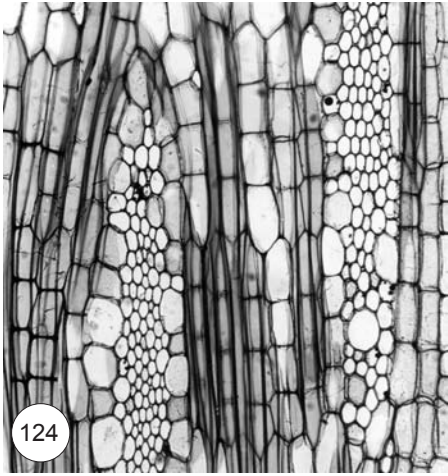
*Comments:*

Tile cells sometimes have been classified into two groups: type *Durio* when they have the same height as the procumbent ray cells, and type *Pterospermum* when they are higher. However, this distinction is dubious because there are intergradations between the two, as in *Guazuma* (Sterculiaceae), and *Grewia* (Tiliaceae).

Tile cells do not occur in uniseriate rays, and as far as is known are restricted to the order Malvales.

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Figs. 124 & 125. Sheath cells (feature 110). – 124: *Ceiba pentandra*, × 75. – 125: *Stemonurus luzoniensis*, × 75. — Figs. 126–129. Tile cells (feature 111). – 126–128: *Durio* type, *Neesia altissima*, radial, transverse, and tangential section, × 115. – 129: *Pterospermum grewiaefolium*, radial section, × 120.



## PERFORATED RAY CELLS

**112. Perforated ray cells***Definition:*

**Perforated ray cells** = ray cells of the same dimensions or larger than the adjacent cells, but with perforations, which generally are on the side walls connecting two vessels on either side of the ray, figs. 130–132, e.g., *Combretum leptostachium* (Combretaceae), *Richeria racemosa* (Euphorbiaceae), *Chanochiton breviflorum* (Olacaceae).

*Comments:*

The type of perforation in a perforated ray cell may be simple, scalariform, reticulate, or foraminant, and does not necessarily coincide with the type of perforation plate occurring in the vessel elements of the same wood. For instance, *Sloanea monosperma* (Elaeocarpaceae) and *Richeria racemosa* (Euphorbiaceae) have simple perforations in the vessel elements and scalariform perforations in the perforated ray cells. In *Siparuna* (Monimiaceae) there is a range of multiple perforations in the ray cells, but the vessel element perforations are simple and/or scalariform with variations depending on species.

Perforated ray cells have bordered pits similar to the intervessel pits. They can occur individually or in radial or tangential rows. Radial rows of perforated ray cells with perforations in the tangential walls have been described as radial vessels (Van Vliet 1976a).

*Caution:* Use this feature positively only and with some caution because species that have perforated ray cells may have them in such low frequency that they could easily have been overlooked when creating a database, or examining an unknown.

## DISJUNCTIVE RAY PARENCHYMA CELL WALLS

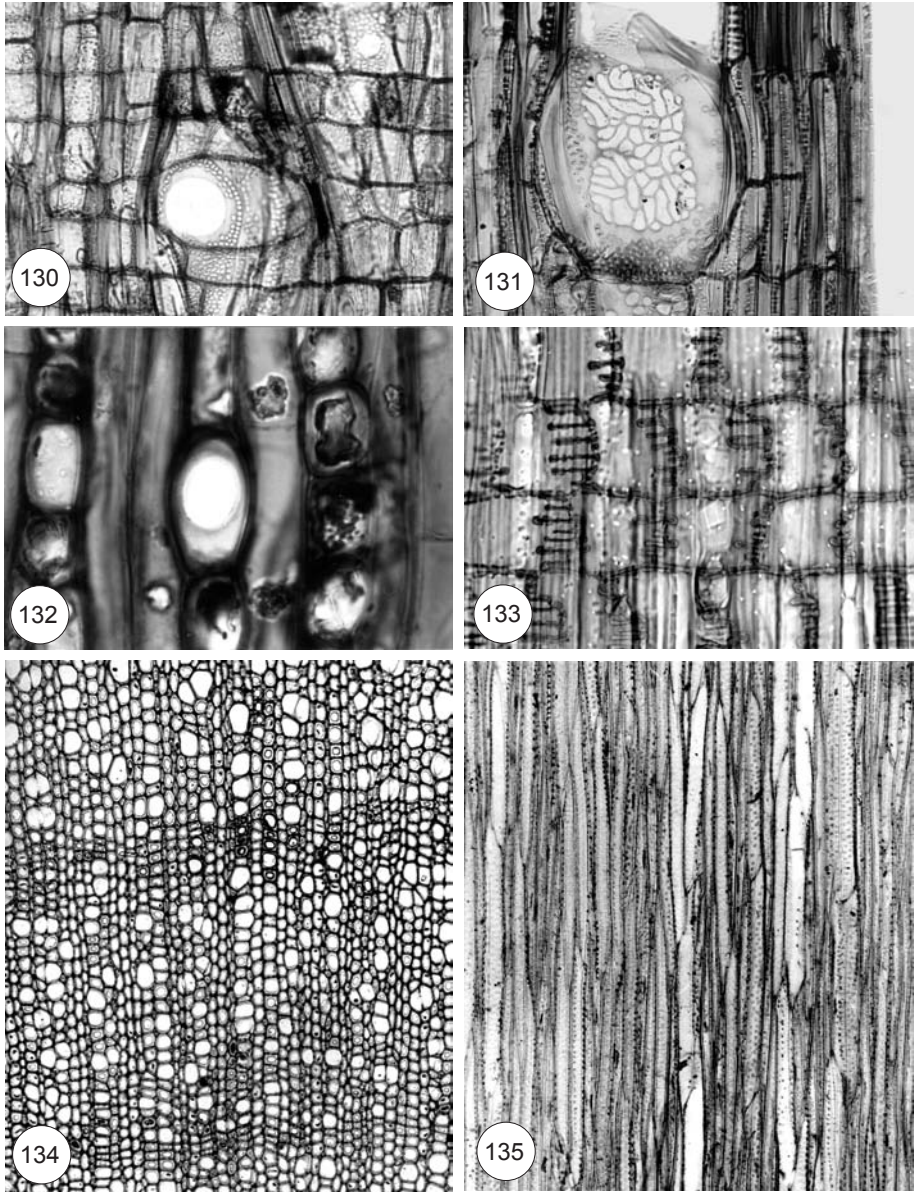
**113. Disjunctive ray parenchyma cell walls***Definition:*

**Disjunctive ray parenchyma cell walls** = ray parenchyma cells partially disjoined but with contact maintained through tubular or complex wall processes, fig. 133, e.g., *Funtumia africana* (Apocynaceae), *Buxus sempervirens* (Buxaceae), *Croton oligandrus*, *Glycydendron amazonicum*, *Suregada laurina* (Euphorbiaceae), *Malpighia incana* (Malpighiaceae), *Gardenia imperialis*, *Randia armata* (Rubiaceae).

*Comment:*

Axial parenchyma may also be disjunctive.





Figs. 130–132. Perforated ray cells (feature 112). – 130: Simple perforation in radial wall, *Chaenochiton breviflorum*,  $\times 115$ . – 131: Reticulate perforation in radial wall, *Richeria racemosa*,  $\times 115$ . – 132: Simple perforation in tangential wall, *Combretum leptostachium*,  $\times 290$ . – Fig. 133. Disjunctive ray parenchyma cell walls (feature 113), *Malpighia incana*,  $\times 290$ . – Figs. 134 & 135. Wood rayless (feature 117), *Veronica traversii*,  $\times 115$ . – 134: Transverse section. – 135: Tangential section.

## RAYS PER MILLIMETRE

**114.  $\leq 4/\text{mm}$** **115. 4–12/mm****116.  $\geq 12/\text{mm}$** *Definitions:*

As per feature descriptors, examples follow:

**$\leq 4/\text{mm}$** , e.g., *Guatteria schomburgkiana* (Annonaceae), *Cussonia arborea* (Araliaceae).

**4–12/mm**, e.g., *Acer rubrum* (Aceraceae), *Acacia* spp. (Mimosaceae).

**$\geq 12/\text{mm}$** , e.g., *Diospyros mespiliformis* (Ebenaceae), *Randia armata* (Rubiaceae).

*Procedure:*

The number of rays per linear unit is best determined from a tangential section along a line perpendicular to the ray's axis; it can also be determined from a cross section. Make ten measurements and record the categories the range falls within.

*Comment:*

The feature 'rays 4–12 per mm' is more common than the features 'rays  $\leq 4$  per mm' or ' $\geq 12$  per mm' (Metcalfe & Chalk 1950). The number of rays per mm cannot sensibly be determined in woods with aggregate rays, or woods with very broad rays and two distinct size classes, e.g., *Quercus* spp. (Fagaceae).

## WOOD RAYLESS

**117. Wood rayless***Definition:*

**Wood rayless** = wood with only axial elements, figs. 134, 135, e.g., *Arthrocnemum macrostachyum* (Chenopodiaceae), *Heimerliodendron brunonianum* (Nyctaginaceae), *Hebe salicifolia*, *Veronica traversii* (Scrophulariaceae).

*Comment:*

Rayless woods are restricted to a small number of families (Carlquist 1988).

*Caution:* In rayless woods with included phloem (e.g., several Chenopodiaceae), the conjunctive parenchyma (i.e., the parenchyma linking two or more phloem strands) may form radial extensions which resemble rays. In such woods there may be a continuum from short radial wedges to long radial strips to 'normal' multiseriate rays (Fahn *et al.* 1986), and the feature 'rayless' should be used with caution in such woods.

## STORIED STRUCTURE

- 118. All rays storied
- 119. Low rays storied, high rays nonstoried
- 120. Axial parenchyma and/or vessel elements storied
- 121. Fibres storied
- 122. Rays and/or axial elements irregularly storied
- 123. Number of ray tiers per axial mm

### Definitions:

**Storied structure** = cells arranged in tiers (horizontal series) as viewed on the tangential surface.

**Low rays storied, high rays nonstoried**, fig. 137, e.g., *Scaphium* spp., *Triplochiton scleroxylon* (Sterculiaceae), *Cercis canadensis* (Caesalpinaceae).

**All rays storied**, figs. 136, 138, e.g., *Dalbergia bariensis*, *Pterocarpus santalinoides* (Papilionaceae), *Quassia amara* (Simaroubaceae).

**Axial parenchyma and/or vessel elements storied**, fig. 136, e.g., *Balanites aegyptiaca* (Balanitaceae), *Dalbergia bariensis*, *Spartium junceum* (Papilionaceae), *Tamarix* spp. (Tamaricaceae).

**Fibres storied**, fig. 138, e.g., *Quassia amara* (Simaroubaceae), *Octomeles sumatrana* (Datisceae), *Zygodphyllum dumosum* (Zygophyllaceae).

**Rays and/or axial elements irregularly storied** = stories of rays and/or axial elements not horizontal or straight, but wavy or oblique (synonym: in echelon), or only locally present, fig. 139, e.g., certain Leguminosae (*Monopetalanthus*, *Tetraberlinia*), *Entandrophragma cylindricum* (Meliaceae), *Fraxinus alba* (Oleaceae), *Tieghemella* spp. (Sapotaceae).

**Number of ray tiers per axial mm** = as per feature descriptor.

### Comments:

The presence of storied structure should be determined from the tangential section, *not* the radial section. These features can be recorded singly or in combination as in some woods all elements are storied (e.g., *Hibiscus tiliaceus*—Malvaceae, *Centrolobium paraense*, *Afrormosia elata*—Papilionaceae), while in others various combinations of elements are storied. Generally, if parenchyma is storied, the vessel elements also are storied. Feature 122, ‘rays and/or axial elements irregularly storied’, is used in combination with the other features when appropriate. There is variability within species and samples. For instance, in some samples of *Swietenia* (Meliaceae) rays are definitely storied, in others irregularly storied, and in still others rays are not storied.

Tiers of rays are visible at low magnification, or with the unaided eye or a hand lens, and appear as fine horizontal striations or ripple marks on the tangential surface. Especially in the Leguminosae, which has many taxa with storied rays, the number of ray tiers per mm (feature 123) can be useful in distinguishing genera and species.

Absence of storied structure (features 118–123 absent) is also of diagnostic value.

*Caution:* Storing of wide vessel elements may be obscured because of cell enlargement during vessel development, and so it is best to examine the narrower vessel elements to determine whether vessel elements are storied.



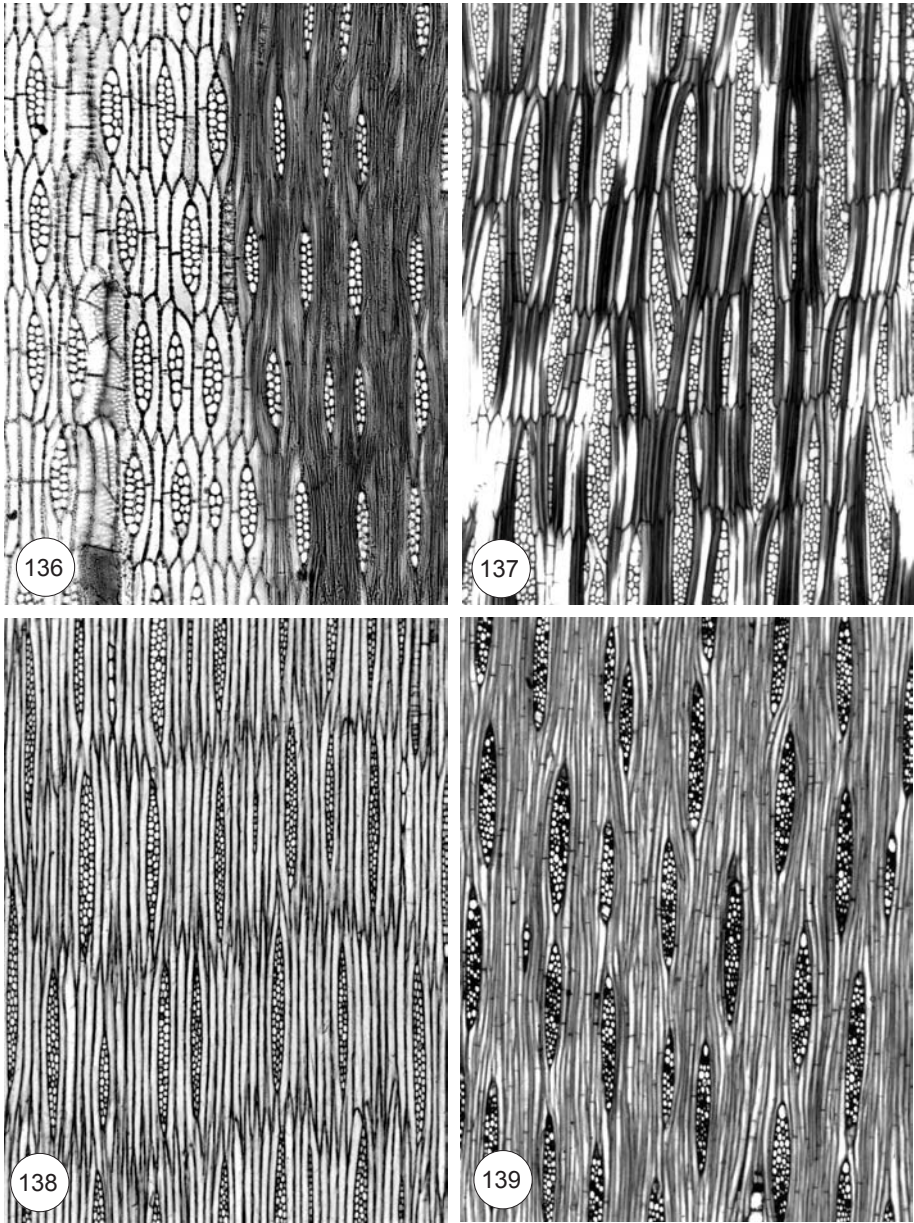


Fig. 136. All rays storied (feature 118) and axial parenchyma and/or vessel elements storied (feature 120), *Dalbergia bariensis*,  $\times 75$ . — Fig. 137. Low rays storied, high rays nonstoried (feature 119), *Triplochiton scleroxylon*. Note also features 120 (parenchyma storied) and 121 (fibres storied);  $\times 45$ . — Fig. 138. Fibres storied (feature 121), *Quassia amara*,  $\times 45$ . — Fig. 139. Irregularly storied structure (feature 122, here expressed as rays in echelon), *Entandrophragma cylindricum*,  $\times 45$ .

**SECRETORY ELEMENTS AND CAMBIAL VARIANTS****OIL AND MUCILAGE CELLS**

- 124. Oil and/or mucilage cells associated with ray parenchyma**
- 125. Oil and/or mucilage cells associated with axial parenchyma**
- 126. Oil and/or mucilage cells present among fibres**

*Definitions:*

**Oil cell** = a parenchymatous idioblast filled with oil; mostly, but not always, enlarged and rounded in outline, occasionally of considerable axial extension, figs. 140, 141, e.g., *Nectandra grandis*, *Ocotea glaucinia*, *O. tenella*, *Phoebe porosa* and many other species of Lauraceae, *Talauma* spp. (Magnoliaceae).

**Mucilage cell** = a parenchymatous idioblast filled with mucilage; typically enlarged and rounded in outline, occasionally of considerable axial extension (resembling fibres), e.g., figs. 142, 143, axial in some species of *Endlicheria* (Lauraceae), and in ray parenchyma of some species of *Persea* (Lauraceae).

*Comments:*

Both oil cells and mucilage cells are commonly associated with axial and/or ray parenchyma, but may also occur among fibres. They are limited to very few woody dicotyledons and are similar to one another, except for their contents, which are easily removed during microtechnical procedures (Richter 1977)

Because it is not practical to distinguish between oil and mucilage cells by their appearance, they are listed together. Various combinations of these features occur together (see Baas & Gregory 1985; Gregory & Baas 1989).

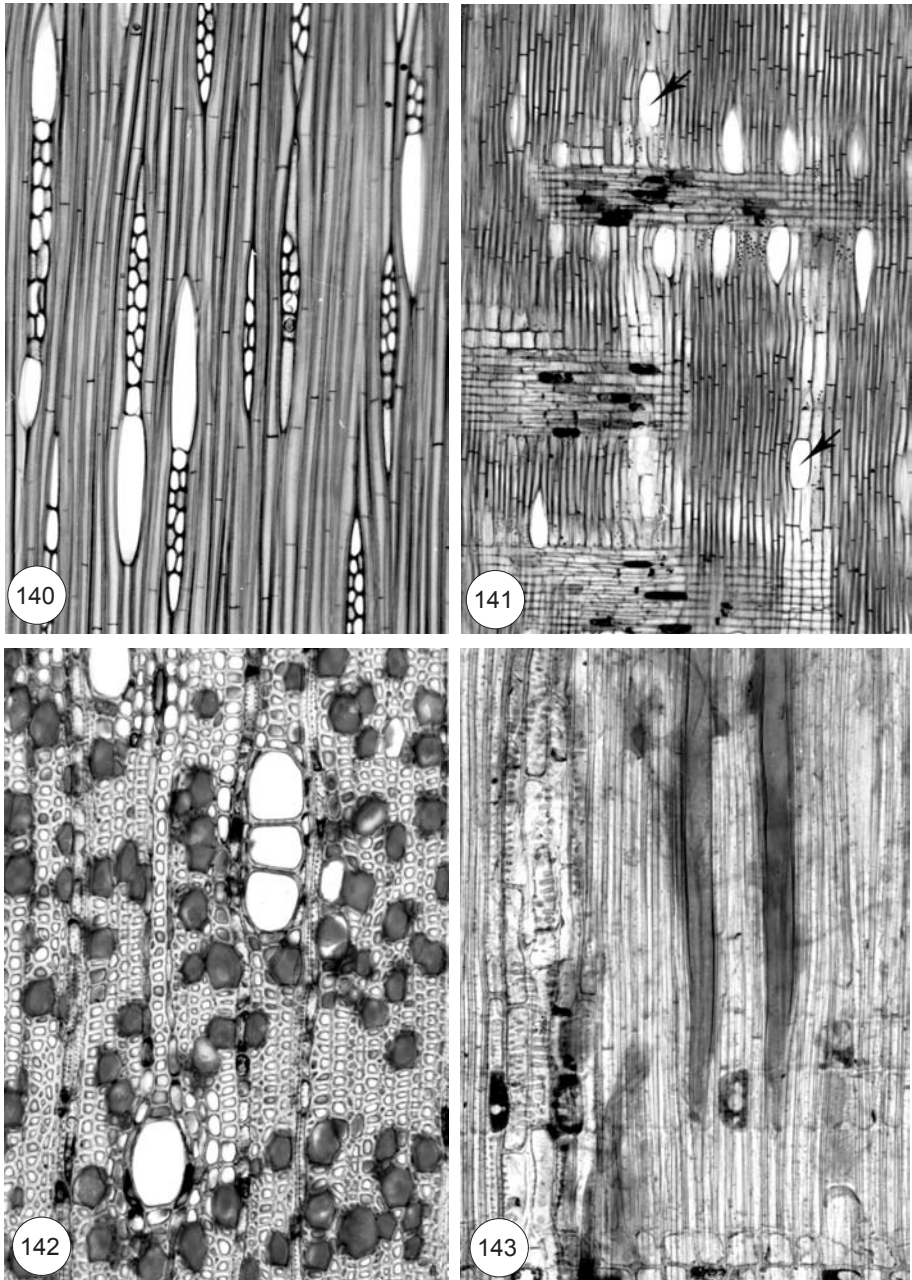


Fig. 140. Oil and/or mucilage cells associated with ray parenchyma (feature 124), *Ocotea glaucinia*,  $\times 115$ . — Fig. 141. Oil and/or mucilage cells associated with axial parenchyma (feature 125, arrows), *Ocotea glaucinia*. Note also feature 124, oil and/or mucilage cells in rays;  $\times 45$ . — Figs. 142 & 143. Oil and/or mucilage cells present among the fibres (feature 126), *Ocotea tenella* (elongated mucilage cells),  $\times 115$ . — 142: Transverse section. — 143: Radial section.

## INTERCELLULAR CANALS

127. Axial canals in long tangential lines  
 128. Axial canals in short tangential lines  
 129. Axial canals diffuse  
 130. Radial canals  
 131. Intercellular canals of traumatic origin

*Definitions:*

**Intercellular canal** = a tubular intercellular duct surrounded by an epithelium, generally containing secondary plant products such as resins, gums, etc., secreted by the epithelial cells. Intercellular canals may be oriented axially (axial/vertical intercellular canal), or radially (radial/horizontal intercellular canal, within a ray), figs. 144–151. Synonyms: gum duct, resin duct.

**Axial canals in long tangential lines** = more than five canals in a line, fig. 145, e.g., *Copaifera* spp., *Sindora* spp. (Caesalpinaceae), *Dryobalanops* spp., *Hopea* spp., *Neobalanocarpus* spp., *Parashorea* spp., *Pentacme* spp., *Shorea* spp. (Dipterocarpaceae). Synonym: concentric axial canals.

**Axial canals in short tangential lines** = two to five axial canals in a line, fig. 146, e.g., *Dipterocarpus* spp. (Dipterocarpaceae).

**Axial canals diffuse** = randomly distributed solitary canals, fig. 147, e.g., *Prioria copaifera* (Caesalpinaceae), *Anisoptera* spp., *Cotylelobium* spp., *Upuna* spp., *Vateria macrocarpa*, *Vatica* spp. (Dipterocarpaceae).

**Radial canals** = canals present in rays, figs. 148–150, e.g., *Pistacia* spp., *Tapirira guianensis* (Anacardiaceae), *Bursera gummifera* (Burseraceae), *Shorea* section *Richetia* (Dipterocarpaceae), and many other genera of Anacardiaceae and Burseraceae. Synonym: horizontal canals.

**Traumatic canals** = canals formed in response to injury, arranged in tangential bands, generally irregular in outline and closely spaced, fig. 151, e.g., *Terminalia procera* (Combretaceae), *Liquidambar styraciflua* (Hamamelidaceae), *Carapa procera* (Meliaceae), *Prunus serotina* (Rosaceae), *Balfourodendron riedelianum*, *Murraya exotica* (Rutaceae), *Quassia amara* (Simaroubaceae).

*Comments:*

It is possible to have a mixture of these features in one wood.

In some species of Dipterocarpaceae, the size of the axial canals is useful in differentiating species, i.e., whether the canals are small (diameter < 100 µm) or large (diameter > 100 µm). The colour of resins in canals of Dipterocarpaceae can also be useful in identification.

The effect of radial canals on ray shape (i.e., whether the canal makes the ray fusiform in shape or not), size, and number of canals per ray are also useful features.

*Caution:* Traumatic canals may not occur consistently in a species, therefore, when identifying an unknown, never use the absence of traumatic canals.



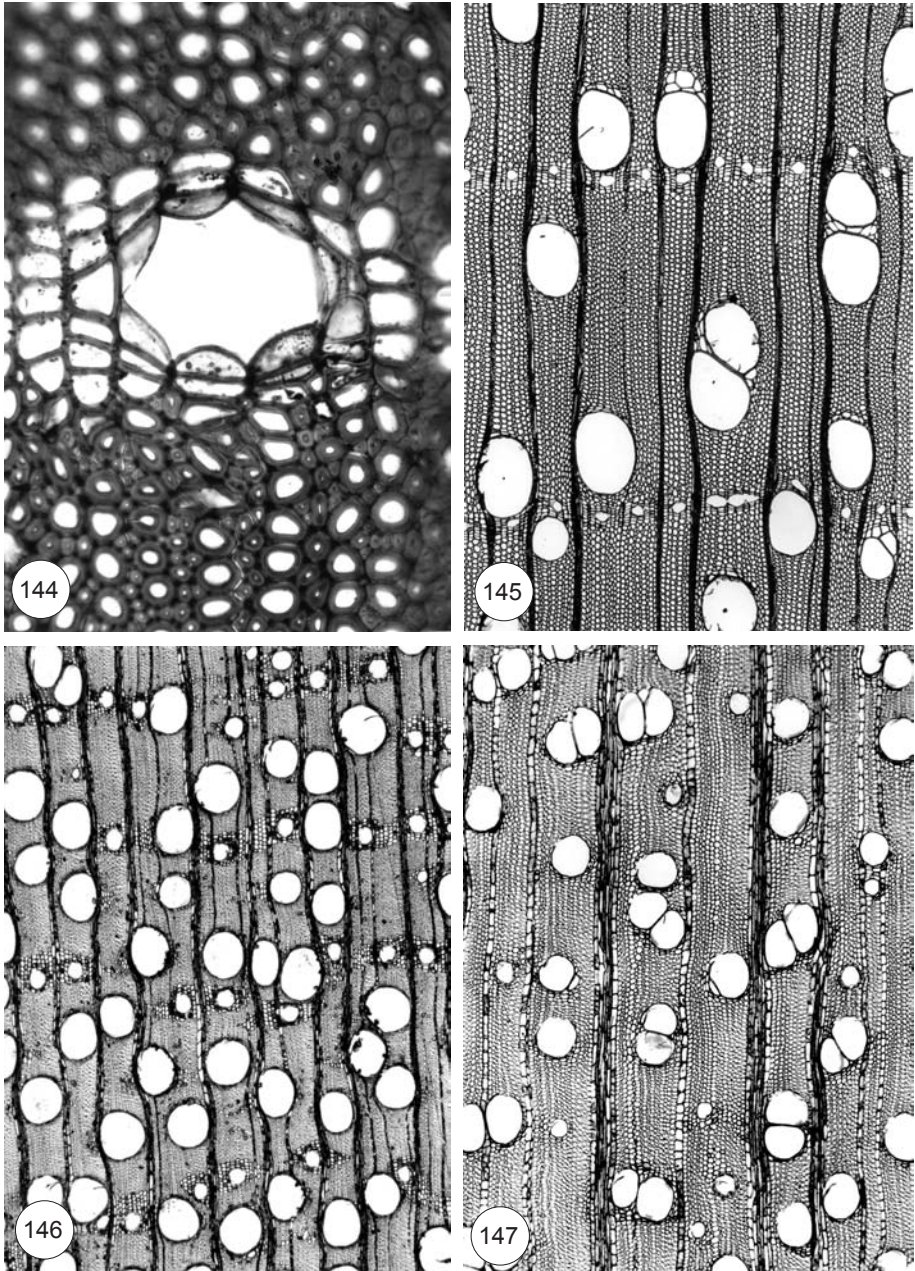
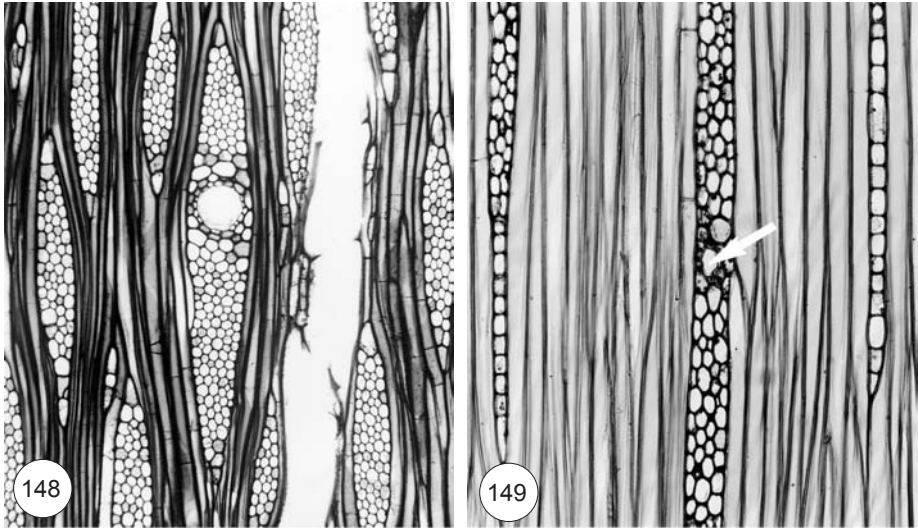


Fig. 144. Axial intercellular canal, *Parashorea smythiesii*,  $\times 290$ . — Fig. 145. Axial intercellular canals in long tangential lines (feature 127), *Shorea parvifolia*,  $\times 29$ . — Fig. 146. Axial intercellular canals in short tangential lines (feature 128), *Dipterocarpus grandiflorus*,  $\times 20$ . — Fig. 147. Axial canals diffuse (feature 129), *Vateria macrocarpa*,  $\times 29$ .



Figs. 148 & 149. Radial canals (feature 130). – 148: *Bursera gummifera*,  $\times 70$ . – 149: *Shorea hopeifolia* (arrow),  $\times 140$ .

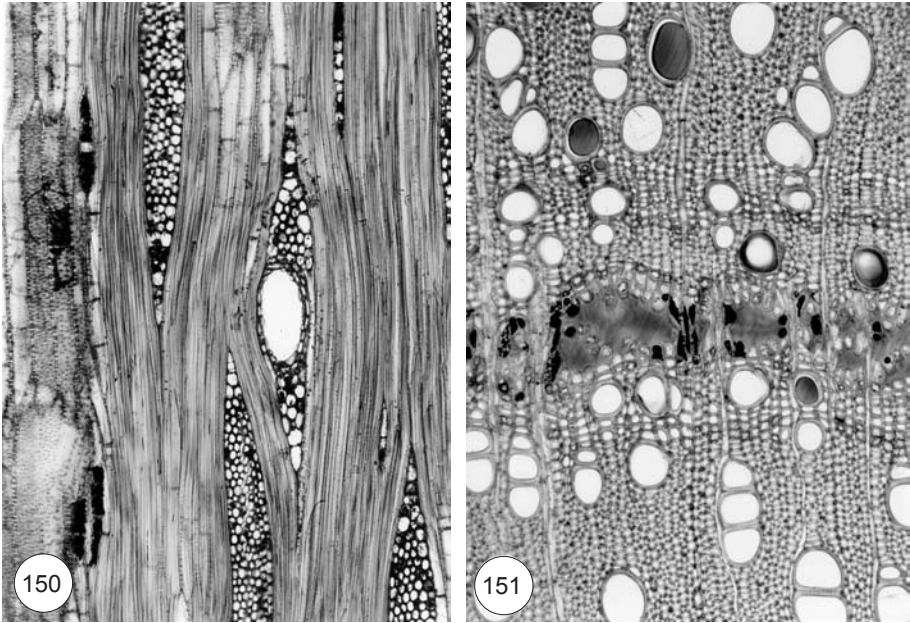


Fig. 150. Radial canals (feature 130), *Parashorea mythiesii*,  $\times 75$ . — Fig. 151. Intercellular canals of traumatic origin (feature 131), *Murraya exotica*,  $\times 115$ .

## TUBES / TUBULES

**132. Laticifers or tanniferous tubes***Definition:*

**Tubes / tubules** = cells or series of cells of indeterminate length, extending radially or vertically (among fibres); according to specific contents two types can be distinguished.

**Laticifers** = tubes containing latex, the latex may be colourless or light yellow to brown; laticifers may extend either radially (in genera of Apocynaceae, Asclepiadaceae, Campanulaceae, Caricaceae, Euphorbiaceae, Moraceae) or axially (interspersed among fibres and so far known only from Moraceae), figs. 152–155. Synonyms: latex tubes, latex canals.

**Tanniferous tubes** = tubes containing tannins, which are reddish-brown, in rays (so far known only from Myristicaceae), figs. 156, 157.

*Comments:*

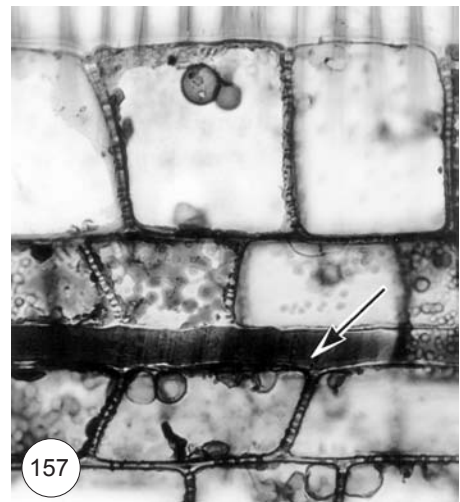
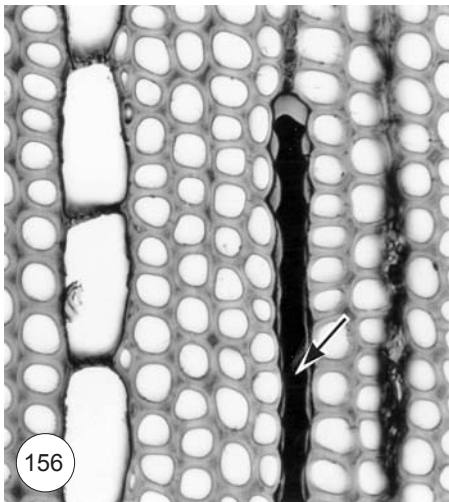
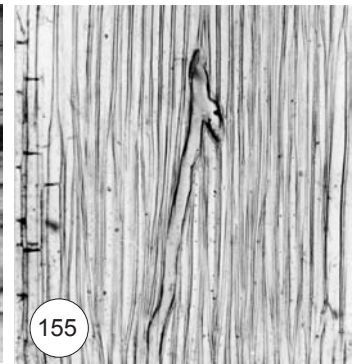
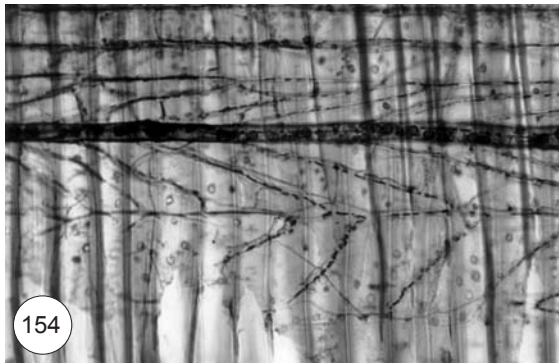
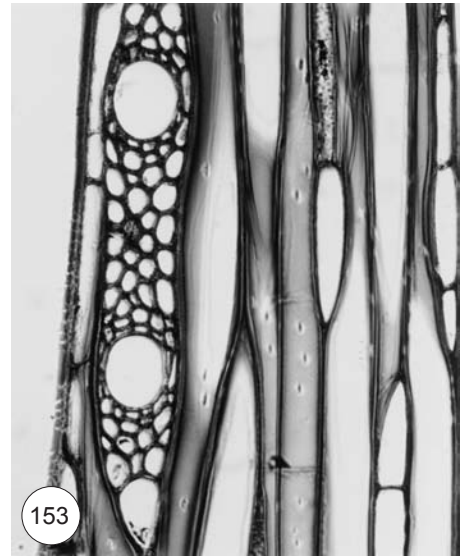
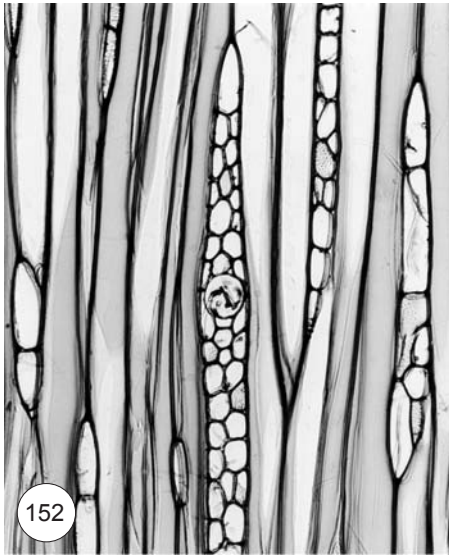
Although latex is often light-coloured, and tannins are dark, colour is not a reliable difference, and chemical tests for tannin are needed to verify tube contents. Structural differences between the laticifers and tanniferous tubes appear minor (Fujii 1988). Therefore, these two features are combined into one descriptor. Latex traces are included in this descriptor.

Tanniferous tubes often are difficult to recognise in tangential sections because in that view their dimensions may appear similar to the ray cells; examining radial sections shows tanniferous tubes to be longer than ray cells.

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Figs. 152–157. Laticifers (latex tubes) or tanniferous tubes (feature 132). – 152: *Alstonia scholaris*, laticifer,  $\times 140$ . – 153: *Dyera costulata*, wide laticifers,  $\times 180$ . – 154: *Croton panamensis*, laticifer with dark-staining contents,  $\times 290$ . – 155: *Artocarpus communis*, axial laticifer,  $\times 75$ . – 156 & 157: *Horsfieldia subglobosa*, tanniferous tube in transverse and radial section (arrows),  $\times 290$ .





## CAMBIAL VARIANTS

**133. Included phloem, concentric****134. Included phloem, diffuse****135. Other cambial variants***Definitions:*

**Included phloem, concentric** = phloem strands in tangential bands alternating with zones of xylem and/or conjunctive tissue, fig. 158, e.g., *Avicennia* spp. (Avicenniaceae), *Suaeda monoica* (Chenopodiaceae).

**Included phloem, diffuse** = scattered, isolated phloem strands. The phloem strands may be surrounded by parenchyma or imperforate tracheary elements, fig. 159, e.g., *Strychnos nuxvomica* (Loganiaceae). Synonym: included phloem, foraminated or island type.

**Other cambial variants** = category for a variety of cambial variants including axes elliptical, flattened, and furrowed in cross section: axes with lobed or furrowed xylem; fissured xylem; compound, divided, corded and cleft xylem masses.

*Comments:*

The features for included phloem type are based on the appearance of the wood, and do not have developmental inferences – they are not defined on the basis of whether there is a single permanent cambium, or successive cambia, or whether the tissue surrounding the phloem strands is xylem or conjunctive tissue. As pointed out by Mikesell and Popham (1976) and Carlquist (1988), it is desirable to restrict the term interxylary phloem to those cases in which the phloem has been produced internally by a single cambium.

Included phloem of the concentric type very often intergrades with diffuse included phloem (e.g., in many Chenopodiaceae); in all cases of doubt use both features. In species with concentric included phloem the phloem bands may branch and anastomose, and the conjunctive parenchyma sometimes forms radial extensions resembling rays.

Because included phloem and other cambial variants are of regular occurrence in the taxa in which they are found, the term ‘anomalous’ must be considered a misnomer.

Feature 135 ‘other cambial variants’ most frequently occurs in lianas; for more information see Carlquist (1988).

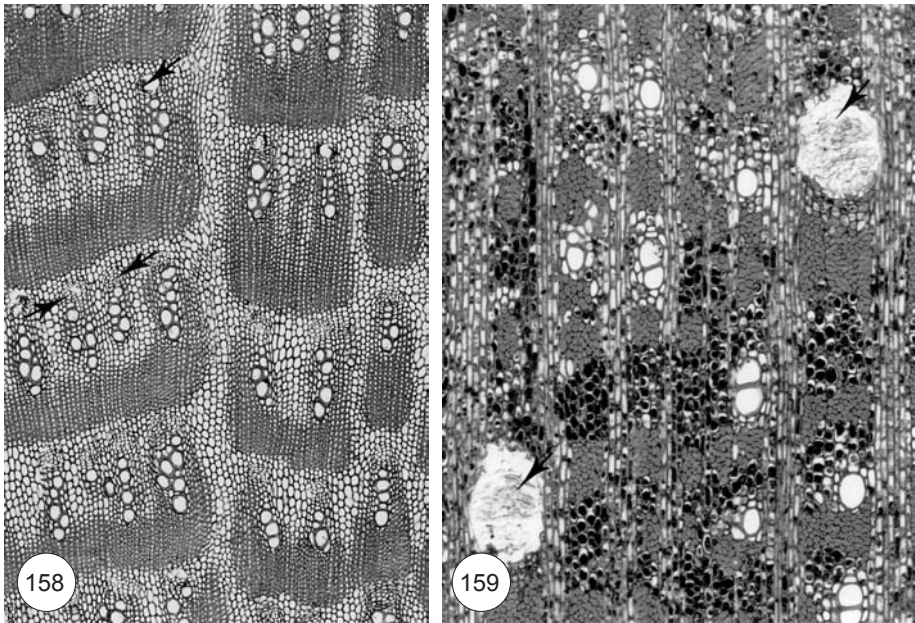


Fig. 158. Included phloem, concentric (feature 133, arrows), *Suaeda monoica*. Note also radial extensions of conjunctive parenchyma (feature 117, wood rayless, variable);  $\times 38$ . — Fig. 159. Included phloem, diffuse (feature 134, arrows), *Strychnos nux-vomica*,  $\times 45$ .

## MINERAL INCLUSIONS

## PRISMATIC CRYSTALS

**136. Prismatic crystals present**

- 137. Prismatic crystals in upright and/or square ray cells**
- 138. Prismatic crystals in procumbent ray cells**
- 139. Prismatic crystals in radial alignment in procumbent ray cells**
- 140. Prismatic crystals in chambered upright and/or square ray cells**
- 141. Prismatic crystals in nonchambered axial parenchyma cells**
- 142. Prismatic crystals in chambered axial parenchyma cells**
- 143. Prismatic crystals in fibres**

*Definitions:*

**Prismatic crystals** = solitary rhombohedral or octahedral crystals composed of calcium oxalate, which are birefringent under polarised light (fig. 160). Synonym: rhomboidal crystal.

**Chambered cell** = an axial parenchyma strand cell or ray parenchyma cell subdivided by septa or by thin to thick cell walls.

Features 137–143 as per descriptors, examples follow:

**Prismatic crystals in upright and/or square ray cells**, fig. 161, e.g., *Astronium* spp. (Anacardiaceae), *Bursera* spp. (Burseraceae), *Khaya anthotheca* spp. (Meliaceae), *Helicostylis* spp. (Moraceae).

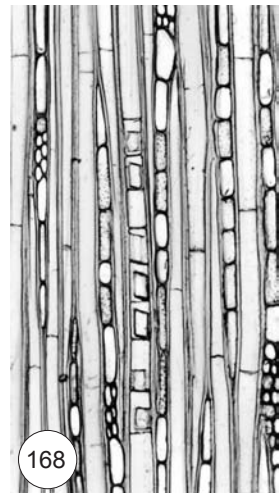
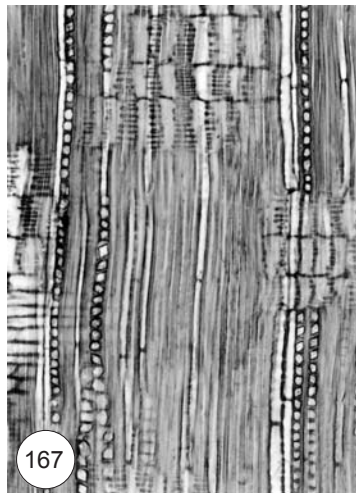
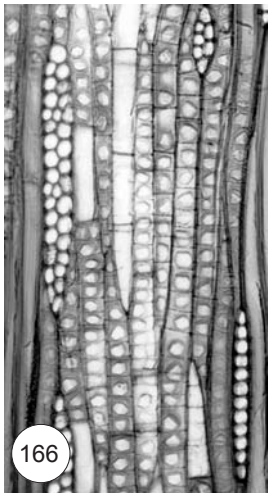
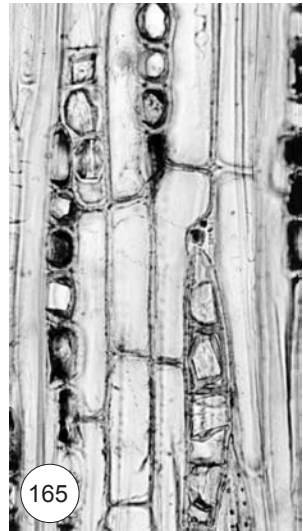
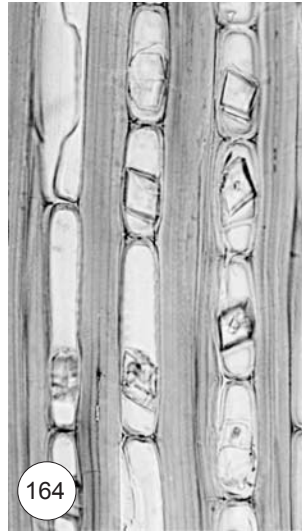
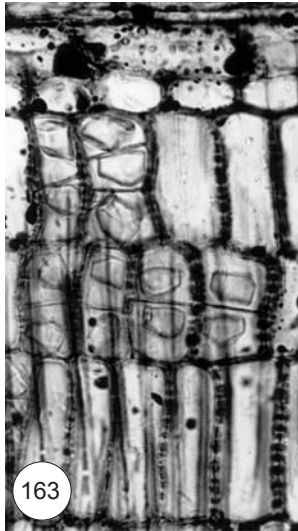
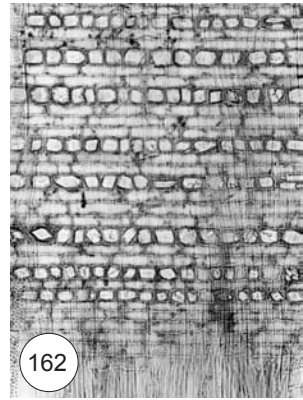
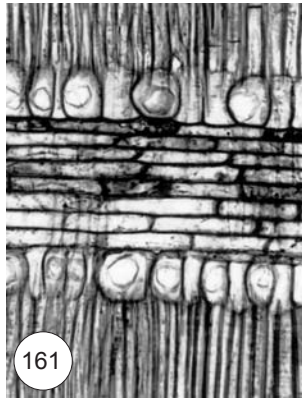
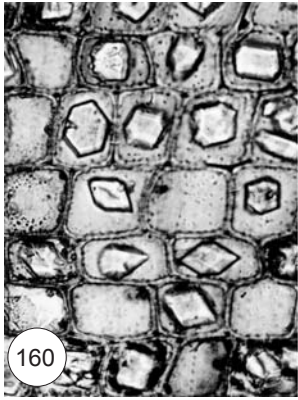
**Prismatic crystals in procumbent ray cells**, fig. 162, e.g. *Anogeissus latifolia* (Combretaceae), *Carpinus* spp. (Corylaceae).

**Prismatic crystals in radial alignment in procumbent ray cells**, fig. 162, e.g., *Aspidosperma quebracho-blanco* (Apocynaceae), *Anogeissus latifolia*, *Bucida buceras* (Combretaceae), *Securinega perrieri* (Euphorbiaceae), *Ouratea surinamensis* (Ochnaceae), *Gonystylus* spp. (Thymelaeaceae).

**Prismatic crystals in chambered upright and/or square ray cells**, fig. 163, e.g., *Elaeocarpus calomala* (Elaeocarpaceae), *Glycydendron amazonicum* (Euphorbiaceae), *Banara nitida* (Flacourtiaceae), *Byrsonima laevigata* (Malpighiaceae), *Fagara flava* (Rutaceae).

Fig. 160. Prismatic crystals (feature 136), *Drypetes keyensis*, × 230. — Fig. 161. Prismatic crystals in upright and/or square ray cells (feature 137), *Astronium graveolens*, × 115. — Fig. 162. Prismatic crystals in procumbent ray cells (feature 138) and in radial alignment (feature 139), *Anogeissus latifolia*, × 75. — Fig. 163. Prismatic crystals in chambered (or divided) upright and/or square ray cells (feature 140), *Elaeocarpus calomala*, × 290. — Fig. 164. Prismatic crystals in nonchambered axial parenchyma cells (feature 141), *Drypetes gerrardii*, × 290. — Figs. 165–167. Prismatic crystals in chambered axial parenchyma cells (feature 142). — 165: Crystals in short chains, *Lithocarpus edulis*, × 290. — 166 & 167. Crystals in long chains. — 166: Tangential section, *Parkia pendula*, × 115. — 167: Radial section, *Malpighia incana*, × 115. — Fig. 168. Prismatic crystals in fibres (feature 143), *Banara regia*, × 115.





**Prismatic crystals in nonchambered axial parenchyma cells**, fig. 164, e.g., *Ceiba* spp., *Ochroma* spp. (Bombacaceae), *Drypetes gerrardii* (Euphorbiaceae), *Ficus* spp. (Moraceae).

**Prismatic crystals in chambered axial parenchyma cells**, figs. 165–167, e.g., *Gilbertiodendron preusii* (Caesalpinaceae), *Pentacme contorta* (Dipterocarpaceae), *Lithocarpus edulis* (Fagaceae), *Juglans nigra* (Juglandaceae), *Couratari* spp. (Lecythidaceae), *Malpighia incana* (Malpighiaceae), *Parkia pendula* (Mimosaceae), *Zanthoxylum hygrophila* (Rutaceae), *Manilkara* spp. (Sapotaceae).

**Prismatic crystals in fibres**, fig. 168, e.g., *Hemandradenia chevalieri* (Connaraceae), *Banara regia* (Flacourtiaceae), *Triplaris americana* (Polygonaceae), *Punica granatum* (Punicaceae), *Majidea zanguebarica* (Sapindaceae).

*Comments:*

Prismatic (rhomboidal) crystals are the most common type of crystal in wood (Chattaway 1955, 1956). The relative abundance of prismatic crystals is variable. In some species, crystals are consistently abundant; in others, they are consistently present, but not abundant; and in still other species, they are present in some samples, but absent in other samples. In some taxa, crystals occur in only one cell type; in other taxa, they occur in more than one cell type. In the latter case, record all features that apply.

Information on the specific location of crystals often is not available from the literature. Consequently, feature 136, 'prismatic crystals present' is useful in constructing a database from existing information. Feature 136 is recorded in combination with other applicable crystal features (137–143).

In some species, crystals occur throughout the ray (for heterocellular rays: features 137 and 138 both present). In other species with heterocellular rays they are restricted to the marginal rows of upright and/or square cells, upright and/or square cells in the body of the ray, or sheath cells (feature 137 present, feature 138 absent). In yet others, crystals are restricted to the procumbent body ray cells (feature 137 absent, feature 138 present). This last condition is not common and usually occurs in combination with crystals in a radial alignment (feature 139). The latter feature may apply to crystals in nonchambered as well as chambered cells.

The descriptors 'prismatic crystals in chambered upright and/or square ray cells' (feature 140) and 'prismatic crystals in chambered axial parenchyma cells' (feature 142) include a considerable diversity in types of chambered or subdivided cells (cf. Parameswaran & Richter 1984) and, particularly for axial parenchyma, in length of the chains of crystalliferous chambers or subdivisions. In some taxa there are only a few chambers in a series, in others there are long chains. Such information should be recorded in a description.

*Cautions:* There are many genera in which prismatic crystals are regularly absent (e.g., *Dipterocarpus* spp.—Dipterocarpaceae, *Betula* spp.—Betulaceae, *Liriodendron* spp.—Magnoliaceae, and *Tilia* spp.—Tiliaceae). But, when identifying an unknown, using absence of crystals is *not* recommended because crystals are of sporadic occurrence in many other taxa (e.g., *Acer* spp.—Aceraceae, *Quercus* spp.—Fagaceae, and *Ulmus*—Ulmaceae).

Care is needed to distinguish between crystals in septate fibres and crystals in chambered axial parenchyma cells.

## DRUSES

**144. Druses present****145. Druses in ray parenchyma cells****146. Druses in axial parenchyma cells****147. Druses in fibres****148. Druses in chambered cells***Definitions:*

**Druse** = a compound crystal, more or less spherical in shape, in which the many component crystals protrude from the surface giving the whole structure a star-shaped appearance, figs. 169–171, e.g., *Hibiscus tiliaceus* (Malvaceae). Synonym: cluster crystal.

Features 145–148 as per feature descriptor, examples follow.

**Druses in ray parenchyma cells**, fig. 169, e.g., *Gleditsia triacanthos* (Caesalpiaceae), *Macaranga barteri*, *M. heudelottii* (Euphorbiaceae), *Colubrina ferruginea* (Rhamnaceae), *Amygdalus communis* (Rosaceae), *Celtis paniculata* (Ulmaceae).

**Druses in axial parenchyma cells**, fig. 170, e.g., *Dacryodes edulis* (Bursaceae), *Terminalia catappa* (Combretaceae).

**Druses in fibres**, e.g., *Combretum fruticosum* (Combretaceae).

**Druses in chambered cells**, fig. 171, e.g., *Macaranga barteri*, *M. occidentalis* (Euphorbiaceae), *Banara regia* (Flacourtiaceae).

*Comments:*

Most of the existing multiple entry keys and the literature do not provide information on the location of druses. Consequently, the feature ‘druses present’ is included so that this information can be used.

In a given species, druses may occur in one or more of the cell types, and the cells may be enlarged as well (feature 156).

## OTHER CRYSTAL TYPES

**149. Raphides****150. Acicular crystals****151. Styloids and/or elongate crystals****152. Crystals of other shapes (mostly small)****153. Crystal sand***Definitions:*

**Raphides** = a bundle of long needle-like crystals, fig. 172, e.g., *Dillenia reticulata*, *Tetracera boliviana* (Dilleniaceae), *Pisonia* spp. (Nyctaginaceae), *Psychotria recordiana* (Rubiaceae), *Tetramerista crassifolia* (Tetrameristaceae), *Vitis vinifera* (Vitaceae).

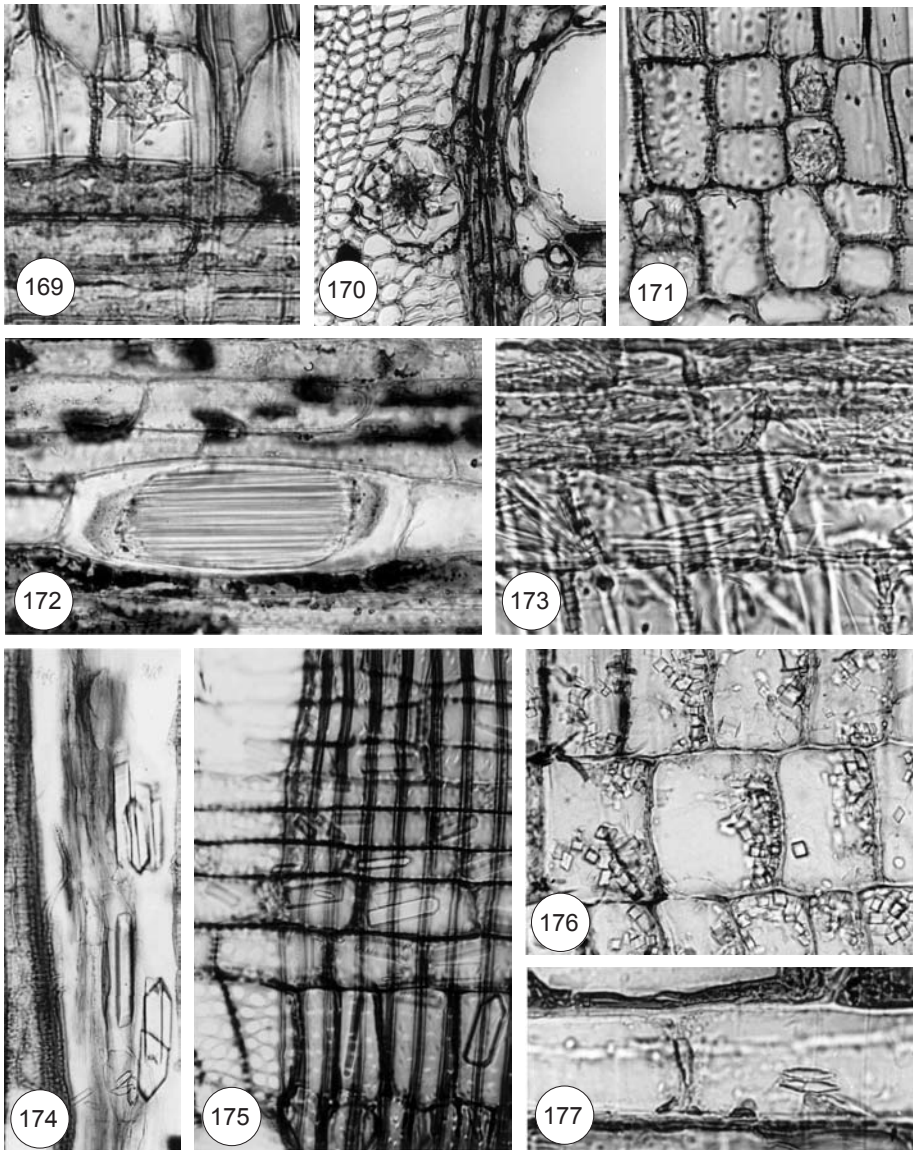


Fig. 169. Druses (feature 144) in ray parenchyma cells (feature 145), *Hibiscus tiliaceus*,  $\times 145$ . — Fig. 170. Druses in axial parenchyma cells (features 144 and 146), *Terminalia catappa*,  $\times 170$ . — Fig. 171. Druses in chambered ray cells (features 144, 145 and 148), *Banara regia*,  $\times 290$ . — Fig. 172. Raphides (feature 149) in procumbent ray cell, *Vitis vinifera*,  $\times 290$ . — Fig. 173. Acicular or needle-shaped crystals (feature 150), *Gmelina arborea*,  $\times 675$ . — Fig. 174. Styloids (feature 151), *Memecylon membranifolium* (in included phloem),  $\times 95$ . — Fig. 175. Elongate crystals (feature 151), *Ligustrum vulgare*,  $\times 220$ . — Fig. 176. Small cubic crystals (feature 152), *Aporusa villosa* (in ray cells),  $\times 290$ . — Fig. 177. Small navicular crystals (feature 152), *Litsea reticulata*,  $\times 675$ .



**Acicular crystals** = small needle-like crystals, not occurring in bundles, fig. 173, e. g., *Tecoma stans* (Bignoniaceae), *Cryptocarya glaucescens* (Lauraceae), and *Gmelina arborea* (Verbenaceae).

**Styloids** = large crystals at least four times as long as broad with pointed or square ends, fig. 174, e. g., *Maytenus obtusifolia* (Celastraceae), *Terminalia amazonica* (Combretaceae), *Gelsemium sempervirens* (Loganiaceae), *Memecylon membranifolium* (Melastomataceae), *Gallesia integrifolia* (Phytolaccaceae), *Gonystylus bancanus* (Thymelaeaceae).

**Elongate crystals** = crystals two to four times as long as broad with pointed ends, fig. 175, e. g., *Siphonodon pendulum* (Celastraceae), *Ligustrum vulgare* (Oleaceae), *Vitex glabrata* (Verbenaceae).

**Crystals of other shapes (mostly small)** = includes all other shapes of crystals, figs. 176, 177, e. g., cubic (e. g., *Aporosa villosa*–Euphorbiaceae), navicular (boat-shaped) (e. g., *Litsea reticulata*–Lauraceae), spindle-shaped (e. g., *Dehaasia* spp.–Lauraceae), pyramidal (e. g., *Caryodaphnopsis tonkinensis*–Lauraceae), tabular (e. g., *Aniba* spp.–Lauraceae), indented (e. g., *Forstiera segregata*–Oleaceae), twinned (e. g., *Nestegis* spp.–Oleaceae), etc.

**Crystal sand** = a granular mass composed of very small crystals, fig. 178, e. g., *Cordia subcordata* (Boraginaceae), *Actinodaphne hookeri* (Lauraceae), *Bumelia obtusifolia* (Sapotaceae), and *Nicotiana cordifolia* (Solanaceae). Synonym: microcrystals.

*Comments:*

Crystals, particularly the small ones, are best detected with polarised light.

These crystals are not common, and their occurrence may be sporadic. Therefore, these features should only be used in the positive sense. Raphides and styloids often occur in enlarged cells, feature 156. For more information on crystal types, see Chattaway (1955, 1956) and Richter (1980).

*Cautions:* Care must be taken not to interpret a cross section of an elongate or acicular crystal as a cubic crystal.

The crystals in raphide bundles often separate during sectioning.

## OTHER DIAGNOSTIC CRYSTAL FEATURES

**154. More than one crystal of about the same size per cell or chamber**

**155. Two distinct sizes of crystals per cell or chamber**

**156. Crystals in enlarged cells**

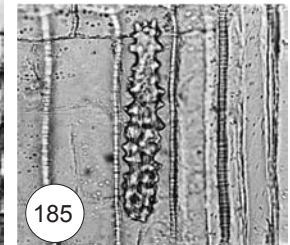
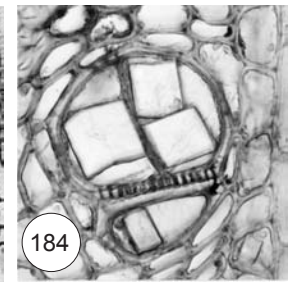
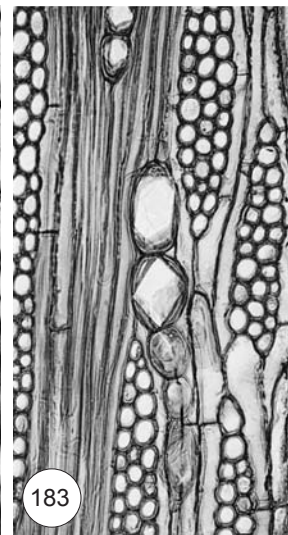
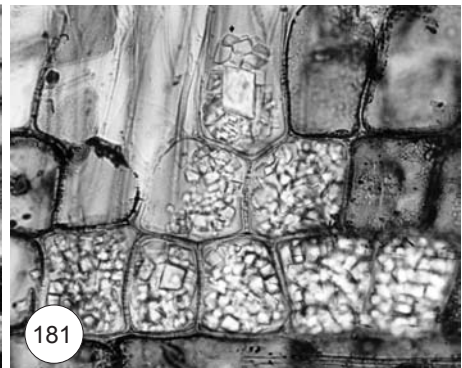
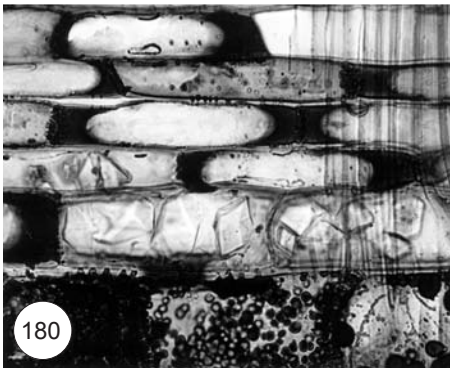
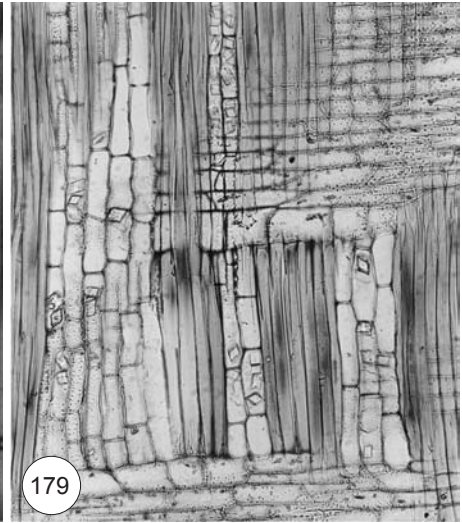
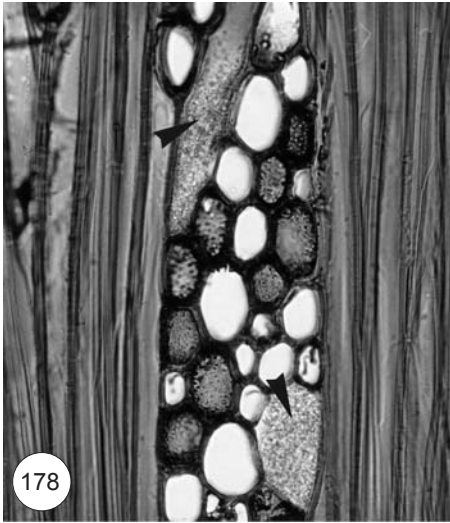
**157. Crystals in tyloses**

**158. Cystoliths**

*Definitions:*

Features 154–157 as per feature descriptor, examples follow.

**More than one crystal of about the same size per cell or chamber**, figs. 179, 182, e. g., *Bouea oppositifolia* (Anacardiaceae), *Garcinia latissima* (Guttiferae), *Aniba duckeii* (Lauraceae), *Ligustrum vulgare* (Oleaceae), *Gmelina arborea*, *Vitex divaricata* (Verbenaceae).



**Two distinct sizes of crystals per cell or chamber**, fig. 181, e. g., *Mangifera altissima* (Anacardiaceae), *Cordia bantamensis* (Boraginaceae), *Pentacme contorta* (Dipterocarpaceae), *Zanthoxylum juniperinum* (Rutaceae), *Bumelia glomerata* (Sapotaceae), *Gonystylus bancanus* (Thymelaeaceae).

**Crystals in enlarged cells** (idioblasts), fig. 183, e. g., *Carpinus carolinianum* (Corylaceae), *Juglans nigra* (Juglandaceae), *Pyrus communis* (Rosaceae), *Citrus aurantium* (Rutaceae), *Camellia japonica* (Theaceae), *Zelkova serrata* (Ulmaceae).

**Crystals in tyloses**, fig. 184, e. g., *Astronium graveolens* (Anacardiaceae), *Cordia gharaf* (Boraginaceae), *Pera bumeliaefolia* (Euphorbiaceae), *Chlorophora tinctoria*, *Pseudolmedia spuria* (Moraceae), *Chrysophyllum auratum* (Sapotaceae).

**Cystoliths** = internal stalked outgrowths of the cell wall that project into the cell lumen and are composed of cellulose impregnated with calcium carbonate. They are irregular in shape and sometimes completely fill a cell, fig. 185, e. g., in some *Trichanthera* spp. (Acanthaceae), *Sparanthelium* spp. (Hernandiaceae), and Opiliaceae.

*Comments:*

Generally, there is only one crystal per cell or chamber. However, two or more similar-sized crystals, especially acicular and/or navicular, and cubic and/or rectangular crystals, may occur in the same cell or chamber. It is rare that there are two distinct sizes of crystals in the same cell or chamber. For more information, see Chattaway (1956).

For feature 156, 'crystals in enlarged cells (idioblasts)', the enlarged cells can be either ray or axial parenchyma cells, or more rarely both. The crystals in enlarged cells may be prismatic crystals, druses, raphides, or any other crystal type.

Cystoliths, as far as is known, occur only in the examples given (Ter Welle 1980).

*Caution:* Raphides are bundles of crystals, but the whole bundle is considered as a single unit, and so feature 154, 'more than one crystal per cell or chamber', does not apply to raphides. Crystal sand should also *not* be coded under feature 154.

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Fig. 178. Crystal sand (feature 153, arrowheads), *Cordia subcordata* (in ray cells),  $\times 290$ . — Figs. 179 & 180. More than one crystal of about the same size per cell or chamber (feature 154). — 179: In axial parenchyma cells, *Garcinia latissima*,  $\times 75$ . — 180: In ray cells, *Bouea oppositifolia*,  $\times 290$ . — Fig. 181. Two distinct sizes of crystals per cell or chamber (feature 155), *Cordia bantamensis* (in ray cells),  $\times 290$ . — Fig. 182. Different size classes of crystals intergrading in some ray cells (feature 155 variable), but more than one crystal of about the same size per cell in others (feature 154 present), *Cordia abyssinica*,  $\times 115$ . — Fig. 183. Crystals in enlarged cells (feature 156), *Citrus aurantium*,  $\times 135$ . — Fig. 184. Crystals in tyloses (feature 157), *Cordia gharaf*,  $\times 140$ . — Fig. 185. Cystoliths (feature 158), *Trichanthera gigantea*,  $\times 220$ .

## SILICA

**159. Silica bodies present****160. Silica bodies in ray cells****161. Silica bodies in axial parenchyma cells****162. Silica bodies in fibres****163. Vitreous silica***Definitions:*

**Silica bodies** = spheroidal or irregularly shaped particles composed of silicon dioxide. Synonyms: silica grains, silica inclusions.

Features 160–162 as per feature descriptor, examples follow.

**Silica bodies in ray cells**, fig. 186, e.g., in *Trattinickia burserifolia*, *T. demararae* (Burseraceae), *Licania leptostachya* (Chrysobalanaceae), *Shorea lamellata* (Dipterocarpaceae), *Mezilaurus itauba* (Lauraceae), *Vitex compressa* (Verbenaceae).

**Silica bodies in axial parenchyma cells**, fig. 187, e.g., in *Bombax nervosum*, *Distemonanthus* spp. (Bombacaceae), *Apuleia leiocarpa*, *Dialium guianense* (Caesalpinaceae).

**Silica bodies in fibres**, fig. 188, e.g., *Canarium hirsutum*, *Protium neglectum*, *Trattinickia burserifolia* (Burseraceae), *Ocotea puberula* (Lauraceae).

**Vitreous silica** = silica that coats cell walls or completely fills the cell lumina, fig. 189, e.g., *Stereospermum chelonoides* (Bignoniaceae), *Hydnocarpus gracilis* (Flacourtiaceae), *Artocarpus vriesianus* (Moraceae), and *Gynotroches axillaris* (Rhizophoraceae).

*Procedures:*

*Silica bodies*: Silica bodies are observed with the light microscope in radial sections of either permanent or temporary mounts or in cells that have been macerated. If large amounts of extractives are present and the silica bodies are difficult to see in section, bleach with a domestic bleaching agent, rinse in water, heat in carbolic acid, and mount in clove oil, or macerate a few chips in any macerating fluid that removes most of the extractives and lignin but not the silica. At low magnification (4–10 × objective lens), silica bodies generally appear as small dark non-birefringent particles. At higher magnification (25–40 × objective lens), they have a ‘glassy’ appearance.

*Vitreous silica*: Thoroughly macerate chips or splinters, leave the wood in the macerating solution until it is white. Decant the macerating fluid, add water, rinse, decant, and repeat until the solution is clear. Place some macerated wood on a slide; warm the slide on a hotplate until the macerated wood is dry. Allow the slide to cool, and then add 2 to 3 drops of concentrated sulfuric acid to dissolve the cellulose. Add a cover slip and observe the cells under a light microscope at low magnification. Vitreous silica appears like pieces of translucent vessel elements and fibres. To distinguish undissolved cells from vitreous silica use polarised light. Undissolved cells are birefringent, whereas vitreous silica is not. Vitreous silica can also be recognised in well-bleached sections because of its ‘glassy’ appearance.



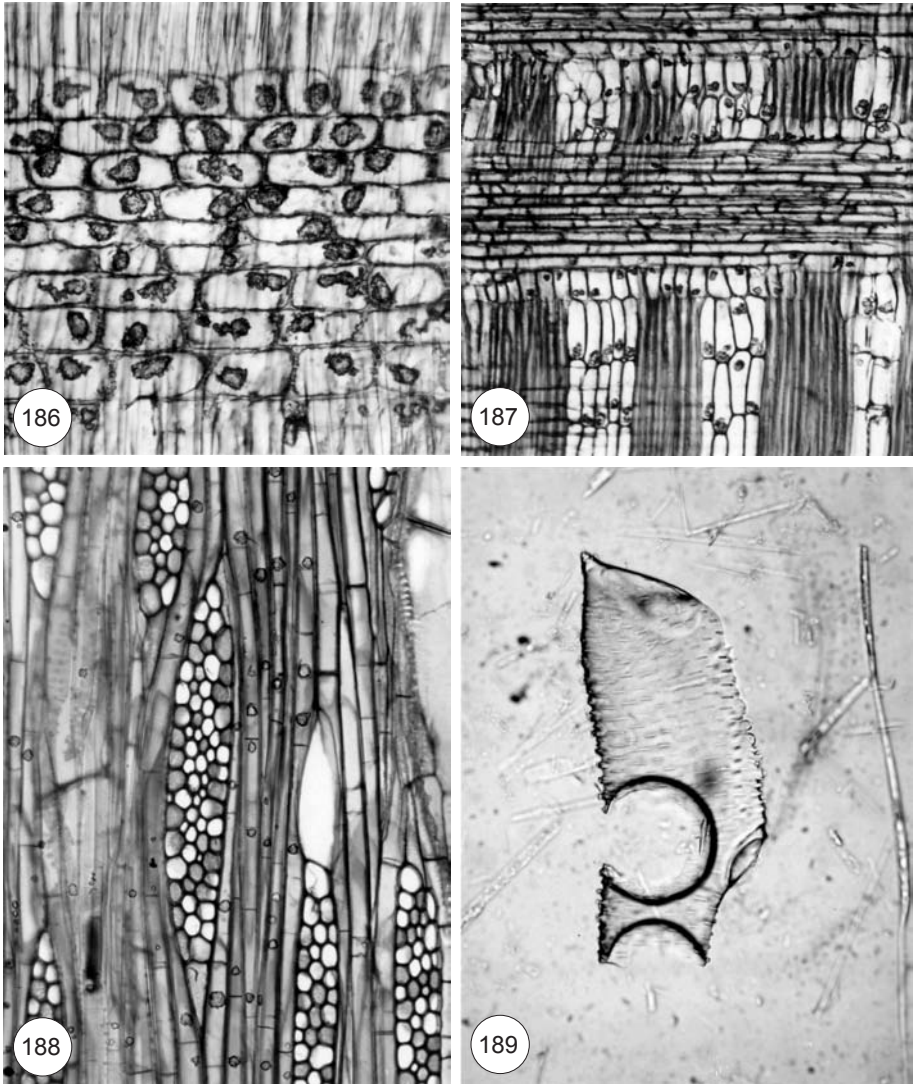


Fig. 186. Silica bodies present (feature 159) in ray cells (feature 160), *Shorea lamellata*,  $\times 150$ . — Fig. 187. Silica bodies in marginal ray cells and axial parenchyma cells (features 159, 160, and 161), *Apuleia leiocarpa*,  $\times 75$ . — Fig. 188. Silica bodies in fibres (features 159 and 162), *Ocotea cf. puberula*,  $\times 115$ . — Fig. 189. Vitreous silica (feature 163), *Hydnocarpus gracilis*,  $\times 150$ .

*Comments:*

Silica bodies most often are restricted to ray cells, particularly the marginal or upright cells. Sometimes they are restricted to axial parenchyma; sometimes they occur in both ray and axial parenchyma. Silica bodies rarely occur in fibres, but if they do the fibres usually are septate.

Whether silica occurs in aggregations, as irregularly shaped or globular bodies, or whether the silica bodies have a smooth or verrucose surface may be diagnostic in certain groups and needs to be recorded in a description. For more information on silica bodies, see Amos (1952), Ter Welle (1976), and Koeppen (1980).

*Cautions:* When looking for silica bodies, do *not* use glycerin as a mounting medium because its refractive index makes it difficult to detect silica bodies.

Hydrofluoric acid, which is sometimes used to soften wood, will dissolve the silica bodies.

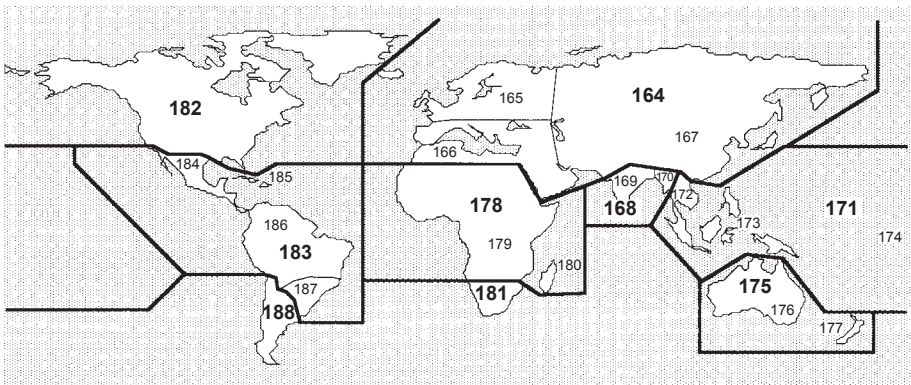


Fig. 190. Geographical distribution (features 164–188).

## APPENDIX

### Non-anatomical Information

#### GEOGRAPHICAL DISTRIBUTION (fig. 190)

- 164.** Europe and temperate Asia (Brazier and Franklin region 74)
  - 165. Europe, excluding Mediterranean
  - 166. Mediterranean including Northern Africa and Middle East
  - 167. Temperate Asia (China), Japan, USSR
- 168.** Central South Asia (Brazier and Franklin region 75)
  - 169. India, Pakistan, Sri Lanka
  - 170. Burma
- 171.** Southeast Asia and the Pacific (Brazier and Franklin region 76)
  - 172. Thailand, Laos, Vietnam, Cambodia (Indochina)
  - 173. Indomalaysia: Indonesia, Philippines, Malaysia, Brunei, Singapore, Papua New Guinea, and Solomon Islands
  - 174. Pacific Islands (including New Caledonia, Samoa, Hawaii, and Fiji)
- 175.** Australia and New Zealand (Brazier and Franklin region 77)
  - 176. Australia
  - 177. New Zealand
- 178.** Tropical mainland Africa and adjacent islands (Brazier and Franklin region 78)
  - 179. Tropical Africa
  - 180. Madagascar & Mauritius, Réunion & Comores
- 181.** Southern Africa (south of the Tropic of Capricorn) (Brazier and Franklin region 79)
- 182.** North America, north of Mexico (Brazier and Franklin region 80)
- 183.** Neotropics and temperate Brazil (Brazier and Franklin region 81)
  - 184. Mexico and Central America
  - 185. Caribbean
  - 186. Tropical South America
  - 187. Southern Brazil
- 188.** Temperate South America including Argentina, Chile, Uruguay, and S. Paraguay (Brazier and Franklin region 82)

#### *Comments:*

There is no single ideal way of dividing the world. The above is a mixture of political and biogeographical criteria. It retains the major geographical regions of Brazier and Franklin (1961), but some regions are subdivided so that more precision is possible.

#### HABIT

- 189. Tree**
- 190. Shrub**
- 191. Vine/liana**

#### *Definitions:*

**Tree** = woody perennial plant with one main stem usually over 3 metres tall.

**Shrub** = a woody perennial plant usually with several stems and usually less than 3 metres tall at maturity.

**Vine/liana** = any plant with a long relatively thin stem that climbs along a support or trails along the ground.

*Comments:*

There will be overlap between these categories in some species, and two or more, rarely all three, may apply.

## WOOD OF COMMERCIAL IMPORTANCE

### 192. Wood of commercial importance

This category is intended for woods of both historical and current commercial importance. The term 'of commercial importance' is somewhat vague, and should be used with caution when identifying an unknown. But when identifying certain wooden artefacts, e.g., furniture, it can be helpful to segregate commercial species from noncommercial species.

## SPECIFIC GRAVITY

### 193. Basic specific gravity low, $\leq 0.40$

### 194. Basic specific gravity medium, $0.40-0.75$

### 195. Basic specific gravity high, $\geq 0.75$

*Definitions:*

**Basic specific gravity** = ratio of the oven-dry weight of a piece of wood to the weight of the water displaced by the wood when it is completely swollen (i.e., green volume). Examples for the feature categories follow.

**Basic specific gravity low,  $\leq 0.40$** , e.g., *Dyera costulata* (Apocynaceae), *Ceiba* spp., *Ochroma* spp. (Bombacaceae), *Populus balsamifera* (Salicaceae), *Triplochiton* spp. (Sterculiaceae), *Tilia* spp. (Tiliaceae).

**Basic specific gravity medium,  $0.40-0.75$** , e.g., *Acer saccharum* (Aceraceae), *Betula lenta* (Betulaceae), *Carapa guianensis*, *Khaya grandifoliola* (Meliaceae), *Fraxinus americana* (Oleaceae), *Tectona* spp. (Verbenaceae).

**Basic specific gravity high,  $\geq 0.75$** , e.g., *Astronium graveolens* (Anacardiaceae), *Ocotea rodiei* (Lauraceae), *Dalbergia melanoxylon* (Papilionaceae), *Manilkara bidentata* (Sapotaceae), *Guaiaacum* spp. (Zygophyllaceae).

*Comments:*

Density is the weight of a substance (mass) per unit volume; specific gravity (s.g.) is the ratio of the density of a material to the density of water and, consequently, specific gravity does not have units. For purposes of computing specific gravity of wood, wood density uses the oven-dry weight of wood as the numerator. Because the volume of wood changes with changes in moisture content below fibre saturation point, it is necessary to specify the moisture content at



which specific gravity is determined. Basic specific gravity (Bsg), which is based on the green volume (wood fully swollen, moisture content of fibre saturation point or higher) is one of the most commonly cited values (Panshin & DeZeeuw 1980).

Other values often given for wood include basic density (Bd) which is equal to the oven-dry weight of wood/green volume and which has units ( $\text{g}/\text{cm}^3$ ,  $\text{kg}/\text{m}^3$ , or  $\text{lbs}/\text{ft}^3$ ). To convert from basic specific gravity (Bsg) to basic density (Bd) multiply the basic s.g. by the density of water as is shown below:

$$\text{Bd in g/cm}^3 = \text{Bsg} \times 1 \text{ g/cm}^3$$

$$\text{Bd in kg/m}^3 = \text{Bsg} \times 1000 \text{ kg/m}^3$$

$$\text{Bd in lbs/ft}^3 = \text{Bsg} \times 62.4 \text{ lbs/ft}^3$$

Therefore

$$\text{Bsg of 0.4} = \text{Bd of } 0.4 \text{ g/cm}^3, 400 \text{ kg/m}^3, \text{ or } 25 \text{ lbs/ft}^3$$

$$\text{Bsg of 0.75} = \text{Bd of } 0.75 \text{ g/cm}^3, 75 \text{ kg/m}^3, \text{ or } 46.8 \text{ lbs/ft}^3$$

## HEARTWOOD COLOUR

**196. Heartwood colour darker than sapwood colour**

**197. Heartwood basically brown or shades of brown**

**198. Heartwood basically red or shades of red**

**199. Heartwood basically yellow or shades of yellow**

**200. Heartwood basically white to grey**

**201. Heartwood with streaks**

**202. Heartwood not as above**

### Definitions:

**Heartwood colour darker than sapwood colour**, e.g., *Astronium* spp. (Anacardiaceae), *Tabebuia guayacan* (Bignoniaceae), *Acacia koa* (Mimosaceae), *Morus alba* (Moraceae), *Robinia* spp. (Papilionaceae).

**Heartwood basically brown or shades of brown**, e.g., *Quercus alba* (Fagaceae), *Albizia (Samanea) saman* (Mimosaceae), *Morus rubra* (Moraceae), *Eucalyptus globulus* (Myrtaceae), *Robinia* spp. (Papilionaceae).

**Heartwood basically red or shades of red**, e.g., *Brosimum rubescens* (Moraceae), *Pterocarpus macrocarpus* (Papilionaceae), *Sickingia* spp. (Rubiaceae).

**Heartwood basically yellow or shades of yellow**, e.g., *Enantia chlorantha* (Annonaceae), *Buxus* spp. (Buxaceae), *Schaefferia frutescens* (Celastraceae), *Gossypiospermum* spp. (Flacourtiaceae), *Cladrastis lutea* (Papilionaceae).

**Heartwood basically white to grey**, e.g., *Ilex opaca* (Aquifoliaceae), *Didymopanax* spp. (Araliaceae), *Ceiba* spp. (Bombacaceae), *Hura* spp. (Euphorbiaceae), *Cecropia* spp. (Moraceae), *Simarouba* spp. (Simaroubaceae).

**Heartwood with streaks**, e.g., *Dracontomelon dao* (Anacardiaceae).

**Heartwood not as above** = colours such as black, purple, orange, green, as in *Diospyros ebenum* (Ebenaceae), *Peltogyne* spp. (Papilionaceae).

*Procedure:*

Time and exposure to light may alter the appearance or vividness of the colour. Therefore, it is best to determine colour from a freshly cut tangential surface of a dry wood sample. The heartwood colour of recently felled trees often differs from that of dry wood samples. These descriptors are for wood samples that are at least air-dry.

*Comments:*

Feature 196, 'heartwood colour darker than sapwood colour', only can be used when both heartwood and sapwood are present, and is recorded in combination with the other heartwood colour features (197–202). The heartwood of some species, e.g., *Quercus alba* (Fagaceae) and *Betula lenta* (Betulaceae), is not markedly darker than the sapwood, but can be distinguished from it, so feature 196 applies to these taxa.

The variety of colours, shades, and combinations of heartwood colour make it impossible to categorise all of them. In general, the colour of heartwood is either brown, red, yellow, white, or some shade or combination of these colours. Basically brown heartwood is very common; basically red and basically yellow are rather rare; basically white or grey is rather frequent.

The heartwood colour of many taxa is not restricted to one colour, but to a combination of colours and, when appropriate, various combinations should be recorded and may be used when identifying an unknown.

Examples of these combinations include: reddish-brown in *Astronium* spp. (Anacardiaceae), *Hymenaea* spp. (Caesalpiniaceae), *Quercus rubra*, *Fagus* spp. (Fagaceae), *Khaya* spp., *Swietenia* spp. (Meliaceae); yellow and brown in *Distemonanthus* spp. (Caesalpiniaceae), *Chlorophora tinctoria* (Moraceae), *Adina cordifolia* (Rubiaceae), *Fagara* spp. (Rutaceae), *Mastichodendron* spp. (Sapotaceae).

Very light coloured woods would be recorded as combinations of white to grey and brown and/or yellow, e.g., *Acer* spp. (Aceraceae), *Alstonia* spp. (Apocynaceae), *Anisoptera* spp. (Dipterocarpaceae), *Gmelina* spp. (Verbenaceae).

Heartwood with streaks is always used in combination with the general heartwood colour, as in *Microberlinia* spp. which has brown heartwood with streaks.

'Heartwood not as above' is a 'catch-all' category for taxa with heartwood colours such as black, green, orange, and purple. This feature may be used alone (e.g., as for *Diospyros ebenum*–Ebenaceae, which has distinctly black heartwood), but more commonly it will be used in combination with other heartwood colours. For example, the combination of basically brown and green occurs in *Bucida buceras* (Combretaceae), *Ocotea rodiei* (Lauraceae), *Liriodendron tulipifera*, *Michelia* spp., *Talauma* spp. (Magnoliaceae); the combination of basically red, brown, yellow, and orange with streaks occurs in *Centrolobium* spp. (Papilionaceae) and *Aspidosperma* spp. (Apocynaceae); the combination of brown, red, purple, black and orange with streaks occurs in *Dalbergia* spp. (Papilionaceae).

*Cautions:*

Do not use heartwood colour features for ancient samples, archaeological material, or other samples whose colour has been altered by burial, time, treatment, or decay.

Be particularly careful when using the feature 'Heartwood basically white to grey', because a whitish coloured sample may represent sapwood and not heartwood.

ODOUR\*

### 203. Distinct odour

*Definition:*

**Distinct odour** = as per feature descriptor, e. g., *Viburnum* (Caprifoliaceae), *Ceratopetalum apetalum* (Cunoniaceae), many species of Lauraceae, *Cedrela* (Meliaceae), and *Santalum* (Santalaceae).

*Procedure:*

In dried wood samples the chemicals responsible for the odour may have volatilised from the surface, so it will be necessary to expose a fresh surface, or take other measures to enhance the odour, e. g., add moisture by breathing on the wood, or wet the wood with water and warm it.

*Caution:* Odour is quite variable, and individual perceptions of odour often differ. Therefore, use this feature with caution and only in the positive sense.

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\*) Taste is deliberately excluded because of safety considerations, particularly a concern that someone may try tasting a wood whose contents could cause a severe allergic reaction.

## HEARTWOOD FLUORESCENCE

### 204. Heartwood fluorescent

*Definition:*

**Heartwood fluorescent** = heartwood fluorescing when illuminated with longwave ultraviolet light, e. g., with a strong yellowish or greenish fluorescence in *Anacardium excelsum* (Anacardiaceae), *Asimina* spp. (Annonaceae), *Aspidosperma eburneum* (Apocynaceae), *Robinia* spp. (Papilionaceae); with a slight tinge of orange fluorescence in *Mangifera indica* (Anacardiaceae), *Vatairea lundellii* and *Symphonia* spp. (Guttiferae), *Nauclea diderrichii* (Rubiaceae); weak, yet positive, fluorescence in many Annonaceae, Lauraceae, and Magnoliaceae.

*Procedure:*

Samples for testing fluorescence must be freshly surfaced; simply removing some shavings with a knife is sufficient for exposing a fresh surface. Place samples under a longwave (365 nm) ultraviolet (UV) light at a distance of less than 10 cm. A high-intensity longwave UV lamp and observation in a darkened room is recommended.

*Comments:*

Fluorescent samples generally appear yellowish or greenish under the UV lamp, although some species show slight tinges of orange or pink.

Samples that are not fluorescent may reflect some of the UV light making the sample appear slightly blue or purple. Some samples with a yellowish heartwood, such as *Chloroxylon* spp. (Rutaceae) and *Gonystylus* spp. (Thymelaeaceae), are not fluorescent, but may seem to have a weak yellow fluorescence because of reflection.

Absence of fluorescence can be important in some families, e. g., Anacardiaceae and Leguminosae. See Avella *et al.* (1989) for a survey of fluorescence in the dicotyledons.

*Cautions:*

This feature applies only to naturally occurring fluorescence and *not* to fluorescence associated with decay or pathological infections. Wood infected with decay organisms may fluoresce with streaks, spots, or a mottled appearance, e.g., wetwood of *Populus tremuloides* (Salicaceae) produces yellow fluorescent streaks. Naturally occurring fluorescence appears more uniform.

Oven-drying of samples or exposure to high temperatures or other extreme environmental conditions may affect fluorescence properties.

## WATER &amp; ETHANOL EXTRACTS: FLUORESCENCE &amp; COLOUR

**205. Water extract fluorescent**

**206. Water extract basically colourless to brown or shades of brown**

**207. Water extract basically red or shades of red**

**208. Water extract basically yellow or shades of yellow**

**209. Water extract not as above**

**210. Ethanol extract fluorescent**

**211. Ethanol extract basically colourless to brown or shades of brown**

**212. Ethanol extract basically red or shades of red**

**213. Ethanol extract basically yellow or shades of yellow**

**214. Ethanol extract not as above**

*Procedures:*

*Preparation of extracts:* Add enough thin heartwood shavings to cover the bottom of a clean vial which is approximately 20 mm × 70 mm. Do not use splinters or chips, because the extraction time is much longer than for shavings. For water extracts, cover the shavings to a depth of approximately 20 mm (approximately 5 ml) with distilled water that is buffered at a pH of 6.86. Packets of buffering agent are available from most scientific supply companies so that only the contents of a packet need to be added to 500 or 1000 ml of distilled water to obtain the desired pH. For ethanol extracts use 95% ethanol.

*Determining fluorescence of water & alcohol extracts:* Cover the vials and shake vigorously for 10 to 15 seconds. Allow the shavings and solution to stand for 1 to 2 minutes, and then hold the vial under a longwave (approximately 365 nm) UV lamp and check for extract fluorescence. Generally, extracts that fluoresce are bluish, but sometimes they are greenish.

*Determining colour of water and alcohol extracts:* After determining the fluorescence of the water and ethanol extracts, place the vials on a hotplate and bring the solution to a boil. As soon as the solution boils, remove the vial and immediately determine the colour.

*Comments & Examples for fluorescence:*

Examples of woods yielding water extracts that fluoresce a brilliant blue include *Strychnos decussata* (Loganiaceae), *Brosimum rubescens* (Moraceae), *Olea europaea* subsp. *africana* (Oleaceae), *Pterocarpus indicus* (Papilionaceae), *Zanthoxylum flavum* (Rutaceae). Examples of wood with weaker fluorescence of water extracts, but still positive, include *Acacia farnesiana* (Mimosaceae) and *Lonchocarpus capassa* (Papilionaceae).

Examples of woods yielding ethanol extracts with bright fluorescence include *Protorhus longifolia* (Anacardiaceae), *Cordia gerascanthus* (Boraginaceae), *Acacia erioloba* (Mimosaceae).



Examples of wood with weaker fluorescence of ethanol extracts, but still positive, include *Kiggelaria africana* (Flacourtiaceae), *Acacia melanoxylon* (Mimosaceae), *Olea capensis* (Oleaceae).

Sometimes the water extract of a species fluoresces, but its ethanol extract does not (e.g., *Leucaena glauca*–Mimosaceae). More often, the ethanol extract fluoresces, while the water extract does not (e.g., *Azelia quanzensis*–Caesalpiniaceae, *Lysiloma bahamensis*–Mimosaceae).

*Comments & Examples for water & alcohol extract colour:*

Water extract basically colourless to brown or shades of brown is the most common of the water extract feature colours.

Examples of woods with water extract basically red or shades of red (feature 206) include *Brasilettia* spp. (Caesalpiniaceae), *Catha edulis* (Celastraceae), *Cunonia capensis* (Cunoniaceae), and *Mimusops caffra* (Sapotaceae).

Examples of woods with water extract basically yellow or shades of yellow (feature 207) include *Gonioma kamassi* (Apocynaceae), *Albizia adianthifolia*, *Acacia caffra* (Mimosaceae).

Feature 209, 'water extract not as above' includes colours such as orange, black, and purple. Various combinations of water extract colours occur as well.

Ethanol extract basically colourless to brown or shades of brown (feature 211) is the most common.

Examples of woods with 'ethanol extract basically red or shades of red' (feature 212) include *Rhus integrifolia* (Anacardiaceae), *Baikiaea plurijuga*, *Peltophorum dubium*, *Swartzia madagascariensis* (Caesalpiniaceae), and *Berchemia discolor* (Rhamnaceae).

Examples of woods with 'ethanol extract basically yellow or shades of yellow' (feature 213) include *Gonioma kamassi* (Apocynaceae), *Ptaeroxylon obliquum*, *Zanthoxylum flavum* (Rutaceae), *Balanites maughanii* (Zygophyllaceae).

Feature 214, 'Ethanol extract not as above', includes colours such as orange, black, and purple.

For more information, see Dyer (1988) and Quirk (1983).

## FROTH TEST

### 215. Froth test positive

*Procedure:*

Follow the procedure for preparing for the water extract tests. Add enough thin heartwood shavings to cover the bottom of a clean vial approximately 20 × 70 mm. Do not use splinters or chips, because the extraction time is much longer than for shavings; if sawdust is used, extraction time will be less. For water extracts, cover the shavings to a depth of approximately 20 mm (approximately 5 ml) with distilled water that is buffered at a pH of 6.86. Packets of buffering agent are available from most scientific supply companies so that only the contents of the packet need to be added to 500 or 1000 ml of distilled water to obtain the desired pH.

Cover the vial and shake vigorously for 10 to 15 seconds. If natural saponins are present in large amounts, tiny bubbles or 'froth' (like foam on a glass of beer) will be formed. Allow the vial to stand for approximately 1 minute from the end of the shaking. If 'froth' still completely covers the surface of the solution after 1 minute, the test is positive. If 'froth' or bubbles form and then disappear within 1 minute, the test is negative. If only some 'froth' remains around the edge of the vial (i.e., forming a ring of 'froth'), but does not cover the entire surface, the test is weakly positive.

*Comments & Examples:*

Positive 'froth' test reactions are produced by, e.g., *Mora* spp. (Caesalpinaceae), *Enterolobium cyclocarpum*, *Lysiloma bahamensis*, *Pseudosamanea* spp. (Mimosaceae), *Dipholis* spp., *Mastichodendron* spp. (Sapotaceae).

Weakly positive reactions (ring of froth) are produced by, e.g., *Peltophorum* spp. (Caesalpinaceae), *Kiggelaria* spp. (Flacourtiaceae), *Ekebergia* spp., *Entandrophragma* spp. (Meliaceae), *Acacia nigrescens* (Mimosaceae), *Millettia* spp. (Papilionaceae), and *Berchemia* spp. (Rhamnaceae).

For more information, see Dyer (1988), Quirk (1983), and Cassens and Miller (1981).

## CHROME AZUROL-S TEST

**216. Chrome Azurol-S test positive***Procedure:*

Prepare a 0.5% solution of chrome azurol-S reagent by dissolving 0.5 g of the dry chrome azurol-S granules and 5.0 g of sodium acetate (buffer) in 80 ml of distilled water. After the chemicals are completely dissolved, add enough distilled water to make 100 ml of reagent. This solution is stable and can be used over a number of years. To test dry wood samples, use an eyedropper to apply one or two drops of the solution to a freshly exposed end-grain.

In highly positive woods, a bright blue colour will develop in a matter of minutes, e.g., *Poga* spp. (Anisophylleaceae), *Cardwellia* spp. (Proteaceae), *Symplocos* spp. (Symplocaceae), and all Vochysiaceae. In those woods which absorb the solution very slowly, e.g., *Anisophyllea* spp. (Anisophylleaceae), *Goupia* spp. (Goupiaceae) or contain low concentrations of aluminum, e.g., *Laplacea* spp. (Theaceae), *Henriettea* spp. (Melastomataceae), several hours may be required for the blue colour to develop.

*Comment:*

Chrome Azurol-S tests for the presence of aluminum in both heartwood and sapwood. For more information on this test, see Kukachka and Miller (1980).

*Caution:* Avoid decayed wood because chrome azurol-S is an indicator for some types of wood decaying fungi.

## BURNING SPLINTER TEST

**217. Splinter burns to charcoal****218. Splinter burns to a full ash: Colour of ash bright white****219. Splinter burns to a full ash: Colour of ash yellow-brown****220. Splinter burns to a full ash: Colour of ash other than above****221. Splinter burns to a partial ash***Definitions:*

**Charcoal** = the blackened and charred remains of a splinter, which usually burned slowly and/or with difficulty, or the black and charred remnant of the splinter with a fine thread of black or grey ash which may remain attached.

**Full or complete ash** = ash more or less retaining the shape of the original splinter.

**Partial ash** = ash that shrinks in size in comparison to the original splinter, has a tendency to drift away, and usually feels gritty when rubbed between the fingers.

*Procedure:*

Prepare match-size (approximately 2 × 2 × 50 mm) splinters from sound outer heartwood, insure the wood is at least air-dry. The splinter must be ignited with a match, and devices (e.g., lighters) producing higher temperatures must be avoided. Ignite the splinter while it is held in a vertical position with a pair of tweezers/forceps. While the splinter is burning, hold it in a horizontal position and turn it slowly.

Some timber species will burn with relative ease (e.g., *Populus* spp.–Salicaceae), while others may show considerable reluctance (e.g., *Eucalyptus paniculata*–Myrtaceae). If it appears that the flame will extinguish before the splinter has burned fully, combustion may be aided by gently returning the splinter to a vertical position and then back to horizontal.

After the flame extinguishes, it is important to allow the glowing part of the splinter to extinguish before placing the remnant on a cold surface.

*Comments:*

Certain splinters may crackle or produce bright sparks (e.g., *Terminalia catappa*–Combretaceae), while others may produce a characteristic smoke coloration (heavy black smoke in *Fлиндерсия лаевичарпа*–Rutaceae) or exude coloured compounds while they burn. All these features may be recorded in a description.

The descriptive classifications for appearance of the burnt splinter are those first recommended by Dadswell and Burnell (1932). In some literature, buff is used to describe splinters that have the colour of pale tanned leather, a yellowy brown, e.g., *Eucalyptus paniculata* (Myrtaceae).

Apart from its use in CSIRO keys, Anonymus (1960) has implemented the feature and suggests that it is of little value except in distinguishing between some timbers which are closely related anatomically.

For further information on the burning splinter test, which so far has only been used on a very limited scale, see Mann (1921), Welch (1922), Swain (1927), Dadswell and Burnell (1932), and Mennega (1948).

*Caution:* Code greyish-white ash as 'other than above', as the white is reserved for obviously (bright) white ash.

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