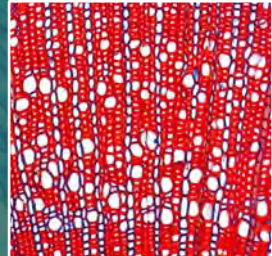
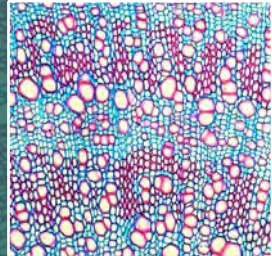
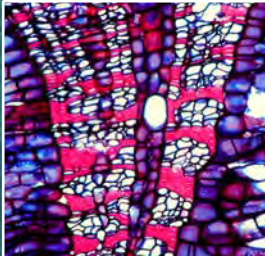
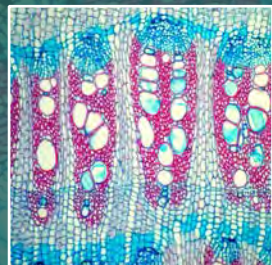
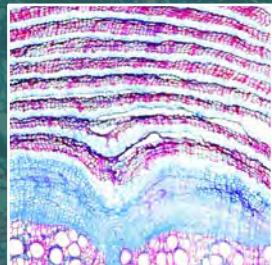


Stem Anatomical Features of Dicotyledons

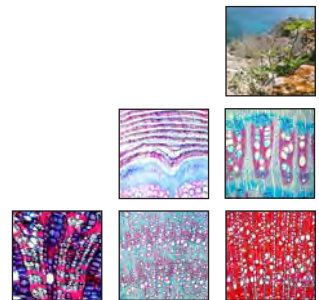
Xylem, phloem, cortex and periderm characteristics for ecological and taxonomical analysis

Alan Crivellaro
Fritz H. Schweingruber



Stem Anatomical Features of Dicotyledons

**Xylem, phloem, cortex and periderm characteristics
for ecological and taxonomical analysis**



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3 Schweingruber FH (*et al.*) (2008) Atlas of Woody Plant Stems. Springer-Verlag Berlin Heidelberg

4 Crivellaro A (*et al.*) (2013) Atlas of Wood, Bark and Pith Anatomy of Eastern Mediterranean Trees and Shrubs. Springer-Verlag Berlin Heidelberg

Cover pictures credit



Cover pictures

Mediterranean environment - Xylofagou, Cyprus

Clematis alpina (L.) Mill. [Ranunculaceae] - Phellem

Bosea cypria Boiss. ex Hook.f. [Amaranthaceae] - Xylem with successive cambia

Liriodendron tulipifera L. [Magnoliaceae] - Phloem

Silene maritima With. [Caryophyllaceae] - Xylem

Pterocephalus multiflorus Poech [Dipsacaceae] - Xylem

Background cover picture

Cross section at the root collar of *Patellifolia patellaris* (Moq.) A.J.Scott, Ford-Lloyd & J.T.Williams [Chenopodiaceae]

Plant names updated on October, 2015

Camera-ready by Alan Crivellaro

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List of abbreviations

ae	aerenchyma	mu	mucilage
ca	cambium	p	perforation
co	cortex	pa	parenchyma
cry	crystal	peri	pericycle
csi	collapsed sieve elements	ph	phloem
ct	conjunctive tissue	phe	phellem
cu	cuticle	phd	phellogen
		phg	phellogen
di	(ray) dilatation	phoi	phelloids
ds	dark-stained substances	pt	pith
du	duct		
		r	ray
en	endodermis	sc	sclereid
ep	epidermis	sf	septate fibres
ew	earlywood	sh	shoot
ewv	earlywood vessel	shc	sheet cell
		sip	sieve plate
f	fibre	si	sieve element
ge	gelatinous fibres	te	tension wood
gr	growth ring	ty	tylosis
grb	growth ring boundary		
he	helical thickenings	ulcw	unlignified cell wall
hyp	hypodermis		
		v	vessel
ivp	intervessel pit	vab	vascular bundle
		vrp	vessel-ray pits
la	laticifers		
le	lenticels		
lw	latewood	xy	xylem
lwv	latewood vessel		

Illustration of stem characteristics

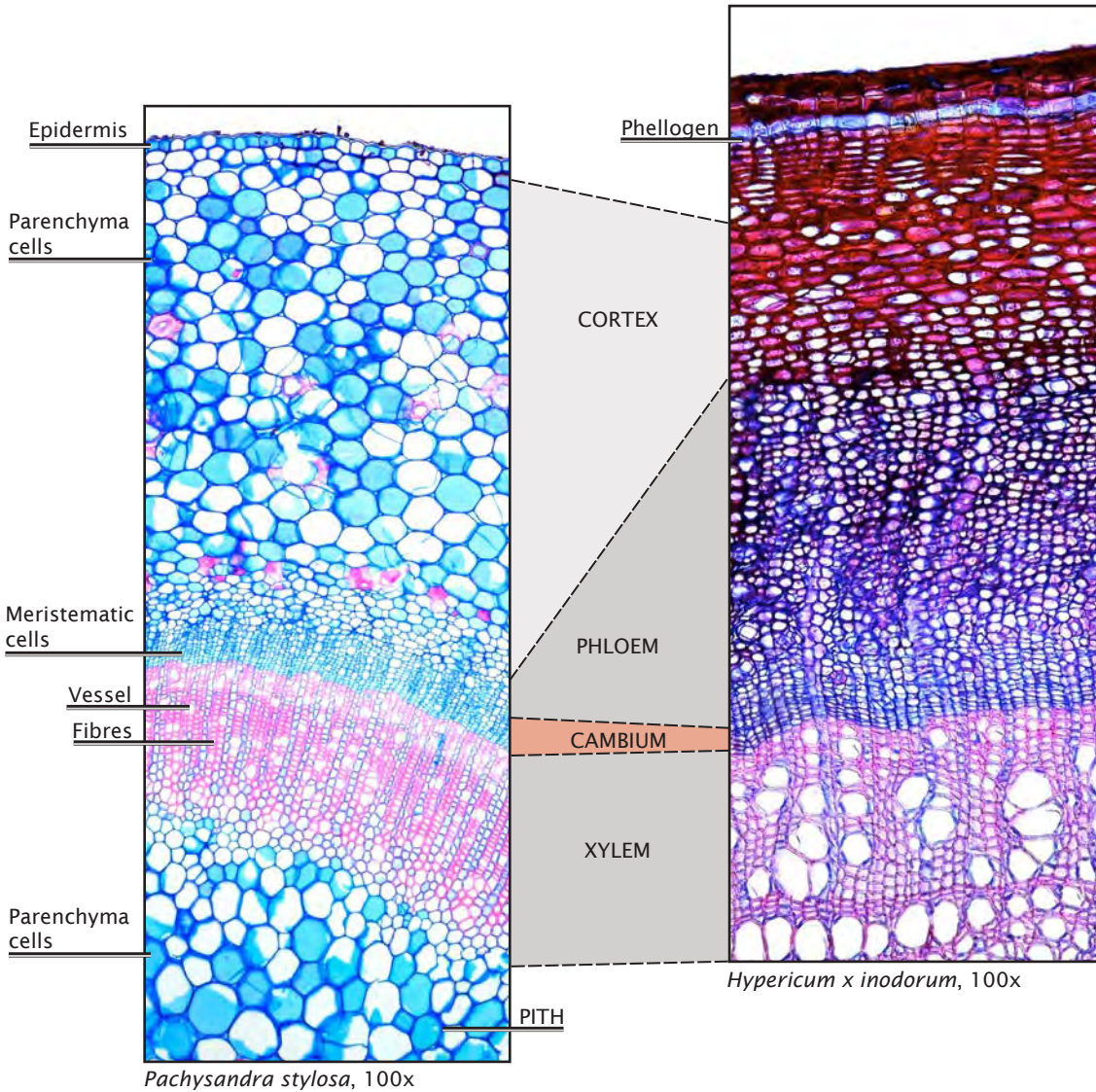
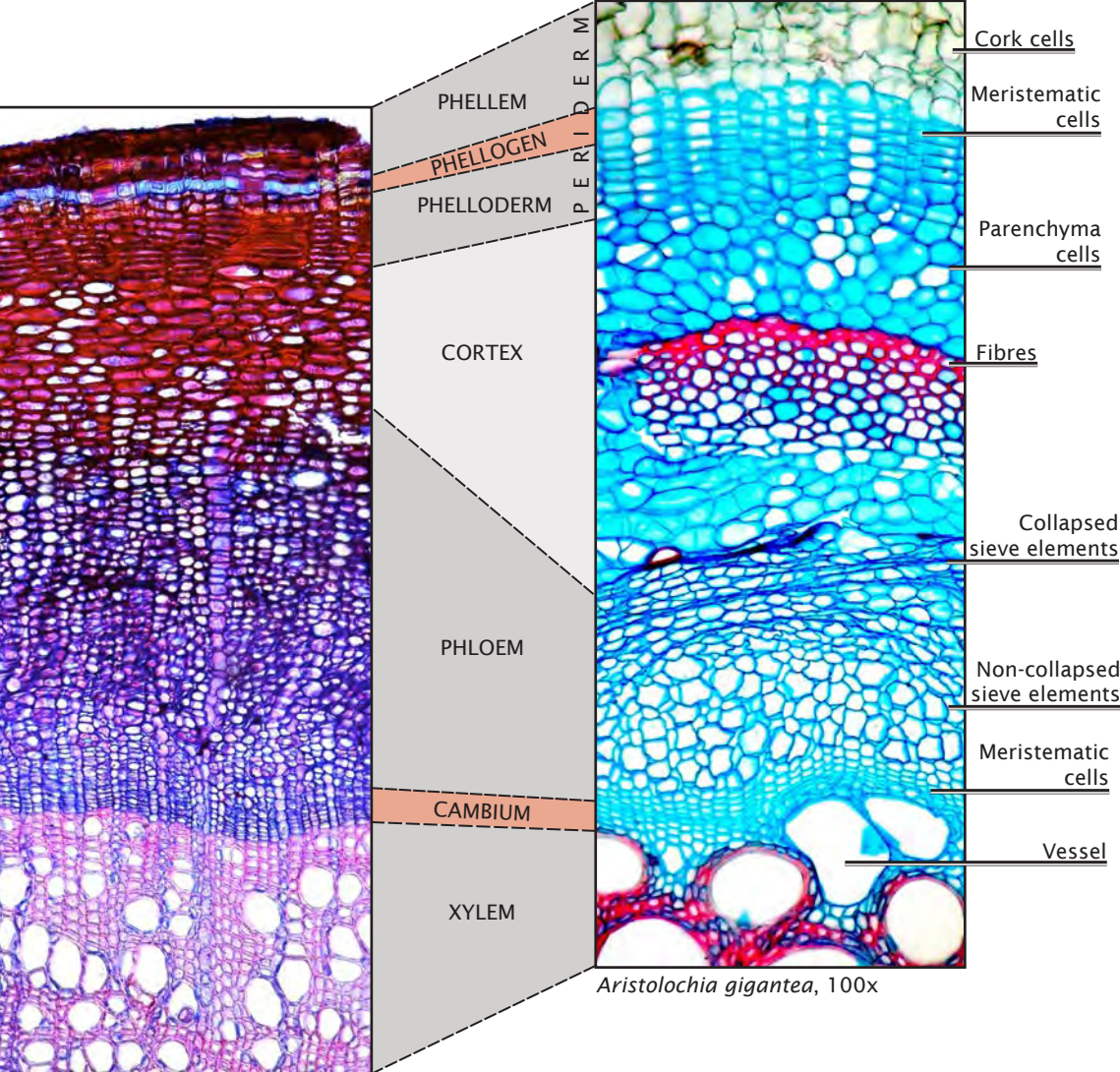


Illustration of stem characteristics



Aristolochia gigantea, 100x

Illustration of stem characteristics

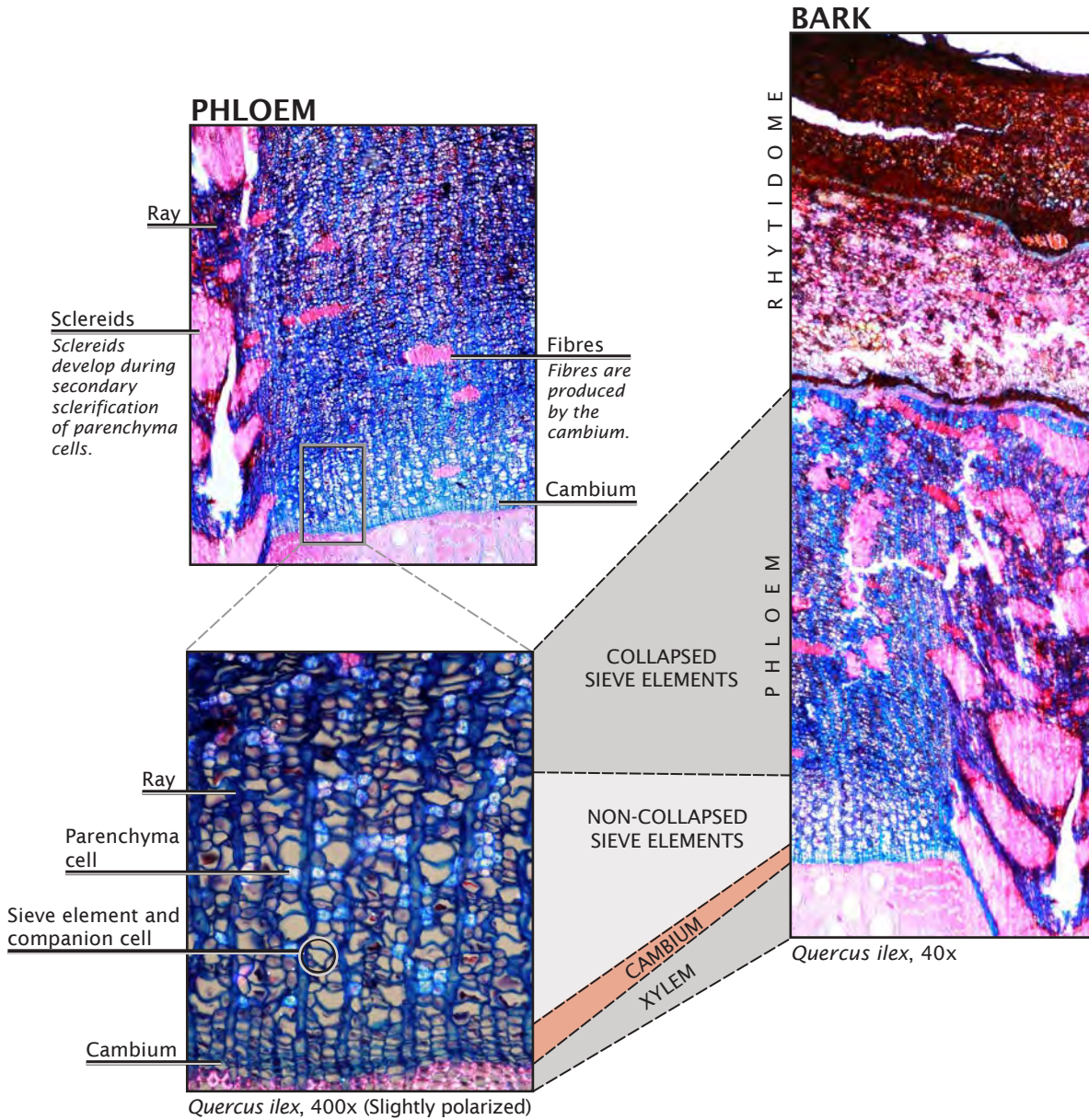
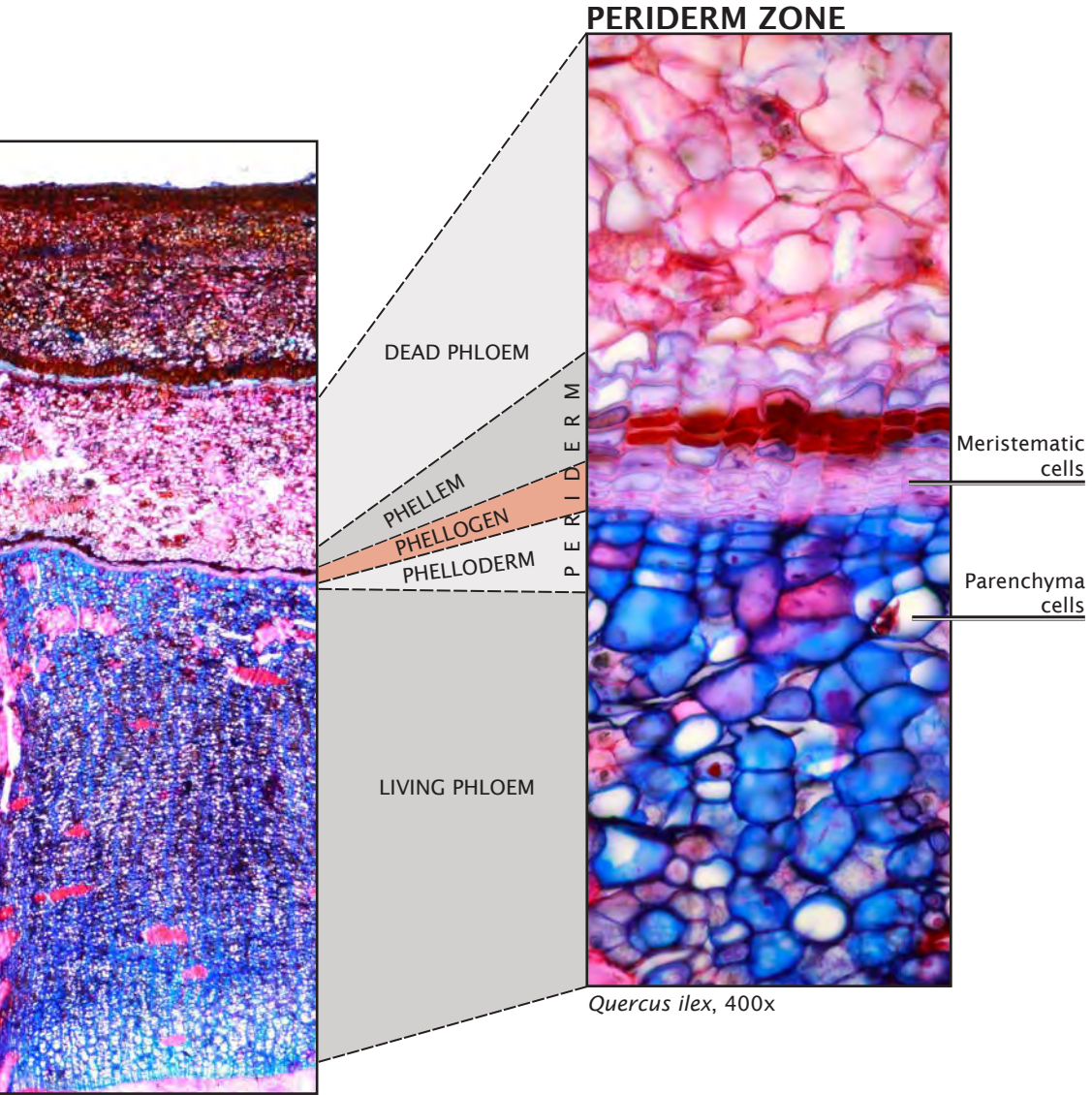


Illustration of stem characteristics



Foreword

Browsing through this book one might be immediately inspired by the technical quality of the sections, by the obsessive collection and description of almost all possible features and (...most romantic of all) by the sheer beauty of some figures reminding us that nature is the most creative and inspiring artist.

However, all these impressions would not justify the enormous effort the Authors have made in collecting plant materials and compiling this superb anatomical guide: there is something much more profound and important here. Mark E. Olson wrote “process causing pattern and pattern diagnosing process” that summarizes the correct and gainful reason for studying nature and the evolution of living organisms. In this book, it seems to me that the Authors have tried to follow this way of reasoning: they have addressed their well-known anatomical expertise to exploring the role of anatomy as powerful picklock for revealing plant functioning.

To be helpful the description of features must be both accurate and comprehensive of all parts of the stem (including the new descriptions of the anatomical traits of bark tissues) and take into account the variation of the traits within a plant (e.g. the basipetal widening of vessel conduits and phloem cells). This is why the Authors also provided

a general protocol for a correct sampling and for allowing the reader to interpret the patterns in a correct and useful way.

The Authors say the book is useful for plant ecologists: however, it partly follows the “traditional” IAWA approach that might be rather puzzling for an ecologist: for example the feature “vessel per square millimeter” ranges from <5 to >500 (feature 46 to 50.1) but within a single tree of *Eucalyptus regnans*, moving from the apex to the stem base, the vessels density spans from 5 to 200 (i.e. almost the entire range of the feature) thus posing the question on how diagnostic of processes can this feature be. As an ecologist I am astonished to see how many different patterns and structures plants have evolved and I am struggling to understand “why” and whether it might be possible to find general and universal explanations.

The Authors have done their job wonderfully: now it is the turn of plant ecologists to use the guide as a “starting point” for asking questions and testing the hypotheses that might arise from the observation of the different features within the plant stem.

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Italy

1. Introduction

Classification of wood anatomical features has a long tradition. Clarke (1938) set the basis with a multiple entry card key designed for the anatomical identification of hardwoods. Then Brazier and Franklin (1961) expanded Clarke's list including new anatomical features. Afterwards different IAWA committees implemented lists and codes of anatomical features useful in hardwood identification (1964, 1981, 1989). The IAWA list of microscopic features for hardwood identification currently in use (IAWA 1989) is well approved for tree-wood and timber species identification. Richter and Trockenbrodt (1995) implemented a computer aided wood identification system (DELTA/INTKEY). Wood identification was the ultimate goal of all these efforts. The development towards bark and various growth forms of plants (e.g., herbs, shrubs) was rarely on focus in the last decades. In the meantime the stem anatomy of hundreds of non-tree species was anatomically investigated. In addition, many anatomical features in stems of trees and dwarf shrubs have been related to environmental factors (Schweingruber and Poschlod 2005). Ecologically oriented anatomical feature keys have been suggested by Schweingruber *et al.* 2011 and 2013 and Crivellaro *et al.* 2013. However, a comprehensive list of stem anatomical

features of plants from very diverse environments (e.g., from swamps to deserts) is still lacking. A draft of the present key has been created on the base of experiences made during Wood Anatomy and Tree-Ring Ecology training schools.

Here we present an image based codification system for xylem (cross and longitudinal sections), and phloem, cortex and periderm anatomy as seen in cross sections. In the periderm region the phellogen and phelloderm are in most cases hard to differentiate, therefore we focused on phellem anatomical features.

Illustrated are stems of trees, shrubs, and perennial and annual Dicotyledon herbs. Therefore many features are illustrated by pictures occurring in trees or shrubs and herbs. Basic codification and definitions of xylem anatomical features correspond to the IAWA list (1989). Xylem features with decimal number codes correspond to new defined features. For this reason, the proposed system can be integrated in the INSIDE-WOOD database (Wheeler 2011). In addition, we suggest to quantify on a continuous scale measurable plant morphological and anatomical features (e.g., plant height, bark thickness, earlywood vessel size, vessel elements length) to facilitate statistical data analysis.

The ecological extension of anatomical

features toward plant characteristics also guarantees integration in large ecological databanks (e.g., the Plant Trait Database - TRY), which quantify hundreds of morphological, physiological, phenological and phylogenetic traits.

The system presented here is geographically adapted to plants of the northern hemisphere from the Sahel and the full arid zone in the Sahara desert, throughout the subtropical climate of the Canary Islands to the Mediterranean and temperate regions up to the arctic zones from the Atlantic to the Pacific in Eurasia and North America, as well as plants from the low land to the alpine zones on the Alps, the Himalaya and the Rocky Mountains. Only a few species from tropical rain forests have been included.

The presented system is designed to combine main anatomical features with some significant environmental and plant morphological characteristics. That includes trees, shrubs, dwarf shrubs, herbs, succulents, lianas, and hydrophytes from annual to perennial, with heights from one centimetre to 100 meters from all families within the Dicotyledons. The system allows the integration of petrified, carbonized and waterlogged archeological material as well as vouchers from herbaria and specimens from wood collections. The codification system is based exclusively on anatomical images from samples we collected from living plants. The sections are double stained with astrablue and safranin, which differentiate lignified (red stained) and unlignified (blue stained) cell walls (Gärtner and Schweingruber 2013).

In this book, we aim to provide a base to enlarge wood anatomical investigations towards bark and species belonging to various growth forms from very diverse environments. Therefore we provide a comprehensive list of stem anatomical features designed as a tool to help in seeing variation in stem anatomical structure. By following the list of features, one by one, and looking for them in the analysed material, structural variation became clear. We also bring some relevant ecological traits and plant morphological features into focus to build data sets in which the relationships between ecological and stem anatomical variables can be investigated. Some of this variation might turn out to be functionally or systematically relevant reflecting important aspects of the life history of the plant.

In summary, this explanatory list is a stem anatomical base for ecological, taxonomical and physiological studies.

The features list and corresponding empty data sheet are available for free download on the following web sites:

- The Xylem Database:

www.wsl.ch/dendropro/xylemdb

- Alan Crivellaro webpage:

www.alancrivellaro.com

2. Sample name and source



Dryas octopetala

Sample name and source

Sample name

Correctly identified plant material is of central importance. For a constantly updated list of scientific plant names refer to The Plant List published on the Internet (www.theplantlist.org).

Sample from a living plant

O.1 - *Sample collected in nature*

Wood and/or bark samples collected from stems, branches and roots of trees, shrubs and herbs living in their natural environment.

O.2 - *Sample collected in botanical garden or cultivated*

Samples collected from botanical gardens and cultivated plants represent often an easy and fast way to get fresh material from species not easily accessible in nature.

Sample not from a living plant: dry material

O.3 - *Dry material collected in nature*

Dry material can be collected in nature from different parts of a dead plant, or from stems remaining.

O.4 - *Herbarium*

Herbarium specimens with a dense xylem are suitable for anatomical investigations.

O.5 - *Wood collection*

Wood collections consist mainly of woods of commercial importance. Most of the sample are not related to ecological and plant morphological information.

O.6 - *Manufactured wood*

That includes wooden building material and wooden art objects in a wider sense.

O.7 - *Charcoal*

Remains from fires of any part of plant.

O.8 - *Coalified wood*

Not petrified fossil wood in Brown Coal beds (5-60 million years ago).

O.9 - *Petrified wood*

Completely fossilized wood which has been preserved over millions of years.

Sample not from a living plant: wet material

O.10 - *Waterlogged wood*

Water saturated wood which has been preserved in wet conditions such as in river beds, lakes, seas, bogs and mud.

O.11 - *Driftwood*

Stems and logs transported by rivers and ocean currents.



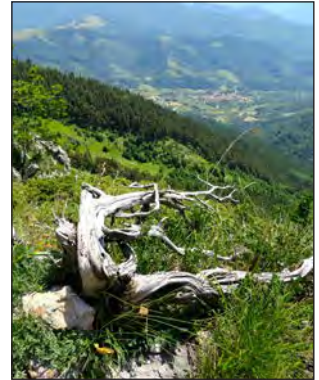
Examples:



O.1 - Sampling living plants



O.2 - Botanical garden



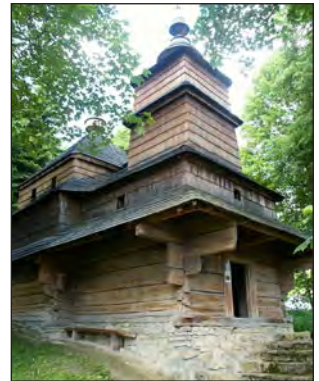
O.3 - Dry wood in nature



O.4 - Herbarium specimen



O.5 - Wood collection



O.6 - Manufactured wood



O.8 - Petrified wood



O.9 - Waterlogged wood
(Photograph courtesy of T. Bartholin)



O.10 - Driftwood

3. Collecting living plants



Site characteristics description must be defined according to research aims. Since anatomical structures vary among individuals it is recommended to collect several individuals of each species. Each analysed sample requires at least some taxonomical and environmental characteristics. Before collecting living plant material, the site should be related to the surrounding landscape and to microtopographic features. Some local environmental variables, considered to be the important for habitat differentiation, should be recorded in the field. Note any evidence of site disturbance. Sketches of the sampling site and photographs are often important for future data interpretation. At the end of sampling activities check that all the required information has been collected before leaving the site.

General information on the site and environmental variables

- *Geographical location*: record locality name, region or county, country and geographical coordinates (e.g., latitude and longitude). Determine sampling site elevation, slope and aspect.
- *Temperature and precipitation*: record at least mean annual temperature and precipitation from the next available meteorological station or consult meteorological data available on the Internet. Site dependent climatic variable should be recorded by data loggers.
- *Vegetation type*: forest/steppe/meadow/ruderal/bog, etc.
- *Light availability at the site*: shaded, partially shaded, full light.
- *Moisture regime*: xeric (water removed very rapidly in relation to supply), mesic (water removed somewhat slowly in relation to supply), hygric (water removed slowly enough to keep soil wet for most of growing season), hydric (water removed so slowly that water table is at or above soil surface all year).
- *Soil/substrate surface stability*: unstable (e.g. screes, dunes), partly stable (e.g. grasslands, steppes), stable (e.g. rocky crevices).
- *Nutrient availability*: low (e.g. semi-deserts, steppes), medium, high (e.g. stables, animal resting places).
- *Soil salinity*: no salt deposits on soil surface, salt deposits scarce, salts forming a continuous crust.

For a detailed description of plant traits and ecological indicators refer to Landolt *et al.* 2010, Klimešová *et al.* 2011 and references therein.

Examples:



Limestone



Granite



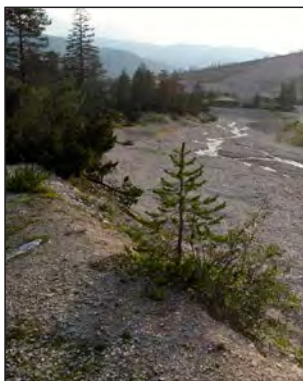
Volcanic rocks



Gravel



Meadow



River bed

Plant growth form

Plant growth form

A.1 - Tree



Pyrus malus



Platanus orientalis

Woody plant that grows taller than 4 m high.

A.2 - Shrub



Leptadenia pyrotechnica



Parolinia ornata

Woody plant, often with multiple stems, that grows not taller than 4 m high.

A.3 - Dwarf shrub, upright



Euphorbia dendroides



Helianthemum obtusifolium

Upright woody plant whose mature branch or shoot system grows not more than 50 cm above ground surface.

A.4 - Dwarf shrub, prostrate



Salix herbacea



Dryas octopetala

Prostrate woody plant whose mature branch or shoot system grows not more than 50 cm above ground surface. Creeping shoots can grow up to some meters in length.

A.5 - Terrestrial herb



Geranium robertianum
Annual



Potentilla nitida

Herbaceous plant with periodic shoot reduction.

A.6 - Succulent



Aeonium spp.



Opuntia ficus-indica

Plant having thick fleshy leaves or stems adapted to store water.

Plant growth form

A.7 - Helophyte



Hippuris vulgaris



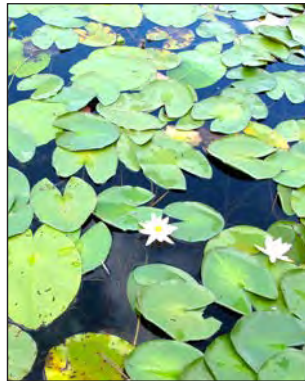
Caltha palustris

Plant having its root system in water saturated ground.

A.8 - Hydrophyte



Myriophyllum verticillatum



Nymphaea alba

Plant which vegetative parts grows in or on water.

A.9 - Vine/liana/climber



Celastrus scandens



Citrullus colocynthis

Plant with extremely long shoots which are supported by self-standing plants or which are creeping on to the ground.

A.10 - Hemiparasite



Viscum album



Melampyrum arvense

Plant obtaining water and nutrients from host plants although being photosynthetic (green leaves).

A.11 - Full parasite



Cytinus hypocistis



Orobanche hederarum

Plant obtaining not only water and nutrients but also sugar from other plants. Leaves without chlorophyll (i.e. no green leaves).

Plant height

Measured plant height should indicate the maximum length of shoots above ground, including flower stalk if present.

A.12 - Plant height less than 5 cm

A.13 - Plant height 5-10 cm

A.14 - Plant height 10-25 cm

A.15 - Plant height 25-50 cm

A.16 - Plant height 50-100 cm

A.17 - Plant height 100-150 cm

A.18 - Plant height 150-300 cm

A.19 - Plant height 300-1000 cm

A.20 - Plant height more than 1000 cm

4. Sample characteristics



Populus alba

Sample location within the plant

Sample location within the plant

A.21 - Stem



Commercial timber



Aeonium arboreum

The main body of a plant above ground (subterranean stems excluded see feature A.26).

A.22 - Branch



Morus spp.

Part of the plant that grows out of the main stem.

A.23 - Twig



Parrotia persica



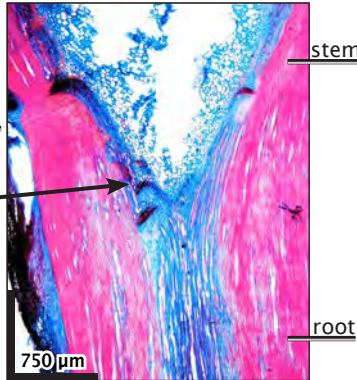
Styrax japonicus

Shoots produced mainly at the outer edge of the plant's canopy.

A.24 - Root collar of a primary root



Draba spp.



Tordylium apulum, 20x

Transition zone between stem and root. This zone contains all tissues which are formed in the germination process. The number of growth rings counted at the root collar gives the plant age.

A.25 - Secondary root



Aquilegia vulgaris



Crepis spp.

Secondary roots are mainly produced after germination. For details on root classification see Klimešová and de Bello (2009).

A.26 - Rhizome (horizontal below ground stem)



Juncus spp.
Monocotyledon

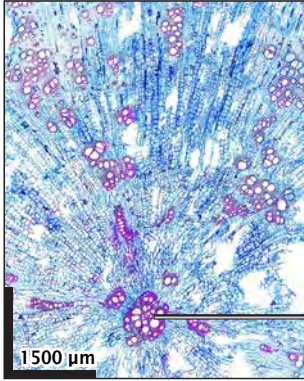


Galium spp.

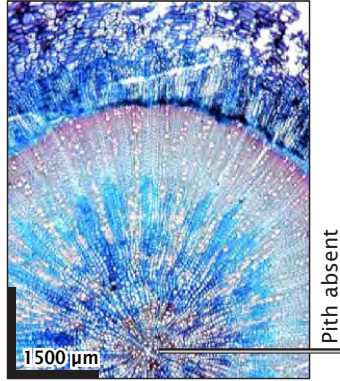
The age of a tissue in a rhizomatous plant can be determined in the oldest remaining part of the rhizome. For details see (Klimešová & de Bello, 2009).

Sample location within the plant

A.27 - Root



Datura innoxia, 20x



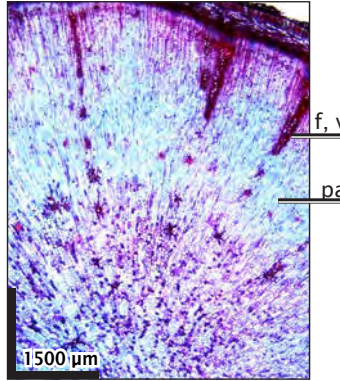
Echium bonnetii, 20x

The root is anatomically characterized by the absence of the pith.

A.28 - Bulb and tuber



Aristolochia fontanesii



Filipendula vulgaris, 20x

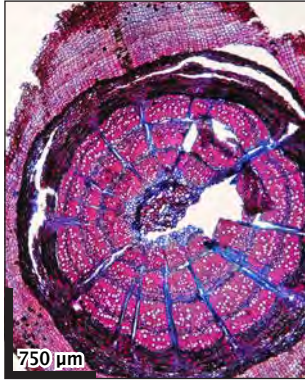
Thick underground storage organ. The ground tissue consists mainly of parenchyma (pa).

The location of the sample within the plant is extremely important in many ecological studies. The sampling point in the plant needs to be noted during sampling (e.g., distance from the apex of the plant). Precise measurement allows tracking the ontogenetic changes in xylem and bark tissues both along the stem and in radial direction (from pith to bark). Continuous measurement of the sample diameter, of xylem and bark thickness should be also considered.

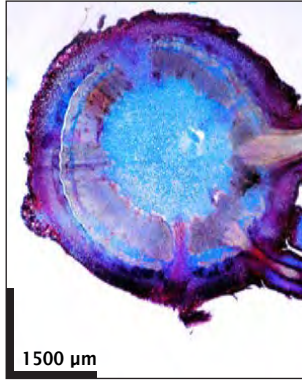
Characteristics of the cross section on the slide

Characteristics of the cross section on the slide

A.29 - Complete cross section



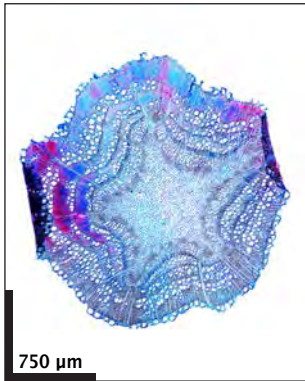
Artemisia alpina, 40x



Crepis paludosa, 20x

Pith, xylem and bark can all be observed on the cross section.

A.29.1 - Bark absent

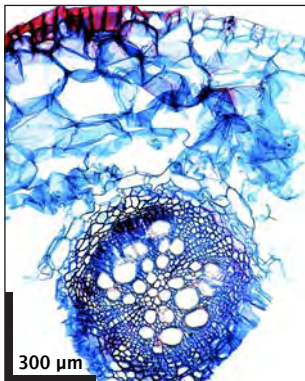


Quercus robur, 40x

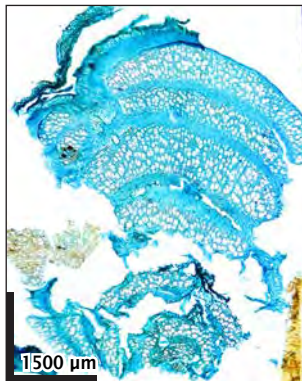


Clematis cirrhosa, 20x

A.30 - Cross section from pith to bark



Drusa glandulosa, 100x

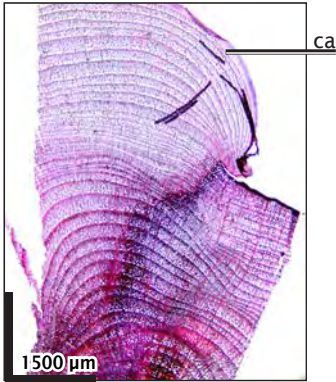


Scrophularia koelzii, 40x

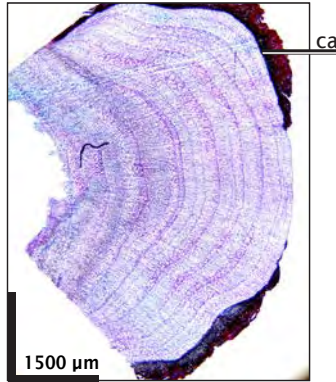
Pith, xylem and bark are visible on a portion of the cross section. The cross section cannot be examined as a whole.

Characteristics of the cross section on the slide

A.31 - Cross section containing the cambial region

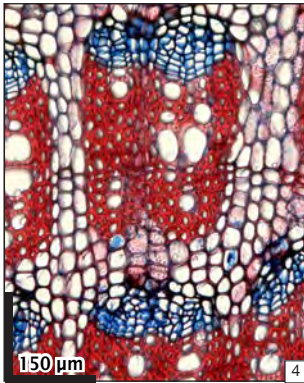


Arctostaphylos uva-ursi, 20x

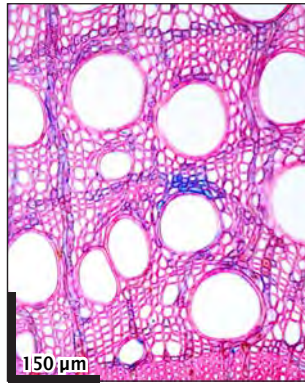


Calluna vulgaris, 20x

A.32 - Cross section cannot be located within the plant



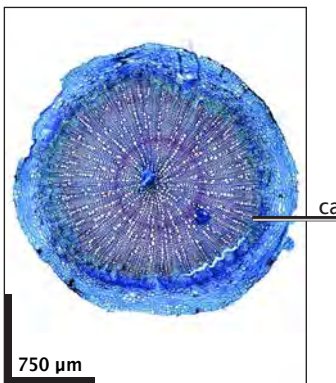
Bosea cypria, 200x



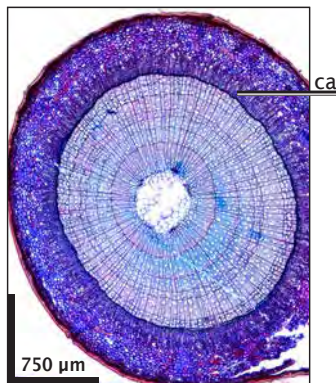
Lycium ruthenicum, 200x

Shape of cross section

A.33 - Cross section round to oval

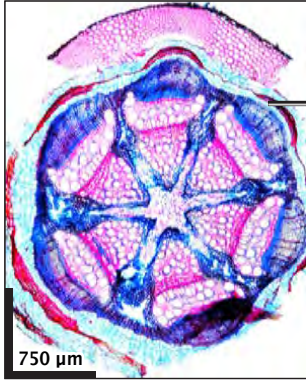


Bupleurum baldense, 40x

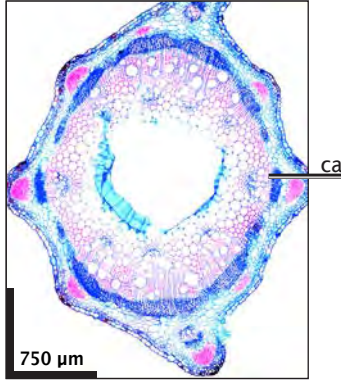


Salix caesia, 40x

A.34 - Cross section polygonal

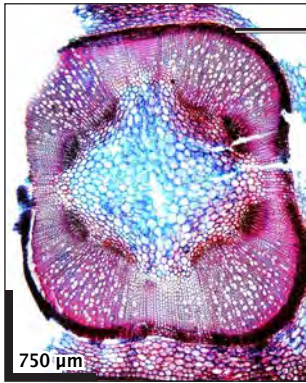


Clematis macropetala, 40x

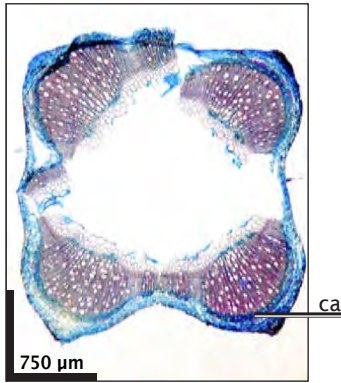


Vicia sepium, 40x

A.34.1 - Cross section square to rectangular

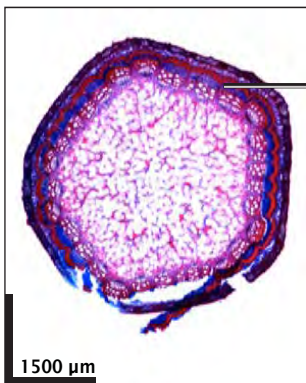


Stachys spinulosa, 40x

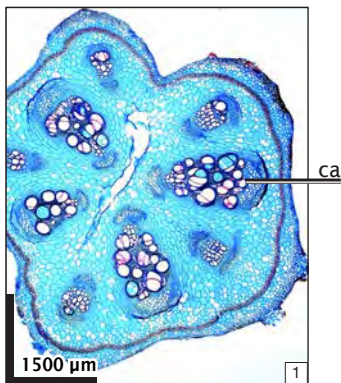


Scutellaria galericulata, 40x

A.34.2 - Cross section pentagonal



Rubus sanctus, 20x



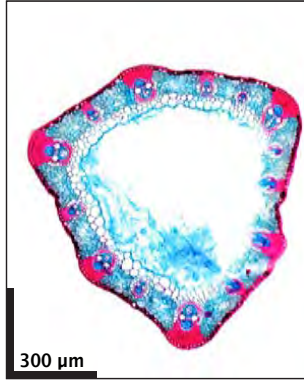
Cucumis sativus, 20x

Shape of cross section

A.34.3 - Cross section triangular

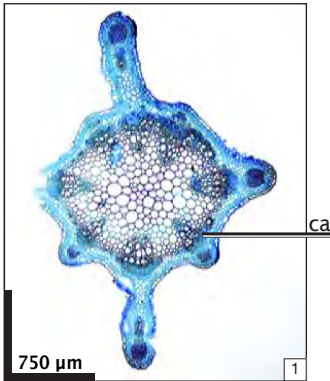


Carex hartmanii, 100x
Monocotyledon

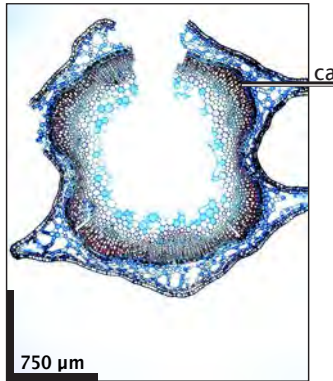


Carex echinata, 100x
Monocotyledon

A.34.4 - Cross section winged

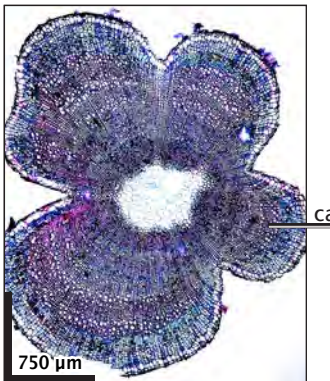


Vicia hirsuta, 40x

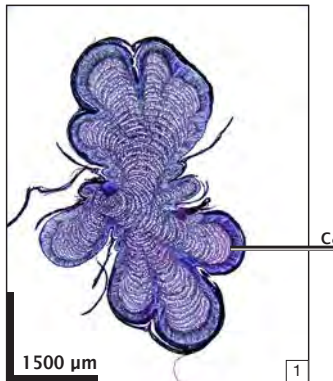


Gratiola officinalis, 40x

A.35 - Cross section lobed

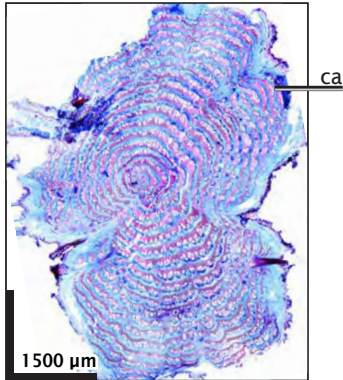


Antennaria dioica, 40x

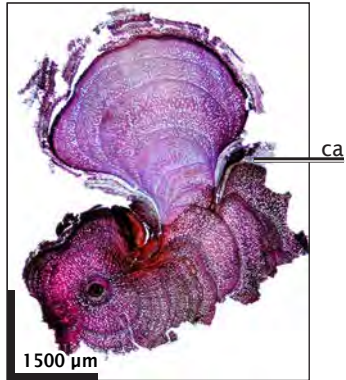


Eriogonum jamesii, 20x

A.36 - Cross section irregular

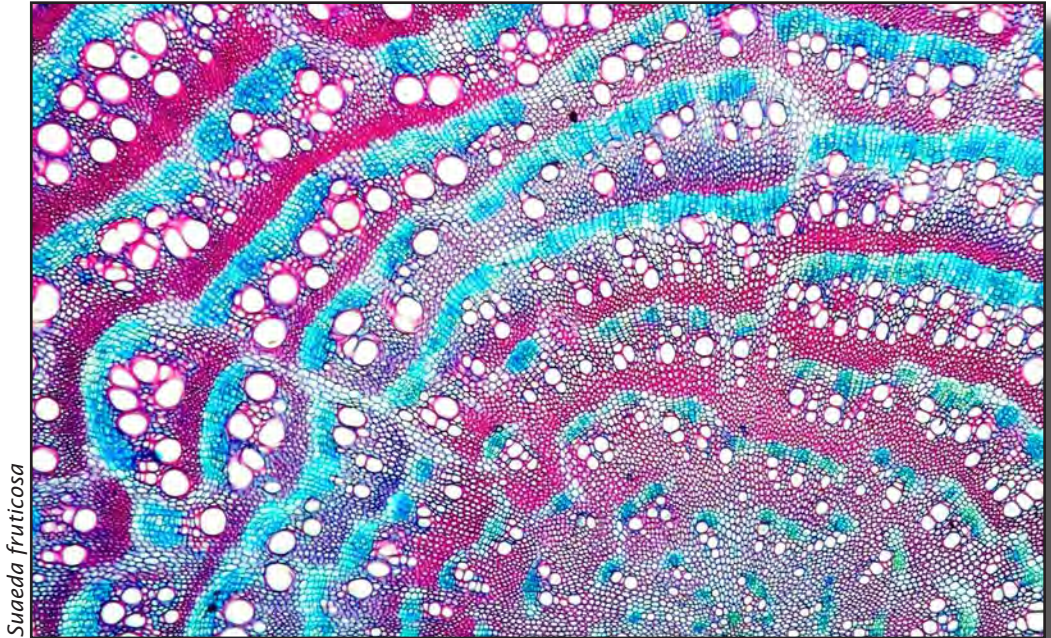


Atriplex semibaccata, 20x



Thymus pallens, 20x

5. Stem construction

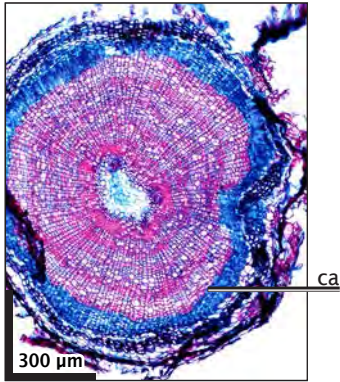


Suaeda fruticosa

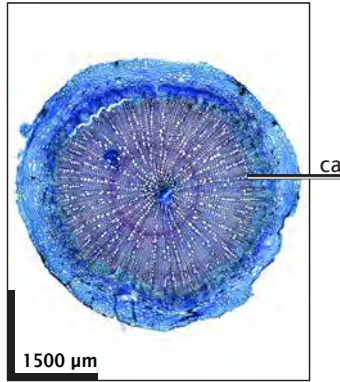
Cambium producing xylem and phloem - Cambial variants

Cambium producing xylem and phloem

A.37 - On cambium producing a single stem



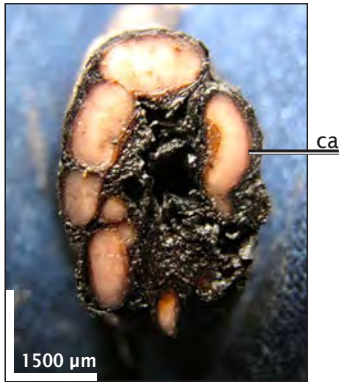
Antennaria alpina, 100x



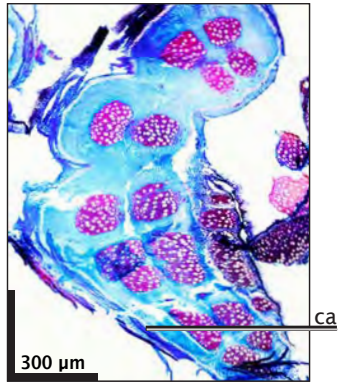
Bupleurum baldense, 20x

One continuous cambium (ca) produces the xylem and the phloem.

A.38 - One cambium producing multiple/segregated stems



Epilobium latifolium, 20x

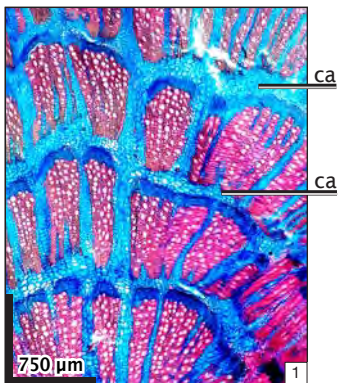


Nepeta discolor, 100x

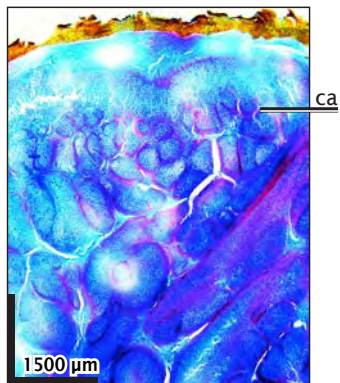
During secondary growth the main stem segregates in partial stems, which remain in a multiple stem.

Cambial variants: several cambia producing xylem and phloem

A.39 (IAWA no. 133) - Successive cambia present

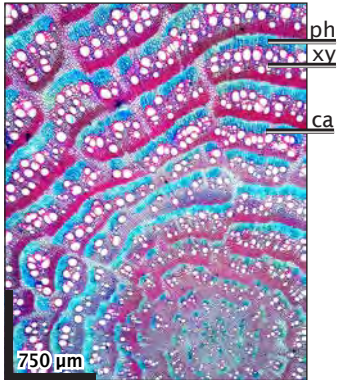


Aizoon canariense, 40x

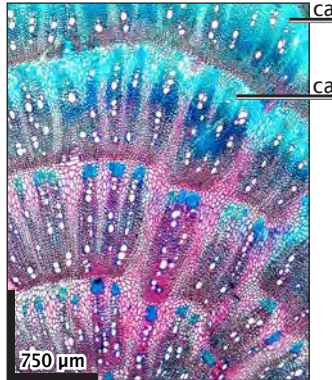


Thylacospermum caespitosum, 20x

A.39.1 - Successive cambia: xylem and phloem zones in continuous tangential bands



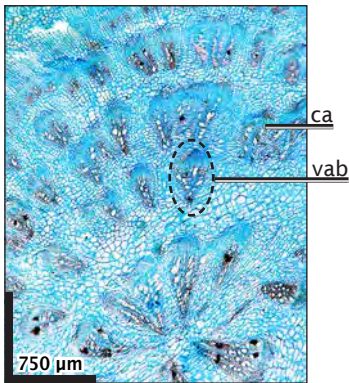
Suaeda fruticosa, 40x



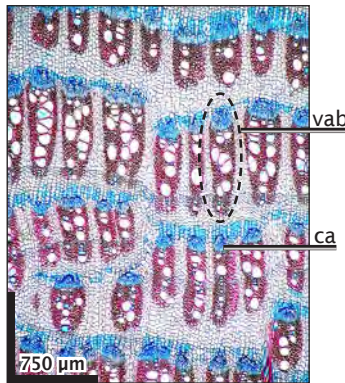
Chenopodium urbicum, 40x

Transitions between features A.35.1 and A.35.2 occurs also within the same stem.

A.39.2 - Successive cambia: single vascular bundles tangentially arranged

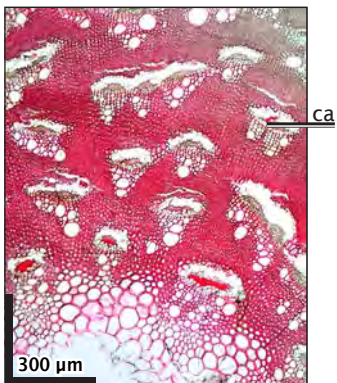


Chenopodium glaucum, 40x

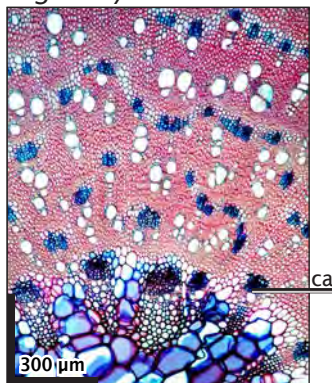


Bosea cypria, 40x

A.39.3 (IAWA no. 134) - Successive cambia: single vascular bundles irregularly distributed



Atriplex dimorphostegia, 100x



Chenopodium strictum, 100x

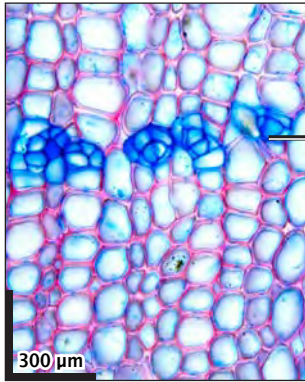
Vascular bundles isolated with an irregular distribution.
Synonym: diffuse or foraminate.

Cambial variants

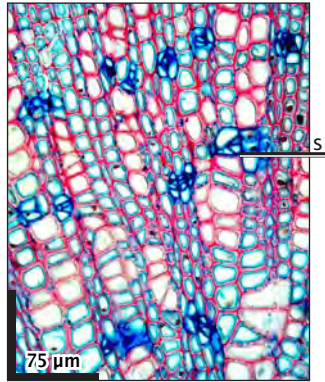
Stem construction

Cambium producing phloem within the xylem

A.40 (IAWA no. 135) - Intra-xylary phloem



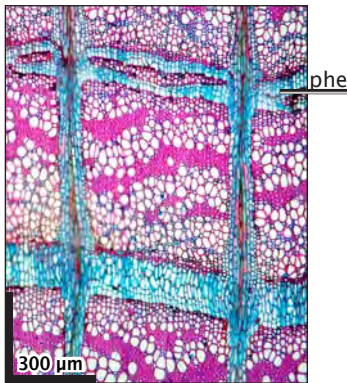
Ixanthus viscosus, 100x



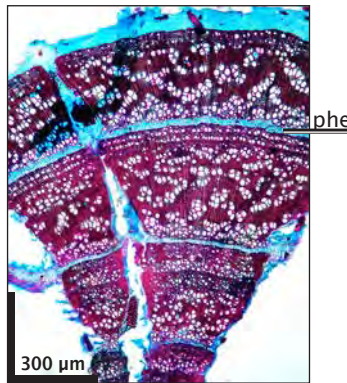
Plantago aschersonii, 400x

Cambium or phellogen producing cork cells within the xylem

A.40.1 - Intraxylary periderm towards the bark



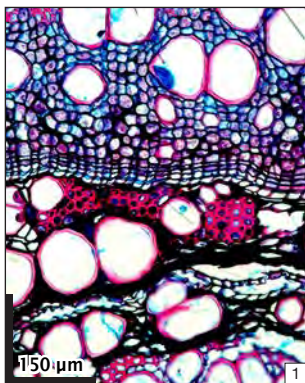
Artemisia tridentata, 100x



Tanacetum millefolium, 100x

Intraxylary periderm produced by the cambia.

A.40.2 - Intraxylary periderm towards the pith



Epilobium angustifolium, 200x



Sedum anopetalum, 40x

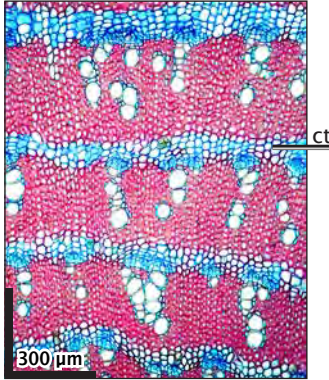
Intraxylary periderm produced dedifferentiated parenchyma cells.

Conjunctive tissue - Without secondary growth

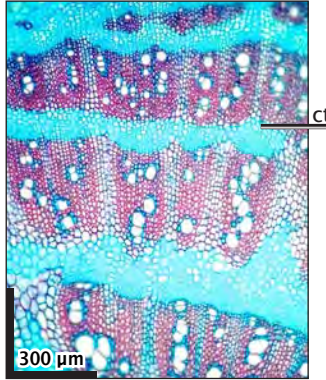
Conjunctive tissue

A.41 - Conjunctive tissue present

A.41.1 - Conjunctive tissue not lignified



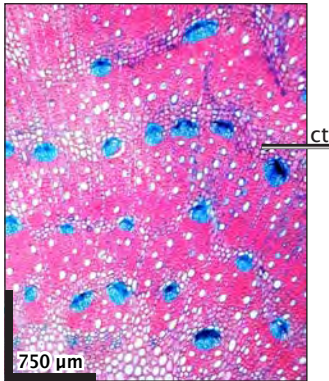
Aerva javanica, 100x



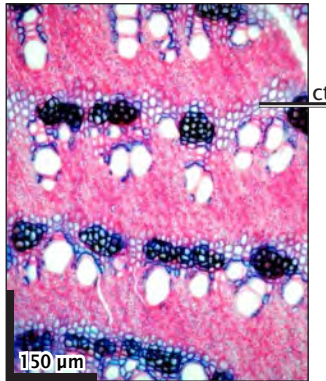
Chenopodium murale, 100x

The conjunctive tissue (ct) consists of tangentially arranged parenchymatic cells between xylem and phloem zones.

A.41.2 - Conjunctive tissue lignified



Simmondsia chinensis, 40x

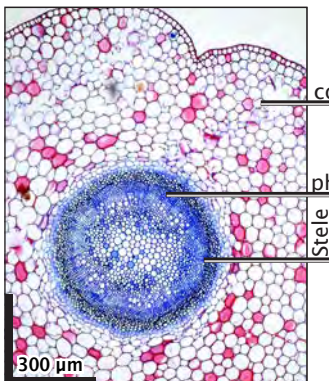


Mesembryanthemum cordifolium, 200x

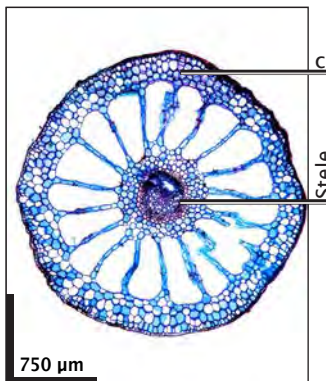
Conjunctive tissue (ct) generally lignified.

Without secondary growth

A.42 - Central cylinder present



Honckenya spp., 100x



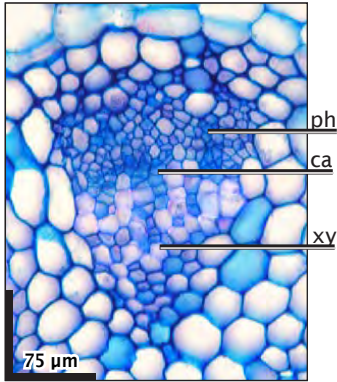
Myriophyllum alternifolium, 40x

The central cylinder (stele) is surrounded by an endodermis, a small phloem and a large cortex (co). This stem type occurs mainly in water plants.

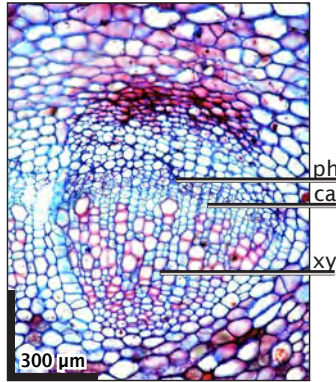
Vascular bundles

Type of vascular bundles

A.43 - Vascular bundles collateral open (with cambium)



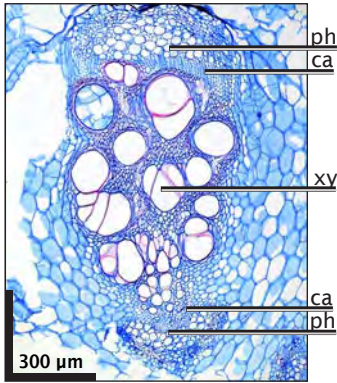
Chrysosplenium alternifolium, 400x



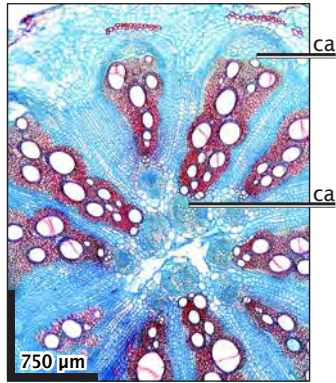
Hacquetia epipactis, 100x

The cambial zone (ca) separates xylem (xy) and phloem (ph) within each vascular bundle.

A.44 - Vascular bundles bi-collateral open (with two cambia)

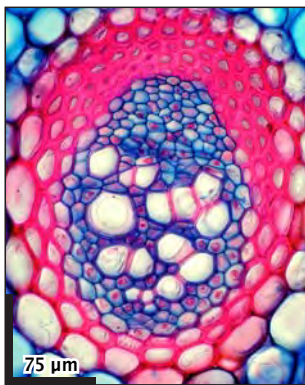


Cucumis sativus, 100x

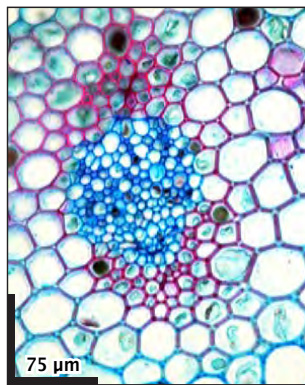


Melothria pendula, 40x

A.45 - Vascular bundles collateral closed (without cambium)

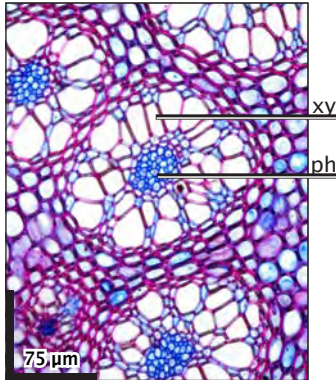


Ranunculus aconitifolius, 400x

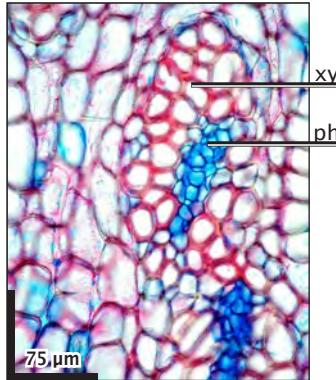


Neottia nidus-avis, 400x

A.46 - Vascular bundles concentric, xylem outside (leptocentric, syn. amphiversal)



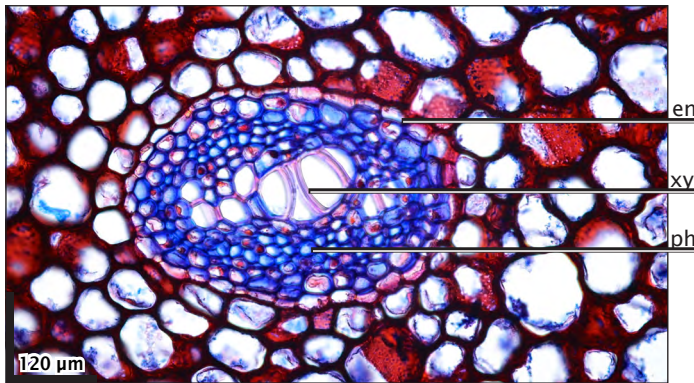
Juncus jacquinii, 400x
Monocotyledon



Dracaena serratula, 400x
Monocotyledon

Vascular bundles without cambium.

A.47 - Vascular bundles concentric, xylem inside (hadrocentric, syn. amphicribal)

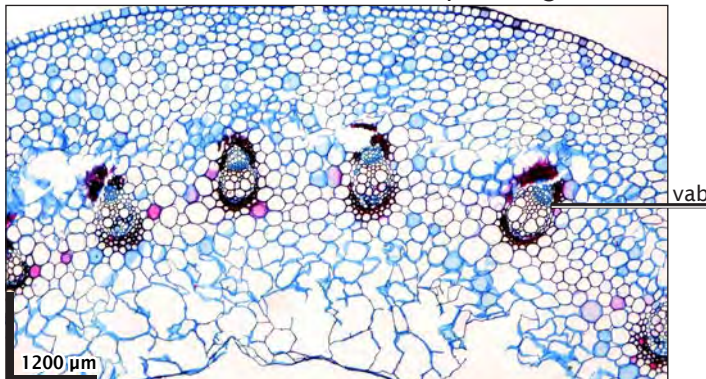


Dryopteris robertiana, 400x.
Pteridophyta

Vascular bundles without cambium.

Vascular bundles arrangement

A.48 - Vascular bundles circularly arranged



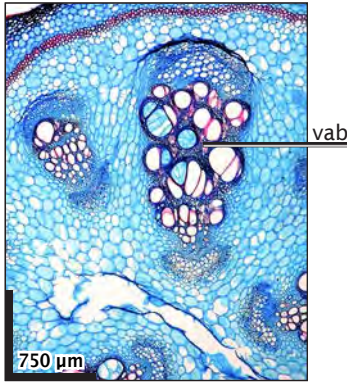
Ranunculus lingua, 40x

Proportion of xylem to bark

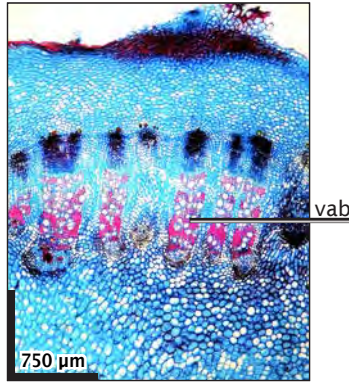
Stem construction

Vascular bundles shape

A.49 - Vascular bundles radially elongated



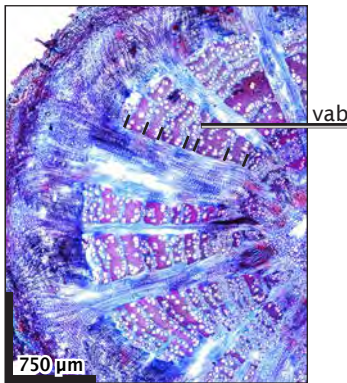
Cucumis sativus, 40x



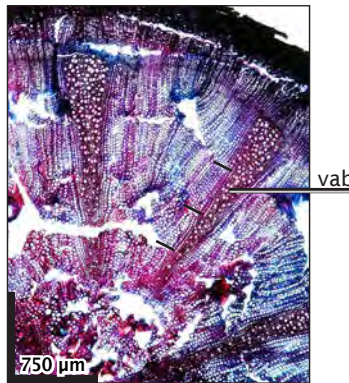
Cirsium oleraceum, 40x

See also figures on feature A.44 on page 44.

A.50 - The shape of vascular bundles remains over several growth rings



Centaurea scabiosa, 40x

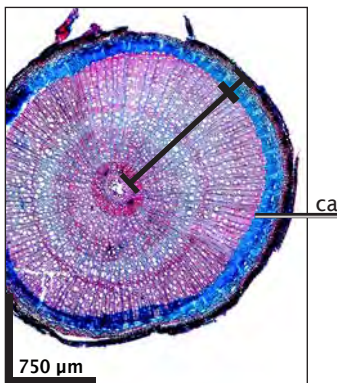


Potentilla pennsylvanica, 40x

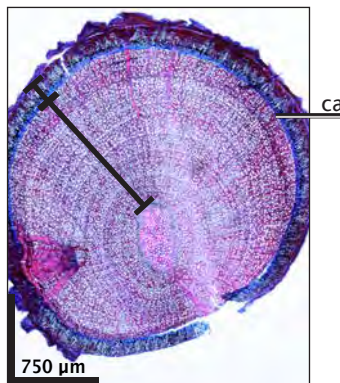
See also figures on feature 100.2 left on page 85.

Proportion of xylem radius in relation to bark radius (stems <1 cm in diameter)

A.51 - Xylem to bark ratio > 2:1



Hypericum ptarmicifolium, 40x

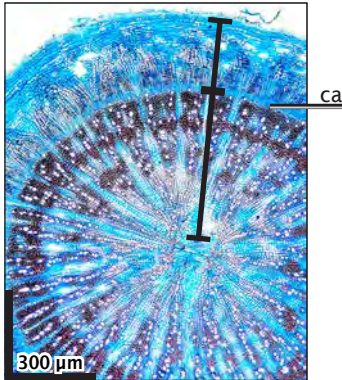


Vaccinium myrtillus, 40x

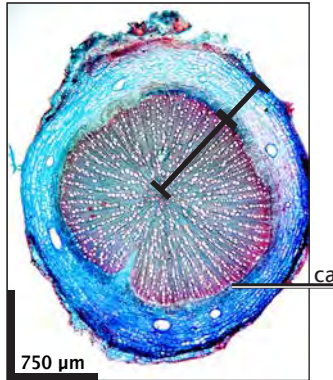
Xylem radius is more than twice the bark radial thickness.

Proportion of xylem to bark

A.52 - Xylem to bark ratio 2:1



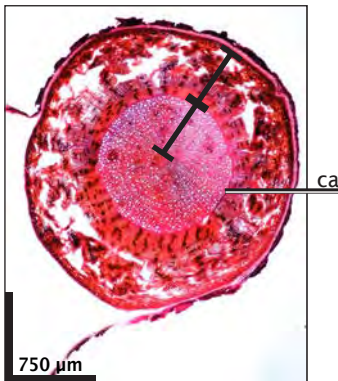
Diplotaxis muralis, 100x



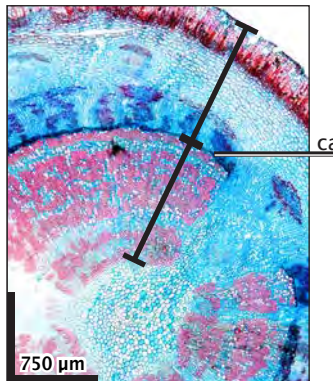
Euphorbia prostrata, 40x

Xylem radius is twice the bark thickness.

A.53 - Xylem to bark ratio 1:1



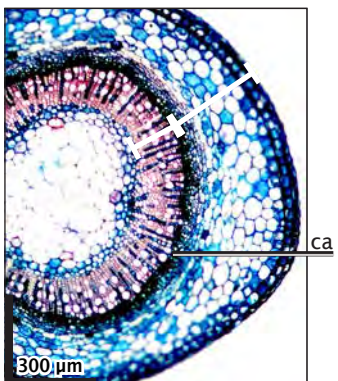
Pritzelago alpina, 40x



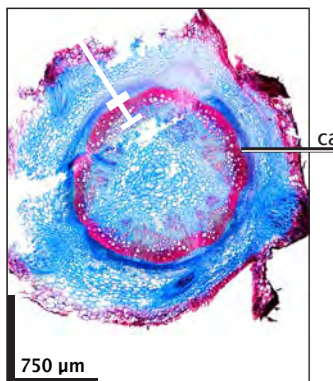
Hypochaeris radicata, 40x

Xylem radius equals the bark thickness.

A.54 - Xylem to bark ratio 1:2



Pyrola grandiflora, 100x

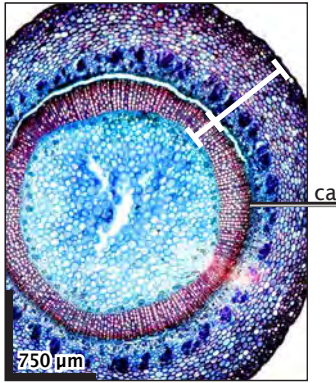


Scandix pecten-veneris, 40x

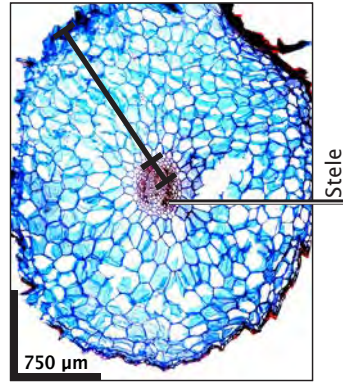
Xylem radius is half the bark thickness.

Pith position in cross section

A.55 - Xylem to bark ratio 1 to more than 2



Vinca major, 40x

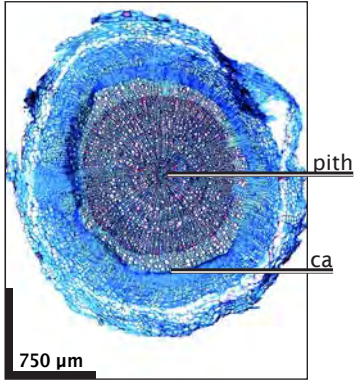


Adoxa moschatellina, 40x

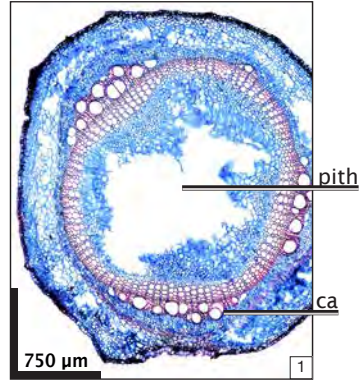
Xylem radius is less than half of the bark thickness.

Pith position in cross section

A.56 - Pith centred



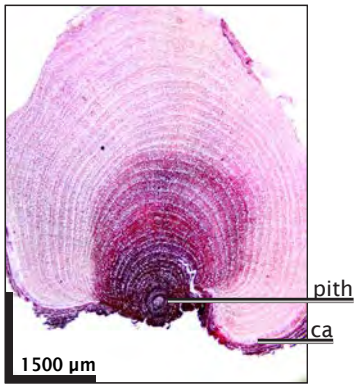
Viola rupestris, 40x



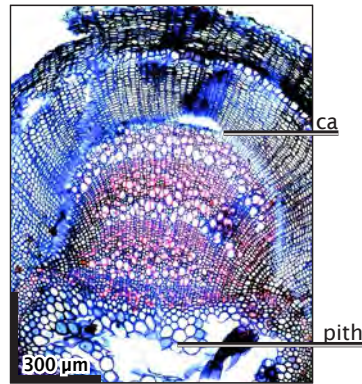
Calystegia sepium, 40x

The pith is located near the geometrical centre of the cross section.

A.57 - Pith eccentric



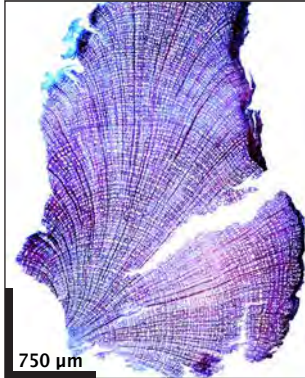
Globularia cordifolia, 20x



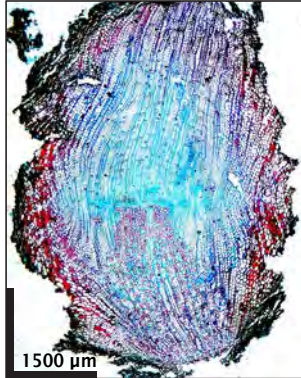
Polemonium viscosum, 100x

The pith is located far from the geometrical centre of the cross section.

A.58 - Pith not present in the cross section



Dryas octopetala, 40x



Pulsatilla alpina, 20x

Feature applies only if a complete cross section can be investigated.

Number of growth rings

The number of growth rings counted at the root collar (see feature A.24) indicate the plant age.

A.59 - One growth ring

A.60 - 2-5 growth rings

A.61 - 6-10 growth rings

A.62 - 11-20 growth rings

A.63 - 21-50 growth rings

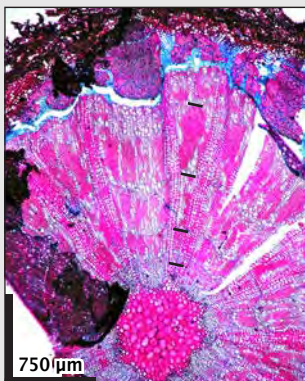
A.64 - More than 50 growth rings

Plant age unknown

A.65 - Plant age unknown

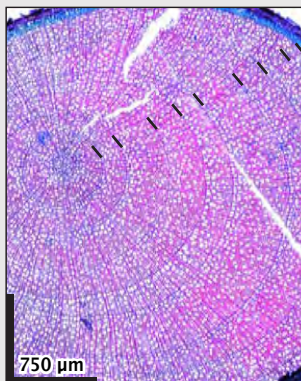
Examples of growth ring counting

5 growth rings



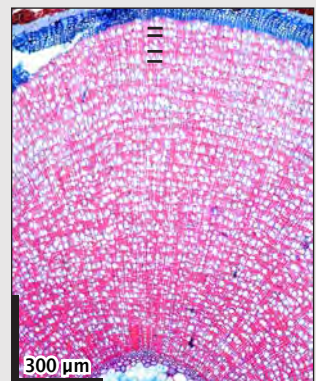
Phagnalon purpurascens, 40x

9 growth rings



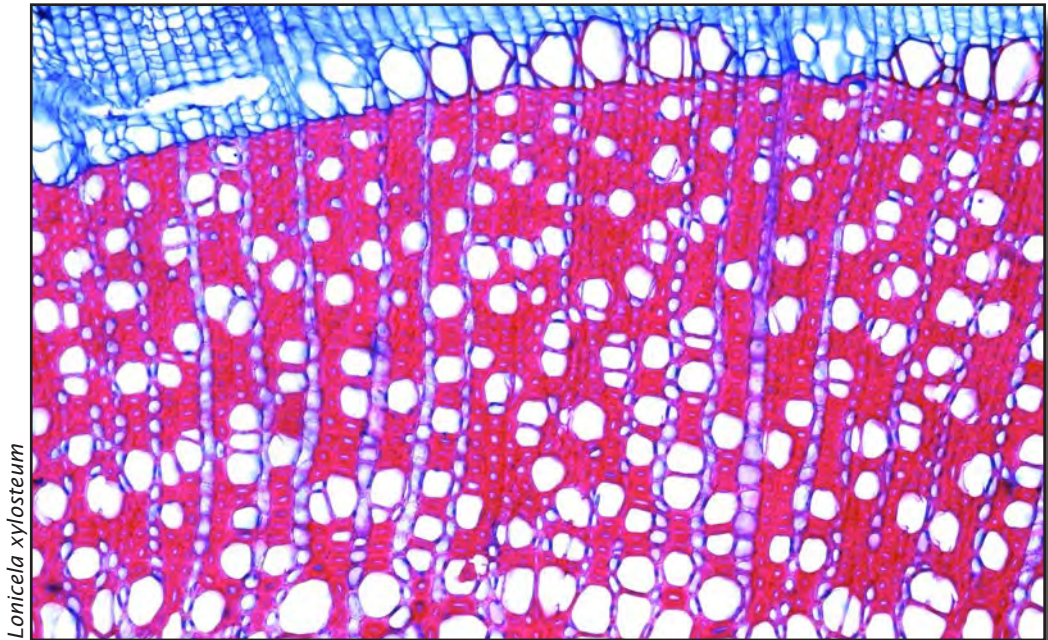
Ledum palustre, 40x

> 50 growth rings



Cassiope tetragona, 100x

6. Xylem anatomical features

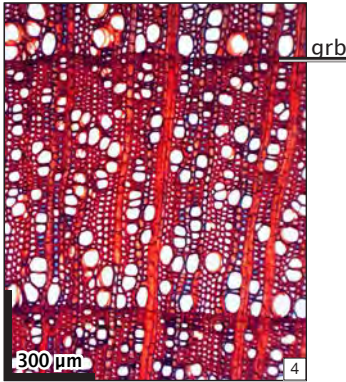


Lonicera xylosteum

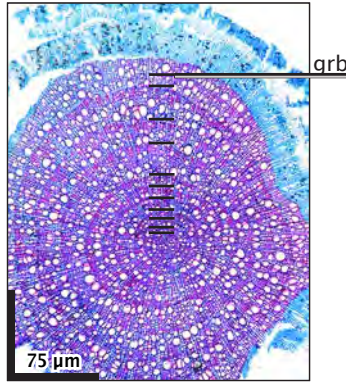
Growth rings

Growth rings

1 - Growth ring boundaries distinct



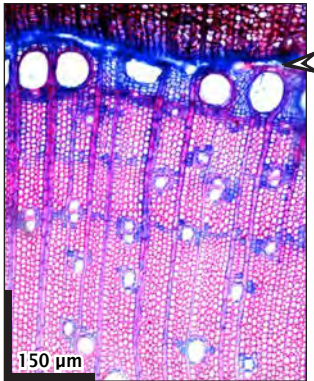
Arbutus unedo, 100x



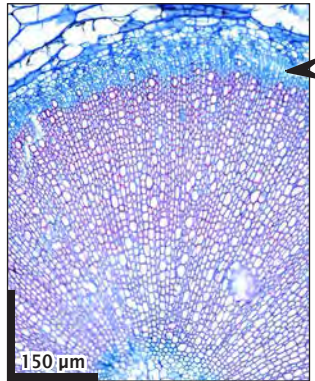
Rubia tibetica, 40x

All growth ring boundaries (grb) are clearly demarcated, consequently the true age of the plant tissue can be exactly determined.

1.1 - Last ring incomplete (cambium active)

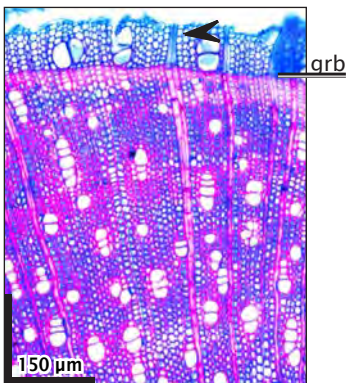


Fraxinus excelsior, 200x

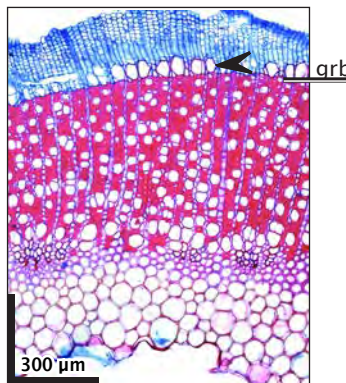


Euphrasia cuspidata, 200x

1.2 - First earlywood cells in formation

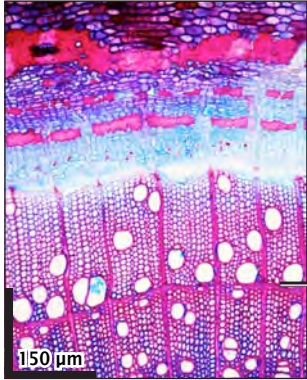


Acer campestre, 200x

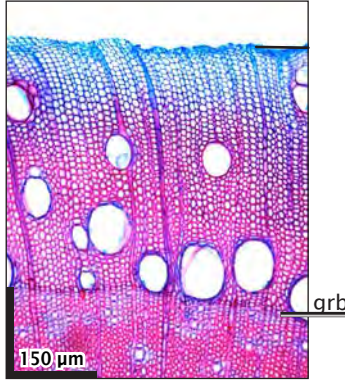


Lonicera xylosteum, 100x

1.3 - Most of the growth ring formed

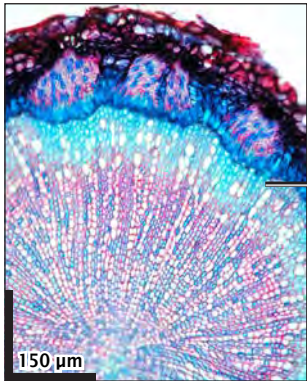


Acer pseudoplatanus, 200x

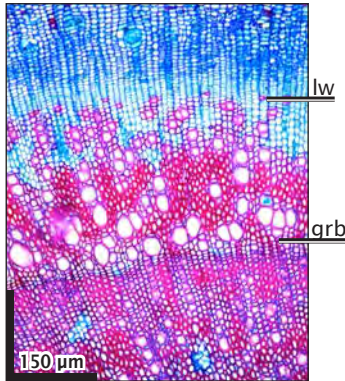


Fraxinus excelsior, 200x

1.4 - Latewood cells in formation

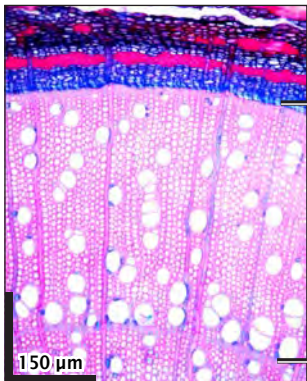


Micropus supinus, 200x

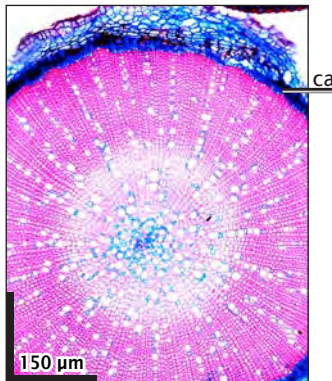


Inula obtusifolia, 200x

1.5 - Last growth ring complete (dormant period)



Acer campestre, 200x

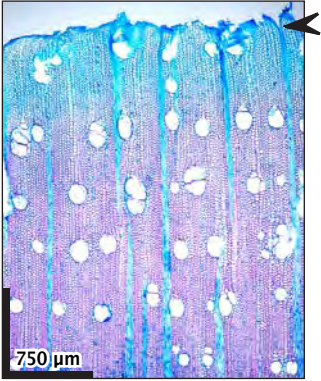


Bupleurum gracile, 200x

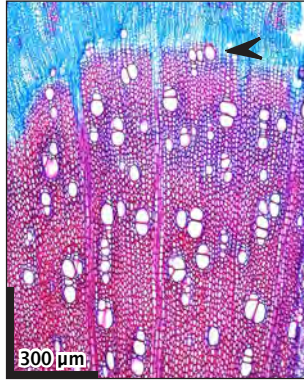
Growth rings

Xylem

1.6 - Cambium active in tropical perennial plants

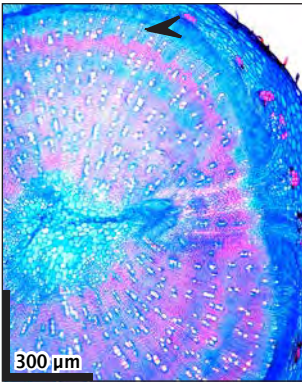


Schefflera abyssinica, 40x

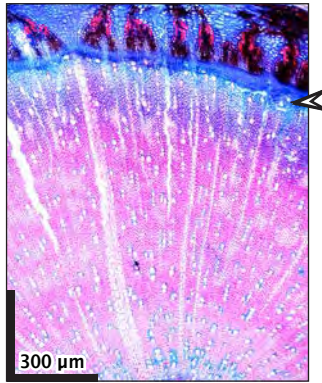


Laggera alata, 100x

1.7 - Cambium active in annual plants

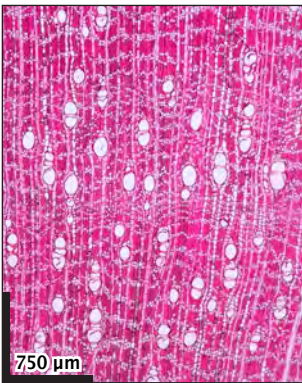


Lepidium densiflorum, 100x

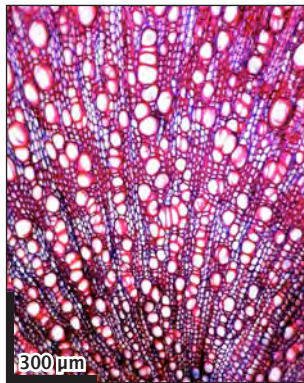


Descurainia sophia, 100x

2 - Growth ring boundaries indistinct or absent



Diospyros mespiliformis, 40x

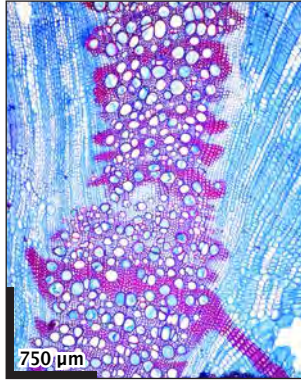


Erodium gruinum, 100x

2.1 - Growth ring boundaries weakly expressed



Vaccinium ovatum, 100x

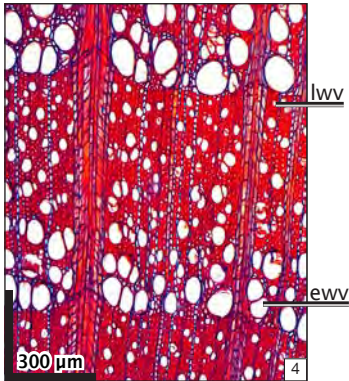


Urtica dioica, 40x

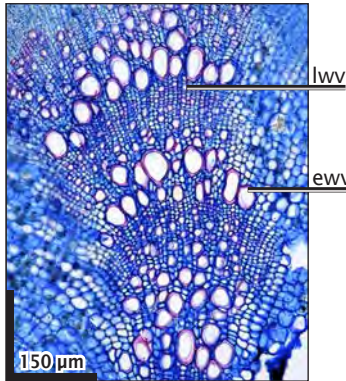
Growth zones may either look like annual rings, or be weakly expressed, or only visible in small areas of the cross section. Age determination is uncertain. Ring numbers indicate a rough age estimation.

Porosity

3 - Wood ring-porous



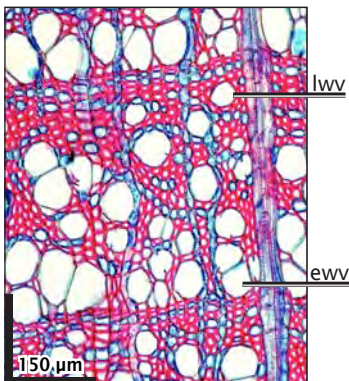
Rosa canina, 100x



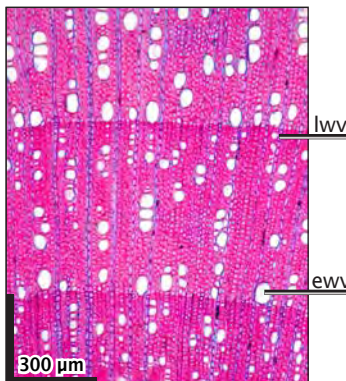
Morina coulteriana, 200x

Wood in which the vessels in the earlywood (ewv) are distinctly larger than those in the latewood, and in which there is an abrupt transition between them (IAWA 1989).

4 - Wood semi-ring-porous



Fagus sylvatica, 200x



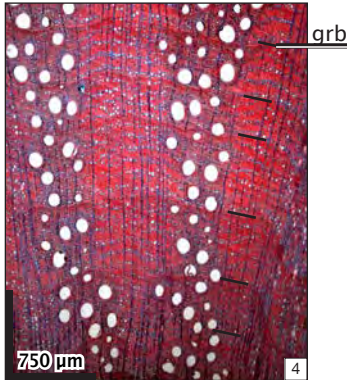
Hypericum canariense, 100x

Wood in which the vessels in the earlywood are distinctly larger than those in the latewood, but in which there is a gradual change between them (IAWA 1989). Intermediate conditions between ring-porous and semi-ring porous are frequent.

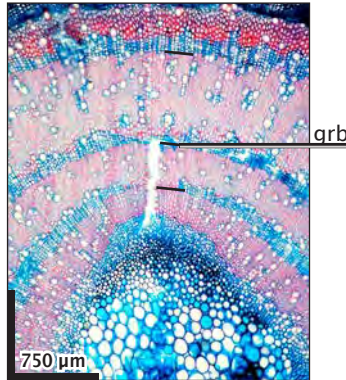
Vessels

Xylem

5 - Wood diffuse-porous



Quercus coccifera, 40x

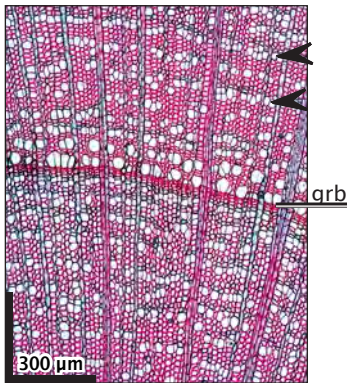


Dianthus cyprius, 40x

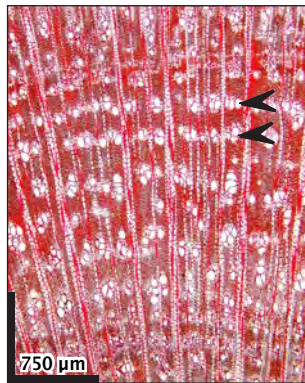
Vessels have more or less the same diameter throughout the growth ring (IAWA 1989).

Vessel arrangement

6 - Vessels in tangential bands



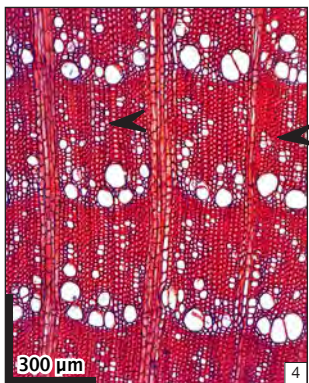
Enkianthus campanulatus, 100x



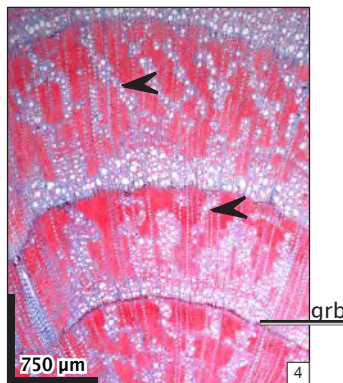
Lavatera olbia, 40x

Vessels arranged perpendicular to the rays and forming short or long tangential bands. These bands can be straight or wavy (IAWA 1989).

7 - Vessels in diagonal and/or radial pattern



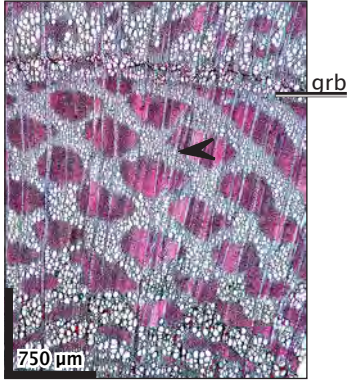
Berberis cretica, 100x



Rosmarinus officinalis, 40x

Vessels arranged radially or intermediate between tangential and radial (i.e., oblique) (IAWA 1989).

8 - Vessels in dendritic pattern



Adenocarpus viscosus, 40x

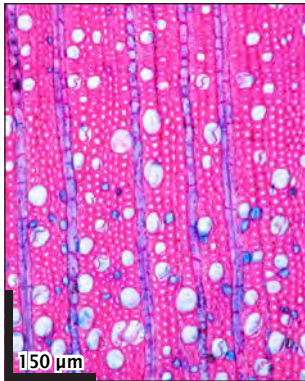


Coronilla valentina, 40x

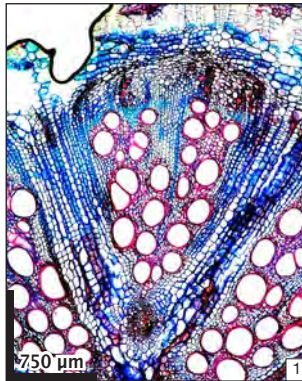
Vessels arranged in a branching pattern, forming distinct tracts, separated by areas without vessels (IAWA 1989).

Vessel groupings

9 - Vessels exclusively solitary (90% or more)



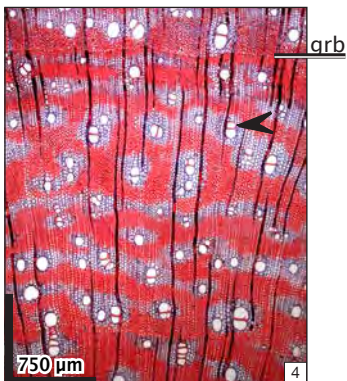
Eriobotrya japonica, 200x



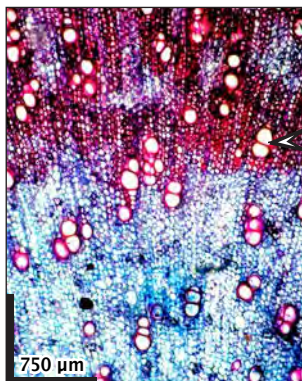
Bryonia cretica subsp. *dioica*, 40x

90% or more of the vessels are completely surrounded by other elements as viewed in cross section (IAWA 1989).

9.1 - Vessels in short radial multiples (2-3 vessels)



Acacia saligna, 40x



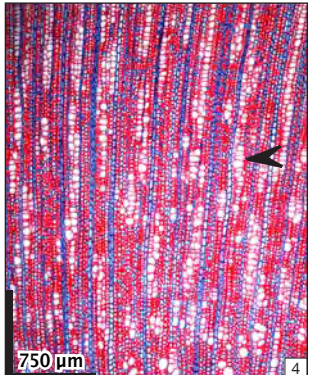
Oenothera flava, 40x

Radial files of 2 to 3 adjacent vessels.

Vessels

Xylem

10 - Vessels in long radial multiples (more than 4 vessels)



Nicotiana glauca, 40x



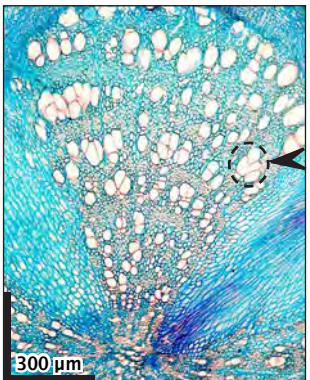
Cleome arabica, 40x

Radial files of 4 or more adjacent vessels (IAWA 1989).

11 - Vessel clusters common



Ruta chalepensis, 200x

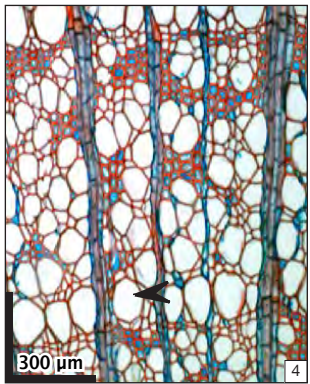


Vicia sativa, 100x

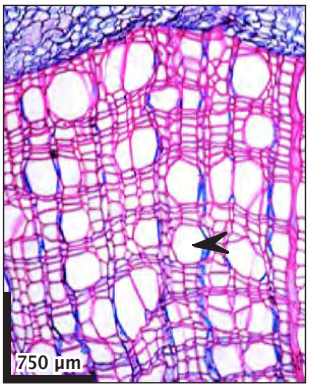
Groups of 3 or more vessels having both radial and tangential contacts (IAWA 1989). Shape and size of clusters are variable and sometimes difficult to define.

Vessels outline

12 - Vessels outline angular



Hedera helix, 100x

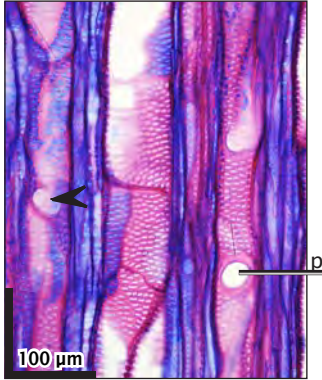


Salix arctica, 200x

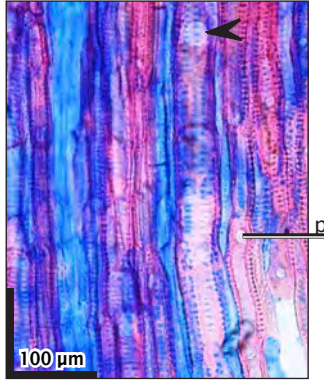
Shape of vessel outline is angular as seen in cross section.

Perforation plates

13 - Simple perforation plates



Rubia tibetica, 400x

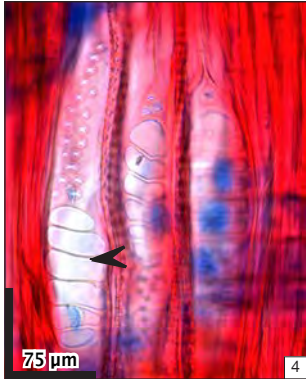


Campanula pallida, 400x

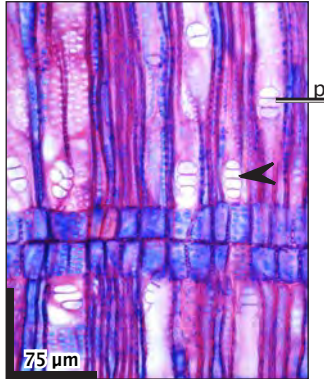
A perforation plate (p) with a single circular or elliptical opening (IAWA 1989).

14 - Scalariform perforation plates

15 - Scalariform perforation plates with less than 10 bars



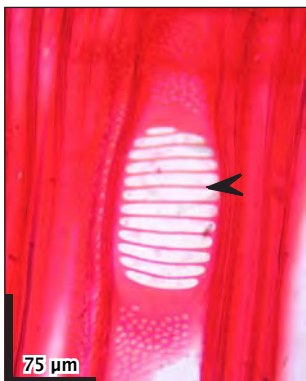
Corylus avellana, 400x



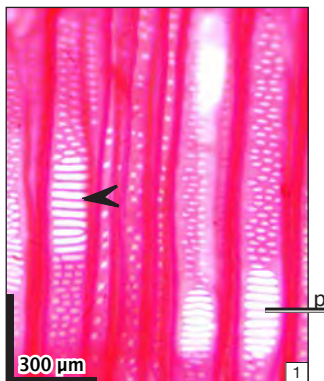
Paeonia x suffruticosa, 400x

A perforation plate (p) with elongated and parallel openings separated by one to many mainly unbranched bars (IAWA 1989).

16 - Scalariform perforation plates with 10-20 bars



Betula humilis, 400x

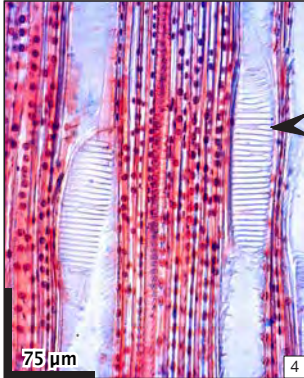


Ledum palustre subsp. *groenlandicum*, 100x

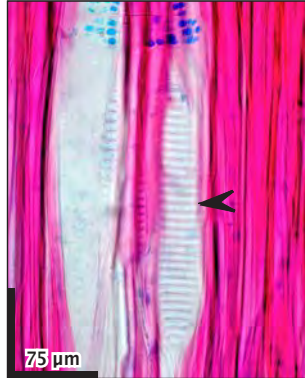
Vessels

Xylem

17 - Scalariform perforation plates with 20-40 bars

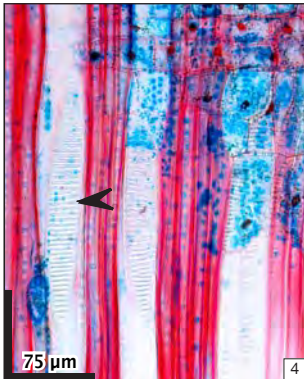


Viburnum tinus, 400x

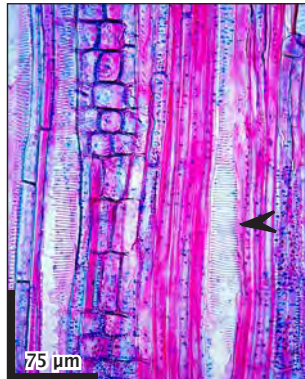


Magnolia acuminata, 400x

18 - Scalariform perforation plates with more than 40 bars

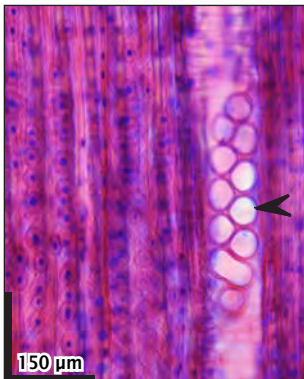


Viburnum opulus, 400x

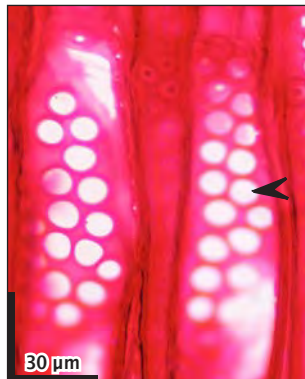


Styloceras brokawii, 400x

19 - Foraminiate perforation plates



Ephedra spp., 200x



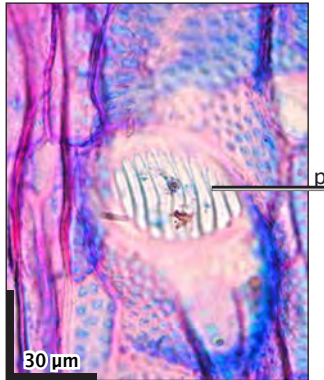
Ephedra spp., 1000x

Perforation plate with circular or elliptical openings (IAWA 1989).

19.1 - Other types of multiple perforation plates



Cirsium eriophorum, 400x

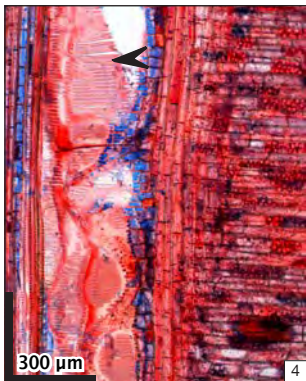


Cirsium oleraceum, 1000x

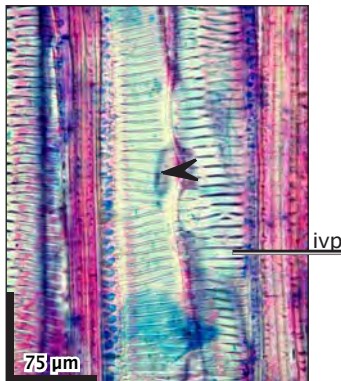
Perforation plates (p) with aberrant forms and positions in vessels. Observed mainly in the xylem of herbs.

Intervessel pits: arrangement

20 - Intervessel pits scalariform



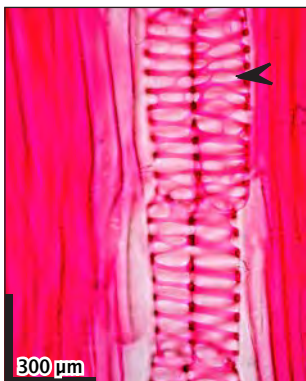
Vitis vinifera, 100x



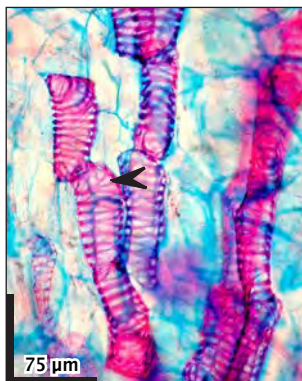
Parthenocissus tricuspidata, 400x

Elongated or linear intervessel pits (ivp) horizontally arranged in a ladder-like series (IAWA 1989).

20.1 - Intervessel pits with very large apertures, arranged in almost annular to reticulate pattern



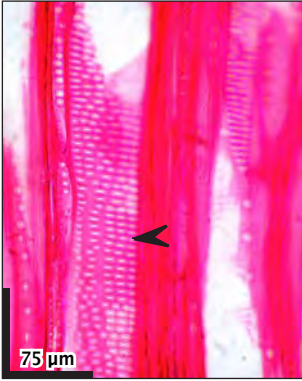
Aeonium urbicum, 100x



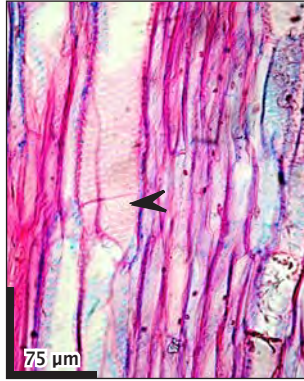
Orobanche canescens, 400x

Vessels

21 - Intervessel pits opposite



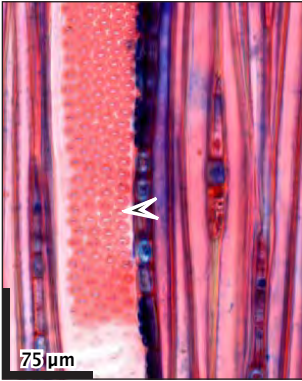
Platanus x hispanica, 400x



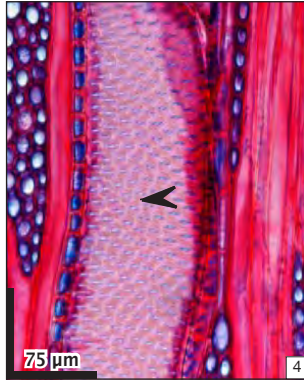
Pedicularis palustris, 400x

Intervessel pits mostly arranged in short to long horizontal rows (i.e. rows orientated transversely across the length of the vessel) (IAWA 1989).

22 - Intervessel pits alternate



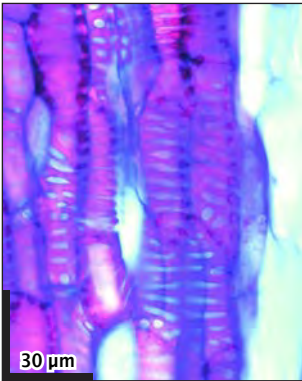
Salix alba, 400x



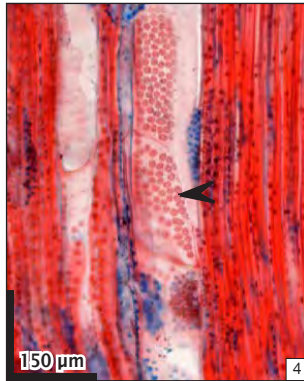
Juglans regia, 400x

Intervessel pits mostly arranged in diagonal rows (IAWA 1989).

22.1 - Intervessel pits arrangement variable along the same vessel



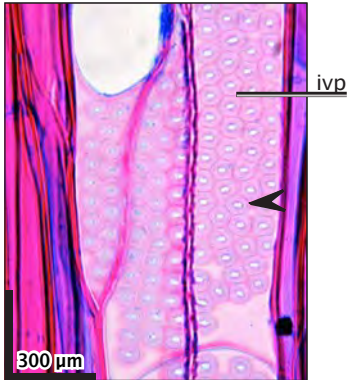
Cytinus hypocistis, 1000x



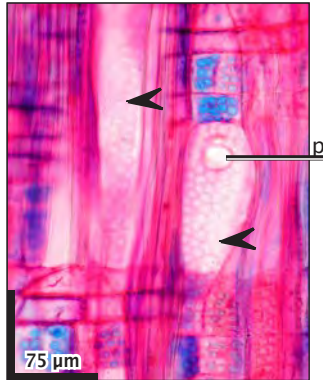
Rosa x damascena, 200x

Intervessel pits: shape

23 - Pits polygonal



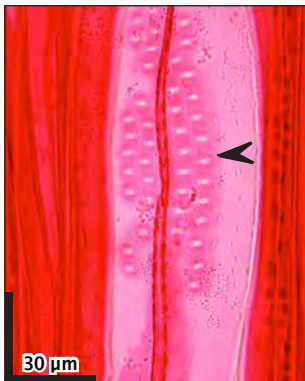
Salix alba, 100x



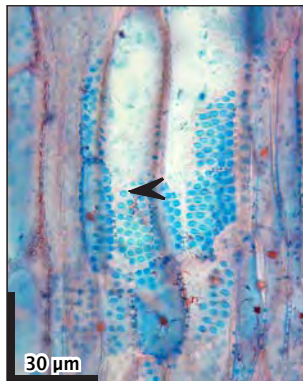
Salix retusa, 400x

Outline of intervessel pits (ivp), as seen in longitudinal sections, angular and with more than 4 sides (IAWA 1989).

23.1 - Pits round



Populus nigra var. italica, 1000x

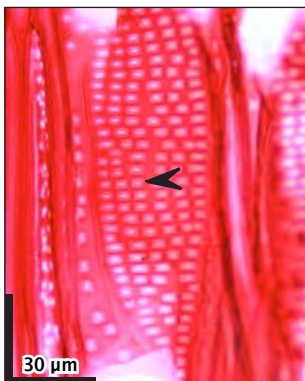


Scutellaria heydeii, 1000x

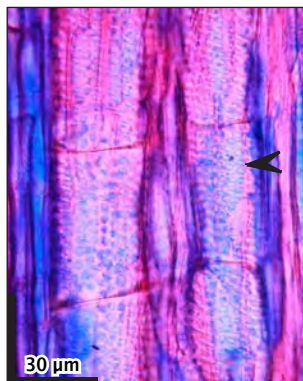
Outline of intervessel pits mostly round to oval.

Intervessel pits: size

24 - Intervessel pits minute (2-4 μm)



Platanus orientalis, 1000x



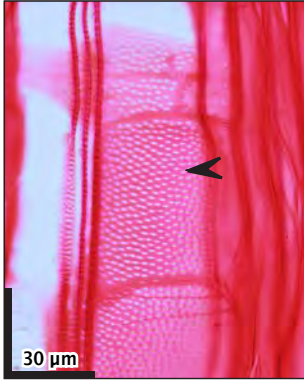
Diplotaxis spp., 1000x

Horizontal diameter of a pit chamber at the broadest point 2-4 μm.

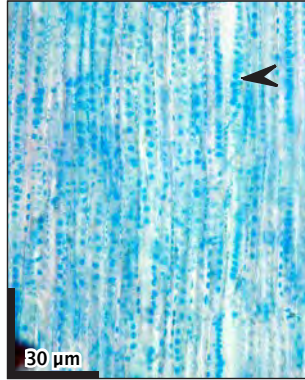
Vessels

Xylem

24.1 - Intervessel pits extremely minute (less than 2 μm)



Betula pendula, 1000x



Linnaea borealis, 1000x

Horizontal diameter of a pit chamber at the broadest point less than 2 μm .

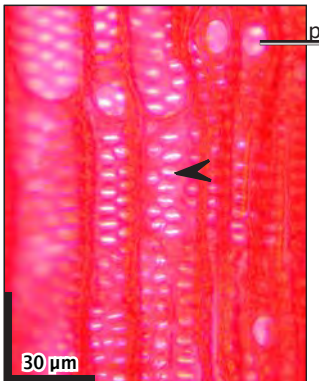
25 - Intervessel pits small (4-7 μm)

26 - Intervessel pits medium (7-10 μm)

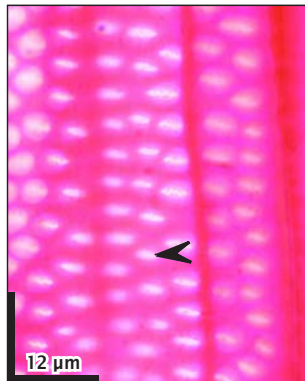
27 - Intervessel pits large (more than 10 μm)

Vestured pits

29 - Vestured pits



Anthyllis cytisoides, 1000x



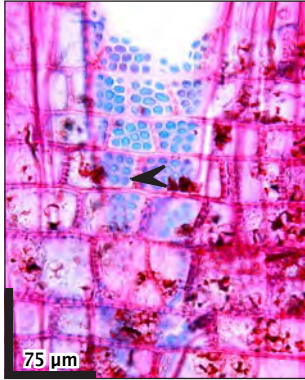
Reseda fruticosa, 1600x

Pits with the pit cavity and/or aperture wholly or partly lined with projections from the secondary cell wall (IAWA 1989).

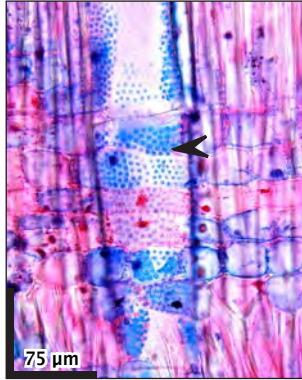
Vesturing in minute pits are not visible because they are below light microscopic resolution.

Vessel-ray pitting

30 - Vessel-ray pits with distinct borders



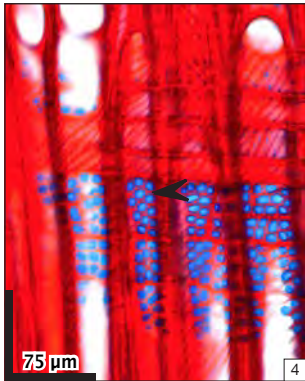
Vitex agnus-castus, 400x



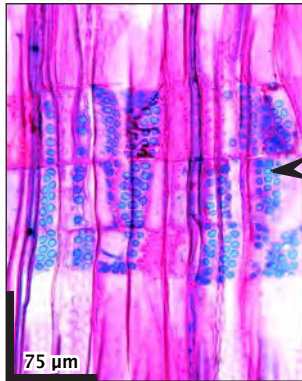
Tamarix tetragyna, 400x

Vessel-ray bordered pits are usually similar to intervessel pits in size and shape throughout the ray cell.

31 - Vessel-ray pits without borders, pits rounded or angular

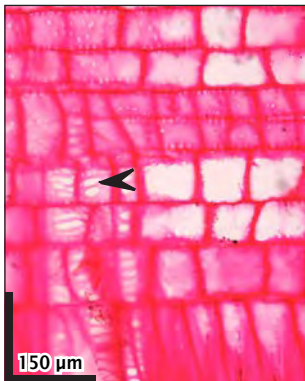


Pistacia terebinthus, 400x

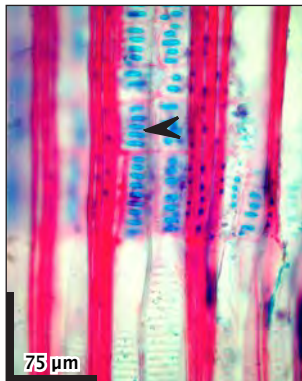


Salix arctica, 400x

32.1 - Vessel-ray pits without borders, pits horizontal (scalariform, gash-like)



Sambucus lanceolata, 200x

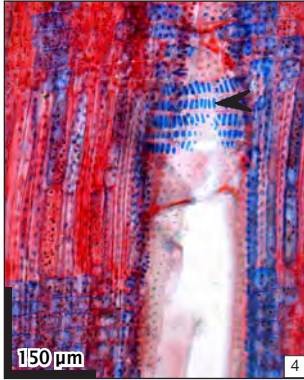


Fothergilla gardenii, 400x

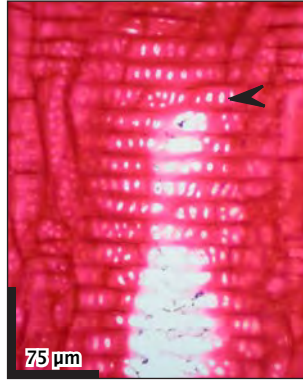
Vessels

Xylem

32.2 - Vessel-ray pits without borders, pits vertical (palisade)



Quercus coccifera, 200x



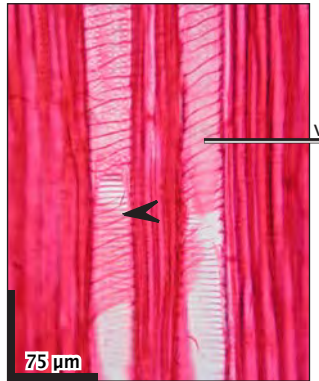
Quercus cerris, 400x

Helical thickenings in secondary xylem

36 - Helical thickenings in vessel elements distinct



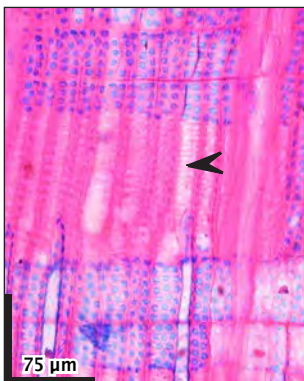
Tilia tomentosa, 400x



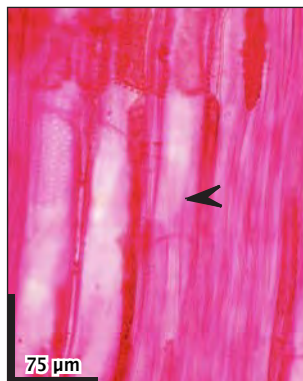
Ilex spinigera, 400x

Distinct ridges on the inner face of the vessel element (v) wall in a roughly helical pattern (IAWA 1989).

36.1 - Helical thickenings in vessel elements slightly visible



Thymelaea tartonraira, 400x

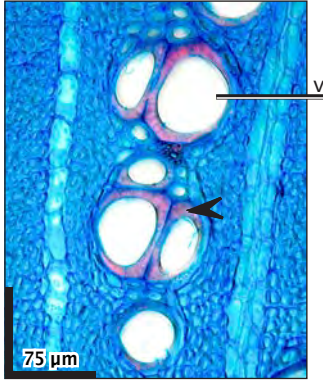


Gochnatia glutinosa, 400x

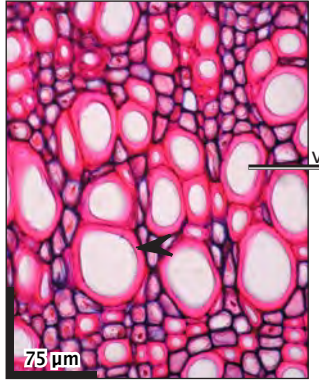
As feature 36, but with thin ridges.

Vessel wall thickness

39.1 - Vessels thick-walled



Cadaba rotundifolia, 400x

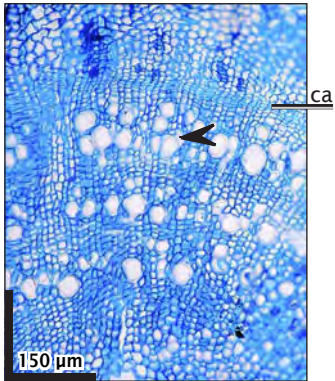


Pulsatilla turczaninovii, 400x

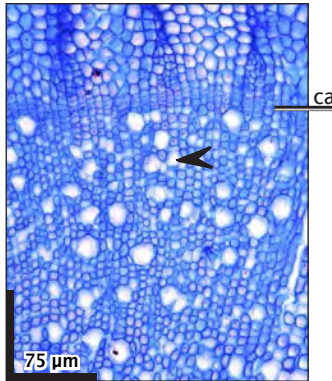
Vessel (v) cell wall thickness more than 2 μm.

Vessel wall lignification

39.2 - Vessels not lignified



Desideria linearis, 200x

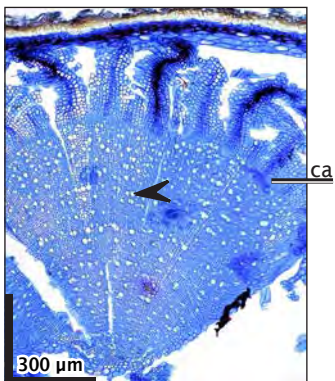


Ladakiella klimesii, 400x

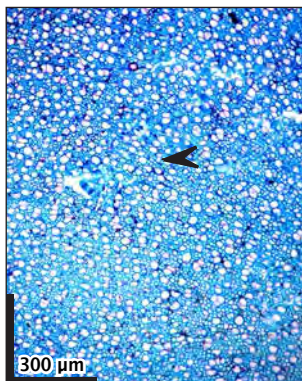
Vessel cell walls do not stain red with astrablue and safranin staining.

Tangential diameter of vessel lumina

40.1 - Mean tangential diameter of earlywood vessel lumina less than 20 μm



Ladakiella klimesii, 100x



Silene acaulis, 100x

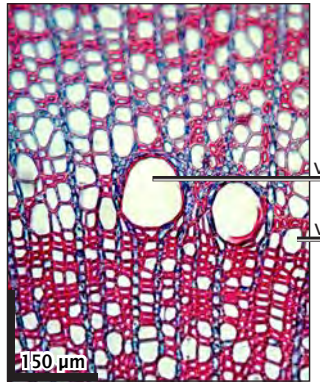
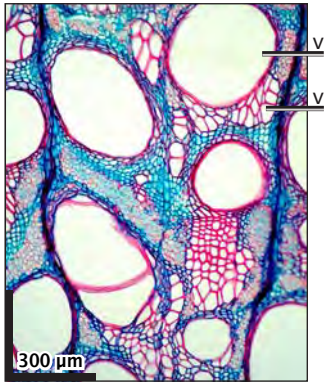
Vessels

- 40.2 - Mean tangential diameter of earlywood vessel lumina 20-50 μm
- 41 - Mean tangential diameter of earlywood vessel lumina 50-100 μm
- 42 - Mean tangential diameter of earlywood vessel lumina 100-200 μm
- 43 - Mean tangential diameter of earlywood vessel lumina more than 200 μm

The vessel diameter is a crucial parameter in plant physiology. Its variation from pith to bark and from plant top to plant base (vessel widening) is proposed as being the most efficient anatomical adjustment for stabilizing hydraulic path-length resistance with the progressive growth in height. It is therefore important to identify the sampling point for vessel size measurement within the plant stem e.g. by knowing the distance of the sampling point to the stem apex (Anfodillo *et al.* 2013).

Vessels of two distinct diameter classes

- 45 - Vessels of two distinct diameter classes, wood not ring-porous



Woods with a bimodal distribution of tangential diameters of vessel (v) lumina (IAWA 1989).

Pueraria montana var. *lobata*, 100x *Lonicera acuminata*, 200x

Vessels per square millimetre

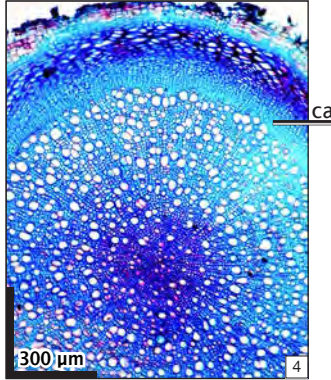
Features from 46 to 50.1 “Vessels per square millimetre” apply only in diffuse-porous and semi-ring-porous woods. Excluded are ring-porous species and species with ray-like zones between vascular bundles (see figures on feature A.38 right on page 40, and A.44 right on page 44).

- 46 - Less than 5 vessels per square mm
- 47 - 5-20 vessels per square mm
- 48 - 20-40 vessels per square mm
- 49 - 40-100 vessels per square mm
- 50 - 100-500 vessels per square mm

50.1 - More than 500 vessels per square mm



Loiseleuria procumbens, 100x



Cerastium arvense, 100x

Vessel element length

Vessel element length classes from IAWA list (1989) were adjusted to classify also short vessels observed in small growth forms. Measure the entire vessel element length, preferably in a maceration (see also page 76).

52.1 - Mean vessel element length less than 50 μm

52.2 - Mean vessel element length 50-150 μm

52.3 - Mean vessel element length 150-350 μm

53.1 - Mean vessel element length 350-600 μm

53.2 - Mean vessel element length 600-800 μm

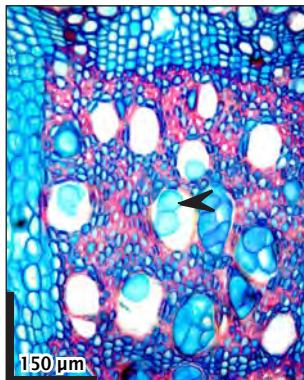
54 - Mean vessel element length more than 800 μm

Tyloses

56 - Tyloses common



Laurus azorica, 400x



Aristolochia clematitis, 200x

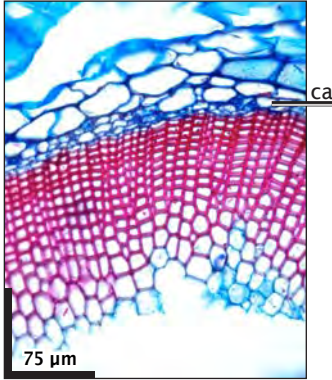
Outgrowth from tertiary walls of adjacent cells into vessel lumen.

For IAWA feature 58 *Gum and other deposits in heartwood vessels* see feature 154 on page 95.

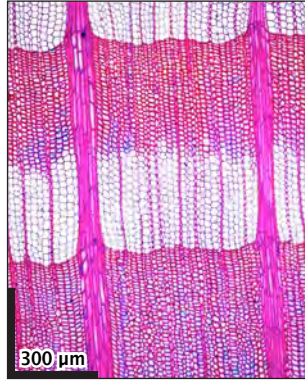
Vessels - Tracheids and fibres

Wood vesselless

59 - Wood vesselless



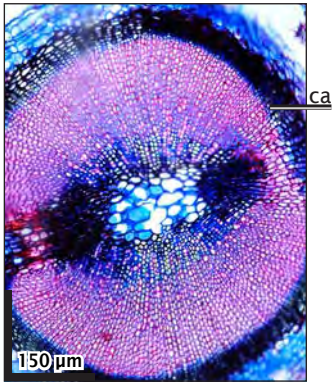
Sedum litoreum, 400x



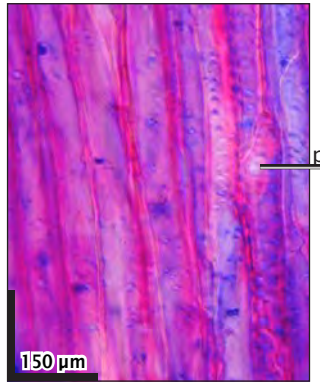
Trochodendron aralioides, 100x

Wood without vessel elements, composed only of imperforate tracheary elements and parenchyma (IAWA 1989).

59.1 - Vessels not distinct in cross section



Silene alexandrina, 200x

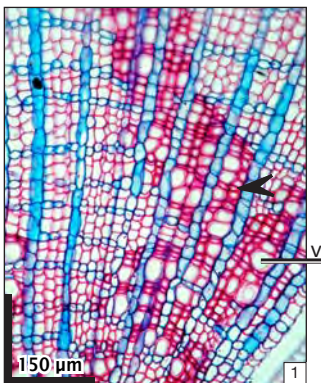


Silene alexandrina, 200x

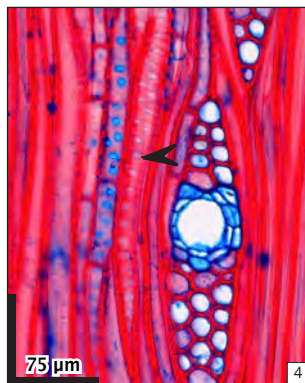
Size of vessel elements is equal to the size of the surrounding fibres and parenchyma cells as seen in cross section. The presence of vessel elements can be evaluated in radial section by checking the presence of perforation plates (p).

Vascular and vasicentric tracheids

60 - Vascular and/or vasicentric tracheids present



Daphne striata, 200x

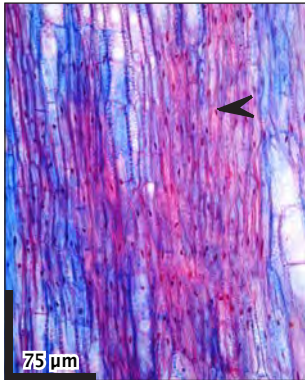


Pistacia terebinthus, 400x

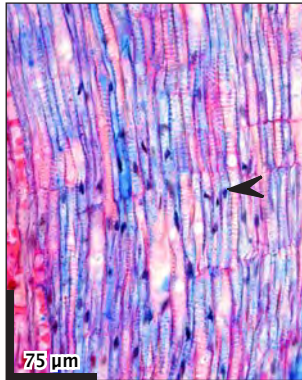
Vascular tracheids are imperforate cells (i.e. without perforation plates) resembling narrow vessel elements (v). Vasicentric tracheids are imperforate cells with numerous distinctly bordered pits (IAWA 1989).

Living fibres

60.0 - Cell nuclei in fibres



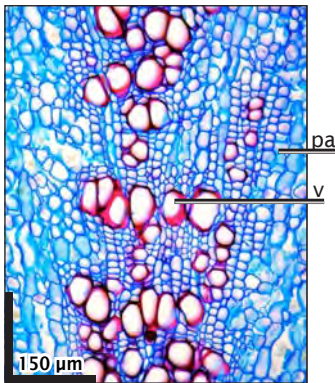
Pedicularis lapponica, 400x



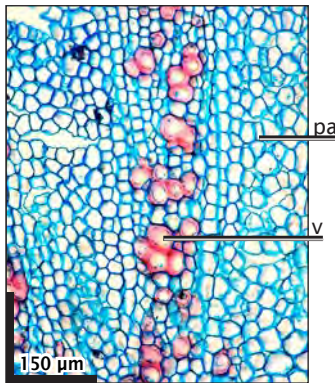
Gnaphalium supinum, 400x

Wood fibreless

60.1 - Wood fibreless



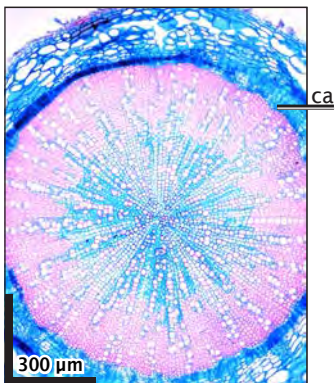
Sanguisorba officinalis, 200x



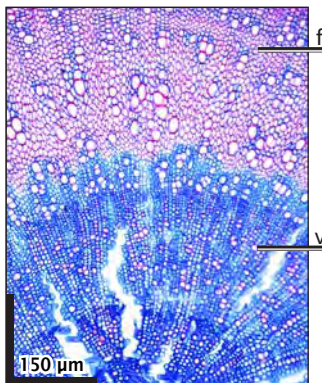
Campanula bechiana, 200x

Wood without fibres (double check in longitudinal sections and in polarized light), composed only of vessel elements (v) and parenchyma (pa).

60.2 - Wood fibreless in stem centre



Clypeola jonthlaspi, 100x



Gentiana leucomelaena, 200x

Fibres (f) occur only in peripheral zones of the stem.

Tracheids and fibres

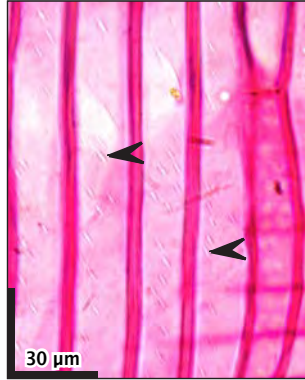
Xylem

Fibre pits

61 - Fibres with simple to minutely bordered pits



Rhinanthus alectorolophus, 400x



Betula glandulosa, 1000x

Fibres (libriform fibres) with simple pits or bordered pits with the chambers less than 3 µm in diameter (IAWA 1989).

61.1 - Fibres without pits

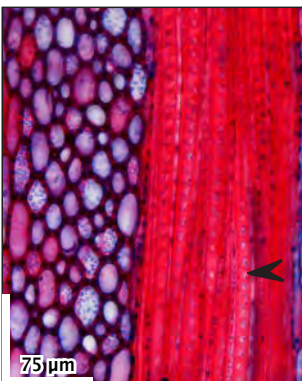


Sedum reflexum, 400x



Sedum reflexum, 400x

62 - Fibres with distinctly bordered pits



Rubus sanctus, 400x

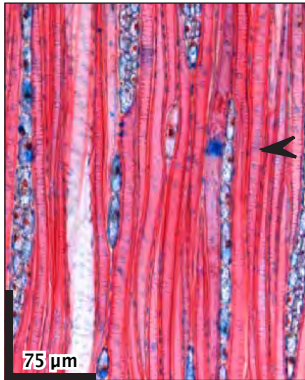


Gaultheria shallon, 1000x

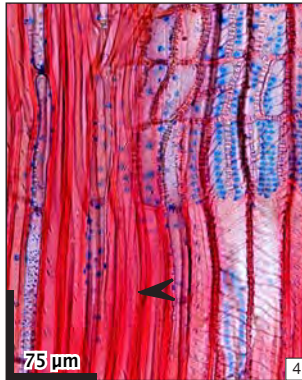
Fibres (or fibre-tracheids or ground tissue tracheids) with bordered pits.

Helical thickenings in fibres and fibre-tracheids

64 - Helical thickenings in fibres and/or fibre-tracheids



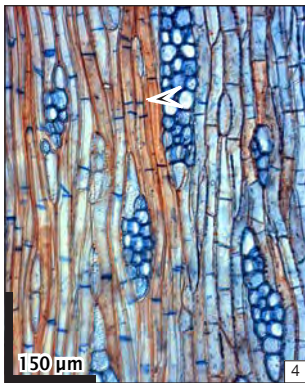
Ziziphus spina-christi, 400x



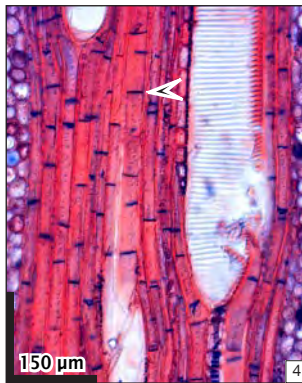
Ilex aquifolium, 400x

Septate fibres

65 - Septate fibres present



Ceratonia siliqua, 200x



Vitis vinifera, 200x

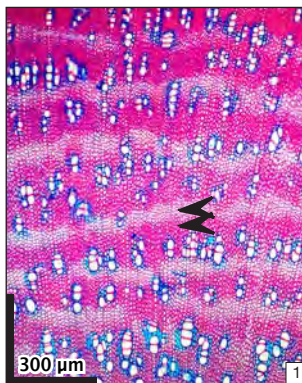
Fibres with thin, unpitted, cross wall(s) blue-stained after astrablue and safranin staining.

Parenchyma like fibre-bands and fibre clusters

67 - Parenchyma-like fibre bands alternating with ordinary fibres



Acer tataricum, 100x



Lepidium campestre, 100x

Tangential bands of relatively thin-walled fibres alternating with bands of thicker-walled fibres (IAWA 1989).

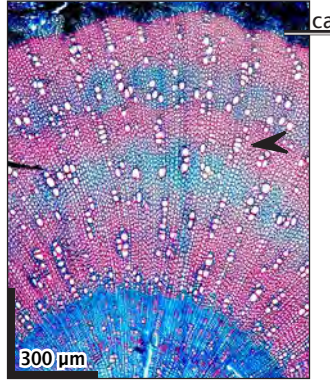
Tracheids and fibres

Xylem

67.1 - Intra-annual fibre bands



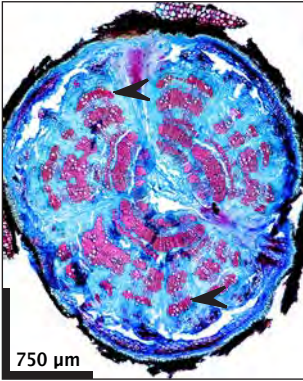
Malva canariensis, 100x



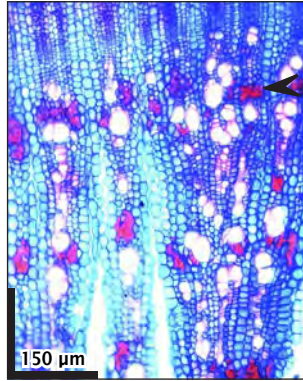
Alyssum alyssoides, 100x

Red-stained bands of fibres alternating blue-stained cells after astrablue and safranin staining.

67.2 - Intra-annual clusters of fibres



Matthiola fruticulosa, 40x

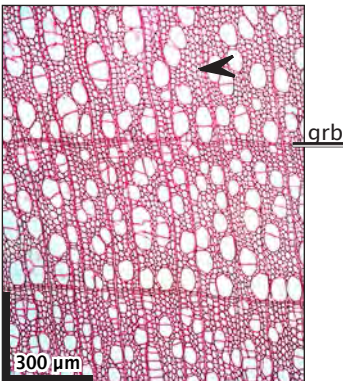


Oxytropis chiliophylla, 200x

Red-stained clusters of fibres embedded in blue-stained cells after astrablue and safranin staining.

Fibre wall thickness

68 - Fibres very thin-walled



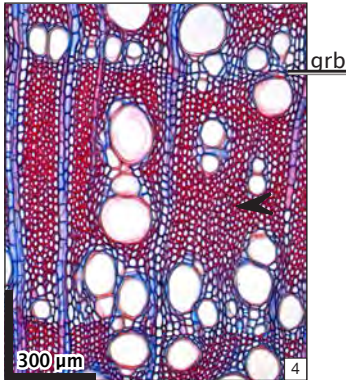
Populus tremuloides, 100x



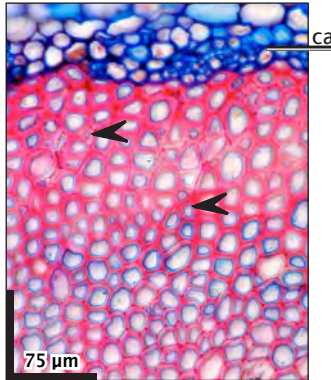
Rhinanthus glacialis, 100x

Fibre lumina 3 or more times wider than the double wall thickness (IAWA 1989).

69 - Fibres thin- to thick-walled



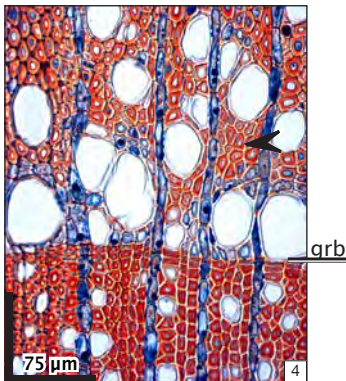
Capparis spinosa, 100x



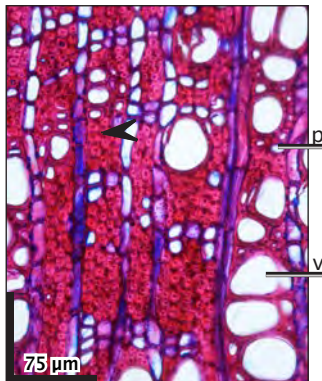
Swertia perennis, 400x

Fibre lumina less than 3 times the double wall thickness, and distinctly open (IAWA 1989).

70 - Fibres very thick-walled



Syringa vulgaris, 400x

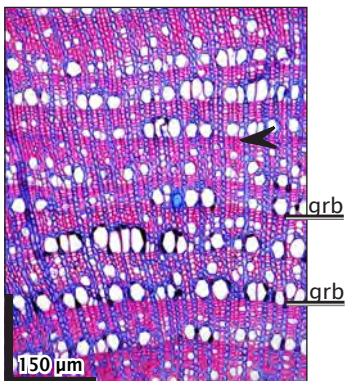


Argania spinosa, 400x

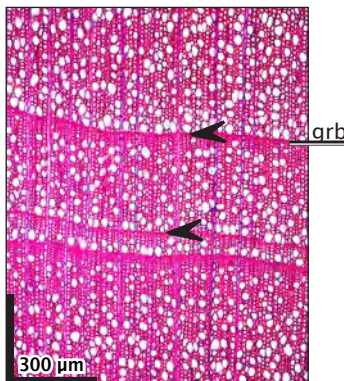
Fibre lumina almost completely closed (IAWA 1989).

Radially flattened fibres

70.1 - Thick-walled and radially flattened latewood fibres



Lonicera semenovii, 200x



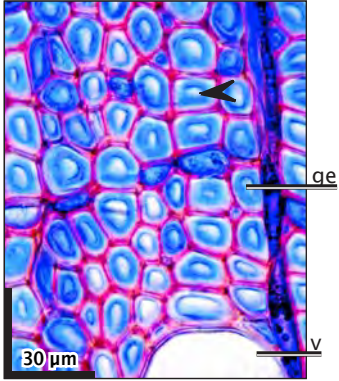
Euonymus europaeus, 100x

Tracheids and fibres

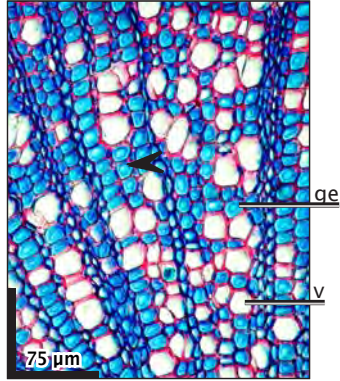
Xylem

Gelatinous fibres

70.2 - Gelatinous fibres (tension wood)



Betula pubescens, 1000x



Linum bienne, 400x

Gelatinous fibres (ge) are characterized by a bluish innermost layer after double staining with astrablue and safranin.

Mean fibre lengths

71 - Mean fibre lengths less than 900 µm

72 - Mean fibre lengths 900-1600 µm

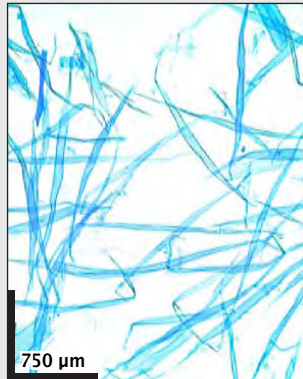
73 - Mean fibre lengths more than 1600 µm

Maceration is needed to desegregate single fibres to be measured.

Examples of macerated wood



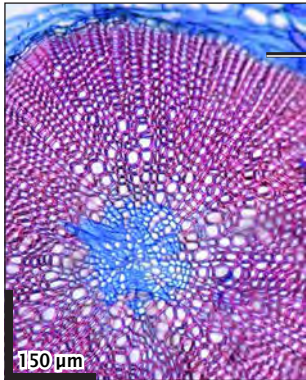
Empetrum nigrum, 100x



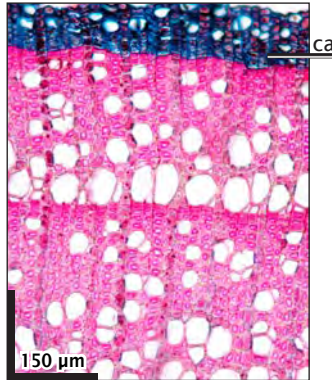
Tilia cordata, 40x

Axial parenchyma absent

75 - Axial parenchyma absent or extremely rare



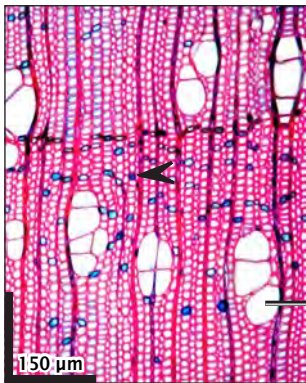
Centaurium tenuiflorum, 200x



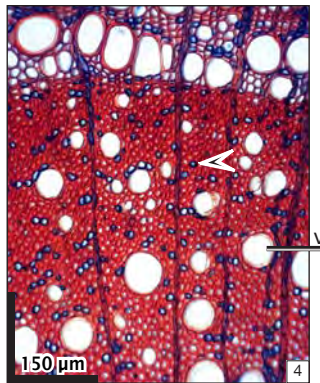
Lonicera caerulea, 200x

Apotracheal axial parenchyma

76 - Apotracheal parenchyma diffuse



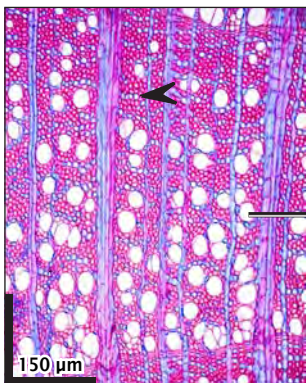
Alnus alnobetula, 200x



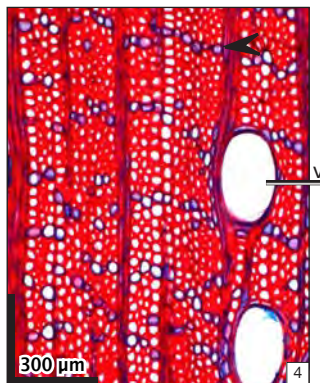
Elaeagnus angustifolia, 200x

Axial parenchyma not associated to vessels (v) irregularly distributed among the fibrous elements of the wood (IAWA 1989).

77 - Apotracheal parenchyma diffuse-in-aggregates



Fagus sylvatica, 200x



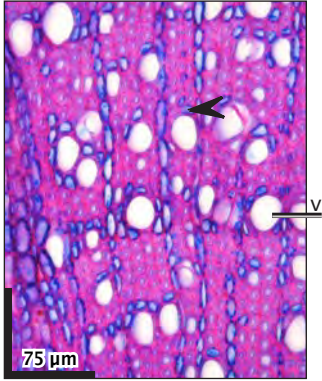
Juglans regia, 100x

Axial parenchyma not associated to vessels (v) grouped into short discontinuous tangential or oblique lines (IAWA 1989).

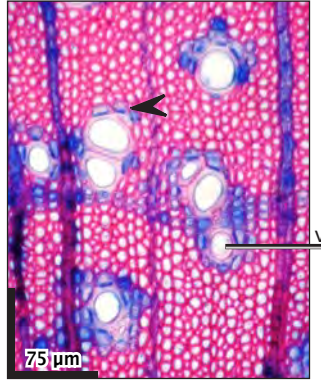
Axial parenchyma

Paratracheal axial parenchyma

78 - Axial parenchyma scanty paratracheal



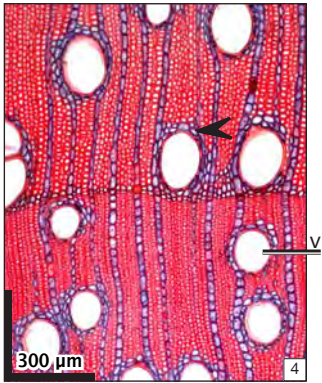
Fumana ericoides, 400x



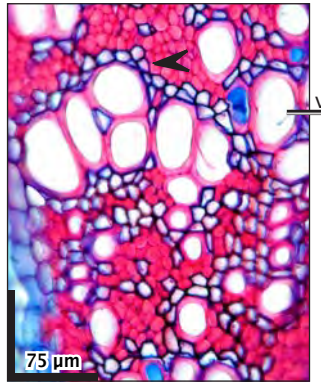
Citrus trifoliata, 400x

Occasional parenchyma cells associated with the vessels (v) or an incomplete sheath of parenchyma around the vessels (IAWA 1989).

79 - Axial parenchyma vasicentric



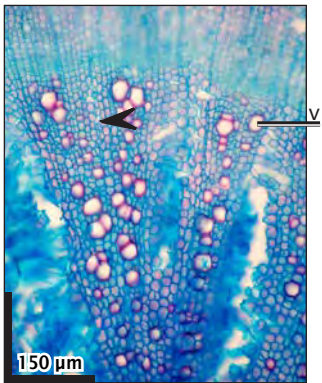
Ziziphus lotus, 100x



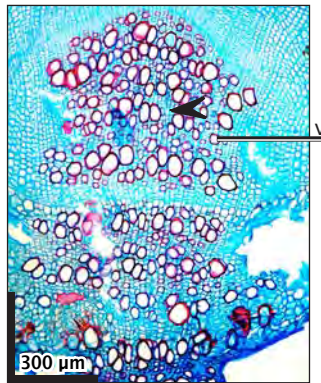
Trifolium ambiguum, 400x

Parenchyma cells forming a complete circular to oval sheath around a solitary vessel (v) or vessel cluster (IAWA 1989).

79.1 - Axial parenchyma pervasive



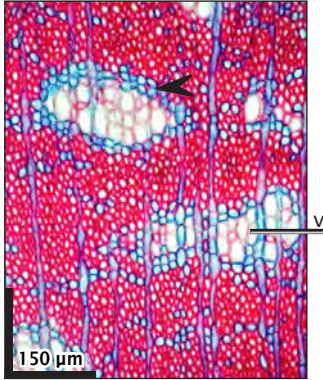
Ligusticum mutellinoides, 200x



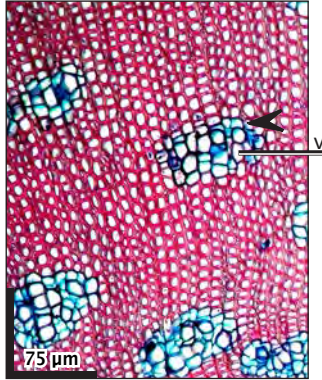
Saussurea spp., 100x

Solitary vessels (v) or vessels clusters embedded in parenchyma cells.

79.2 - Axial parenchyma inter-vascular



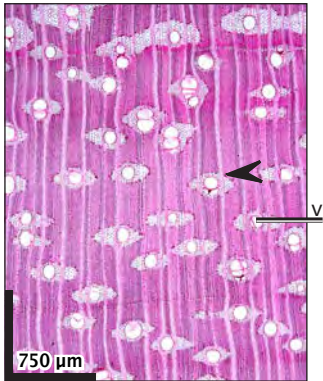
Thymelaea hirsuta, 200x



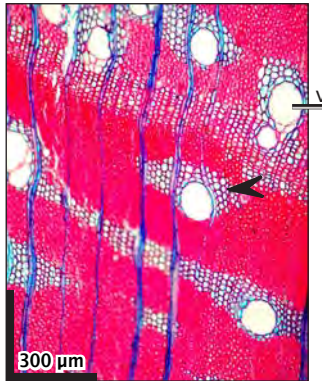
Aeonium urbicum, 400x

Vessel (v) clusters surrounded by a sheath of parenchyma cells (Carlquist 2001).

80 - Axial parenchyma aliform



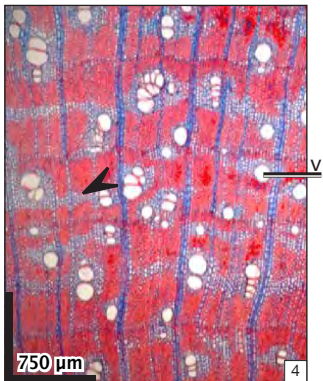
Afzelia africana, 40x



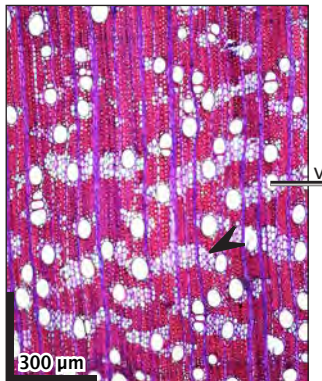
Acacia tortilis subsp. *raddiana*, 100x

Parenchyma surrounding or to one side of the vessels (v) with lateral extensions being tangentially elongate and large (IAWA 1989).

83 - Axial parenchyma confluent



Ceratonia siliqua, 40x



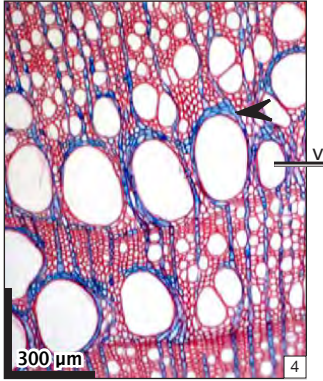
Hugonia arborescens, 100x

Coalescing vasicentric or aliform parenchyma surrounding or to one side of two or more vessels (v), and often forming irregular bands (IAWA 1989).

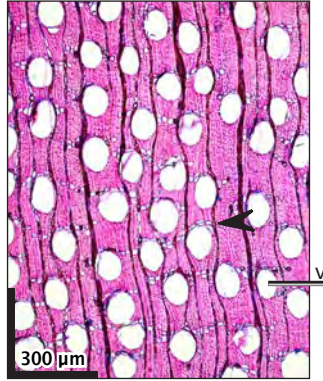
Axial parenchyma

Xylem

84 - Axial parenchyma unilateral paratracheal



Cyprinia gracilis, 100x

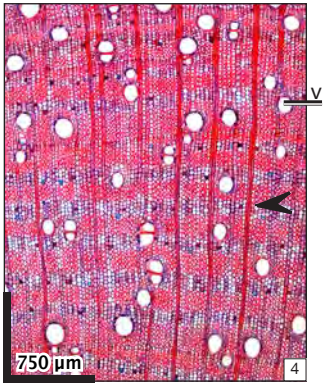


Ctenolophon parviflorum, 100x

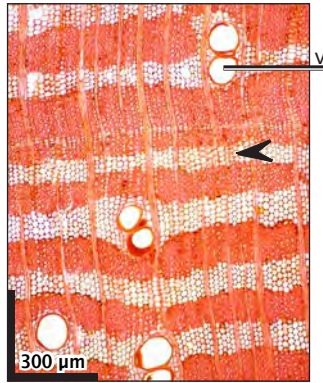
Paratracheal parenchyma forming semicircular hoods or caps only on one side of the vessels (v) and which can extend tangentially or obliquely in an aliform or confluent or banded pattern (IAWA 1989).

Banded parenchyma

85 - Axial parenchyma bands more than 3 cells wide



Ficus carica, 40x

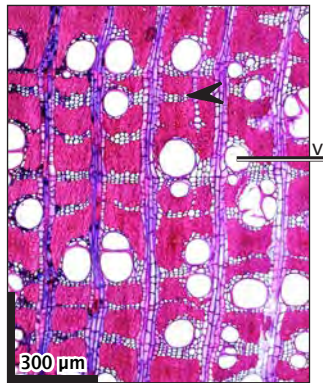


Millettia thonningii, 100x

86 - Axial parenchyma in narrow bands or lines up to 3 cells wide



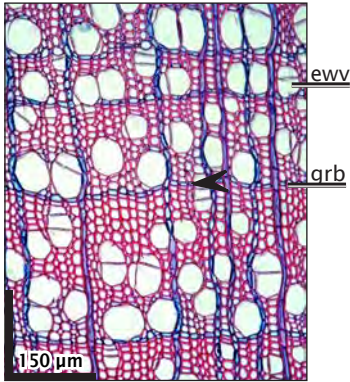
Quercus congesta, 40x



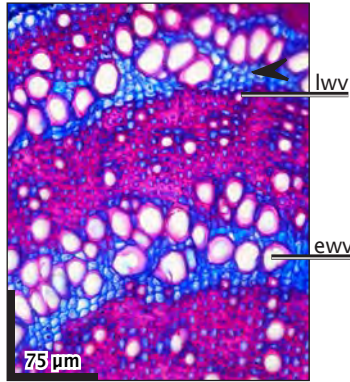
Cordia sinensis, 100x

89 - Parenchyma in marginal bands

89.1 - Parenchyma in initial marginal bands



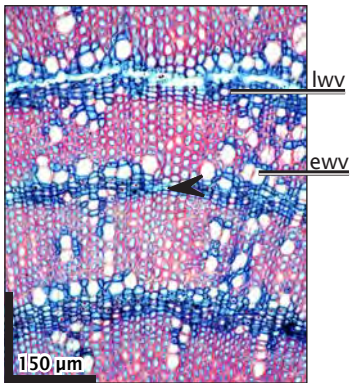
Salix foetida, 200x



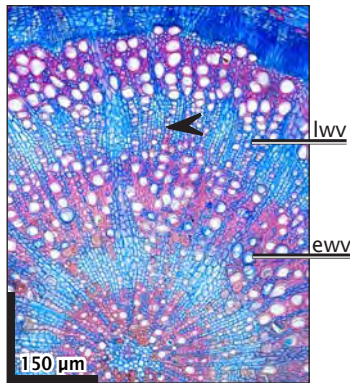
Pedicularis elongata, 400x

Features 89.1 and 89.2 apply only if parenchyma marginal bands can be clearly located either at the beginning or at the end of the growth ring.

89.2 - Parenchyma in terminal marginal bands



Bupleurum longifolium, 200x

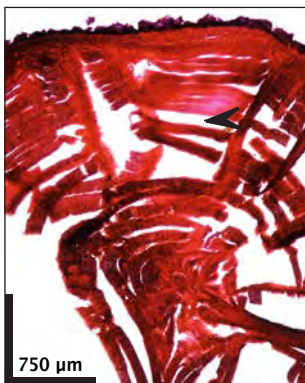


Thesium arvense, 200x

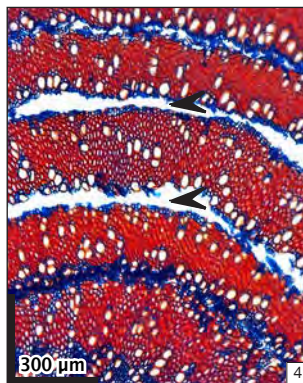
Parenchyma bands which form a more or less continuous layer of variable width at the end of a growth ring.

Ring shake

89.3 - Ring shake



Androsace helvetica, 40x



Arabis purpurea, 100x

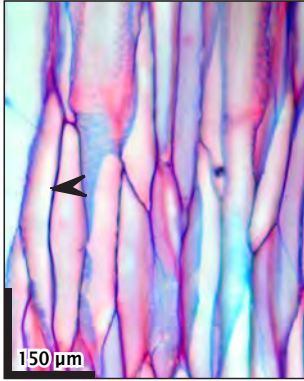
Tangential separation of the xylem axial elements along parts or an entire growth ring(s).

Axial parenchyma

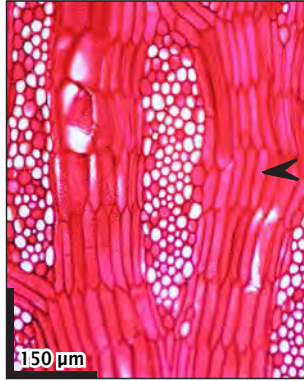
Xylem

Axial parenchyma cell type

90 - Fusiform parenchyma cells



Silene baccifera, 200x



Retama monosperma, 200x

Parenchyma cells derived from fusiform cambial initials without subdivisions or tip growth. In shape they resemble a short fibre (IAWA 1989).

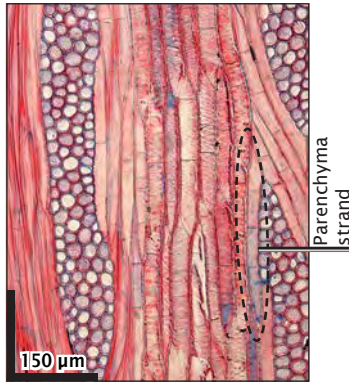
Axial parenchyma strand length

91 - 2 cells per parenchyma strand

92 - 3-4 cells per parenchyma strand

93 - 5-8 cells per parenchyma strand

94 - More than 8 cells per parenchyma strand

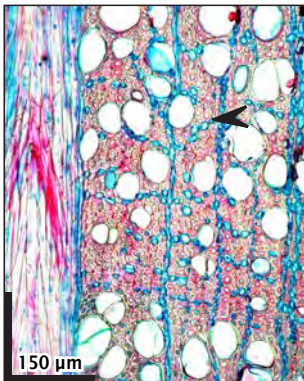


Robinia pseudoacacia, 200x

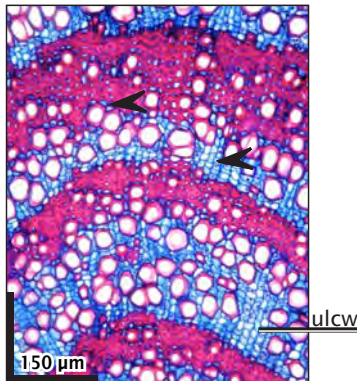
A parenchyma strand is a series of axial parenchyma cells formed through transverse division(s) of a single fusiform cambial initial cell (IAWA 1989).

Unlignified parenchyma

95 - Unlignified parenchyma



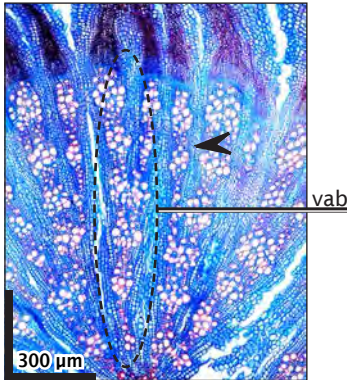
Fagus sylvatica, 200x



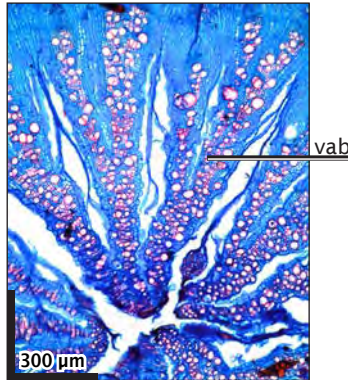
Pedicularis elongata, 200x

Rays in vascular bundles

96.0 - Rays within the vascular bundle



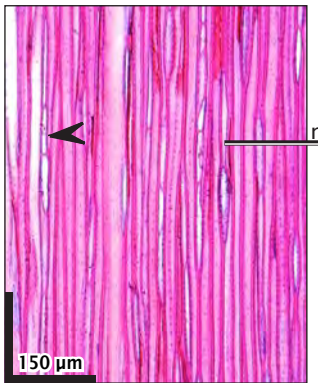
Thesium hookeri, 100x



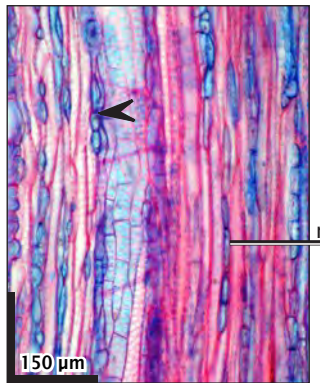
Chesneya cuneata, 100x

Ray width

96 - Rays exclusively uniseriate

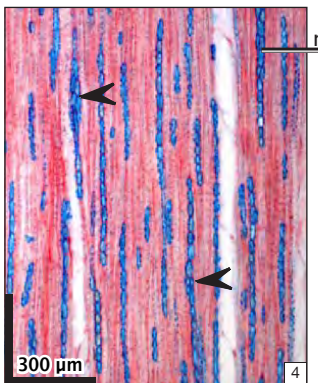


Roridula gorgonias, 200x

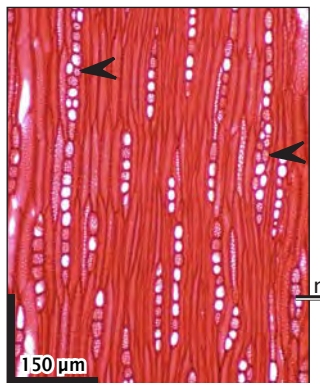


Convolvulus arvensis, 200x

96.1 - Rays mostly uniseriate



Convolvulus oleifolius, 100x



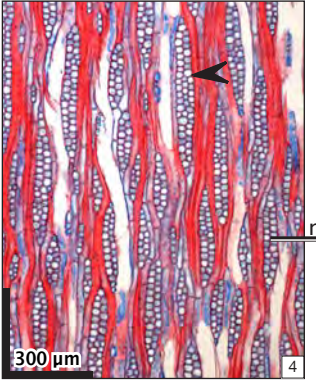
Thymelaea sanamunda, 200x

Most of the rays (r) are uniseriate, a few biseriate rays occur.

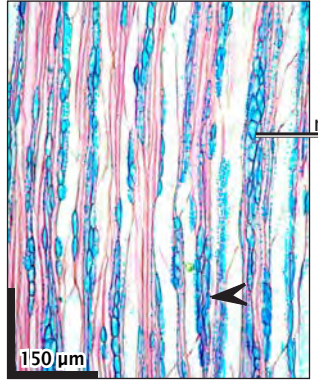
Rays

Xylem

97 - Ray uniseriate to 3-seriate

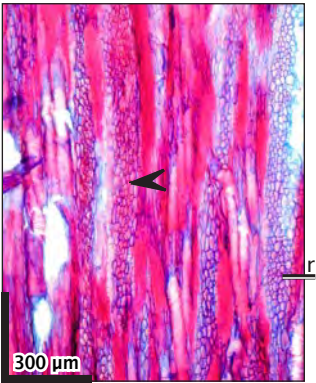


Pyrus communis, 100x

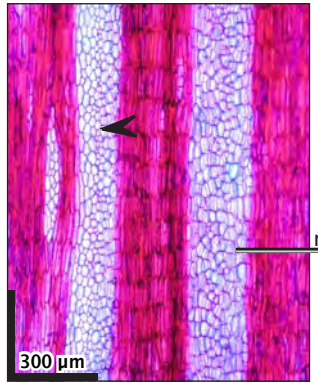


Linum austriacum, 200x

98 - Larger rays commonly 4- to 10-seriate



Hedysarum gmelinii, 100x

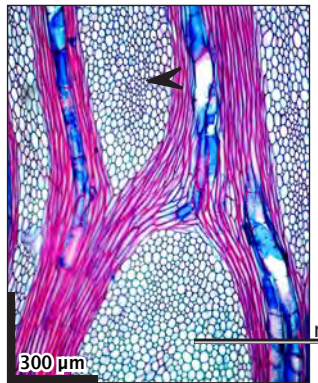


Trifolium ambiguum, 100x

99 - Larger rays commonly more than 10-seriate



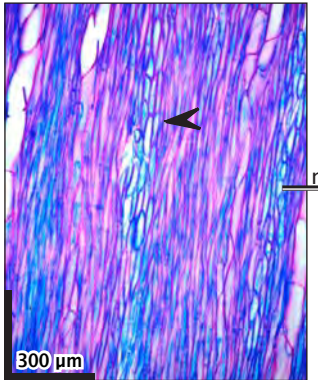
Rumex alpinus, 40x



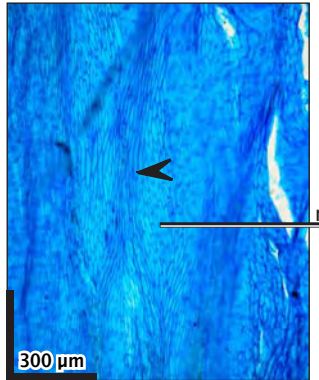
Brassica nigra, 100x

Rays confluent

100.1 - Rays confluent with ground tissue



Anchusa officinalis, 100x



Oxytropis tatarica, 100x

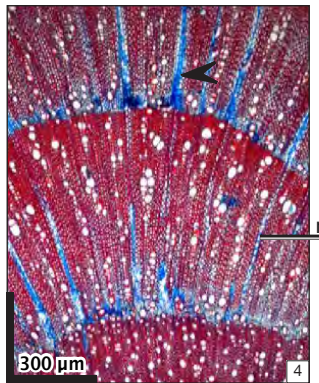
Lateral borders of rays (r) merge with axial tissue.

Rays not lignified

100.2 - Rays not lignified



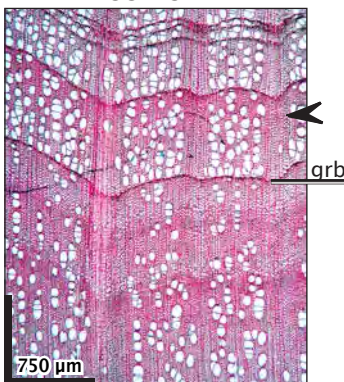
Clematis montana, 40x



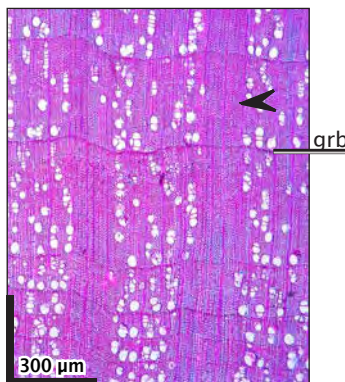
Echium angustifolium, 100x

Aggregate rays

101 - Aggregate rays



Alnus glutinosa, 40x



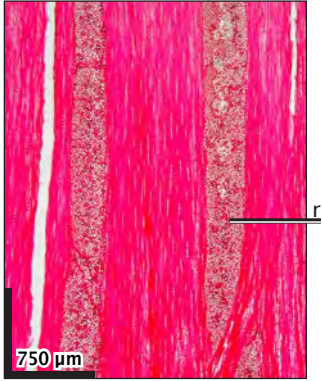
Carpinus betulus, 100x

A number of closely associated individual rays separated by axial elements (IAWA 1989).

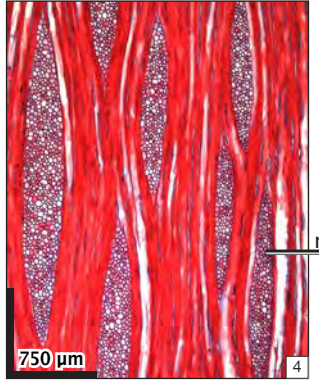
Rays

Ray height

102 - Ray height more than 1 mm



Quercus cerris, 40x

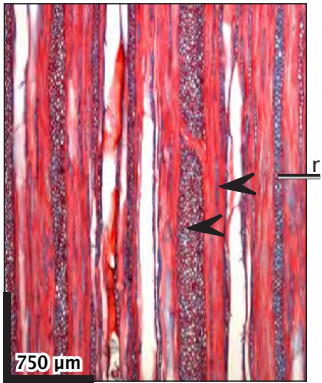


Rosa micrantha, 40x

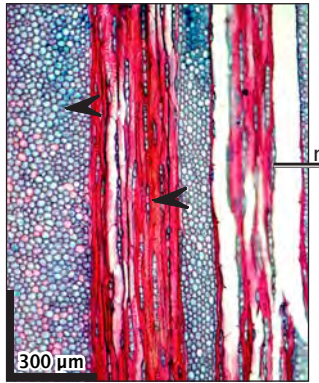
Total ray (r) height as measured in tangential section, along the ray axis.

Rays of two distinct sizes

103 - Rays of two distinct sizes



Rubus ulmifolius, 40x

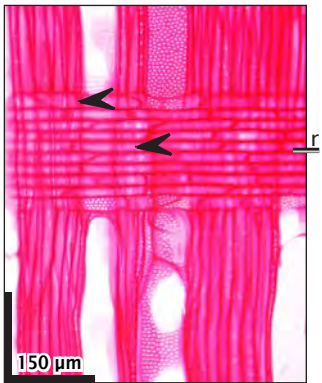


Rosa arkansana, 100x

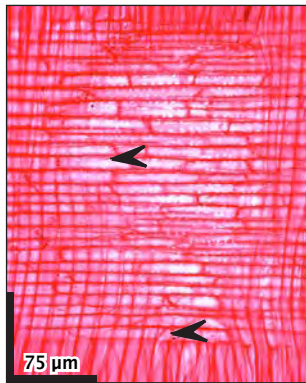
Tangential section rays (r) form two distinct populations by their width and usually by their height (IAWA 1989).

Rays: cellular composition

104 - All ray cells procumbent



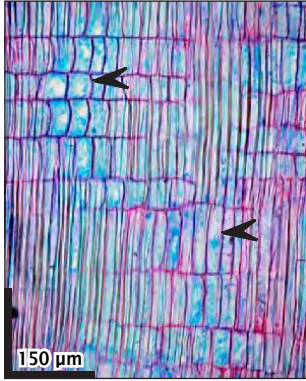
Aesculus hippocastanum, 200x



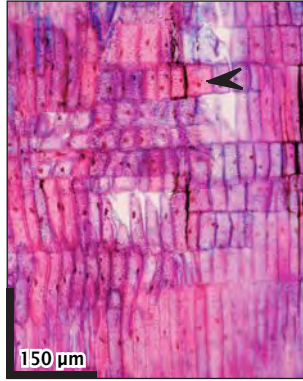
Acacia mearnsii, 400x

Marginal cells often slightly larger compare to body ray cells.

105 - All ray cells upright and/or square

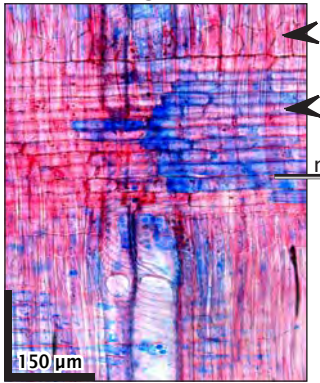


Boswellia sacra, 200x

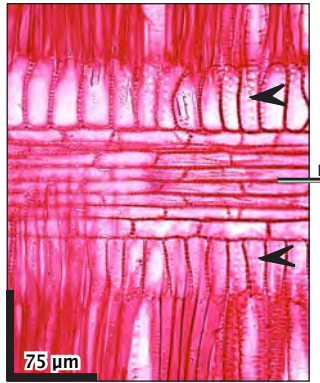


Austrobrickellia patens, 200x

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

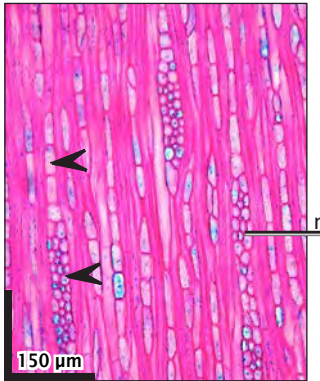


Pistacia terebinthus, 200x

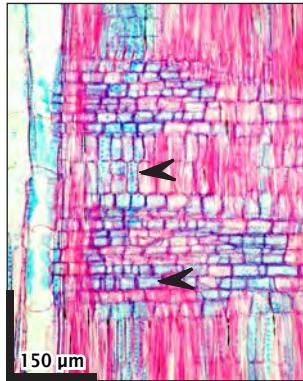


Ligustrum japonicum, 400x

107.1 - Body ray cells procumbent with 2 to more than 4 rows of upright and/or square marginal cells



Lonicera involucrata, 200x



Cytisophyllum sessilifolium, 200x

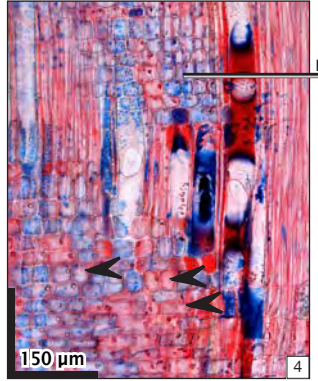
Rays

Xylem

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



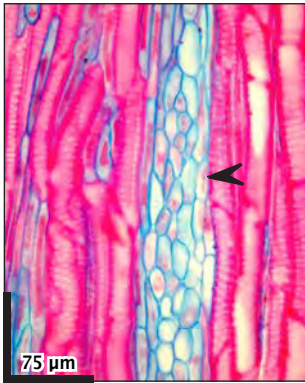
Laurus nobilis, 100x



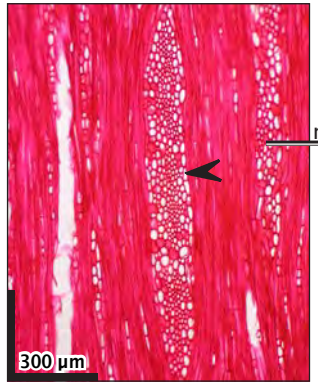
Prunus armeniaca, 200x

Sheath cells

110 - Sheath cells



Astragalus praelongus, 400x

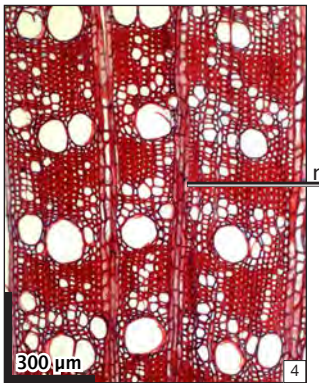


Rosa arvensis, 100x

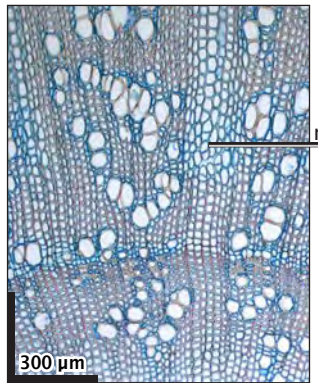
Ray (r) cells located along the side of the rays as viewed in tangential section and are larger than the central ray cells (IAWA 1989)

Rays per millimetre

114 - Less than 4 rays per mm

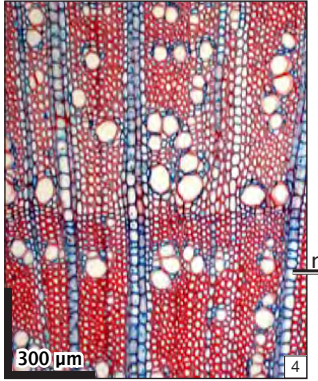


Berberis cretica, 100x

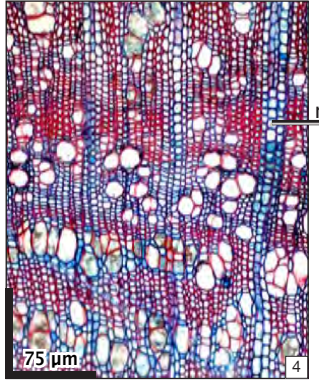


Antirrhinum majus, 100x

115 - 4-12 rays per mm

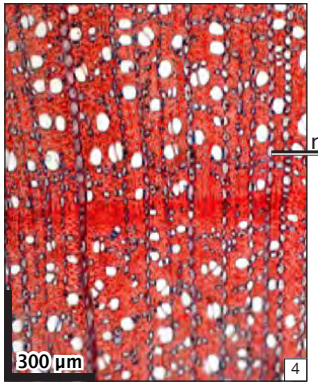


Artemisia arborescens, 100x

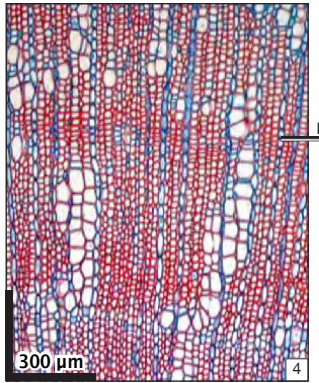


Salvia dominica, 200x

116.1 - 12-20 rays per mm

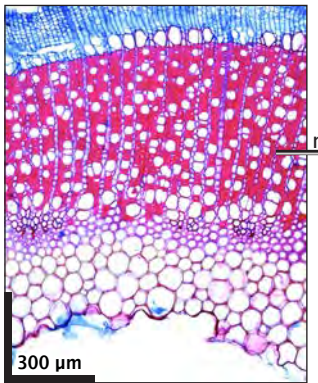


Viburnum tinus, 100x

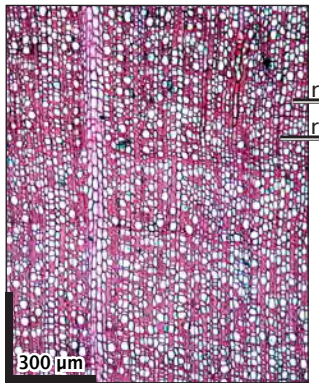


Euphorbia thompsonii, 100x

116.2 - More than 20 rays per mm



Lonicera xylosteum, 100x



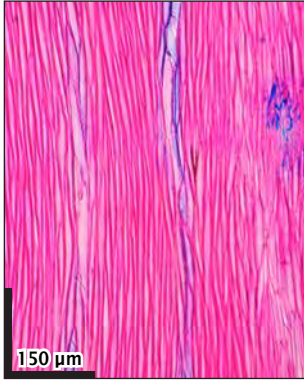
Vaccinium ovatum, 100x

Rays

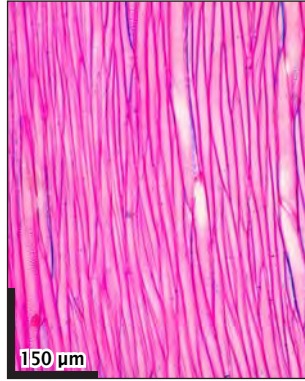
Xylem

Wood rayless

117 - Wood rayless



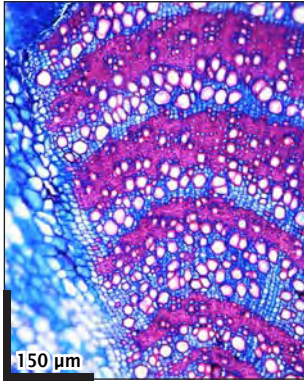
Lepidium sativum, 200x



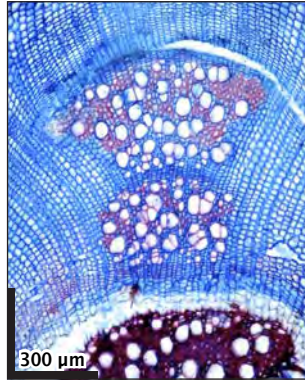
Rhinanthus glacialis, 200x

This feature applies to plants with a continuous xylem cylinder. See also figures in feature 59.1.

117.1 - Rays absent within the vascular bundles



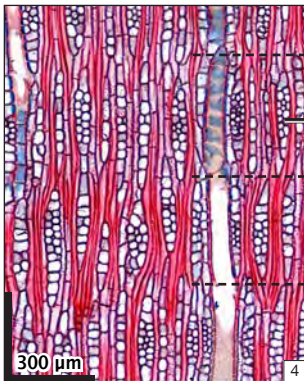
Pedicularis elongata, 200x



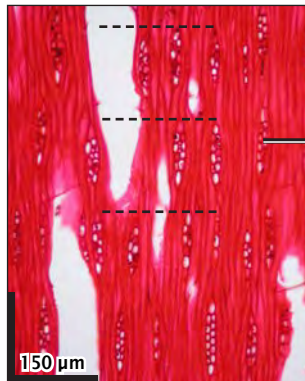
Nepeta discolor, 100x

Storied structure

118 - Rays storied



Diospyros kaki, 100x

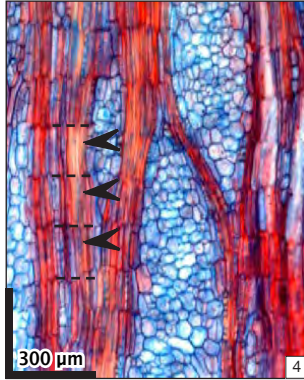


Elaeagnus rhamnoides, 200x

120 - Axial parenchyma and/or vessel elements storied



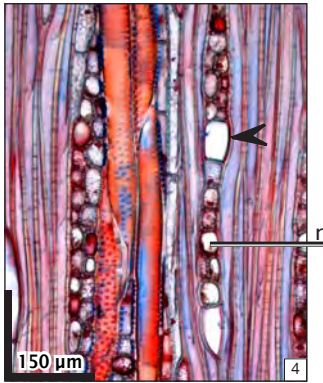
Genista fasselata, 100x



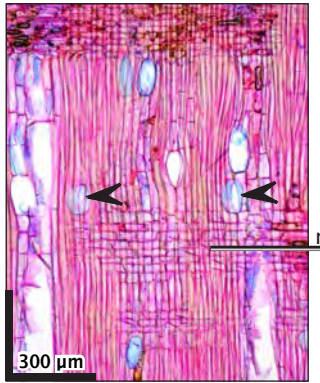
Ononis spinosa, 100x

Oil cells

124 - Oil cells associated with ray parenchyma



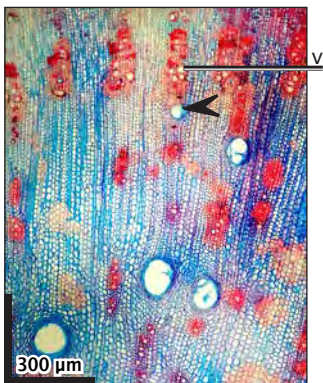
Laurus nobilis, 200x



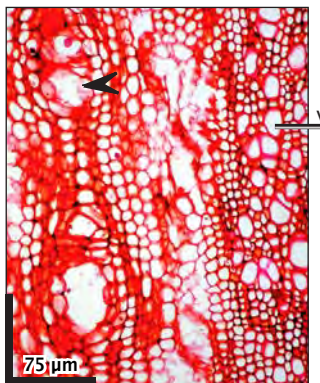
Machilus nanmu, 100x

Intercellular canals

129 - Axial canals



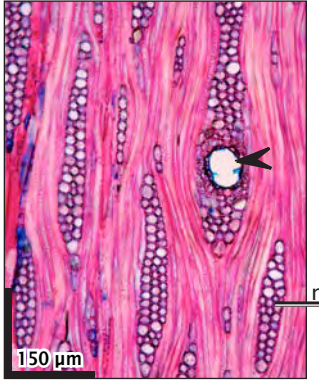
Inula helenium, 100x



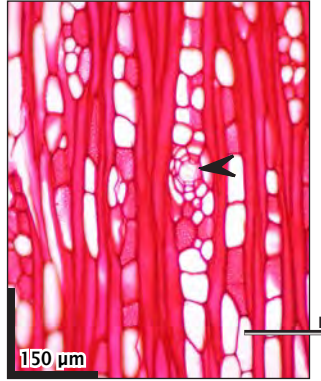
Carlina acaulis, 400x

Secretory elements - Crystals

130 - Radial canals

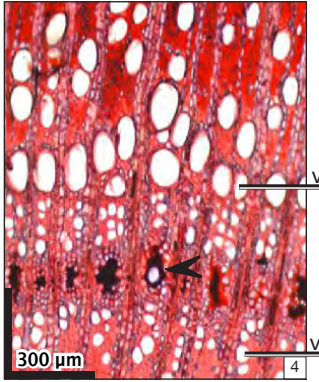


Pistacia atlantica, 200x

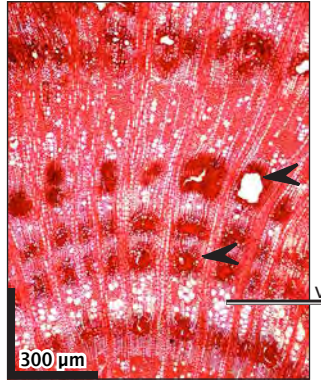


Euphorbia pulcherrima, 200x

131 - Intercellular axial canals of traumatic origin



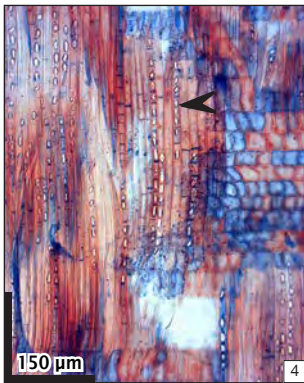
Prunus dulcis, 100x



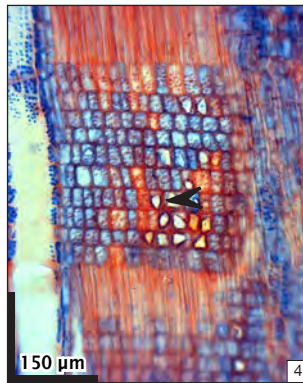
Prunus mahaleb, 100x

Crystal shape

136 - Prismatic crystals



Punica granatum, 200x



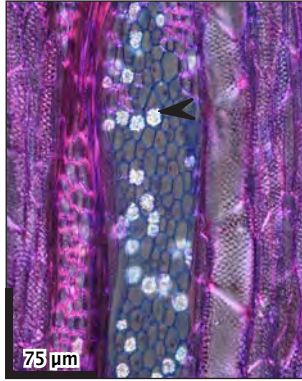
Ziziphus lotus, 200x

Solitary rhomboidal or octagonal crystals, which are birefringent in polarized light. The form of rhomboidal crystals varies. They can have 4 to 8 sides in face view (IAWA 1989).

144 - Druses



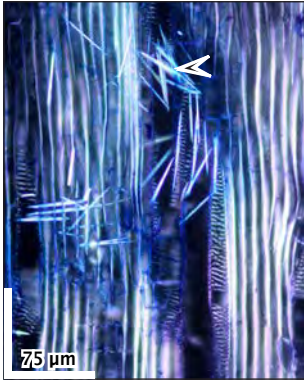
Atriplex glauca, 400x



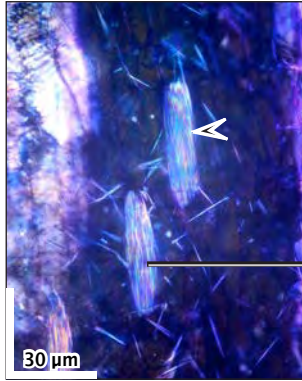
Sphaeralcea ambigua, 400x

Compound crystals with a star-shaped appearance. The size greatly varies (IAWA 1989).

149 - Raphides



Oenothera biennis, 400x

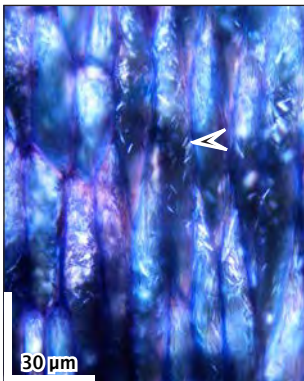


Boerhavia boissieri, 1000x

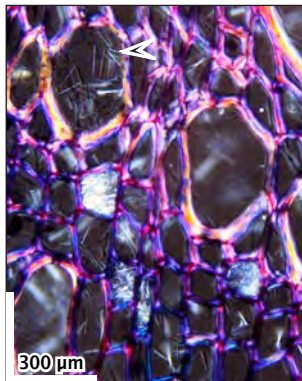
Long needle-like crystals with pointed ends. Raphides occur in bundles within chambers (IAWA 1989).

Raphides in chambers

150 - Acicular crystals



Stachys tibetica, 1000x



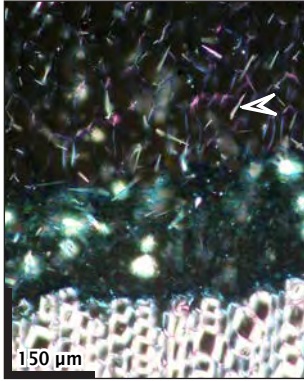
Rubia fruticosa, 100x

Small needle-like crystals, not occurring in bundles (IAWA 1989).

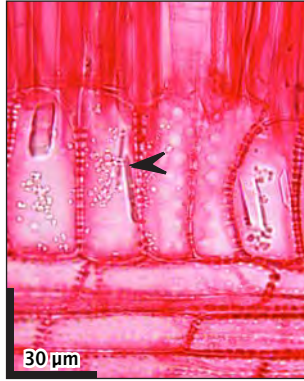
Crystals

Xylem

151 - Styloids and/or elongate crystals



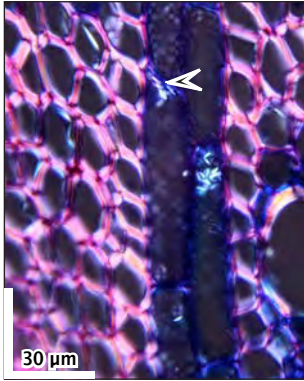
Asperula taygetea, 200x



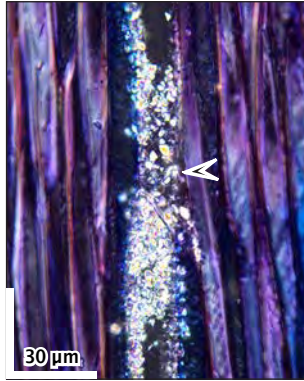
Ligustrum japonicum, 1000x

Needle-like crystals with square ends never occurring in bundles.

152 - Crystals of other shapes (mostly small)



Ferula communis subsp. *linkii*, 1000x

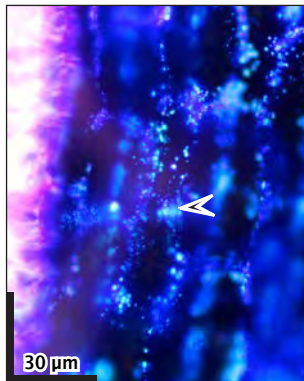


Traganum moquinii, 1000x

153 - Crystal sand



Atropa belladonna, 1000x



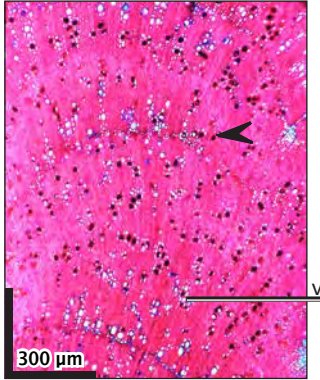
Ephedra gerardiana, 1000x

A granular mass composed by very small crystals.

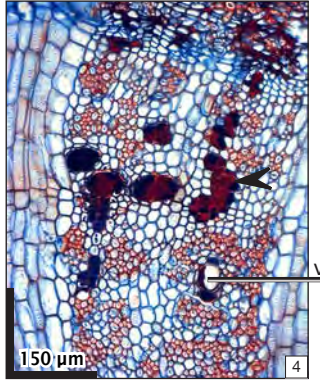
Cell content in different cells types

Cell content in vessels

154 (IAWA no. 58) - Gums and other deposits in vessels



Frankenia thymifolia, 100x

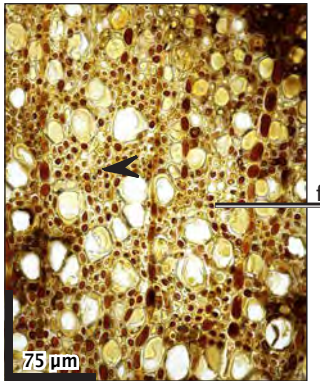


Ononis spinosa, 200x

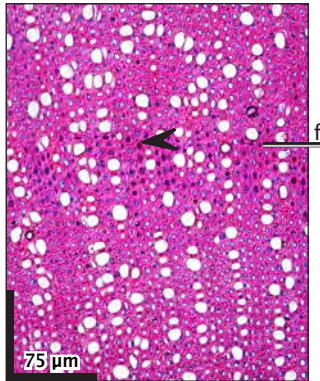
'Gums and other deposits' includes a wide variety of chemical compounds, which are variously coloured (e.g. white, yellow, red, brown, black) (IAWA 1989).

Cell content in fibres

154.1 - Deposits in fibres



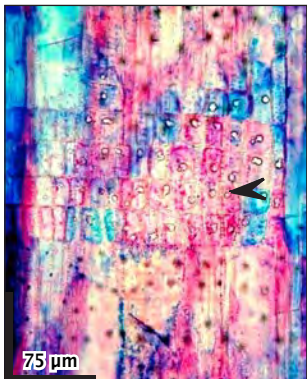
Arctostaphylos uva-ursi, 400x



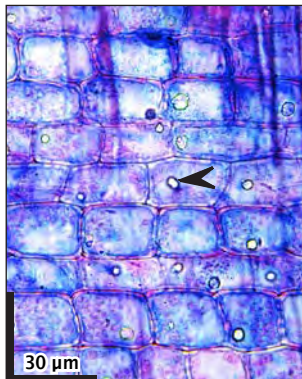
Hebe salicifolia, 400x

Cell content in ray cell

154.2 - Oil drops in ray cells



Nepenthes ampullaria, 400x



Hypericum canariense, 1000x

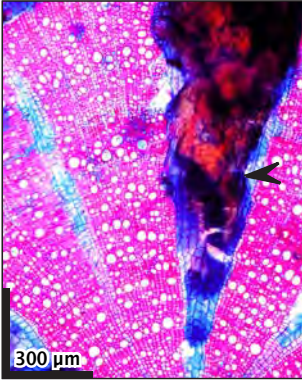
Oil drops do not appear in polarized light.

Cell content in different cell types

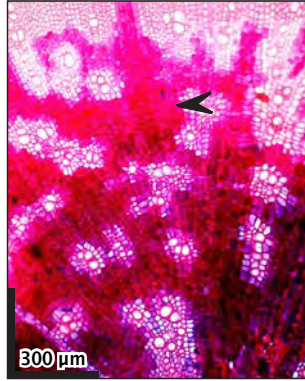
Xylem

Mucilage (slime)

154.3 - Mucilage



Sphaeralcea coccinea, 100x



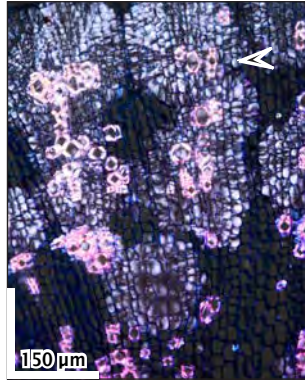
Cynoglossum creticum, 100x

Mucilage appears in normal light only. Mucilage disappears in polarized light.

154.4 - Mucilage-like cell content, bright in polarized light



Symphytum creticum, 100x



Symphytum creticum, 200x

7. Bark anatomical features



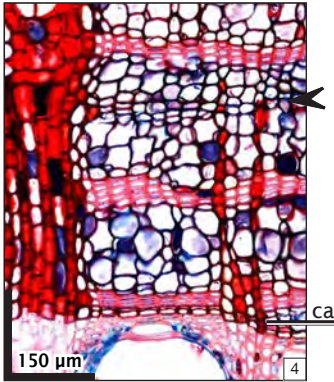
Glycyrrhiza glabra

Growth zones - Sieve elements

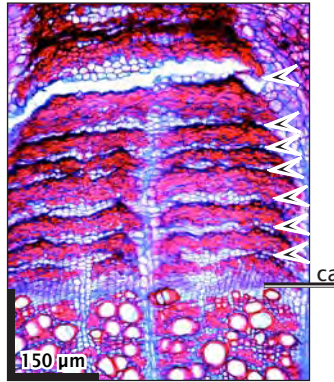
Phloem

Growth zones

B.1 - Growth zones



Vitis vinifera, 200x

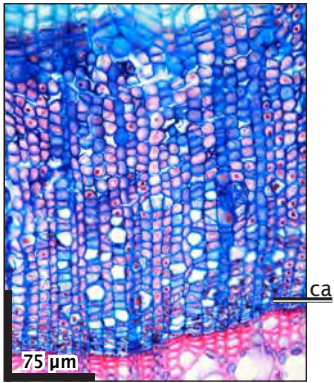


Astracantha echinus, 200x

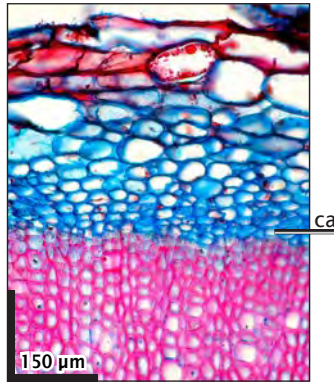
Growth zones are characterized by tangential layers of sieve elements, parenchyma cells and/or fibres.

Sieve elements as seen in cross section

B.2 - Sieve elements not distinct in cross section



Loniceria semenovii, 400x

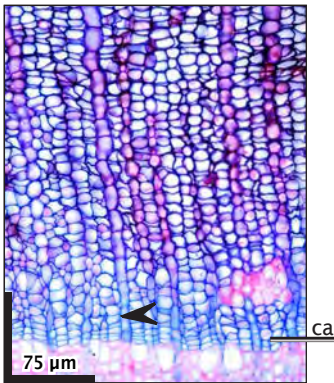


Rhinanthus antiquus, 200x

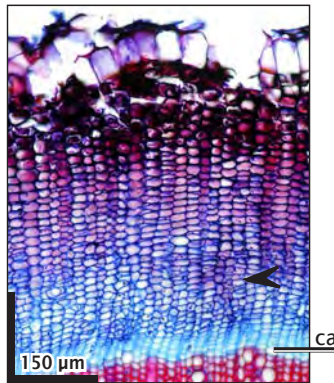
Sieve elements, companion cells and parenchyma cells are not or hardly differentiable.

Sieve element groupings in non-collapsed phloem

B.3 - Sieve elements mostly solitary



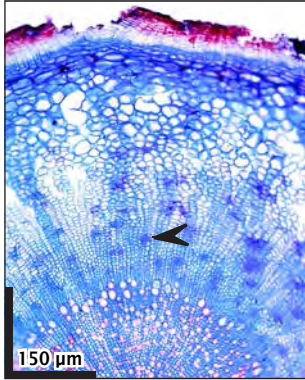
Hamamelis virginiana, 400x



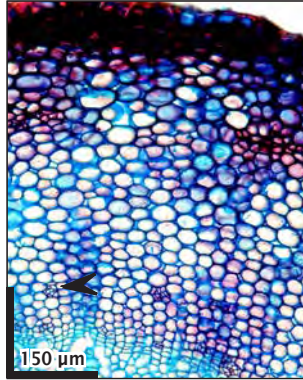
Phlomis lychnitis, 200x

Most of the sieve elements are completely surrounded by other cell types, mainly by parenchyma cells.

B.4 - Sieve elements in clusters



Pritzelago alpina, 200x

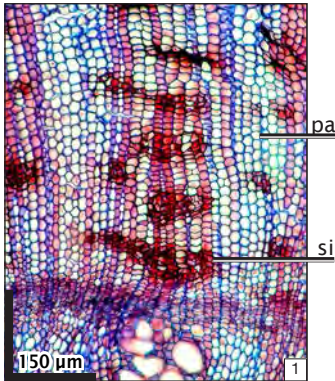


Swertia perennis, 200x

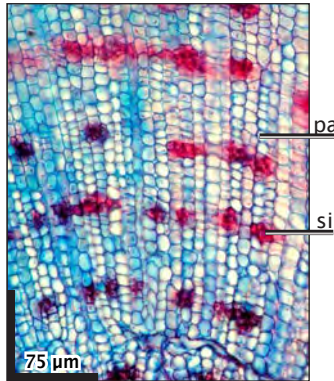
Groups of 3 or more sieve elements including companion cells having both radial and tangential contacts, and of common occurrence. Clusters can be arranged in radial lines or in groups between parenchyma cells.

Sieve element arrangement

B.5 - Sieve elements tangentially arranged



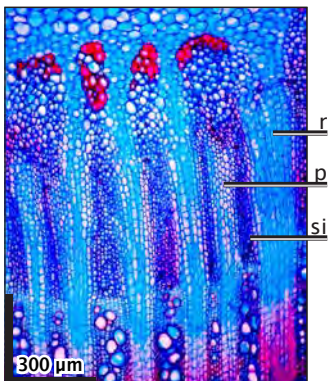
Thalictrum alpinum, 200x



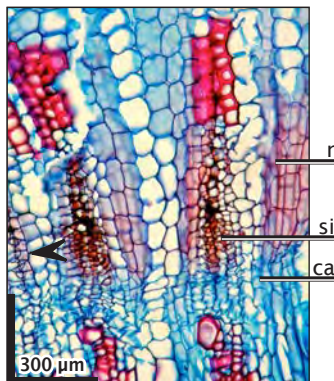
Taraxacum alpinum, 400x

Sieve elements (si) arranged perpendicular to the rays.

B.6 - Sieve elements radially arranged



Brassica nigra, 100x

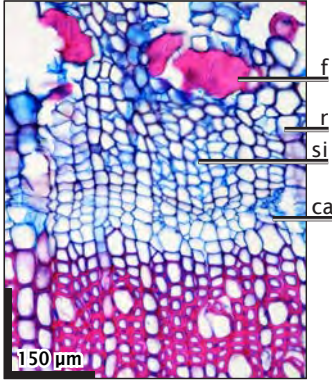


Limbarda crithmoides, 100x

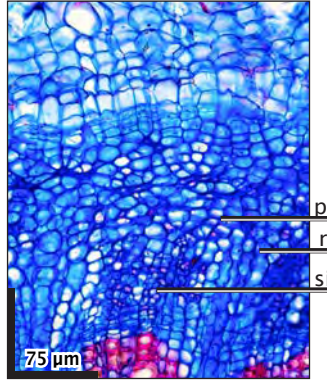
Solitary or groups of sieve elements (si) arranged in rows parallel to the rays (r).

Sieve elements

B.7 - Sieve elements without distinct pattern



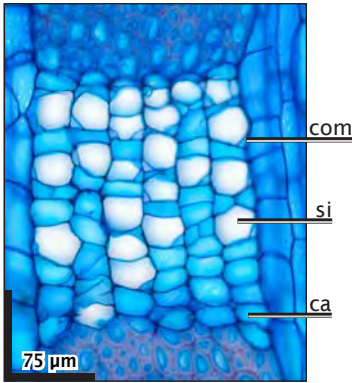
Viburnum tinus, 200x



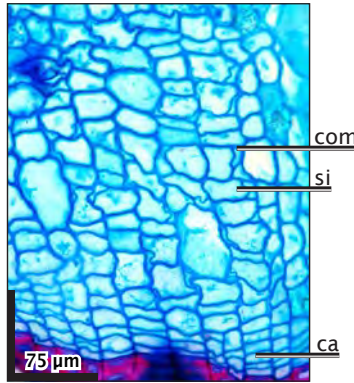
Campanula pallida, 400x

Sieve elements and companion cells

B.8 - Sieve elements and companion cells distinctly differentiated in cross section



Adansonia digitata, 400x

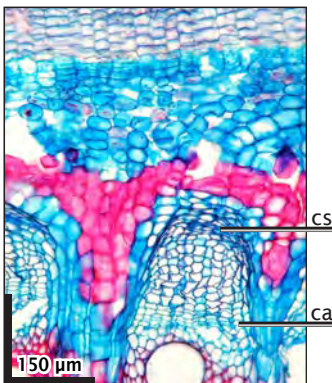


Parthenocissus quinquefolia, 400x

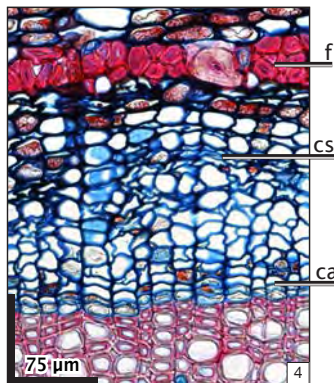
Sieve elements (si) are accompanied by one or more small companion cells (com).

Sieve elements collapsed

B.9 - Collapsed sieve elements



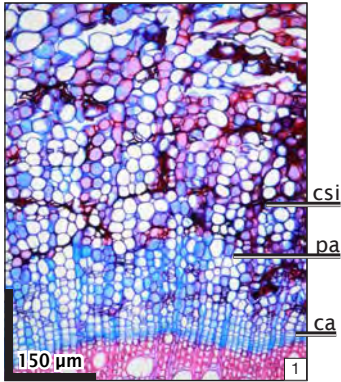
Cocculus pendulus, 200x



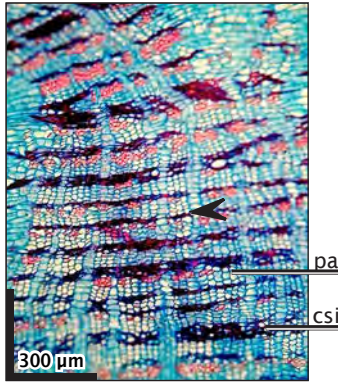
Ziziphus spina-christi, 400x

Collapsed sieve elements (csi) characterized by minimal lumen and squeezed cell walls.

B.9.1 - Collapsed sieve elements tangentially arranged



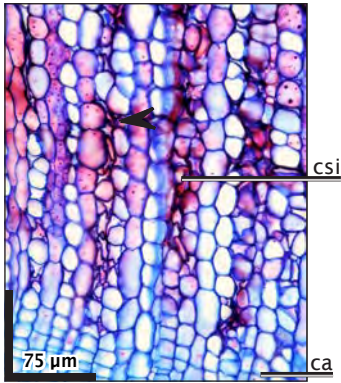
Cneorum tricoccon, 200x



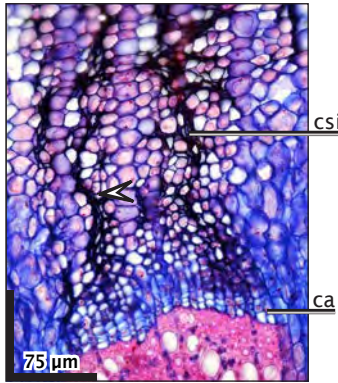
Lygos raetam, 100x

Collapsed sieve elements (csi) in distinct lines or bands perpendicular to rays. Lines can be straight or wavy.

B.9.2 - Collapsed sieve elements radially arranged



Calotropis procera, 400x

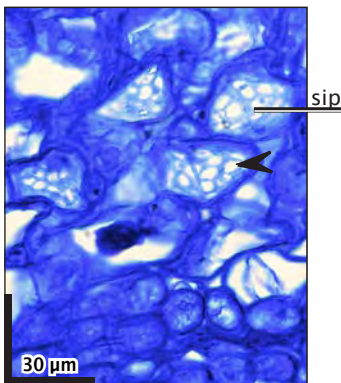


Convolvulus lineatus, 400x

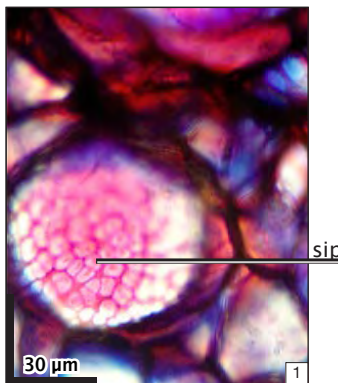
Collapsed sieve elements (csi) in distinct lines or bands parallel to rays. Lines can be straight or wavy.

Sieve plates

B.10 - Sieve plates visible in cross section



Robinia pseudoacacia, 1000x



Bryonia cretica subsp. dioica, 1000x

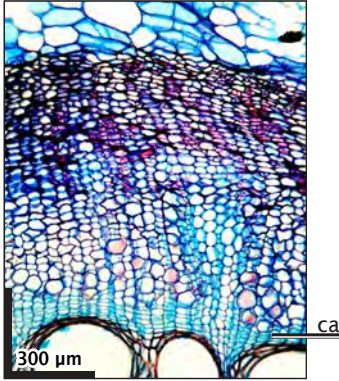
Sieve plates (sip) in sieve elements are characterized by a net-like structure. They can be observed only with high magnifications.

Sclerenchyma

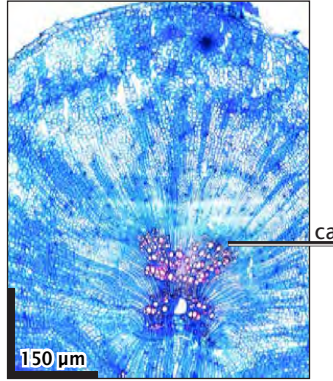
Phloem

Distinction of sclerenchyma cell type

B.11 - Sclerenchyma absent or extremely rare



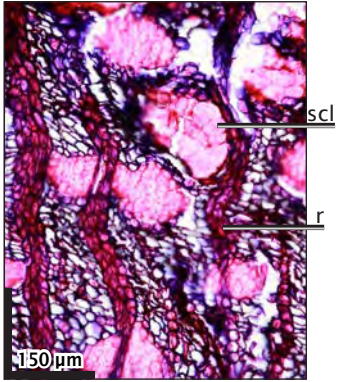
Bryonia verrucosa, 100x



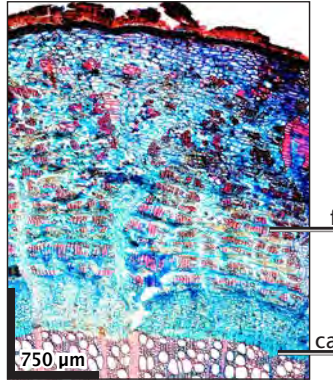
Corydalis tibetoalpina, 200x

The phloem consists only of not lignified sieve elements and axial parenchyma cells. Phloem rays can be present. Red stained cells are absent after astrablue and safranin staining.

B.12 - Sclerenchyma cells present (fibres and sclereids)

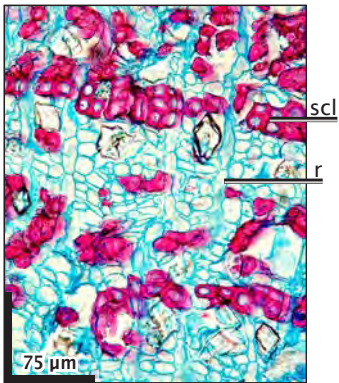


Fortunearia sinensis, 200x

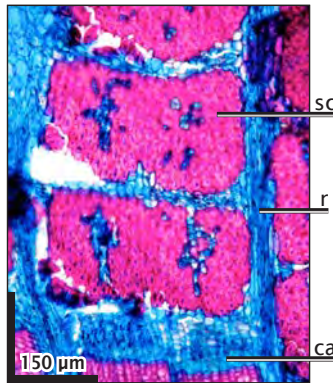


Hedera canariensis, 40x

B.13 - Fibres and sclereids cannot be distinguished in cross section



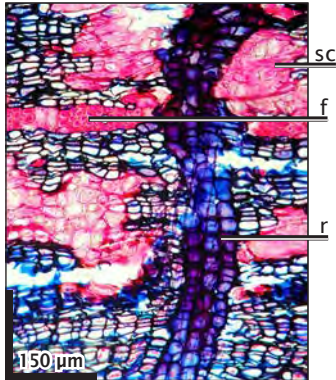
Aesculus hippocastanum, 400x



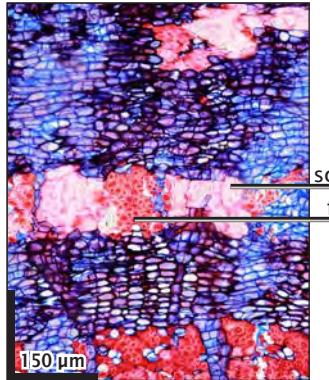
Chrysothamnus parryi, 200x

Observation of longitudinal sections is needed.

B.13.1 - Fibres and sclereids occur simultaneously



Acer pseudoplatanus, 200x

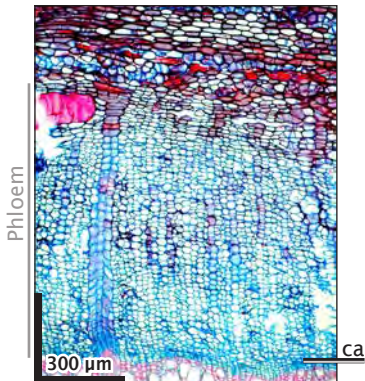


Fraxinus excelsior, 200x

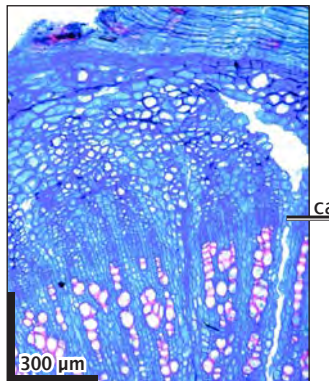
Fibres (f) as seen in cross section are characterized by regular round or angular outlines. A sclereid (sc) outline is normally irregular and its cell wall is layered.

Fibres absent

B.14 - Fibres absent in axial tissue



Staphylea pinnata, 100x

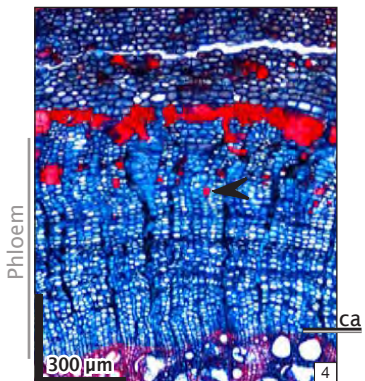


Euphorbia tibetica, 100x

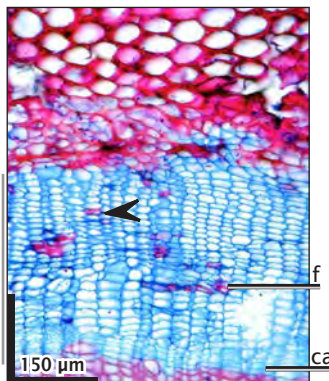
Phloem without fibres. Sclereids can occasionally be present after parenchyma cells sclerification.

Fibre groupings

B.15 - Fibres mostly solitary



Fraxinus angustifolia, 100x



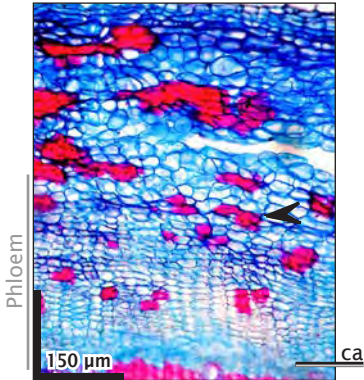
Phlox paniculata, 200x

Single fibres (f) are completely surrounded by other cell types.

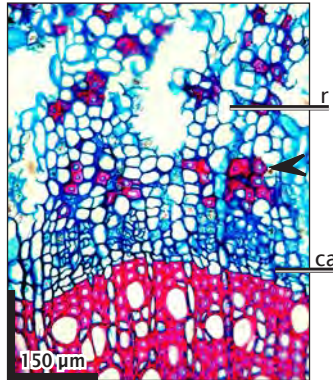
Fibres

Phloem

B.16 - Fibre clusters small (2-5 cells)



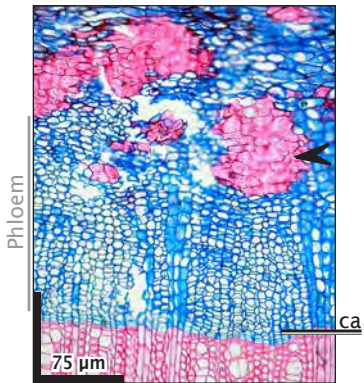
Biscutella laevigata, 200x



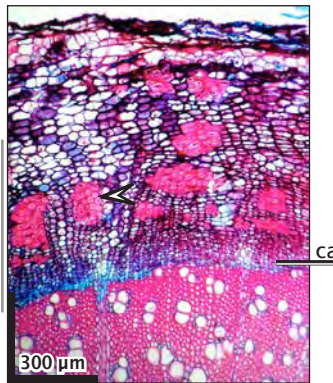
Fumana ericoides, 200x

Fibres (f) occur closely together in small groups.

B.17 - Fibre clusters large (more than 5 cells)



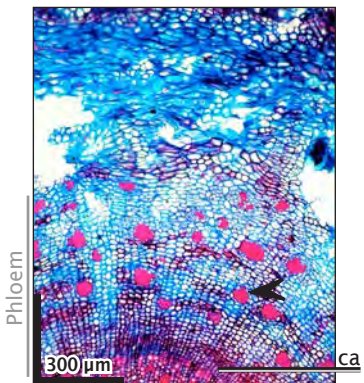
Ilex aquifolium, 400x



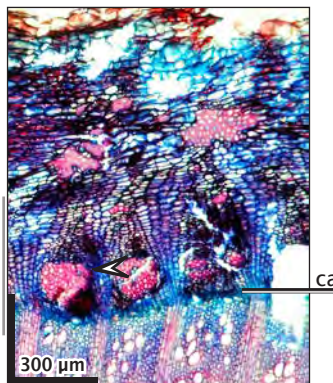
Ratibida columnifera, 100x

Groups of 5 or more fibres having both radial and tangential contacts, and of common occurrence.

B.17.1 - Fibre clusters round



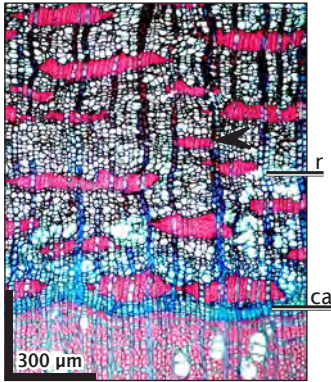
Armeria alliacea, 100x



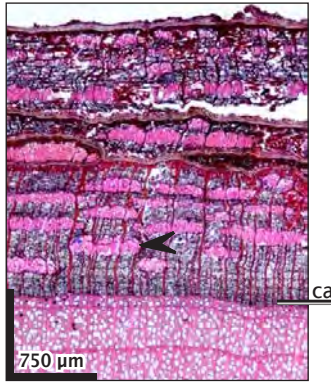
Carduus crispus, 100x

The outline of fibre clusters in cross section varies from round to oval.

B.17.2 - Fibre clusters tangentially elongated



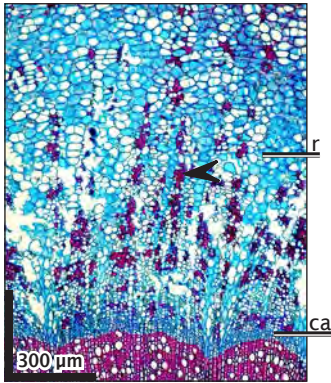
Ostrya carpinifolia, 100x



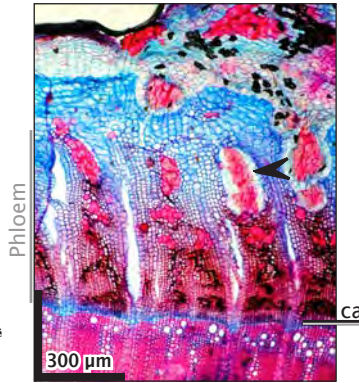
Crataegus monogyna, 40x

Fibre clusters may or may not encompass rays (r).

B.17.3 - Fibre clusters radially elongated



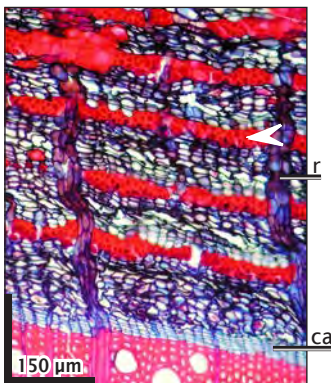
Fumana ericoides, 100x



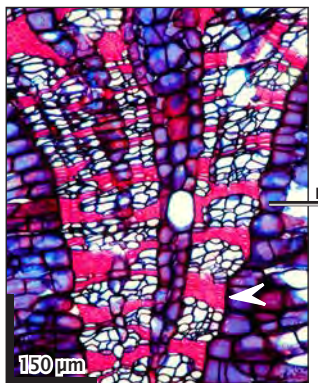
Cleome isomeris, 100x

Fibre arrangement

B.17.4 - Fibres in tangential bands more than 3 cells wide



Acer monspessulanus, 200x



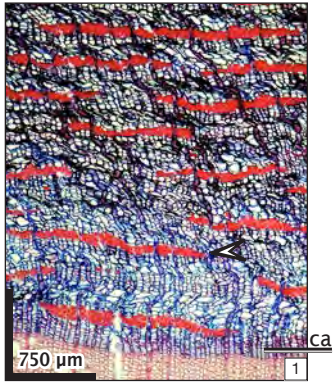
Liriodendron tulipifera, 200x

Bands with variable fibre densities are more or less continuous. In most cases the fibre bands encompass the rays (r).

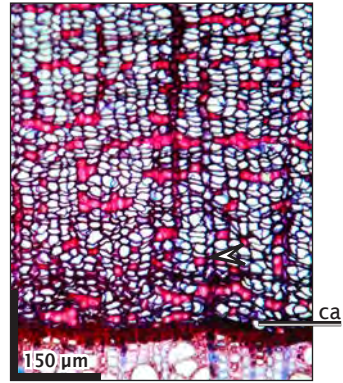
Fibres

Phloem

B.18 - Fibres in tangential bands less than 3 cells wide

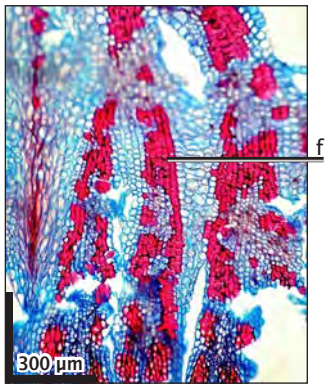


Castanea sativa, 40x

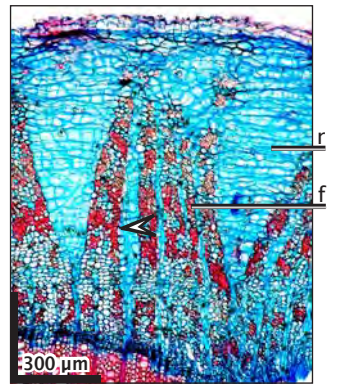


Arbutus andrachne, 200x

B.19 - Radially arranged fibres



Coincya monensis subsp. *cheiranthos*, 100x

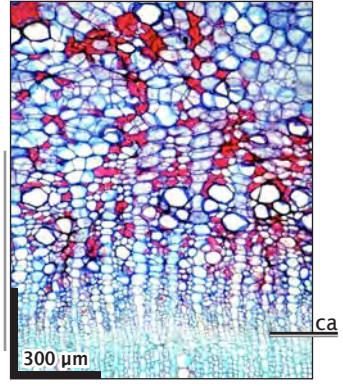


Cannabis sativa, 100x

B.20 - Irregularly dispersed fibres



Sorbus aria, 100x



Euphorbia canariensis, 100x

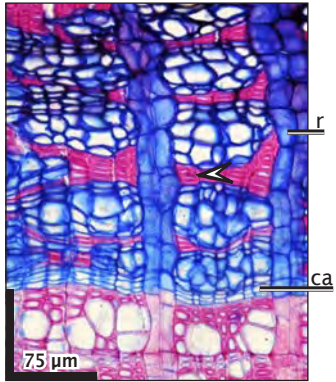
Single fibres are arranged in irregular patterns.

Phloem

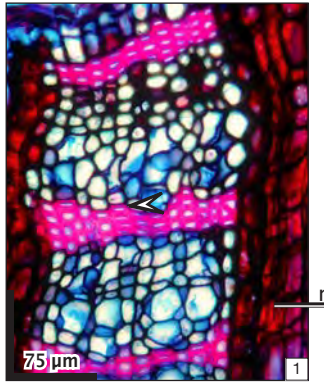
Phloem

Fibre shape as seen in cross section

B.21 - Fibres square or rectangular



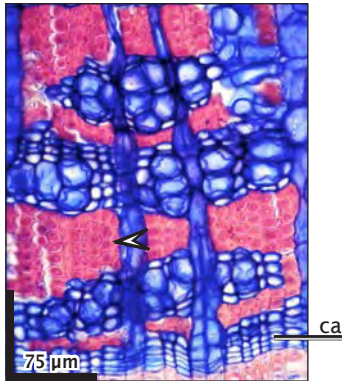
Liriodendron tulipifera, 400x



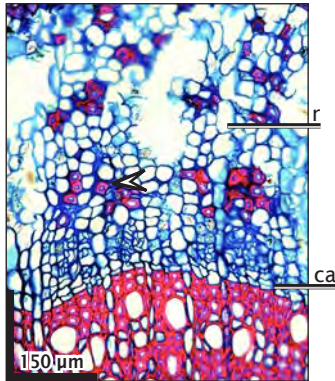
Vitis vinifera, 400x

Fibre outline square to rectangular.

B.22 - Fibres polygonal



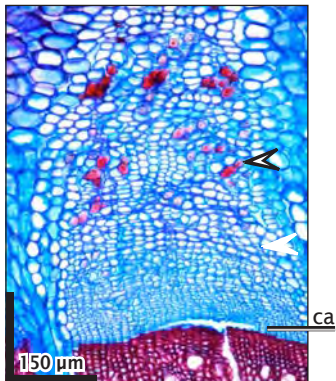
Magnolia acuminata, 400x



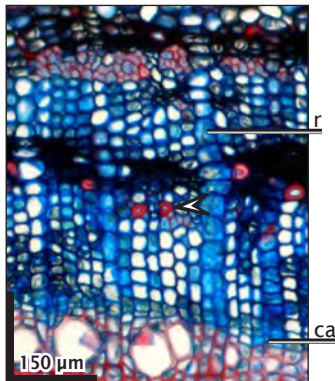
Fumana ericoides, 200x

Fibre outline angular to polygonal.

B.23 - Fibres round



Ephedra viridis, 200x



Spartium junceum, 200x

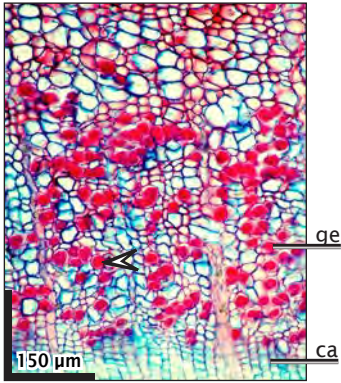
Fibre outline round.

Fibres - Sclereids

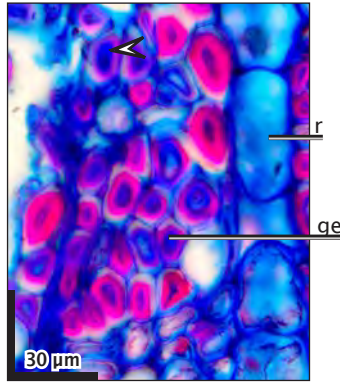
Phloem

Gelatinous fibres

B.24 - Gelatinous fibres



Morus alba, 200x

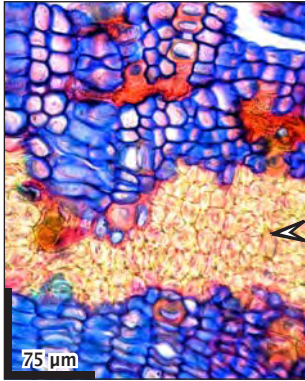


Daphne cneorum, 1000x

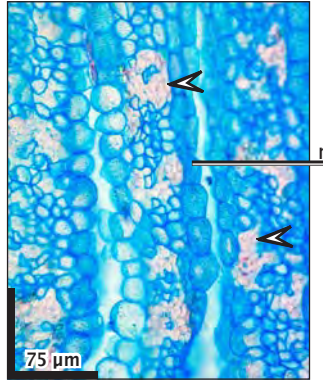
Mature fibres with an innermost unlignified layer (similar to the gelatinous layer in xylem tension wood fibres). Gelatinous fibres (ge) may be solitary, irregularly dispersed or in groups.

Fibre wall structure

B.25 - Sclerenchyma cell walls not red stained by safranin



Thalictrum foetidum, 400x

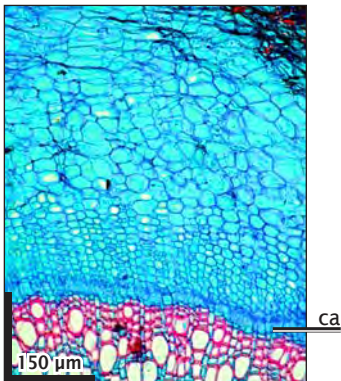


Cicer microphyllum, 400x

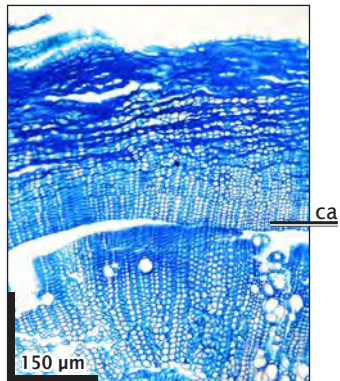
Fibre cell wall not red stained after astrablue and safranin staining. Fibres can be either unstained or blue stained.

Sclereids absent

B.26 - Sclereids absent in axial tissue



Polygala pedemontana, 200x

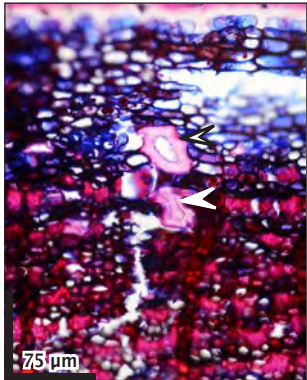


Potentilla multifida, 200x

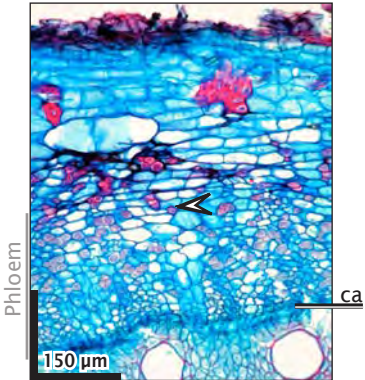
Phloem without sclereids. Fibres can be present.

Sclereid groupings

B.27 - Sclereids mostly solitary



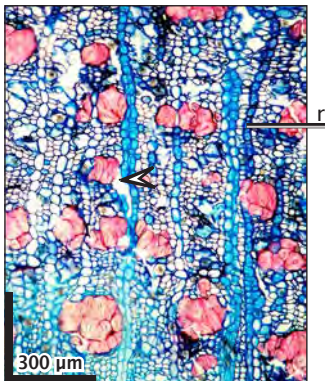
Eucalyptus gomphocephala, 400x



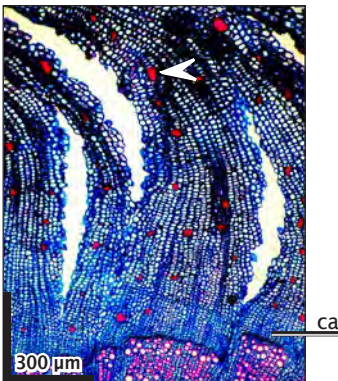
Glycine max, 200x

Single sclereids are completely surrounded by other cell types.

B.28 - Sclereid clusters small (2-5 cells)



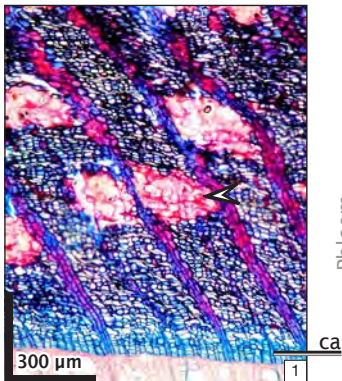
Viburnum opulus, 100x



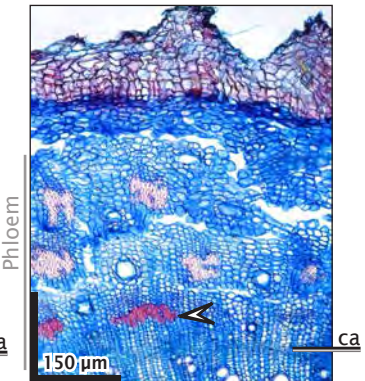
Armeria alpina, 100x

Sclereids occur closely together in small groups. The size of the clusters greatly varies.

B.29 - Sclereid clusters large (more than 5 cells)



Betula pendula, 100x



Ajania tibetica, 200x

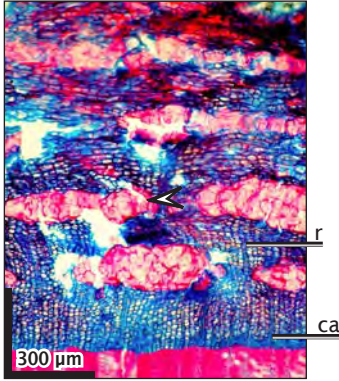
Groups of 5 or more sclereids are irregularly dispersed.

Sclereids

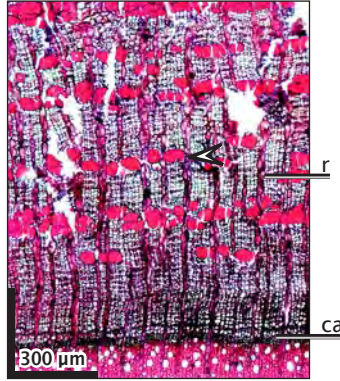
Phloem

Sclereid clusters arrangement

B.29.1 - Sclereid clusters tangentially arranged



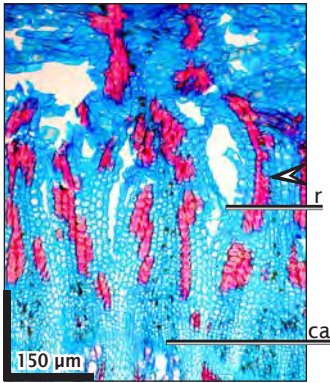
Phillyrea latifolia, 100x



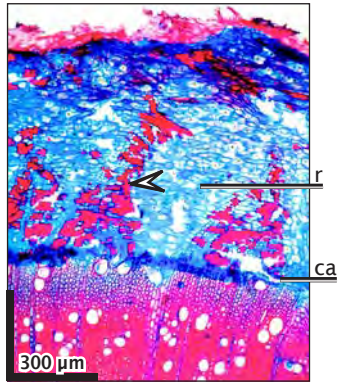
Canotia holocantha, 100x

Single groups of sclereid arranged perpendicular to the rays (r).

B.29.2 - Sclereid clusters radially arranged



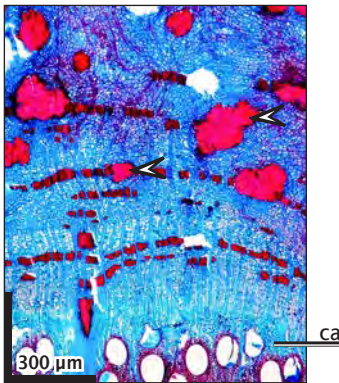
Rhyncosinapis spp., 200x



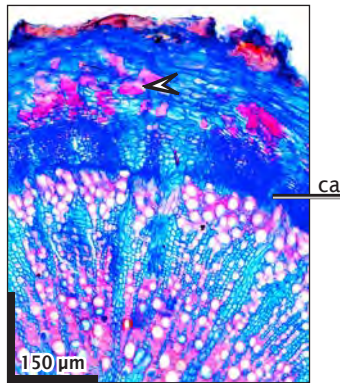
Ruta montana, 100x

Single groups of sclereid arranged parallel or within the rays (r).

B.29.3 - Sclereid clusters irregularly dispersed



Quercus pyrenaica, 100x

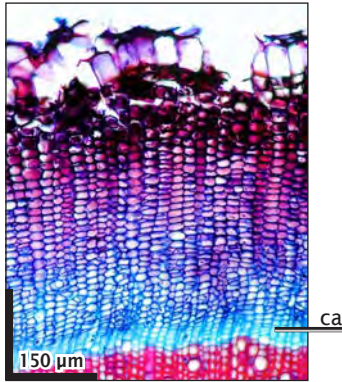


Thesium arvense, 200x

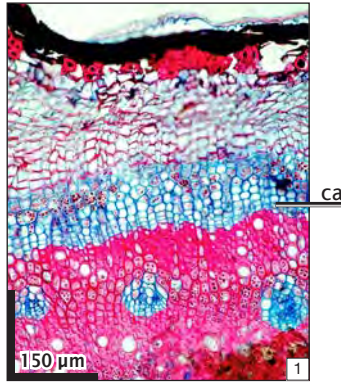
Groups of sclereids irregularly dispersed.

Phloem rayless

B.30 - Phloem rayless



Phlomis lychnitis, 200x

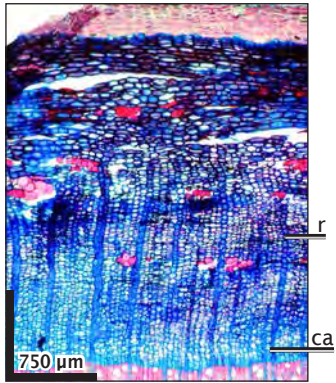


Simmondsia chinensis, 200x

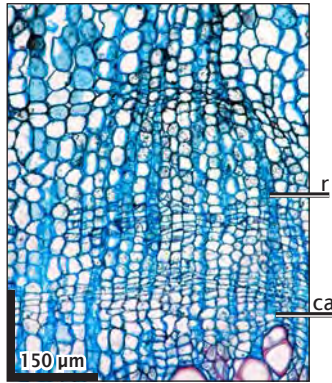
Rays absent or not differentiated from axial tissues.

Ray course

B.31 - Ray course straight



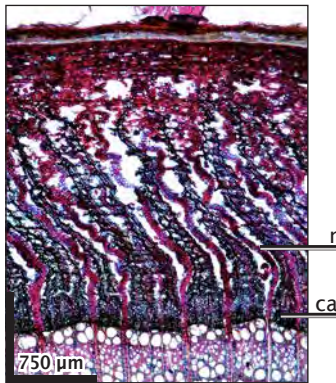
Ligustrum ovalifolium, 40x



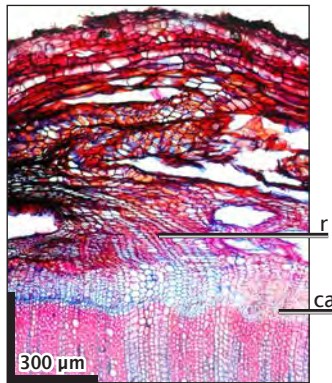
Rumex hydrolapathum, 200x

Rays (r) straight throughout the entire phloem.

B.32 - Ray course undulated or wavy



Prunus amygdaliformis, 40x



Echinops transcaucasicus, 100x

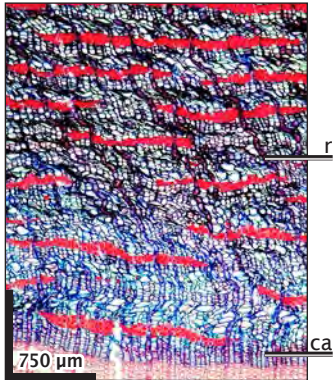
Rays (r) wavelike or bent throughout the collapsed phloem.

Rays

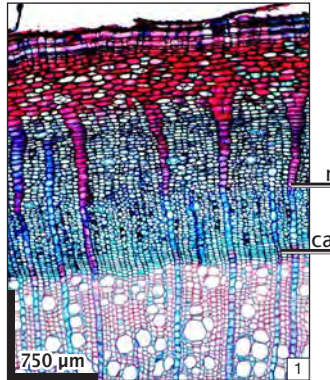
Phloem

Ray width in the cambial zone

B.33 - Rays uniseriate



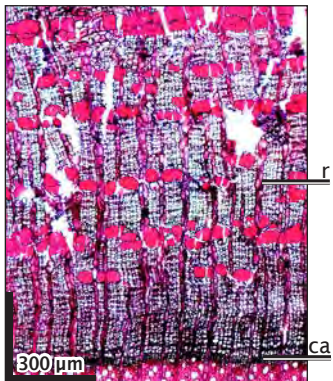
Castanea sativa, 40x



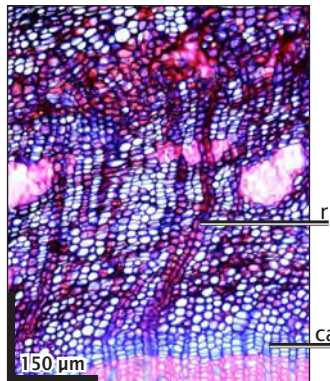
Hypericum calycinum, 40x

Features from B33 to B36 can occur in combination (e.g., in *Quercus*).

B.34 - Rays uniseriate to 3-seriate

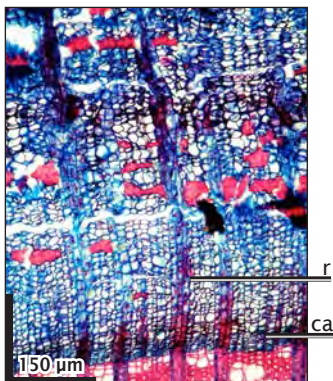


Canotia holacantha, 100x

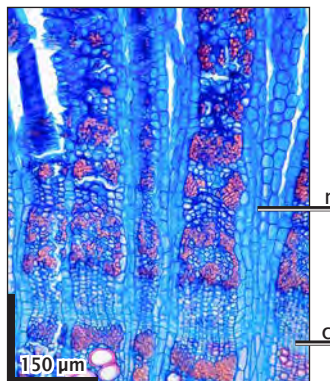


Diospyros lotus, 200x

B.35 - Larger rays commonly 4- to 10-seriate



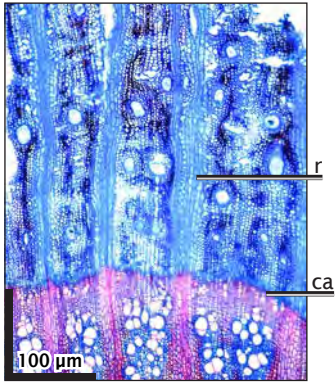
Sambucus nigra, 200x



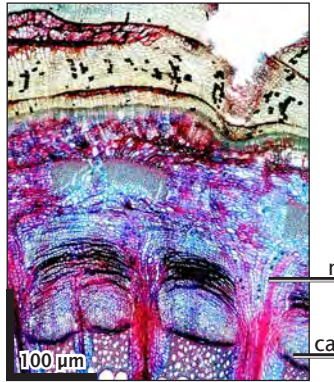
Astragalus oplites, 200x

This feature applies also to ray-like zones between vascular bundles.

B.36 - Larger rays commonly more than 10-seriate



Ligusticum lucidum, 100x

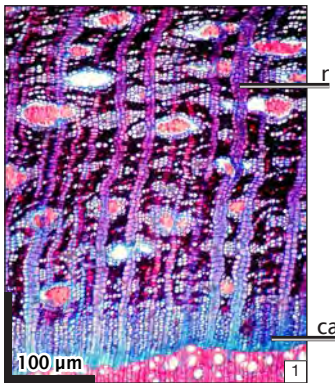


Aristolochia macrophylla, 40x

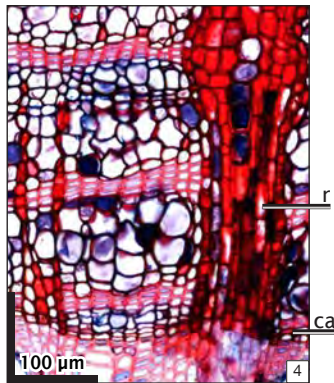
This features applies also to ray-like zones between vascular bundles. For rays within the vascular bundles see feature 96.0.

Ray dilatation

B.37 - Ray dilatation absent or extremely rare



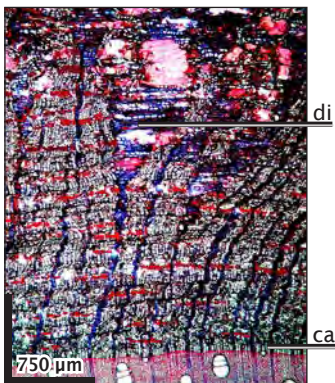
Rhamnus crenulata, 100x



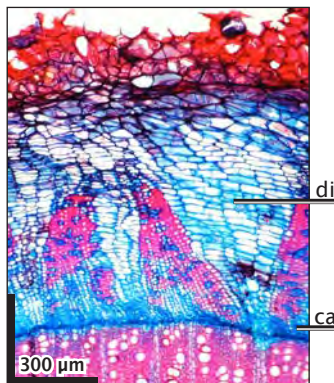
Vitis vinifera, 200x

Rays (r) with approximately the same width from the cambium (ca) throughout the phloem.

B.38 - Some rays dilated



Juglans regia, 40x



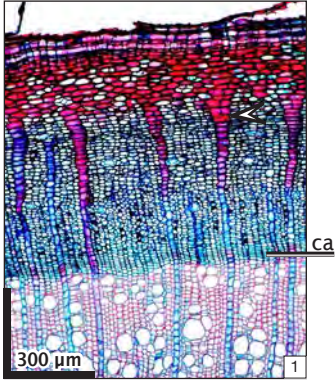
Carduus acicularis, 100x

A few rays distinctly dilated (di) towards the outside of the phloem. Most of the rays do not enlarge.

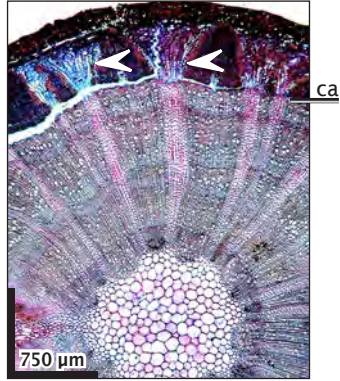
Rays

Phloem

B.39 - Most rays dilated



Hypericum calycinum, 100x

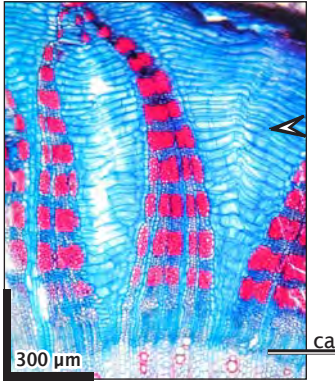


Phagnalon sordidum, 40x

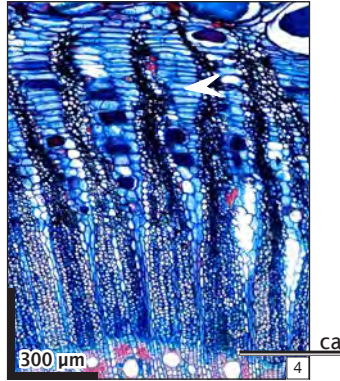
Most of rays distended towards the outside of the phloem.

Rays not lignified

B.40 - Rays not lignified



Malva parviflora, 100x

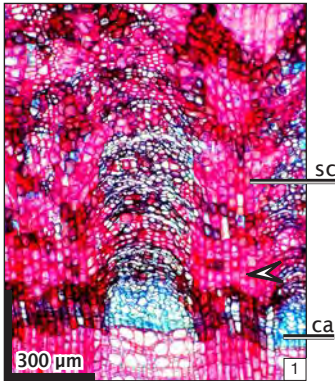


Alhagi maurorum, 100x

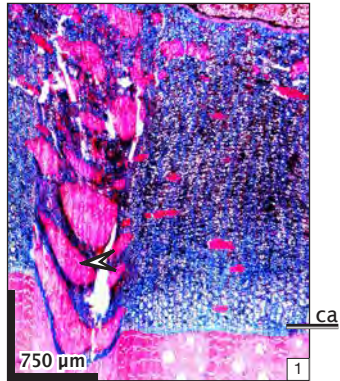
Ray cell walls remain blue-stained after astrablue and safranin staining.

Ray: cellular composition

B.41 - Rays with sclereids



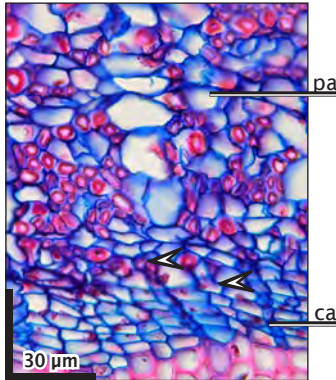
Platanus wrightii, 100x



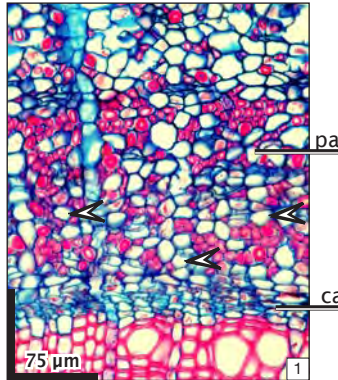
Quercus ilex, 40x

Axial parenchyma arrangement

B.42 - Axial parenchyma diffuse (irregularly dispersed)



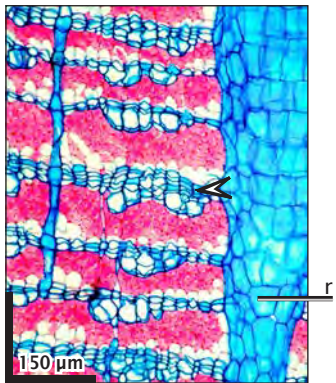
Daphne pontica, 1000x



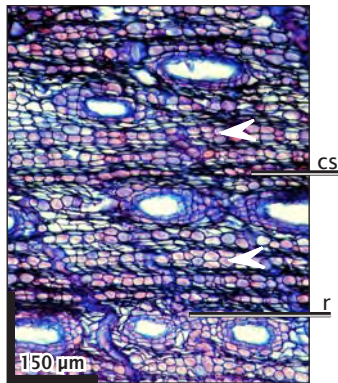
Daphne pontica, 400x

Axial parenchyma (pa) cells mostly isolated or in small aggregates, not in a regular pattern.

B.43 - Axial parenchyma in tangential lines/rows/bands

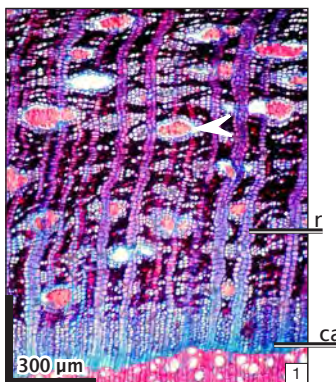


Tilia cordata, 200x

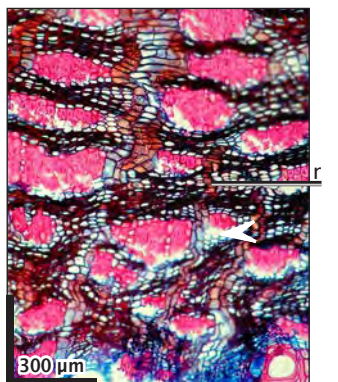


Rhus typhina, 200x

B.44 - Axial parenchyma sheath around sclerenchyma clusters



Rhamnus crenulata, 100x



Ziziphus obtusifolia, 100x

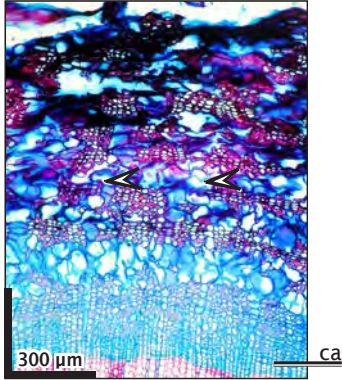
A layer of not lignified parenchyma cells surrounds fibre groups.

Axial parenchyma - Secretory elements

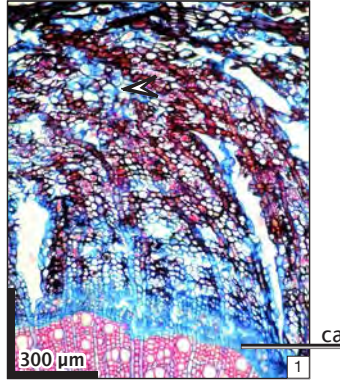
Phloem

Axial parenchyma dilatation

B.45 - Axial parenchyma cells dilated



Daphne laureola, 100x

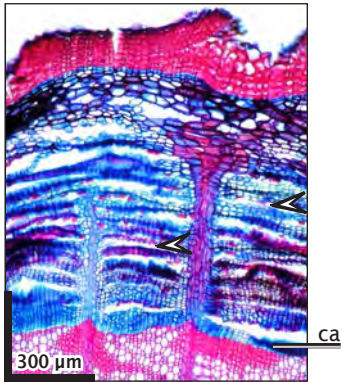


Thymelaea dioica, 100x

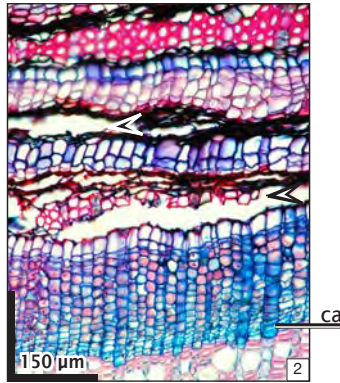
Axial parenchyma cells are distinctly distended towards the outside of the phloem.

Ring shake

B.46 - Ring shake present



Berberis julianae, 100x

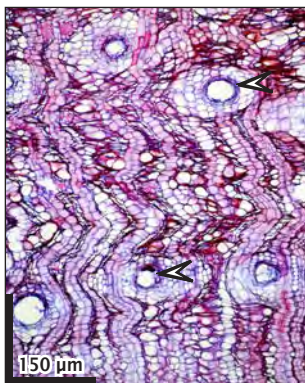


Lonicera etrusca, 200x

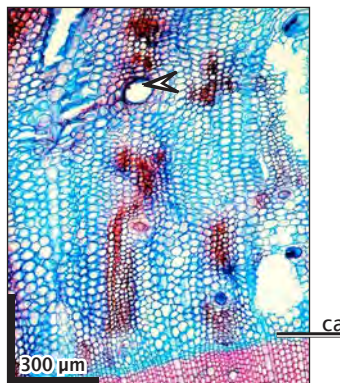
Layers of sieve elements, parenchyma and fibres are tangentially split. Splitting might be partially an artefact caused by sectioning.

Intercellular canals

B.47 - Axial secretory ducts surrounded by epithelial cells (excretion cells)



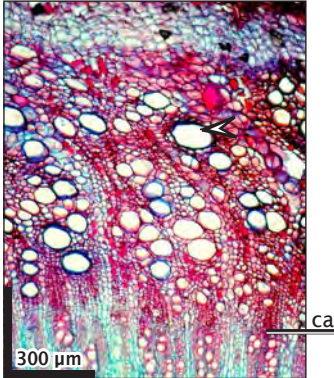
Boswellia sacra, 200x



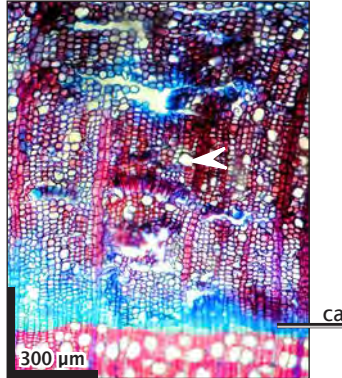
Angelica sylvestris, 100x

The feature includes all canals which produce resin, gum and oil by epithelial cells.

B.48 - Axial canals without epithelial cells (laticifers)



Euphorbia marschalliana, 100x

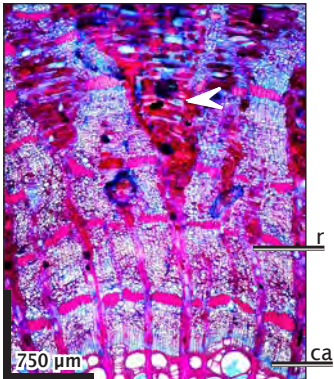


Hydrangea heteromalla, 100x

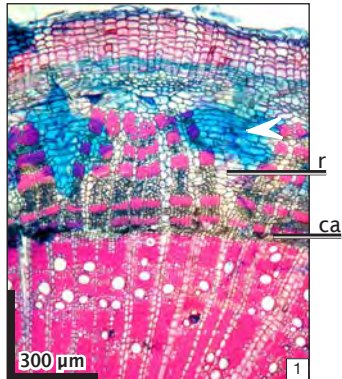
The feature includes all canals which produce latex (milky substances), as visible in freshly collected living material.

Mucilage and cell content

B.49 - Mucilage in rays



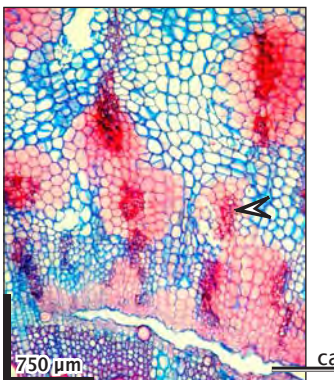
Parthenocissus tricuspidata, 40x



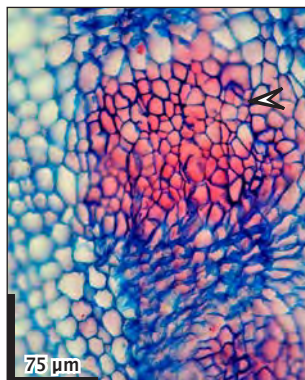
Malva canariensis, 100x

Axial mucilage cells are difficult to distinguish from laticifers in cross section. Here we mention only those in rays (r).

B.50 - Mucilage in and/or around sieve elements



Cichorium intybus, 40x



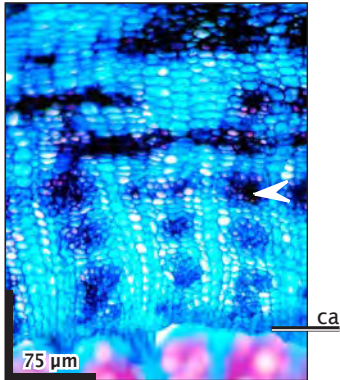
Crepis tectorum, 400x

Mucilage occurs around sieve elements or in any other cellular context. Mucilage cells are not differentiated from other cells.

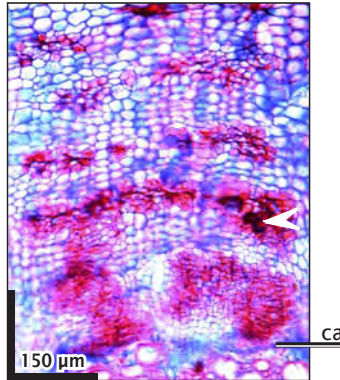
Secretory elements

Phloem

B.51 - Dark staining substances in sieve elements



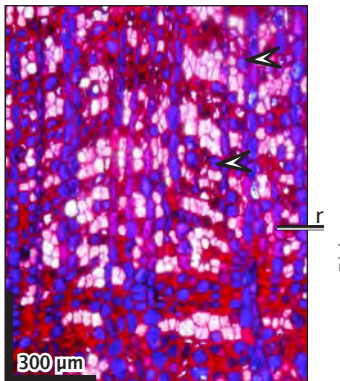
Picris hieracioides, 400x



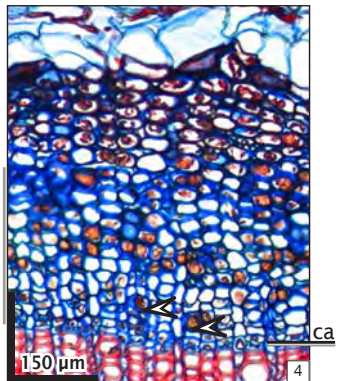
Andryala ragusina, 200x

Deposits occur exclusively in non-functional, mostly collapsed sieve elements.

B.52 - Dark staining substances in axial parenchyma cells and/or in rays



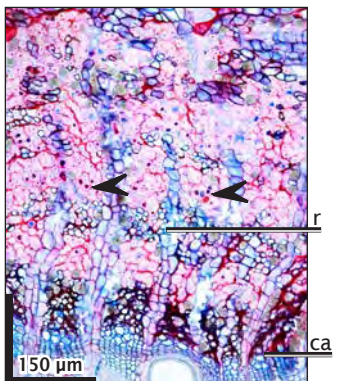
Artemisia genipi, 100x



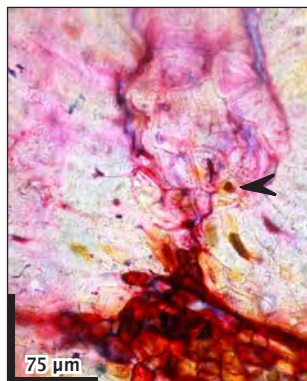
Teucrium creticum, 200x

Dark stained deposits occur mostly in parenchyma cells.

B.53 - Deposits in sclerenchyma cells



Calligonum azel, 200x

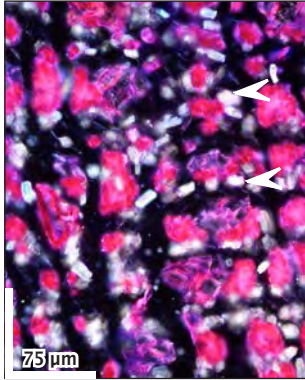


Nothofagus antarctica, 400x

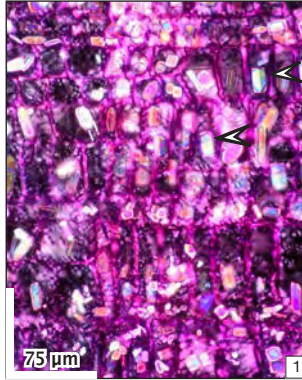
Crystal types

B.54 - Crystals absent

B.55 - Prismatic crystals



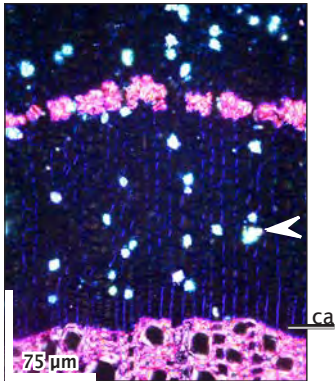
Eucalyptus globulosus, 400x



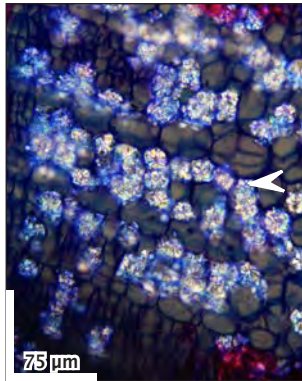
Marrubium alyssoides, 400x

Solitary rhomboidal or octahedral crystals, which are birefringent under polarized light. The form of rhomboidal crystals varies. They can have 4 to 8 sides in face view.

B.56 - Druses



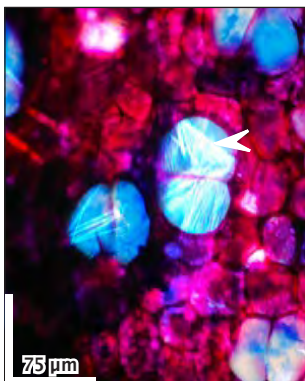
Lonicera pyrenaica, 400x



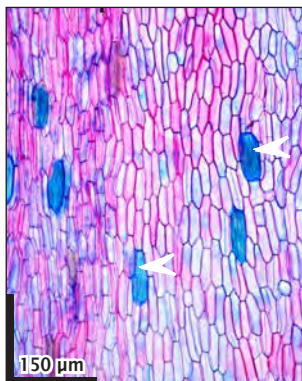
Fumana procumbens, 400x

Compound crystals with a star-shaped appearance. The size greatly varies.

B.57 - Raphides



Ludwigia grandiflora, 400x

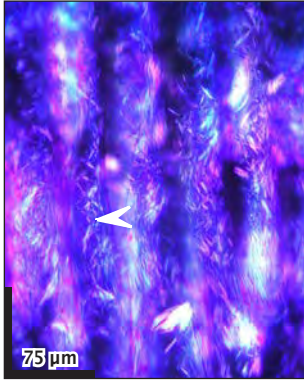


Epilobium latifolium, 200x

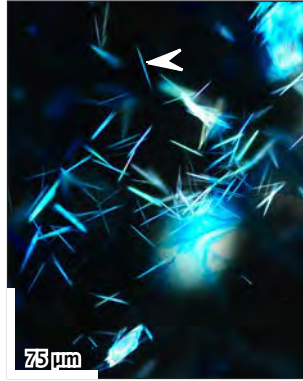
Long needle-like crystals with pointed ends. Raphides occur in bundles within chambers.

Crystals

B.58 - Acicular crystals



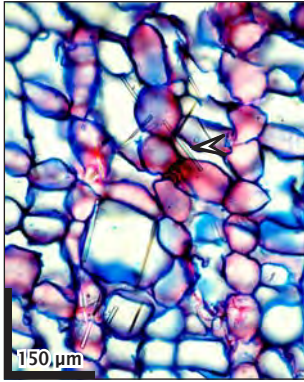
Stachys tibetica, 400x



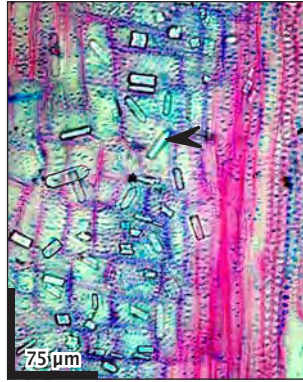
Impatiens balfourii, 400x

Needle-like crystals with pointed ends, which never occur in bundles and chambers.

B.59 - Styloids and/or elongated crystals



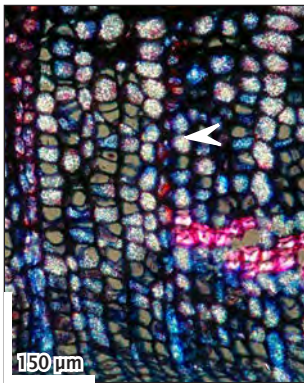
Actinidia deliciosa, 200x



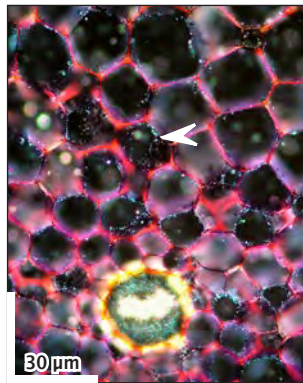
Ballota acetabulosa, 400x

Needle-like crystals with square ends. They never occur in bundles and chambers.

B.60 - Crystal sand



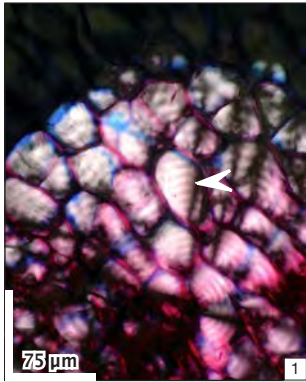
Olea europaea, 200x



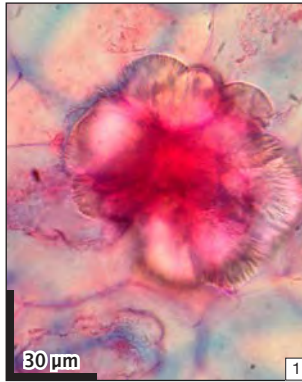
Davallia canariensis 1000x
Pteridophyta

A granular mass composed of very small crystals.

B.61 - Crystals of other shapes



Cichorium intybus, 400x

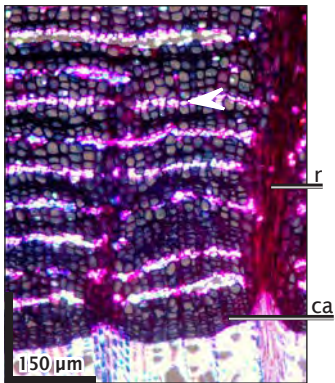


Peucedanum ostruthium, 1000x

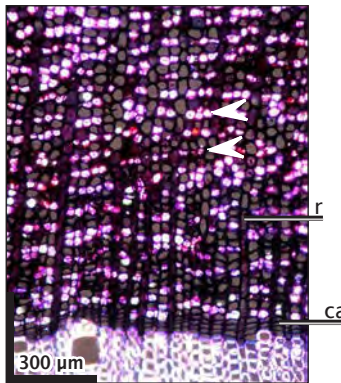
Crystal like structures which are birefringence in polarized light.

Crystal arrangement

B.62 - Crystals in tangential lines



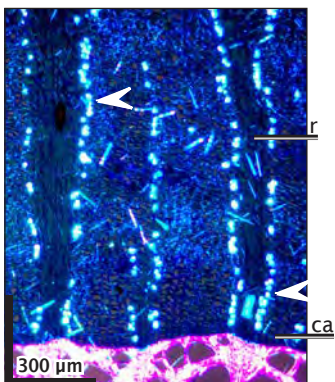
Ribes petraeum, 200x



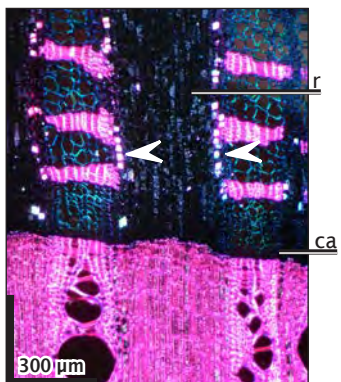
Punica granatum, 100x

Crystals forming tangentially elongated groups or tangential bands.

B.63 - Crystals in radial lines



Parthenocissus inserta, 100x



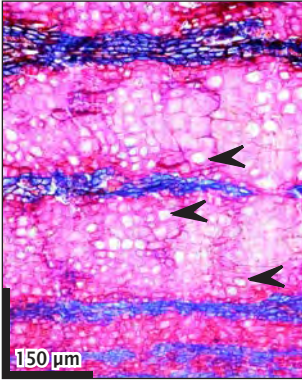
Vitis vinifera, 100x

Crystals arranged in radial lines. The term includes radial lines of crystals in and along rays (r).

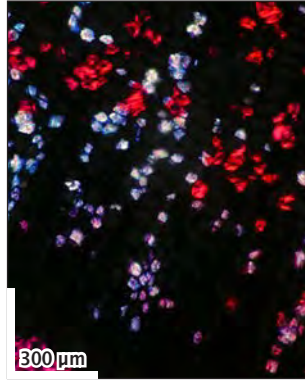
Crystals

Phloem

B.64 - Crystals irregularly dispersed

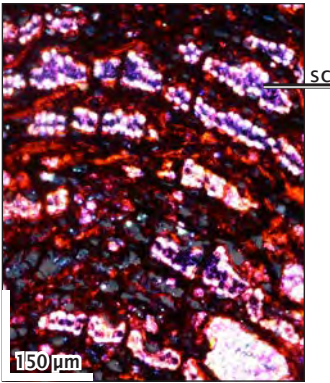


Celtis australis, 200x

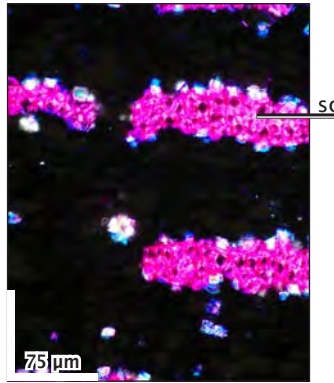


Fumana procumbens, 100x

B.65 - Crystals surround sclereid clusters



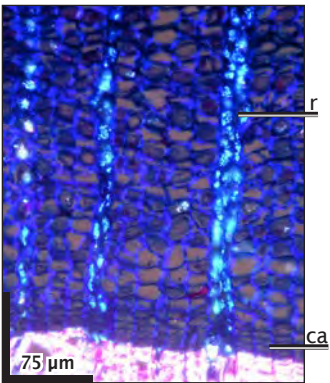
Quercus petraea, 200x



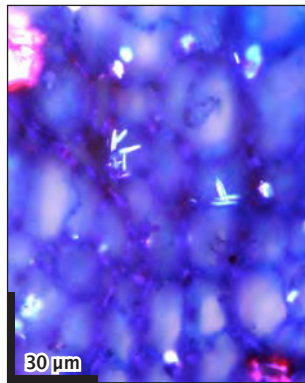
Salix purpurea, 400x

Crystals surround groups of sclereids (sc).

B.66 - More than one crystal in a cell



Ligustrum ovalifolium, 400x

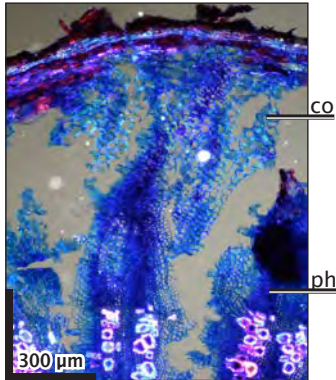


Lantana camara, 1000x

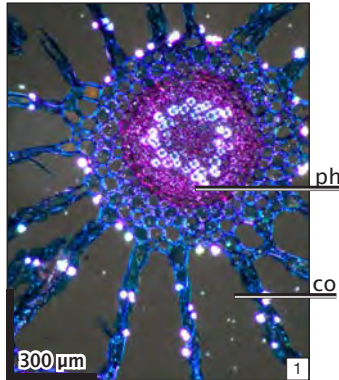
More crystals occur in a single cell.



Crystal frequency B.67 - Crystals rare



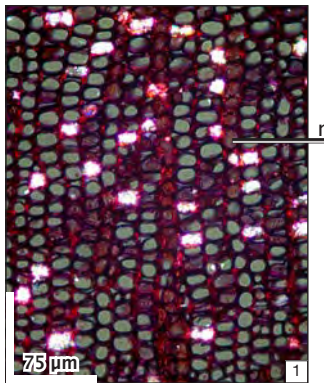
Oxyria digyna, 100x



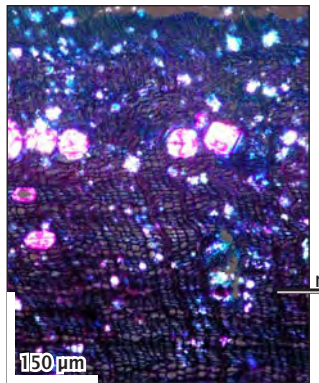
Myriophyllum alterniflorum, 100x

Very few crystals occur in the phloem (ph).

B.68 - Crystals frequent



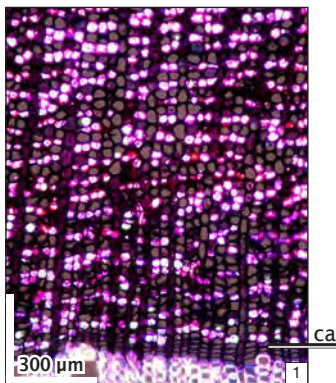
Buxus sempervirens, 400x



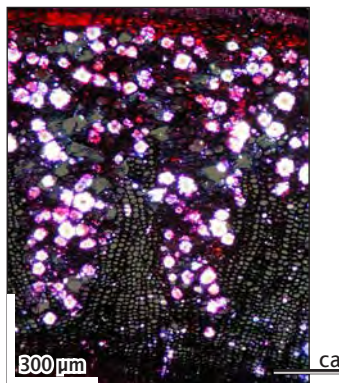
Euonymus verrucosus, 200x

Crystals consistently present, but not abundant.

B.69 - Crystals very frequent



Punica granatum, 100x



Gypsophila repens, 100x

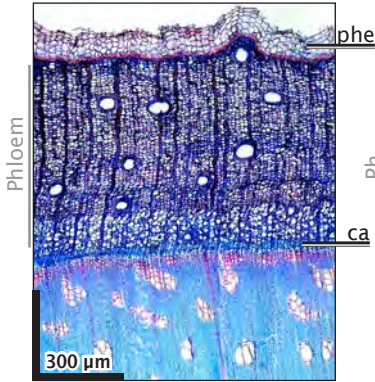
Crystals consistently abundant. As dense as stars in the Milky Way.

Cortex thickness

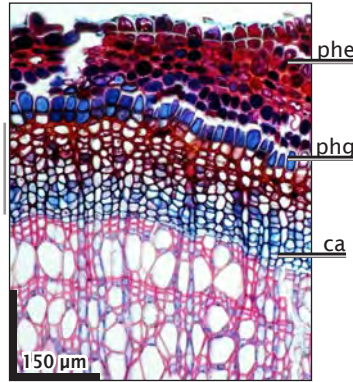
Cortex

Cortex absent

B.70 - Cortex absent



Cotinus coggygria, 100x

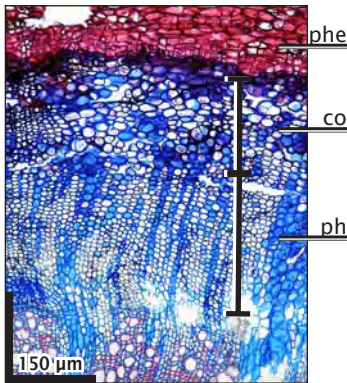


Empetrum nigrum, 200x

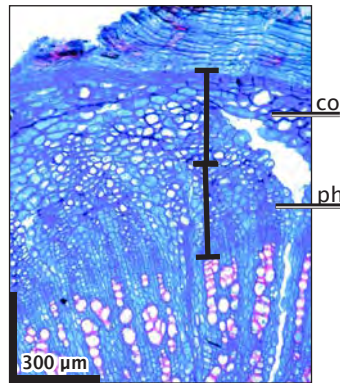
Specimen in which the cortex already disappeared after bark shedding.

Cortex width

B.71 - Cortex width similar or smaller than phloem width



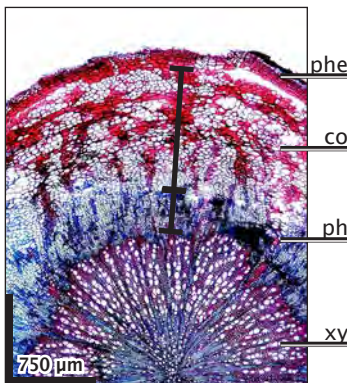
Allardia tomentosa, 200x



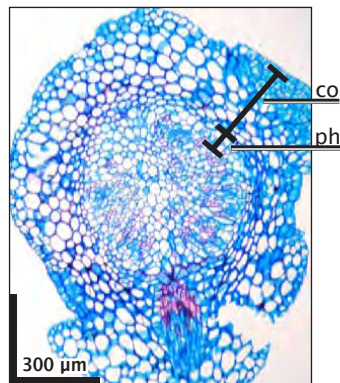
Euphorbia tibetica, 100x

Cortex (co) thickness along a radius similar to phloem (ph) thickness.

B.72 - Cortex distinctly larger than phloem



Geranium columbinum, 40x



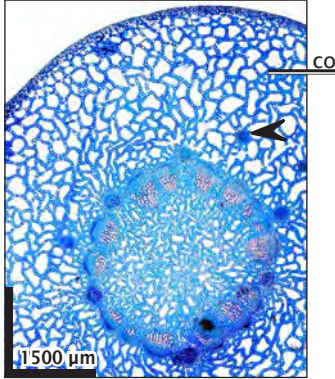
Drosera anglica, 100x

Cortex (co) thickness along a radius greater than phloem (ph) thickness.

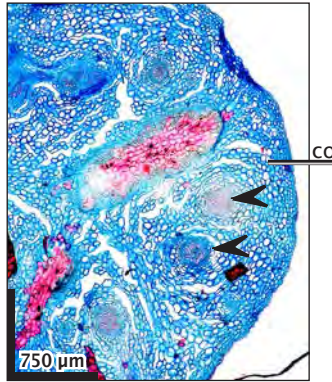
Vascular bundles in the cortex - Axial parenchyma

Vascular bundles in the cortex

B.73 - Vascular bundles



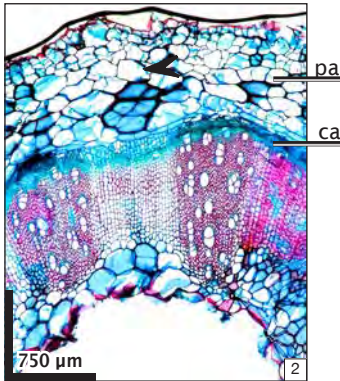
Menyanthes trifoliata, 20x



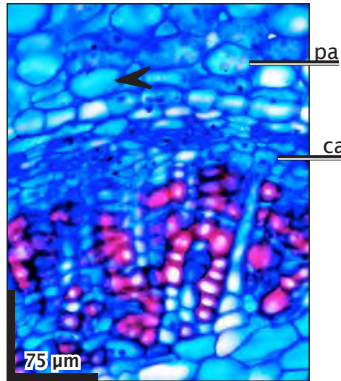
Primula integrifolia, 40x

Axial parenchyma: cells size

B.74 - Axial parenchyma cells large (more than 100 μm)



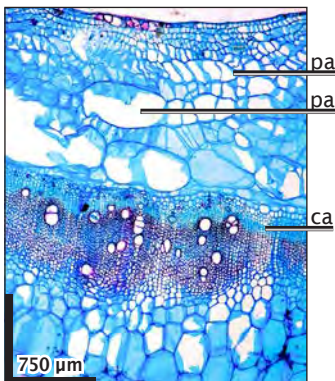
Impatiens noli-tangere, 40x



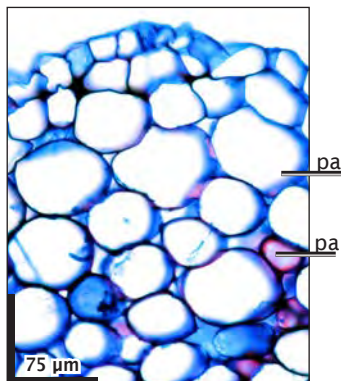
Littorella uniflora, 400x

Tangential diameter more than 100 μm.

B.75 - Axial parenchyma cells of two distinct sizes



Impatiens glandulifera, 40x



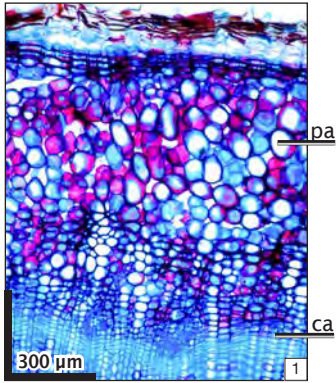
Drosera anglica, 400x

Axial parenchyma

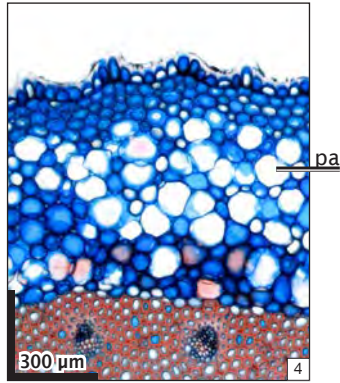
Cortex

Axial parenchyma: cells shape

B.76 - Axial parenchyma cells round

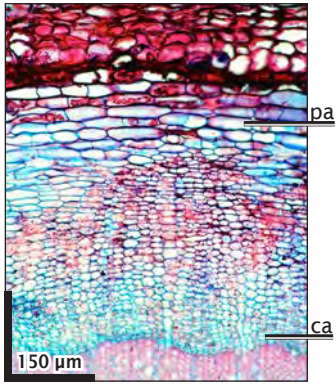


Sedum ochroleucum, 100x

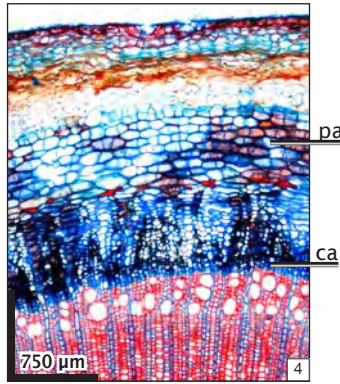


Ruscus aculeatus, 100x
Monocotyledon

B.77 - Axial parenchyma cells oval



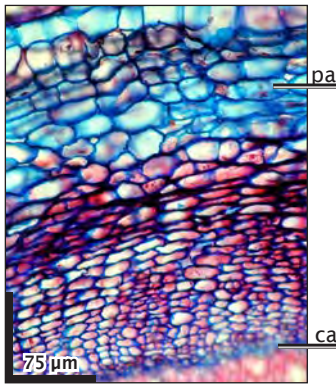
Staehelina dubia, 200x



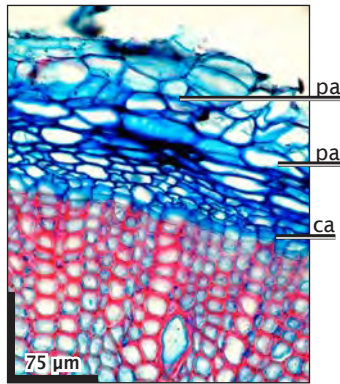
Nicotiana glauca, 40x

Most cells at least twice as long as wide.

B.78 - Axial parenchyma cells of mixed shapes



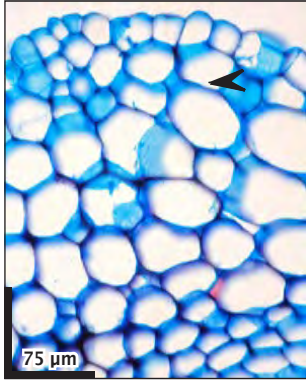
Plantago albicaulis, 400x



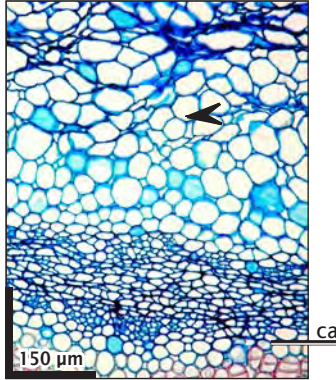
Legousia falcata, 400x

Axial parenchyma: cell wall thickness

B.79 - Axial parenchyma cell walls thin-walled

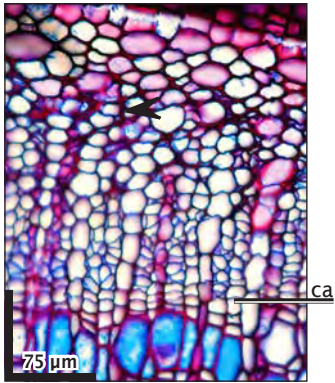


Drosera anglica, 400x

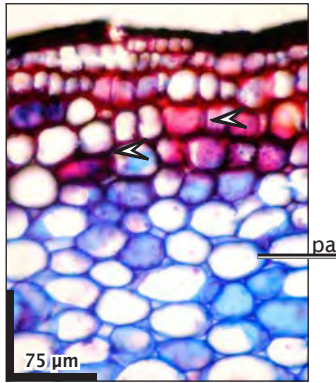


Gentiana lutea, 200x

B.80 - Axial parenchyma cell walls thin- and thick-walled

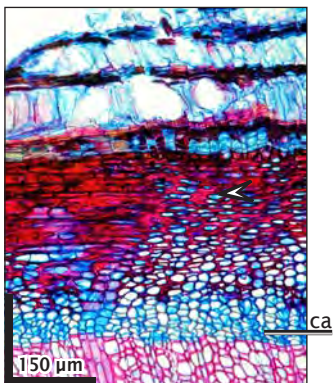


Potentilla palustris, 400x

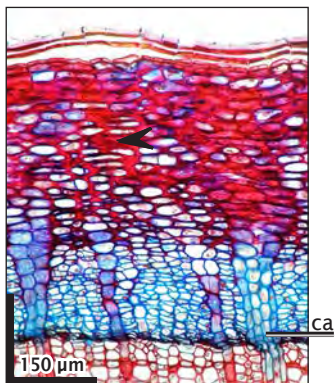


Filipendula ulmaria, 400x

B.81 - Axial parenchyma cell walls thick-walled



Rhododendron macrophyllum, 200x

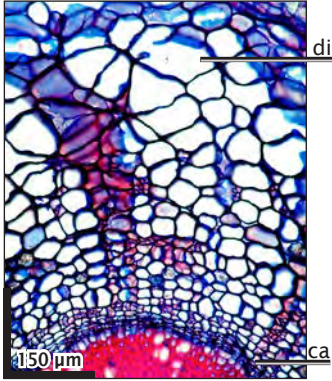


Enkianthus campanulatus, 200x

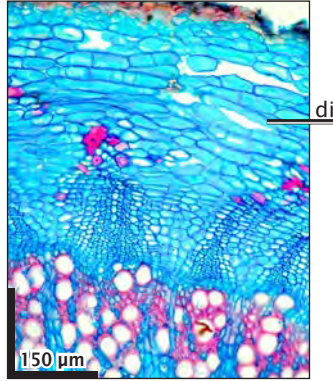
Axial parenchyma

Cortex

Axial parenchyma: cells dilatation B.82 - Axial parenchyma cells dilated



Erodium laciniatum, 200x

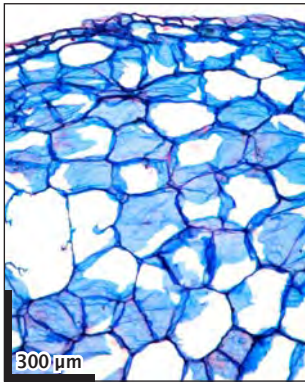


Thesium arvense, 200x

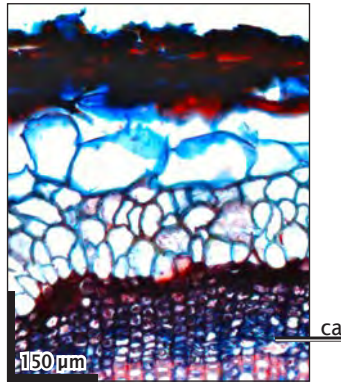
Most of the external cortex cells are much larger than the inner ones.

Intercellular spaces (including aerenchyma)

B.83 - Intercellular spaces absent

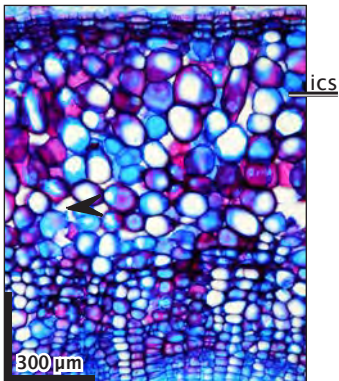


Adoxa moschatellina, 100x

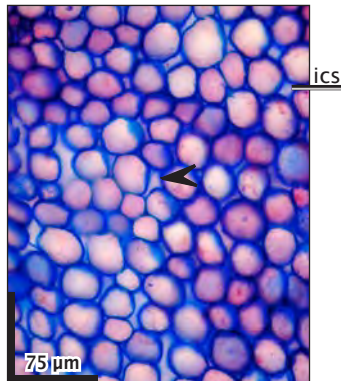


Origanum majorana, 200x

B.84 - Intercellular spaces small (between 2-4 cells)



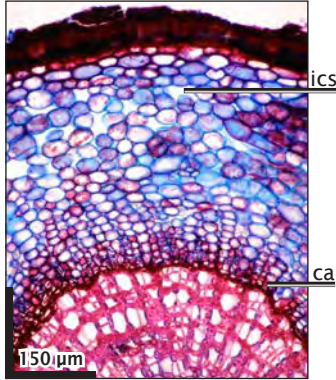
Sedum anopetalum, 100x



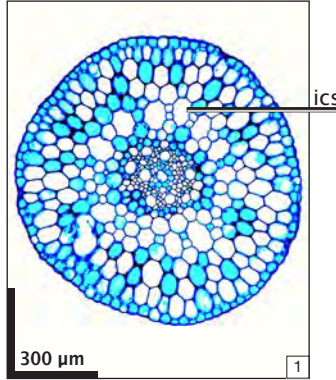
Swertia perennis, 400x

Intercellular spaces (ics) are smaller than the diameter of neighbouring cells.

B.85 - Intercellular spaces large (between more than 5 cells)



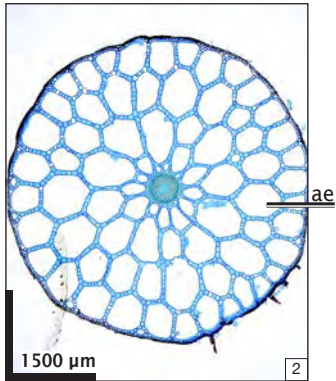
Salix herbacea, 200x



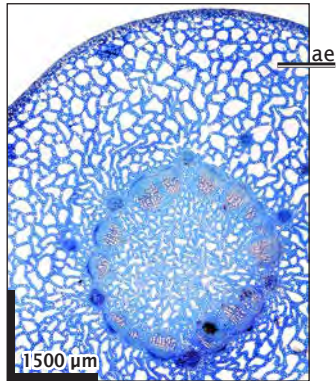
Ceratophyllum demersum, 100x

Intercellular spaces (ics) are partially as wide as the diameter of neighbouring cells. Their form can be canal like or irregular.

B.86 - Net-like



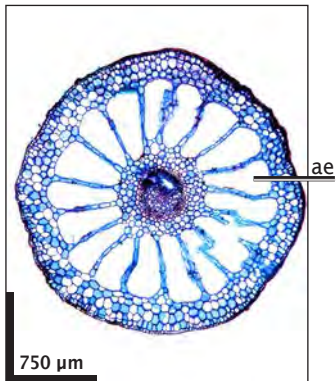
Hippuris vulgaris, 20x



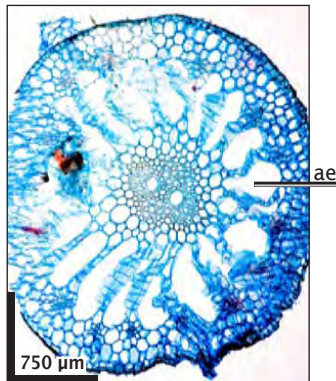
Menyanthes trifoliata, 20x

Intercellular spaces (aerenchyma, ae) are formed by a net of small parenchyma cells.

B.87 - Radially expanded spaces



Myriophyllum alternifolium, 40x



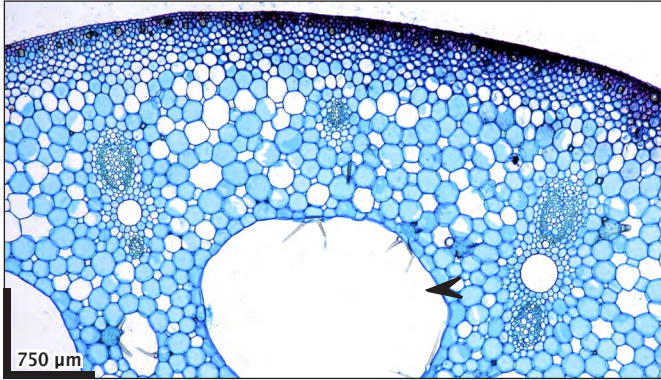
Hydrocharis morsus-ranae, 40x
Monocotyledon

The cortex contains large intercellular spaces (aerenchyma, ae) which are separated by radial strips of parenchyma cells.

Axial parenchyma

Cortex

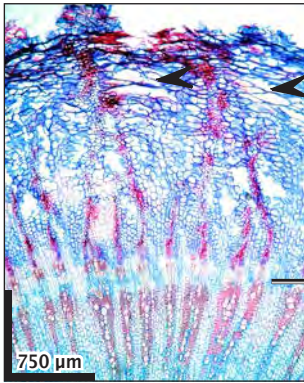
B.88 - Canal-like



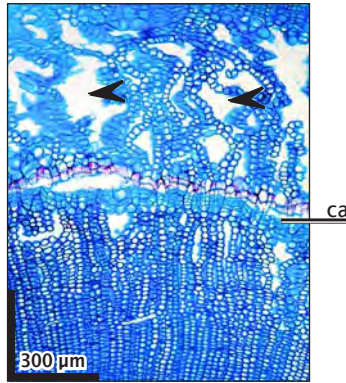
Nymphaea alba, 40x

Cortex contains large canals. They are partially surrounded by one row of small cells (like secretory canals, see B.48).

B.89 - Irregular



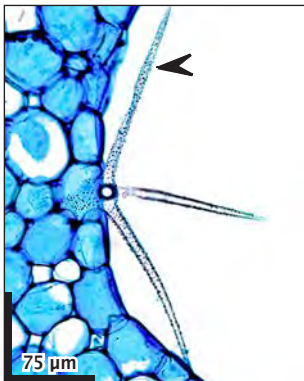
Leysera leyseroides, 40x



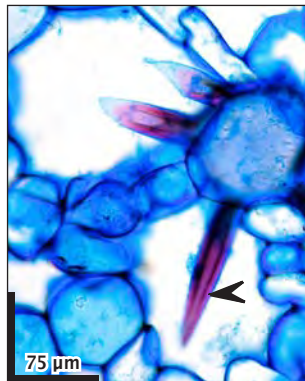
Plantago maritima, 100x

Intercellular spaces with hairs

B.90 - Hairs in intercellular canals



Nymphaea alba, 400x



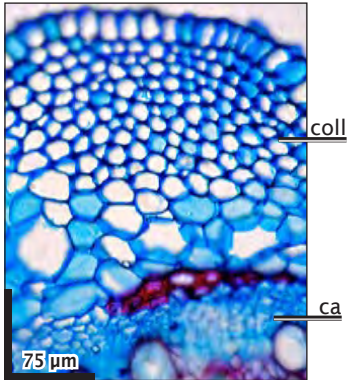
Nymphoides peltata, 400x

Hairs consist of thick-walled cells, which are externally occupied by small prismatic crystals.

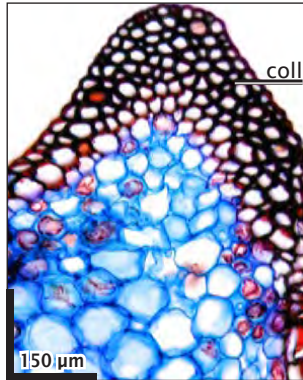
Collenchyma - Sclerenchyma

Collenchyma

B.91 - Collenchyma present



Beta vulgaris, 400x

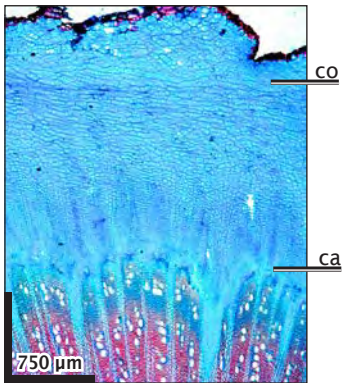


Galium palustre, 200x

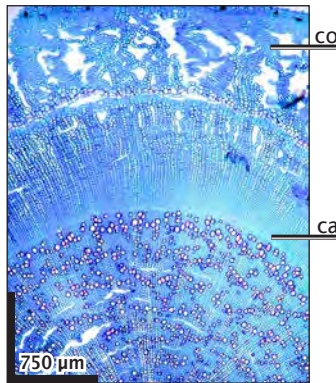
Groups of cells with unevenly thickened, un lignified primary walls (Evert 2006).

Sclerenchyma absent

B.92 - Sclerenchyma (fibres and sclereids) absent



Calendula officinalis, 40x

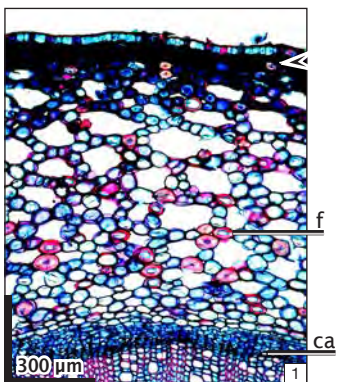


Plantago maritima, 40x

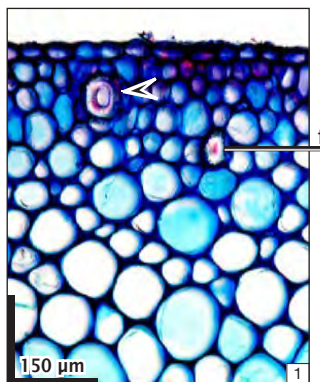
Cortex (co) without red stained cells after astrablue and safranin staining.

Fibre arrangement

B.93 - Fibres mostly solitary



Lysimachia vulgaris, 100x

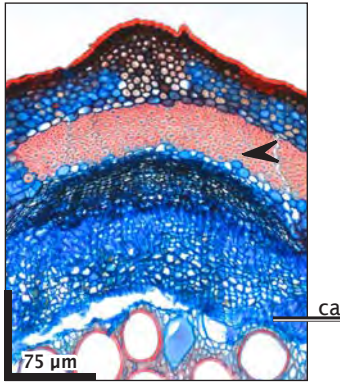


Nymphaea alba, 200x

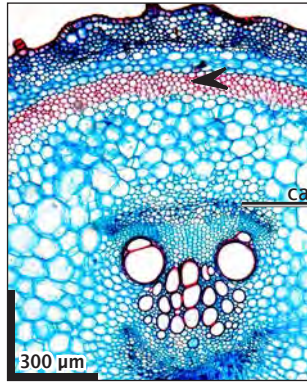
Sclerenchyma

Cortex

B.94 - Fibres in belt



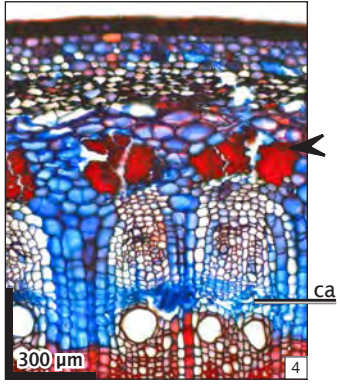
Plumbago europaea, 200x



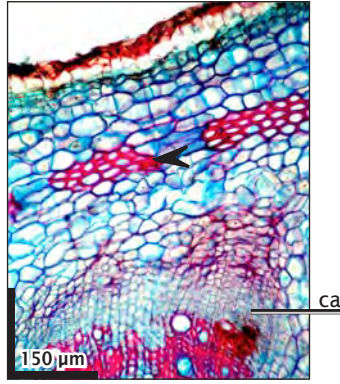
Cucurbita pepo, 100x

Fibre belts break apart by expansion of stems.

B.95 - Fibres in groups

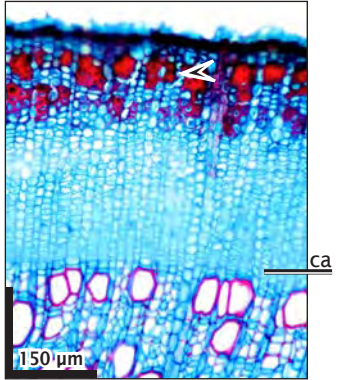


Lavatera bryoniifolia, 100x

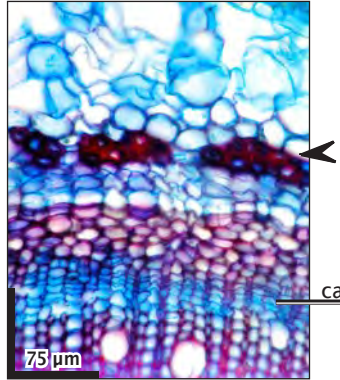


Aristolochia pallida, 200x

B.95.1 - Fibre groups tangentially arranged

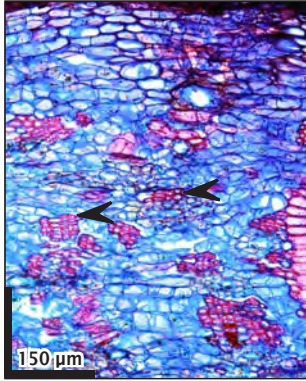


Dryas octopetala, 200x

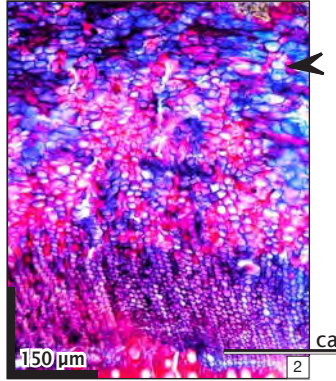


Lythrum virgatum, 400x

B.95.2 - Fibre groups irregularly arranged



Hedera canariensis, 200x

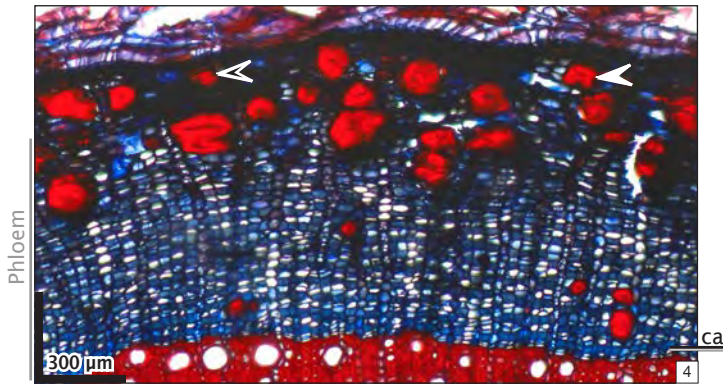


Frankenia laevis, 200x

More than 6 cells surrounding an intercellular space

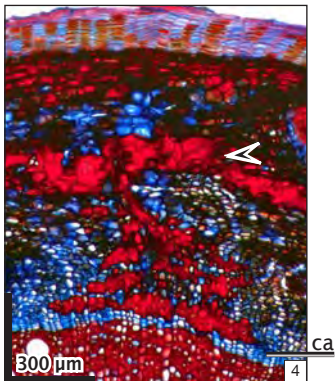
Sclereids arrangement

B.96 - Sclereids mostly solitary

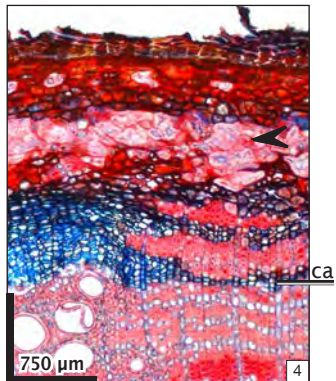


Myrtus communis, 100x

B.97 - Sclereids in groups



Pistacia terebinthus, 100x

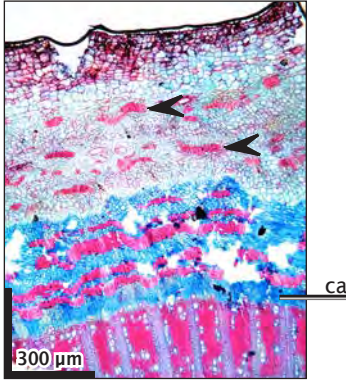


Quercus coccifera, 40x

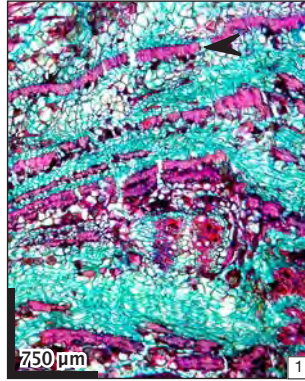
Sclerenchyma - Secretory elements

Cortex

B.97.1 - Sclereid groups tangentially arranged

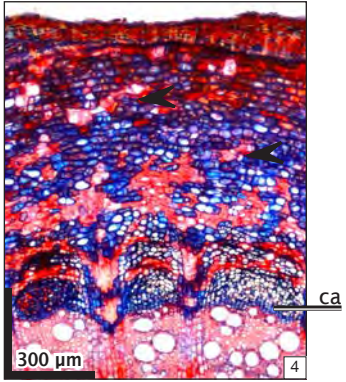


Schizogyne sericea, 100x



Anabasis brevifolia, 40x

B.97.2 - Sclereid groups irregularly arranged



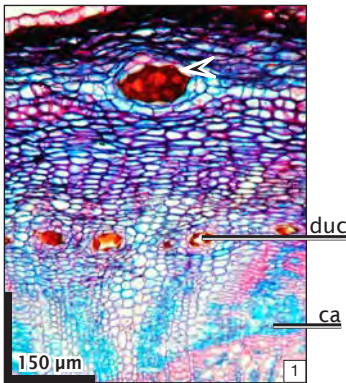
Tamarix smyrnensis, 100x



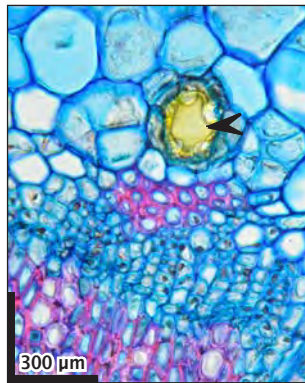
Capparis spinosa, 100x

Type of intercellular canals

B.98 - Axial secretory ducts surrounded by epithelial cells (excretion cells)



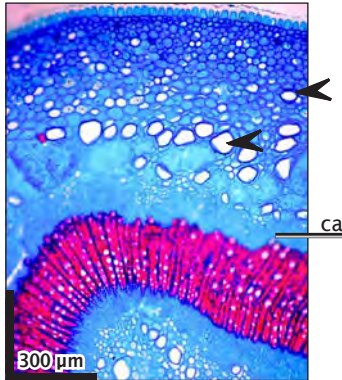
Centaurea solstitialis, 200x



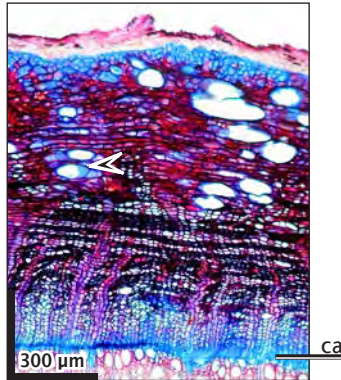
Gymnostegia stolonifera, 100x

Tubular intercellular axial canals surrounded by an epithelium.

B.99 - Axial canals without epithelial cells (laticifers)



Acokanthera oblongifolia, 100x

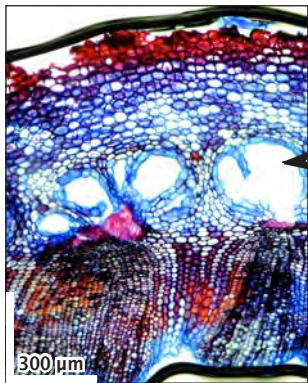


Cneorum tricoccon, 100x

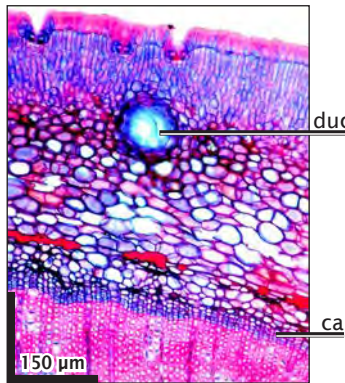
Tubes conduct a milky fluid (latex) as visible in freshly collected material.

Size of intercellular canals

B.100 - Ducts and/or laticifers very large at the periphery of the cortex



Cirsium helenioides, 100x

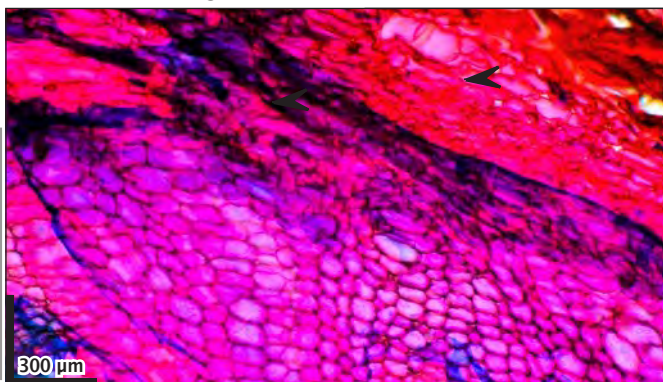


Poncirus trifoliata, 200x

Due to dilatation secretory ducts become very large.

Mucilage and cell content

B.101 - Mucilage



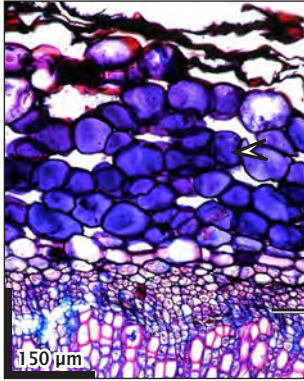
Anchusa officinalis, 100x

Mucilage producing cells cannot be recognized but the mucilage itself is visible.

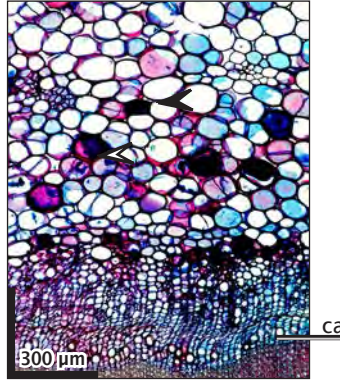
Secretory elements - Crystals

Cortex

B.102 - Dark staining substances



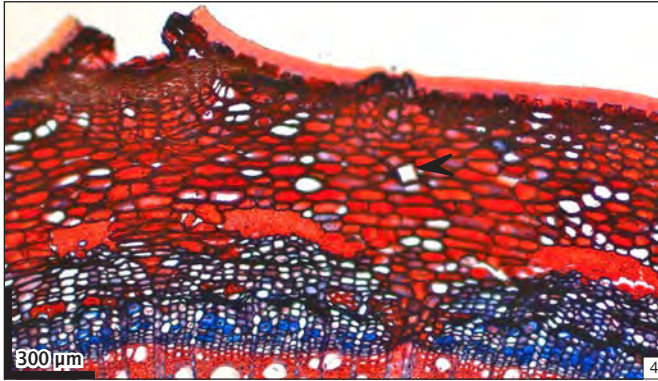
Myosotis caespitosa, 200x



Aeonium simthii, 100x

Crystal types

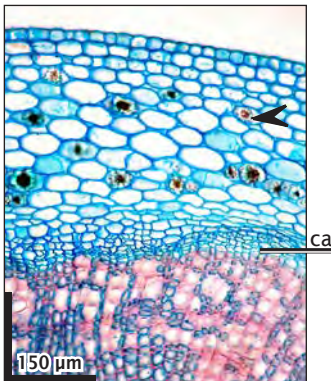
B.103 - Prismatic crystals



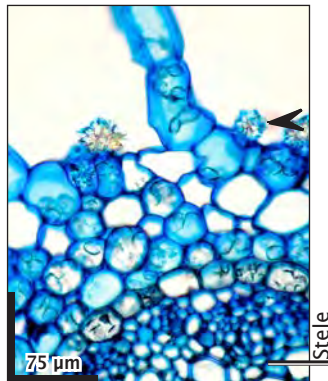
Rosa x damascena, 100x

Solitary rhomboedral or octahedral crystals are birefringent in polarized light.

B.104 - Druses



Mercurialis ovata, 200x



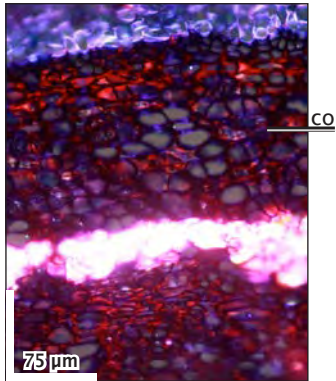
Myriophyllum spicatum, 400x

Compound crystals with a star-shaped appearance.

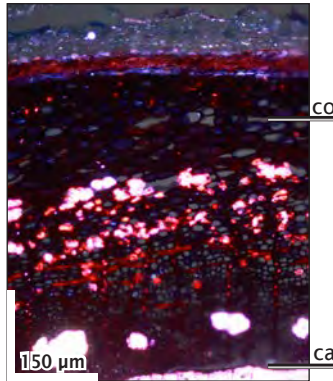
- B105** - *Raphides* (see also features 149 and B.57)
- B106** - *Acicular crystals* (see also features 150 and B.58)
- B107** - *Styloids and/or elongated crystals* (see also features 151 and B.59)
- B108** - *Crystal sand* (see also features 153 and B.60)
- B109** - *Crystals of other shapes* (see also features 152 and B.61)

Crystal frequency

B.110 - *Crystals absent or rare*



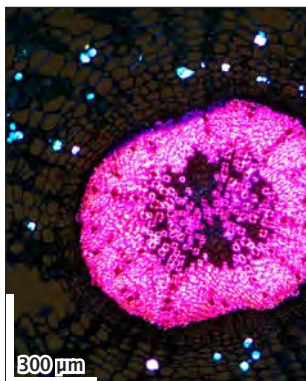
Olea europaea, 400x



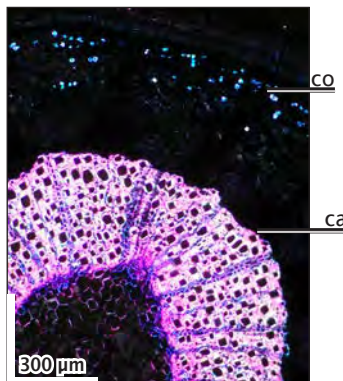
Elaeagnus rhamnoides, 200x

Crystals with a limited relative abundance.

B.111 - *Crystals frequent*



Erodium laciniatum, 100x



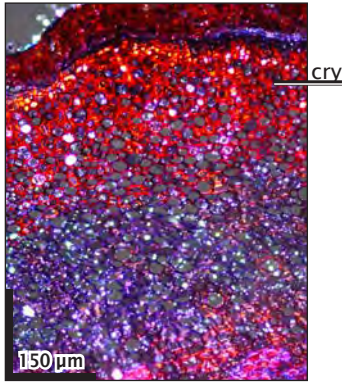
Comandra umbellata, 100x

Crystals consistently present, but not abundant.

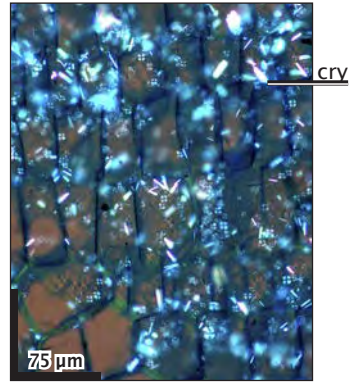
Crystals - Endodermis and pericycle

Cortex

B.112 - Crystals very frequent



Ficus carica, 200x



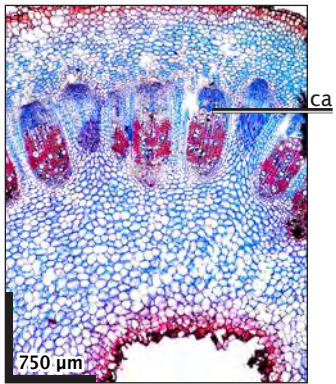
Lamium galeobdolon, 400x

Crystals consistently abundant.

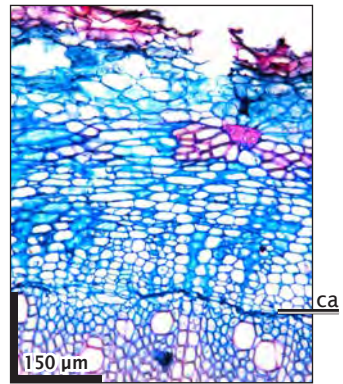
Endodermis and pericycle

The endodermis (en) is the innermost layer of the cortex. The pericycle (peri) is the outermost layer of the stele. Endodermis and pericycle are mostly difficult to differentiate in Dicotyledon plants.

B.113 - Endodermis and pericycle absent or not visible

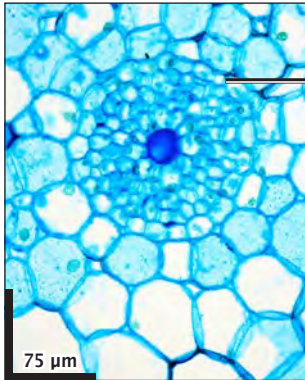


Cirsium oleraceum, 40x

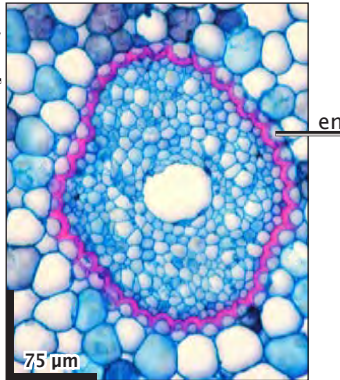


Bidens frondosa, 200x

B.114 - One cell layer around the central cylinder



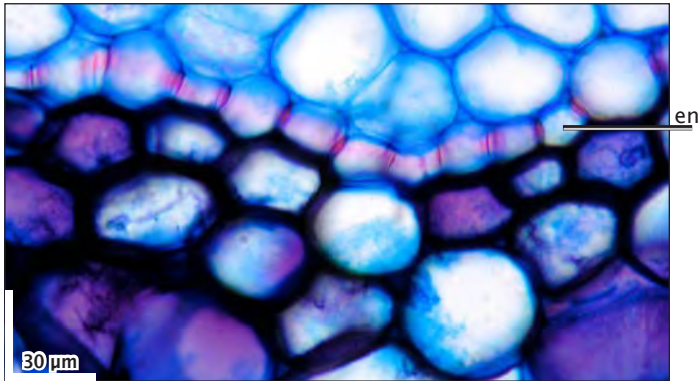
Najas minor, 400x
Monocotyledon



Potamogeton pectinatus, 400x
Monocotyledon

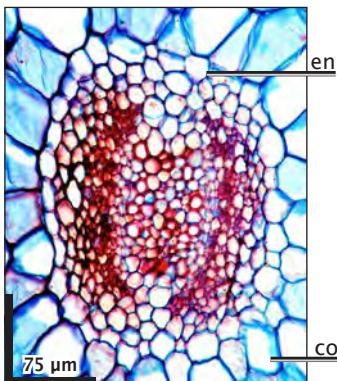
In *Najas* the layer of single cells surrounding the central cylinder could be either a pericycle or an endodermis. In *Potamogeton* it is an endodermis.

B.115 - Typical endodermis with Casparian strips, pericycle absent

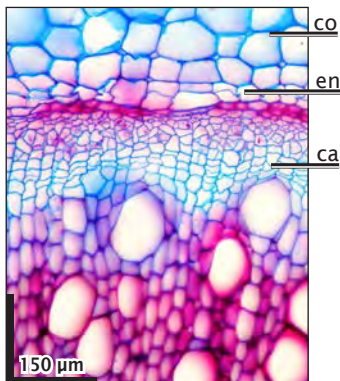


Drosera anglica, 1000x

B.116 - One layer between cortex and the central cylinder



Adoxa moschatellina, 400x



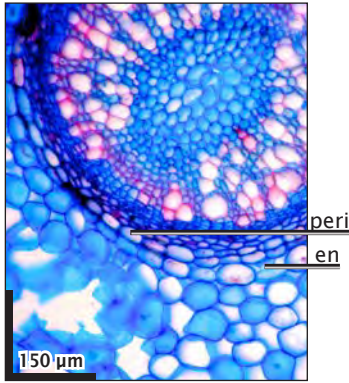
Mimulus guttatus, 200x

Endodermis and pericycle not differentiated.

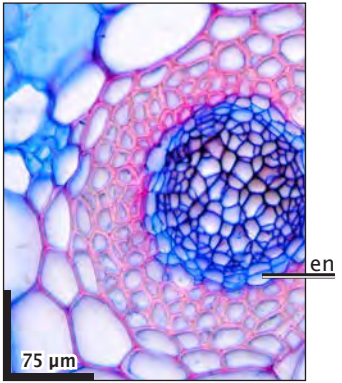
Endodermis and pericycle

Cortex

B.117 - Several layers between cortex and the central cylinder



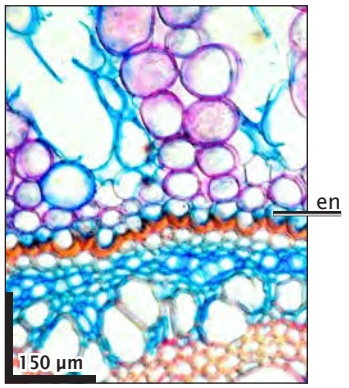
Veronica scutellata, 200x



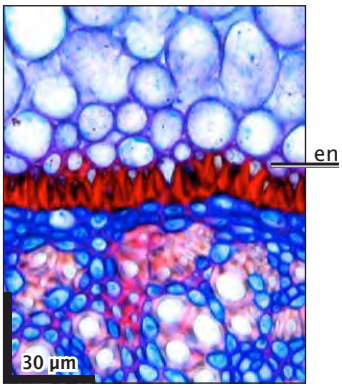
Oenanthe pimpinelloides, 400x

Endodermis (en) and pericycle (peri) not differentiated.

B.118 - Endodermis with U shaped thick-walled cells

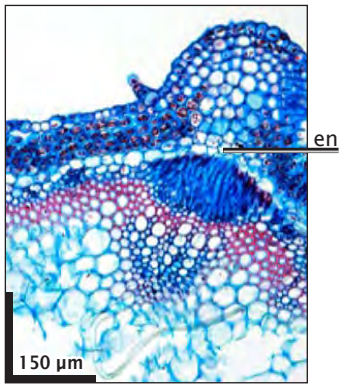


Carex acutiformis, 200x
Monocotyledon

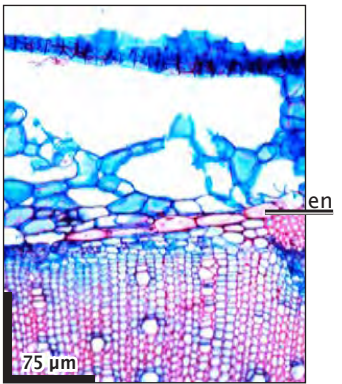


Juncus gerardii, 1000x
Monocotyledon

B.119 - Endodermis and pericycle cells round to oval and thin walled



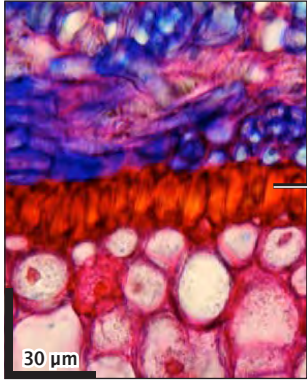
Crepis paludosa, 200x



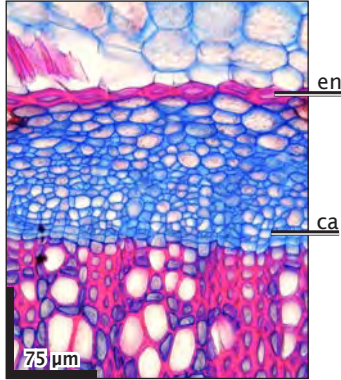
Bidens cernua, 400x

Endodermis and pericycle - Epidermis and cuticle

B.120 - Endodermis cells thick-walled



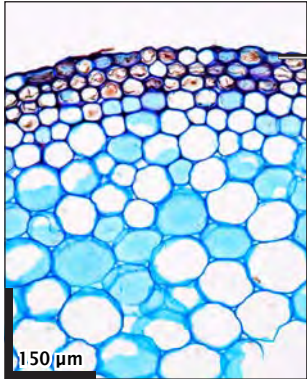
Juncus jaquinii, 1000x
Monocotyledon



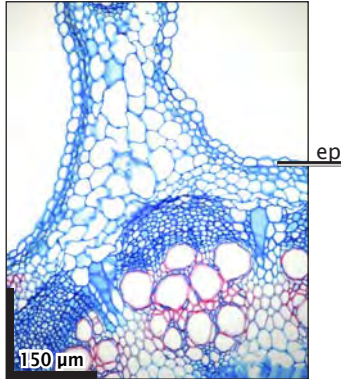
Nasturtium officinale, 400x

Epidermis and cuticle

B.121 - Epidermis distinct

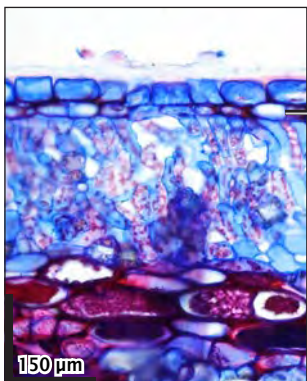


Asarum europaeum, 200x

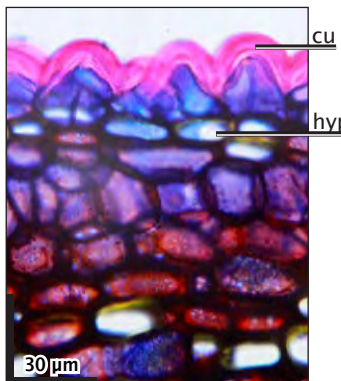


Vicia dumetorum, 200x

B.122 - Hypodermis distinct



Euphorbia larica, 200x



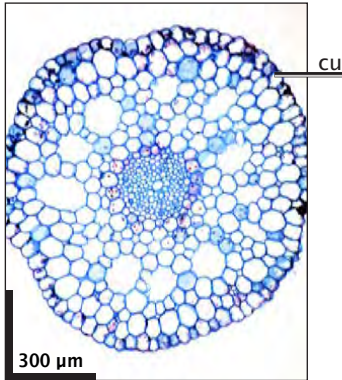
Euonymus europaeus, 1000x

Epidermis and cuticle - Lenticels and spines

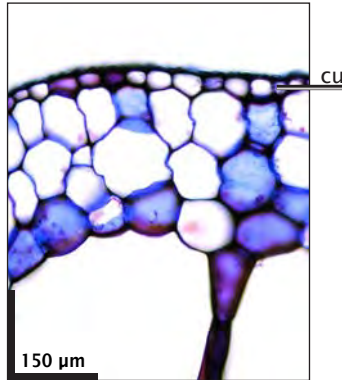
Cortex

Cuticle thickness

B.123 - Cuticle thin

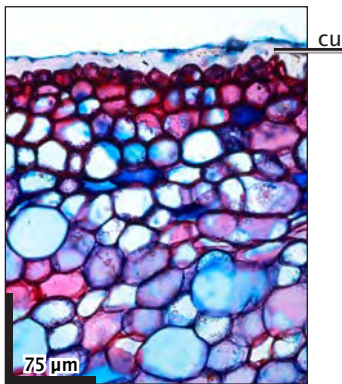


Elodea canadensis, 100x
Monocotyledon

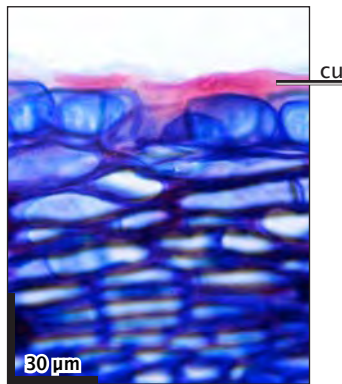


Myriophyllum verticillatum, 200x

B.124 - Cuticle thick



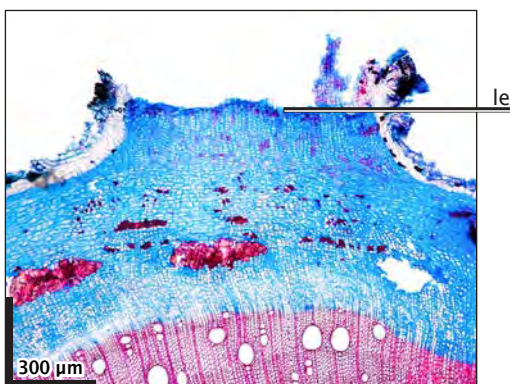
Persea indica, 400x



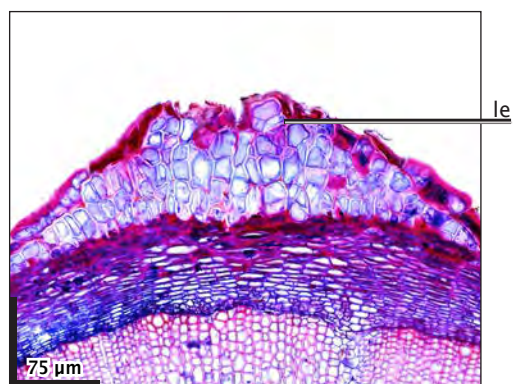
Dionysia aretioides, 1000x

Lenticels and spines

B.125 - Lenticels



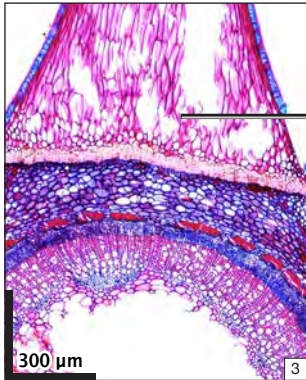
Alnus glutinosa, 100x



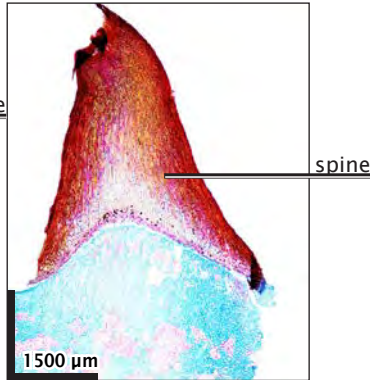
Dionysia involucreta, 200x

Lenticels and spines - Trichomes and glands

B.126 - Spines



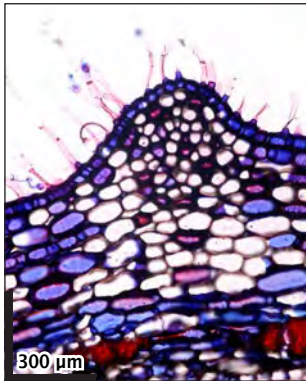
Rosa arvensis, 100x



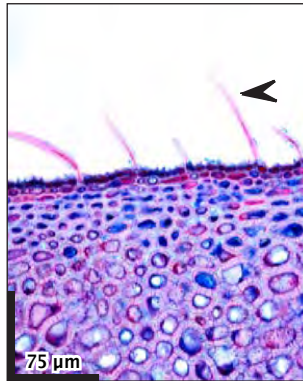
Pachira quinata, 20x

Trichomes and glands

B.127 - Trichomes



Ptilostemon chamaepeuce, 100x



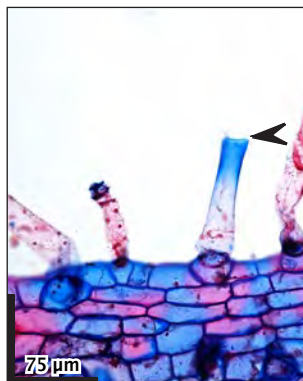
Corylus avellana, 400x

Trichomes are an outgrowth of the epidermis.

B.128 - Glands



Lysimachia vulgaris, 1000x



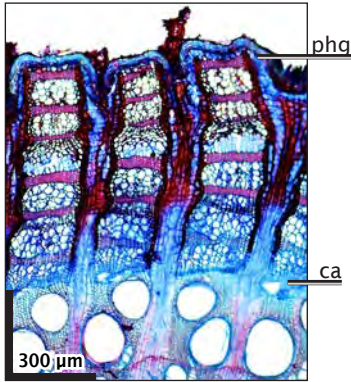
Scrophularia peregrina, 400x

Glands are multicellular structures.

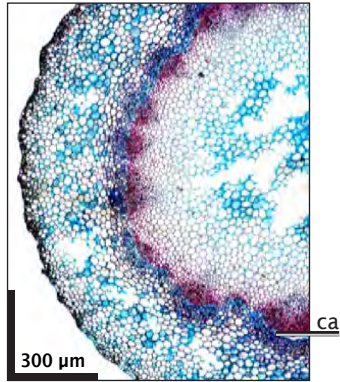
Phellem

Phellem structure (see also pages 12-13)

B.129 - *Phellem absent or not visible*

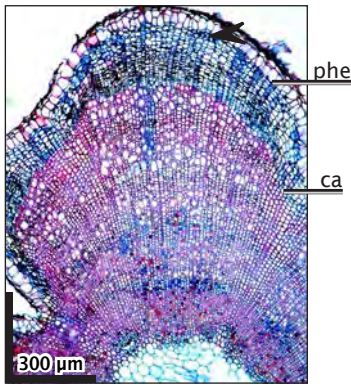


Vitis vinifera, 100x

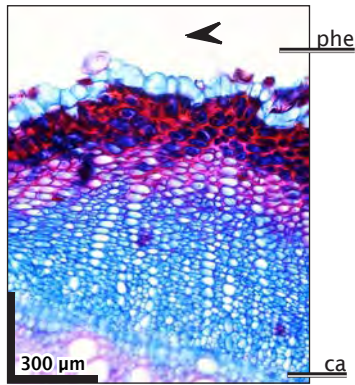


Orobanche alba, 100x

B.130 - *One-layered phellem*

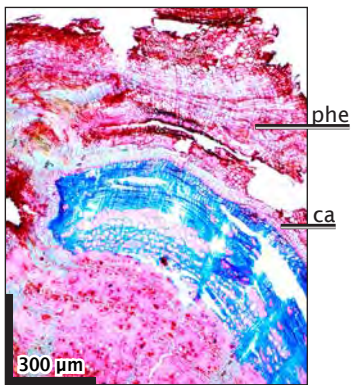


Antennaria dioica, 100x

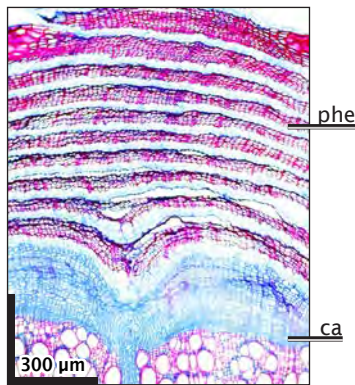


Erica carnea, 100x

B.131 - *Multilayered phellem*

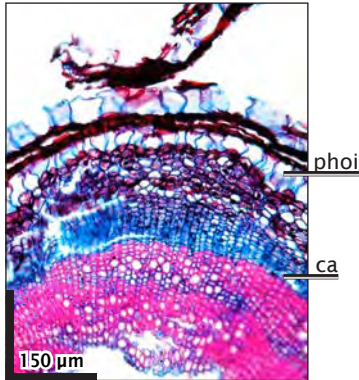


Artemisia frigida, 100x

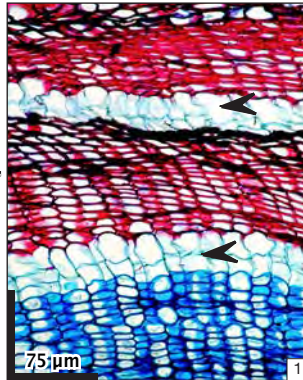


Clematis alpina, 100x

B.132 - Phelloid-like cells in the phellem



Antennaria alpina, 200x

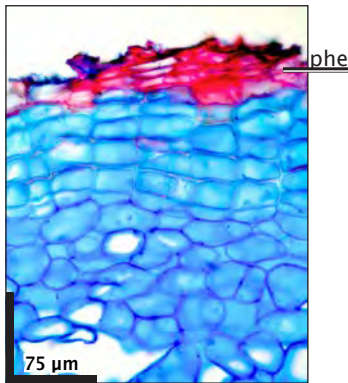


Clematis alpina, 400x

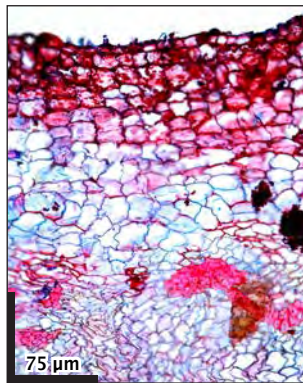
Thin-walled, not lignified layers of cells.

Phellem cells shape

B.133 - Square

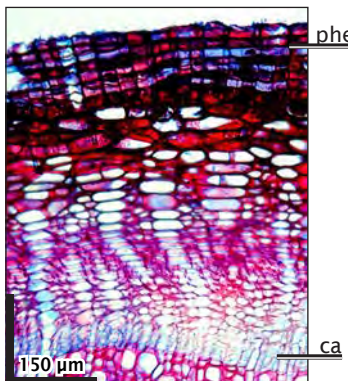


Primula auricula, 400x

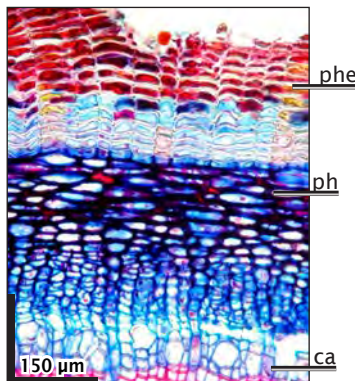


Schizogyne sericea, 400x

B.134 - Rectangular



Rubus saxatilis, 200x

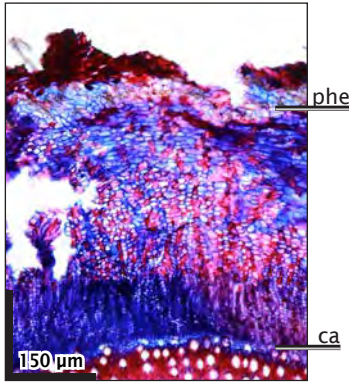


Rhododendron ferrugineum, 200x

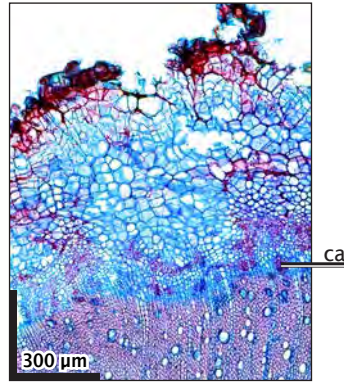
Phellem

Periderm

B.135 - Irregular



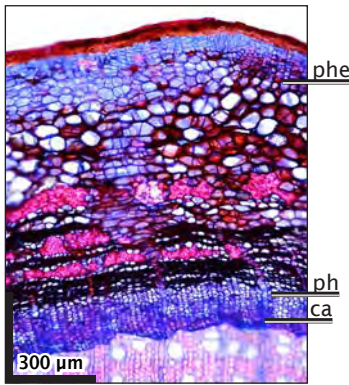
Frankenia laevis, 200x



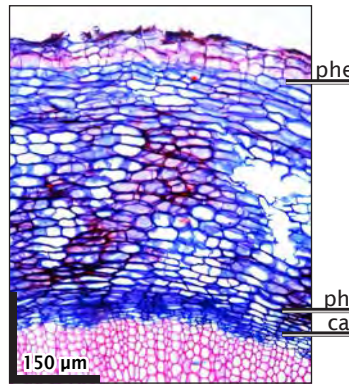
Sonchus paludosus, 100x

Phellem thickness

B.136 - Phellem width similar or smaller than phloem width



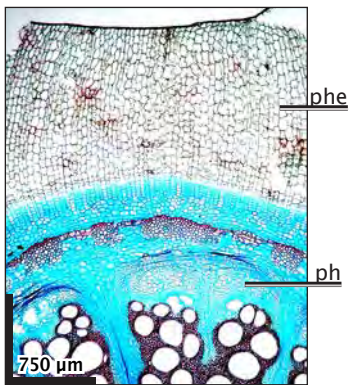
Citrus sinensis, 100x



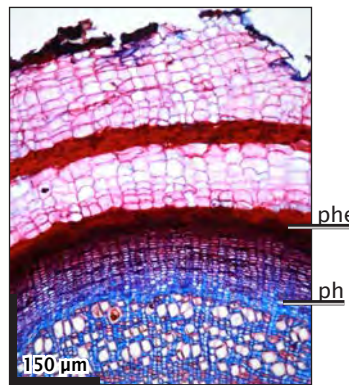
Centranthus calcitrapa, 200x

Phellem (phe) width much smaller than phloem (ph) width.

B.137 - Phellem width distinctly larger than phloem width



Aristolochia gigantea, 40x

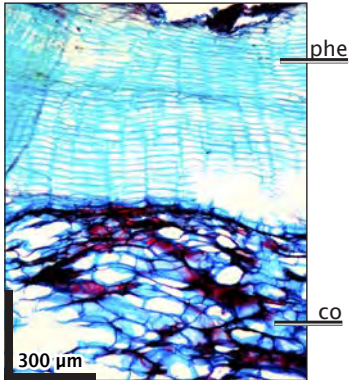


Penstemon comarrhenus, 200x

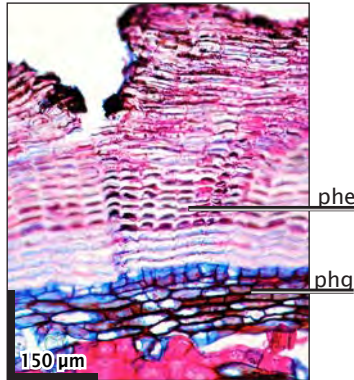
Phellem (phe) width much larger than phloem (ph) width.

Phellem: cell arrangement

B.138 - Phellem cells radially oriented

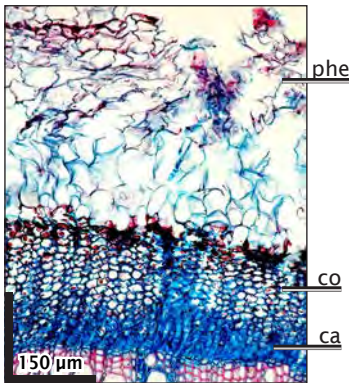


Astydamia latifolia, 100x

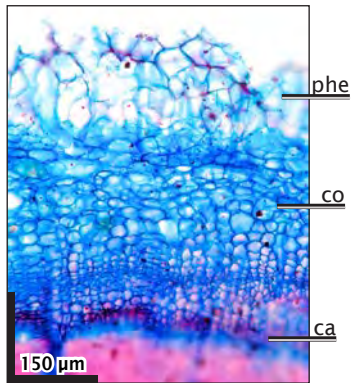


Ilex aquifolium, 200x

B.139 - Phellem cells irregularly oriented



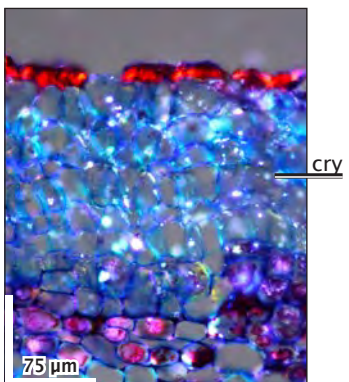
Mimulus dentatus, 200x



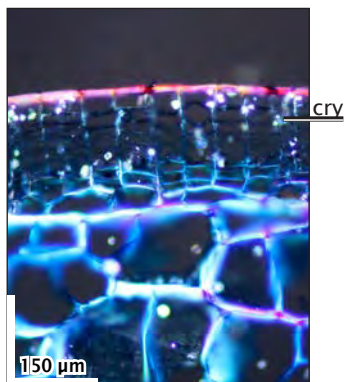
Mesembryanthemum nodiflorum, 200x

Crystals

B.140 - Crystals present



Convolvulus linearis, 400x



Portulaca oleracea, 200x

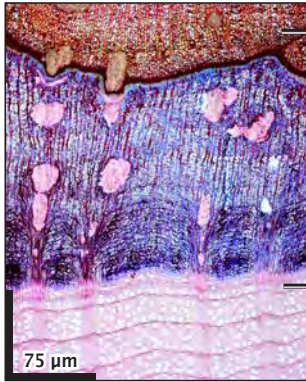
Crystals (cry) of various shapes present within the phellem.

Rhytidome

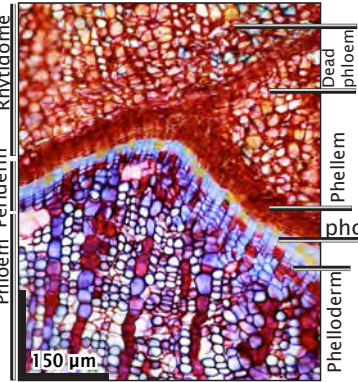
Periderm

Rhytidome

B.141 - Rhytidome present



Alnus glutinosa, 40x



Alnus glutinosa, 200x

The rhytidome is the outermost dead part of the bark. The last formed periderm cuts off the living phloem and the cortex. The periderm delimits the innermost living phloem from the rhytidome.

8. List of features

List of features

SAMPLE NAME AND SOURCE

Record the scientific plant name

Sample from a living plant

- O.1** Sample collected in nature
- O.2** Sample collected in botanical garden or cultivated

Sample not from a living plant: dry material

- O.3** Dry material collected in nature
- O.4** Herbarium
- O.5** Wood collection
- O.6** Manufactured wood
- O.7** Charcoal
- O.8** Petrified wood

Sample not from a living plant: wet material

- O.9** Waterlogged wood
- O.10** Driftwood

COLLECTING LIVING PLANTS

Plant growth form

- A.1** Tree
- A.2** Shrub
- A.3** Dwarf shrub, upright
- A.4** Dwarf shrub, prostrate
- A.5** Terrestrial herb
- A.6** Succulent
- A.7** Helophytes
- A.8** Hydrophytes
- A.9** Vine/liana/climber
- A.10** Hemiparasite
- A.11** Full parasite

Plant height

Record the measured plant height

- A.12** Plant height less than 5 cm
- A.13** Plant height 5-10 cm
- A.14** Plant height 10-25 cm
- A.15** Plant height 25-50 cm
- A.16** Plant height 50-100 cm
- A.17** Plant height 100-150 cm
- A.18** Plant height 150-300 cm
- A.19** Plant height 300-1000 cm
- A.20** Plant height more than 1000 cm

SAMPLE CHARACTERISTICS

Sample location within the plant

- A.21** Stem
- A.22** Branch
- A.23** Twig
- A.24** Root collar of a primary root
- A.25** Secondary root
- A.26** Rhizome (horizontal below ground stem)
- A.27** Root
- A.28** Bulbs and tubes

Characteristics of the cross section available on the slide

- A.29** Complete cross section
- A.29.1** Bark absent
- A.30** Cross section from pith to bark
- A.31** Cross section containing the cambial region
- A.32** Cross section that cannot be located within the plant

Shape of cross section

- A.33** Cross section round to oval
- A.34** Cross section polygonal
- A.34.1** Cross section square to rectangular
- A.34.2** Cross section pentagonal
- A.34.3** Cross section triangular
- A.34.4** Cross section winged
- A.35** Cross section lobed
- A.36** Cross section irregular

STEM CONSTRUCTION

Cambium producing xylem and phloem

- A.37** On cambium producing a single stem
- A.38** One cambium producing multiple/ segregated stems

Cambial variants: several cambia producing xylem and phloem

- A.39** (IAWA no. 133) Successive cambia present
- A.39.1** Successive cambia: xylem and phloem zones in continuous tangential bands
- A.39.2** Successive cambia: single vascular bundles tangentially arranged
- A.39.3** (IAWA no. 134) Successive cambia: single vascular bundles irregularly distributed

Cambium producing phloem within the xylem

- A.40** (IAWA no. 135) Intraxylary phloem

Cambium or phellogen producing cork cells within the xylem

- A.40.1** Intraxylary periderm towards the bark
- A.40.2** Intraxylary periderm towards the pith

Conjunctive tissue

- A.41** Conjunctive tissue present
- A.41.1** Conjunctive tissue not lignified
- A.41.2** Conjunctive tissue lignified

Without secondary growth

- A.42** Central cylinder present

Type of vascular bundles

- A.43** Vascular bundles collateral open (with cambium)
- A.44** Vascular bundles bi-collateral open (with two cambia)
- A.45** Vascular bundles collateral closed (without cambium)
- A.46** Vascular bundles concentric, xylem outside (leptocentric or amphiversal)

A.47 Vascular bundles concentric, xylem inside (hadrocentric or amphicribal)

Vascular bundles arrangement

A.48 Vascular bundles circularly arranged

Vascular bundles shape

A.49 Vascular bundles radially elongated

A.50 The shape of vascular bundles remain over several growth rings

Proportion of xylem radius in relation to bark radius (stem less than 1 cm in diameter)

A.51 Xylem to bark ratio > 2:1

A.52 Xylem to bark ratio 2:1

A.53 Xylem to bark ratio 1:1

A.54 Xylem to bark ratio 1:2

A.55 Xylem to bark ratio 1 to more than 2

Pith position in cross section

A.56 Pith centred

A.57 Pith eccentric

A.58 Pith outside of the cross section

Number of growth rings

Record the counted number of growth rings

A.59 One growth ring

A.60 2-5 growth rings

A.61 6-10 growth rings

A.62 11-20 growth rings

A.63 21-50 growth rings

A.64 More than 50 growth rings

Plant age unknown

A.65 Plant age unknown

XYLEM ANATOMICAL FEATURES

Growth rings

1 Growth ring boundaries distinct

1.1 Last ring incomplete (cambium active)

1.2 First earlywood cells in formation

1.3 Most of the ring formed

1.4 Latewood cells in formation

1.5 Last ring complete (dormant period)

1.6 Cambium active in annual plants

1.7 Cambium active in tropical perennial plants

2 Growth ring boundaries indistinct or absent

2.1 Growth ring boundaries weakly expressed

Vessels

Porosity

3 Wood ring-porous

4 Wood semi-ring-porous

5 Wood diffuse-porous

Vessel arrangement

6 Vessels in tangential bands

7 Vessels in diagonal and/or radial pattern

8 Vessels in dendritic pattern

Vessel groupings

9 Vessels exclusively solitary (90% or more)

9.1 Vessels in short radial multiples (< 3 vessels)

10 Vessels in long radial multiples (>4 vessels)

11 Vessel clusters common

Vessels outline

12 Vessels outline angular

Perforation plates

13 Simple perforation plates

14 Scalariform perforation plates

15 Scalariform perforation plates with < 10 bars

16 Scalariform perforation plates with 10-20 bars

17 Scalariform perforation plates with 20-40 bars

18 Scalariform perforation plates with over 40 bars

19 Foraminate perforation plates

19.1 Other types of multiple perforation plates

Intervessel pits: arrangement

20 Intervessel pits scalariform

20.1 Intervessel pits with very large apertures arranged in annular to reticulate pattern

21 Intervessel pits opposite

22 Intervessel pits alternate

22.1 Intervessel pits arrangement variable along the same vessel

Intervessel pits: shape

23 Pits polygonal

23.1 Pits round

Intervessel pits: size

24 Intervessel pits minute (2-4 μm)

24.1 Intervessel pits extremely minute (< 2 μm)

25 Intervessel pits small (4-7 μm)

26 Intervessel pits medium (7-10 μm)

27 Intervessel pits large (more than 10 μm)

Vestured pits

29 Vestured pits

Vessel-ray pitting

30 Vessel-ray pits with distinct borders

31 Vessel-ray pits without borders, pits rounded or angular

32.1 Vessel-ray pits without borders, pits horizontal (scalariform, gash-like)

32.2 Vessel-ray pits without borders, pits vertical (palisade)

Helical thickenings in secondary xylem

36 Helical thickenings in vessel elements distinct

36.1 Helical thickenings in vessel elements slightly visible

Vessel wall thickness

39.1 Vessels thick-walled

Vessels lignification

39.2 Vessels not lignified

Tangential diameter of vessel lumina

Measured tangential diameter of vessel lumina

40.1 Mean tangential diameter of earlywood vessel lumina less than 20 μm

40.2 Mean tangential diameter of earlywood vessel lumina 20-50 μm

List of features

41 Mean tangential diameter of earlywood vessel lumina 50-100 µm

42 Mean tangential diameter of earlywood vessel lumina 100-200 µm

43 Mean tangential diameter of earlywood vessel lumina more than 200 µm

Vessels of two distinct diameter classes

45 Vessels of two distinct diameter classes, wood not ring-porous

Vessels per square millimetre

Measured number of vessels per square mm

46 Less than 5 vessels per square mm

47 5-20 vessels per square mm

48 20-40 vessels per square mm

49 40-100 vessels per square mm

50 100-500 vessels per square mm

50.1 More than 500 vessels per square mm

Vessel element length

Record the measured vessel element length

52.1 Mean vessel element length less than 50 µm

52.2 Mean vessel element length 50-150 µm

52.3 Mean vessel element length 150-350 µm

53.1 Mean vessel element length 350-600 µm

53.2 Mean vessel element length 600-800 µm

54 Mean vessel element length more than 800 µm

Tyloses

56 Tyloses common

Wood vesselless

59 Wood vesselless

59.1 Vessels not distinct in cross section

Tracheids and fibres

Vascular and vasicentric tracheids

60 Vascular and/or vasicentric tracheids present

Living fibres

60.0 Cell nuclei in fibres

Wood fibreless

60.1 Wood fibreless

60.2 Wood fibreless in stem centre

Fibre pits

61 Fibres with simple to minutely bordered pits

61.1 Fibres without pits

62 Fibres with distinctly bordered pits

Helical thickenings in fibres and fibre-tracheids

64 Helical thickenings in fibres and/or fibre-tracheids

Septate fibres

65 Septate fibres present

Parenchyma like fibre-bands and fibre clusters

67 Parenchyma-like fibre bands alternating with ordinary fibres

67.1 Intra-annual fibre bands

67.2 Intra-annual clusters of fibres

Fibre wall thickness

68 Fibres very thin-walled

69 Fibres thin- to thick-walled

70 Fibres very thick-walled

Radially flattened fibres

70.1 Thick-walled and radially flattened latewood fibres

Gelatinous fibres

70.2 Gelatinous fibres (tension wood)

Mean fibres length

Record measured fibres length

71 Mean fibre lengths < 900 µm

72 Mean fibre lengths 900-1600 µm

73 Mean fibre lengths > 1600 µm

Axial parenchyma

Axial parenchyma absent

75 Axial parenchyma absent or extremely rare

Apotracheal axial parenchyma

76 Apotracheal parenchyma diffuse

77 Apotracheal parenchyma diffuse-in-aggregates

Paratracheal axial parenchyma

78 Axial parenchyma scanty paratracheal

79 Axial parenchyma vasicentric

79.1 Axial parenchyma pervasive

79.2 Axial parenchyma inter-vascular

80 Axial parenchyma aliform

83 Axial parenchyma confluent

84 Axial parenchyma unilateral paratracheal

Banded parenchyma

85 Axial parenchyma bands more than 3 cells wide

86 Axial parenchyma in narrow bands or lines up to 3 cells wide

89 Parenchyma in marginal bands

89.1 Parenchyma in initial marginal

89.2 Parenchyma in terminal marginal

89.3 Ring shake

Axial parenchyma cell type

90 Fusiform parenchyma cells

Axial parenchyma strand length

91 2 cells per parenchyma strand

92 3 to 4 cells per parenchyma strand

93 5 to 8 cells per parenchyma strand

94 More than 8 cells per parenchyma strand

Unlignified parenchyma

95 Unlignified parenchyma

Rays

Rays in vascular bundles

96.0 Rays within the vascular bundle

Ray width

96 Rays exclusively uniseriate

96.1 Rays mostly uniseriate

97 Ray uniseriate to 3-seriate

98 Larger rays commonly 4- to 10-seriate

99 Larger rays commonly more than 10-seriate

Rays confluent

100.1 Rays confluent with ground tissue

Rays not lignified

100.2 Rays not lignified

Aggregate rays

101 Aggregate rays

Ray height

102 Ray height more than 1 mm

Rays of two distinct sizes

103 Rays of two distinct sizes

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

107.1 Body ray cells procumbent with 2 to more than 4 rows of upright and/or square marginal cells

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

Sheath cells

110 Sheath cells

Rays per millimetre

114 Less than 4 rays per mm

115 4-12 rays per mm

116.1 12-20 rays per mm

116.2 More than 20 rays per mm

Wood rayless

117 Wood rayless

117.1 Rays absent within the vascular bundles

Storied structure

118 Rays storied

120 Axial parenchyma and/or vessel elements storied

Secretory elements

Secretory elements

124 Oil cells associated with ray parenchyma

Intercellular canals

129 Axial canals

130 Radial canals

131 Intercellular canals of traumatic origin

Crystals

Crystals shape

136 Prismatic crystals

144 Druses

149 Raphides

150 Acicular crystals

151 Styloids and/or elongate crystals

152 Crystals of other shapes (mostly small)

153 Crystal sand

Cell content in different cell types

Cell content in vessels

154 (IAWA no. 58) Gums and other deposits in vessels

Cell content in fibres

154.1 Deposits in fibres

Cell content in ray cells

154.2 Oil drops in ray cells

Mucilage (slime)

154.3 Mucilage present

154.4 Mucilage-like cell content, bright in polarized light

BARK ANATOMICAL FEATURES

PHLOEM

Growth zones

B.1 Growth zones

Sieve elements

Sieve elements as seen in cross section

B.2 Sieve elements not distinct in cross section

Sieve element groupings in non-collapsed phloem

B.3 Sieve elements mostly solitary

B.4 Sieve elements in clusters

Sieve element arrangement

B.5 Sieve elements tangentially arranged

B.6 Sieve elements radially arranged

B.7 Sieve elements without distinct pattern

Sieve elements and companion cells

B.8 Sieve elements and companion cells distinctly differentiated in cross section

Sieve elements collapsed

B.9 Collapsed sieve elements

B.9.1 Collapsed sieve elements tangentially arranged

B.9.2 Collapsed sieve elements radially arranged

Sieve plates

B.10 Sieve plates visible in cross section

Sclerenchyma

Distinction of sclerenchyma cell type

B.11 Sclerenchyma absent or extremely rare

B.12 Sclerenchyma cells present (fibres and sclereids)

B.13 Fibres and sclereids cannot be distinguished in cross section

B.13.1 Fibres and sclereids occur simultaneously

Fibres

Fibres absent

B.14 Fibres absent in axial tissue

Fibre groupings

B.15 Fibres mostly solitary

B.16 Fibre clusters small (2-5 cells)

B.17 Fibre clusters large (more than 5 cells)

B.17.1 Fibre clusters round

B.17.2 Fibre clusters tangentially elongated

B.17.3 Fibre clusters radially elongated

Fibre arrangement

B.17.4 Fibre in tangential bands more than 3 cells wide

List of features

B.18 Fibres in tangential bands less than 3 cells wide

B.19 Radially arranged fibres

B.20 Irregularly dispersed fibres

Fibre shape as seen in cross section

B.21 Fibres square or rectangular

B.22 Fibres polygonal

B.23 Fibres round

Gelatinous fibres

B.24 Gelatinous fibres

Fibre wall structure

B.25 Sclerenchyma cell walls not red stained by using safranin

Sclereids

Sclereids absent

B.26 Sclereids absent in axial tissue

Sclereid groupings

B.27 Sclereids mostly solitary

B.28 Sclereid clusters small (2-5 cells)

B.29 Sclereid clusters large (more than 5 cells)

Sclereid clusters arrangement

B.29.1 Sclereid clusters tangentially arranged

B.29.2 Sclereid clusters radially arranged

B.29.3 Sclereid clusters irregularly dispersed

Rays

Phloem rayless

B.30 Phloem rayless

Ray course

B.31 Ray course straight

B.32 Ray course undulated or wavy

Ray width in the cambial zone

B.33 Rays uniseriate

B.34 Ray uniseriate to 3-seriate

B.35 Larger rays commonly 4- to 10-seriate

B.36 Larger rays commonly more than 10-seriate

Ray dilatation

B.37 Ray dilatation absent or extremely rare

B.38 Some rays dilated

B.39 Most rays dilated

Rays not lignified

B.40 Rays not lignified

Ray: cellular composition

B.41 Rays with sclereids

Axial parenchyma

Axial parenchyma arrangement

B.42 Axial parenchyma diffuse (irregularly dispersed)

B.43 Axial parenchyma in tangential lines/rows/bands

B.44 Axial parenchyma sheath around sclerenchyma clusters

Axial parenchyma dilatation

B.45 Axial parenchyma cells dilated

Ring shake

B.46 Ring shake present

Secretory elements

Intercellular canals

B.47 Axial secretory ducts surrounded by epithelial cells (excretion cells)

B.48 Axial canals without epithelial cells (laticifers)

Mucilage and cell content

B.49 Mucilage in rays

B.50 Mucilage in and/or around sieve elements

B.51 Dark staining substances in sieve elements

B.52 Dark staining substances in axial parenchyma cells and/or in rays

B.53 Deposits in sclerenchyma cells

Crystals

B.54 Crystals absent

Crystal types

B.55 Prismatic crystals

B.56 Druses

B.57 Raphides

B.58 Acicular crystals

B.59 Styloids and/or elongated crystals

B.60 Crystal sand

B.61 Crystals of other shapes

Crystal arrangement

B.62 Crystals in tangential lines

B.63 Crystals in radial lines

B.64 Crystals irregularly dispersed

B.65 Crystals surround sclereid clusters

B.66 More than one crystal in a cell

Crystal frequency

B.67 Crystals rare

B.68 Crystals frequent

B.69 Crystals very frequent

CORTEX

Cortex absent

B.70 Cortex absent

Cortex width

B.71 Cortex width similar or smaller than phloem width

B.72 Cortex distinctly larger than phloem

Vascular bundles in the cortex

B.73 Vascular bundles

Axial parenchyma

Axial parenchyma: cells size

B.74 Axial parenchyma cells large (> 100 µm)

B.75 Axial parenchyma cells of two distinct sizes

Axial parenchyma: cells shape

B.76 Axial parenchyma cells round

B.77 Axial parenchyma cells oval

B.78 Axial parenchyma cells of mixed shapes

Axial parenchyma: cell walls thickness

B.79 Axial parenchyma cell walls thin-walled

B.80 Axial parenchyma cell walls thin- and thick-walled

B.81 Axial parenchyma cell walls thick-walled

Axial parenchyma: cells dilatation

B.82 Axial parenchyma cells dilated

Intercellular spaces (including aerenchyma)

B.83 Intercellular spaces absent

B.84 Intercellular spaces small (between 2-4 cells)

B.85 Intercellular spaces large (between more than 5 cells)

B.86 Net-like

B.87 Radially expanded spaces

B.88 Canal-like

B.89 Irregular

Intercellular spaces with hairs

B.90 Hairs in intercellular canals

Collenchyma

Collenchyma

B.91 Collenchyma present

Sclerenchyma

Sclerenchyma absent

B.92 Sclerenchyma (fibres and sclereids) absent

Fibres arrangement

B.93 Fibres mostly solitary

B.94 Fibres in belt

B.95 Fibres in groups

B.95.1 Fibre groups tangentially arranged

B.95.2 Fibre groups irregularly arranged

Sclereids arrangement

B.96 Sclereids mostly solitary

B.97 Sclereids in groups

B.97.1 Sclereid groups tangentially arranged

B.97.2 Sclereid groups irregularly distributed

Secretory elements

Type of intercellular canals

B.98 Axial secretory ducts surrounded by epithelial cells (excretion cells)

B.99 Axial canals without epithelial cells (laticifers)

Size of intercellular canals

B.100 Ducts and/or laticifers very large at the periphery of the cortex

Mucilage and cell content

B.101 Mucilage

B.102 Dark staining substances

Crystals

Crystal types

B.103 Prismatic crystals

B.104 Druses

B.105 Raphides

B.106 Acicular crystals

B.107 Styloids and/or elongated crystals

B.108 Crystal sand

B.109 Crystals of other shapes

Crystal frequency

B.110 Crystals absent or rare

B.111 Crystals frequent

B.112 Crystals very frequent

Endodermis and pericycle

Endodermis and pericycle

B.113 Endodermis and pericycle absent or not visible

B.114 One cell layer around the central cylinder

B.115 Typical endodermis with Casparian strips, pericycle absent

B.116 One layer between cortex and the central cylinder

B.117 Several layers between cortex and the central cylinder

B.118 Endodermis with U shaped thick-walled cells

B.119 Endodermis and pericycle cells round to oval and thin walled

B.120 Endodermis cells completely thick-walled

Epidermis and cuticle

Epidermis and cuticle

B.121 Epidermis distinct

B.122 Hypodermis distinct

Cuticle thickness

B.123 Cuticle thin

B.124 Cuticle thick

Lenticels and spines

B.125 Lenticels

B.126 Spines

Trichomes and glands

B.127 Trichomes

B.128 Glands

PERIDERM

Phellem

Phellem structure

B.129 Phellem absent or not visible

B.130 One-layered phellem

B.131 Multilayered phellem

B.132 Phelloid-like cells in the phellem

Phellem cells shape

B.133 Square

B.134 Rectangular

B.135 Irregular

Phellem thickness

B.136 Phellem width similar or smaller than phloem width

B.137 Phellem width distinctly larger than phloem width

Phellem: cell arrangement

B.138 Phellem cells radially oriented

B.139 Phellem cells irregularly oriented

Crystals

B.140 Crystals present

Rhytidome

Rhytidome

B.141 Rhytidome present

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This book presents a list of morphological and anatomical characteristics designed to combine anatomical features with ecologically relevant plant traits. It includes dicotyledon trees, shrubs, dwarf shrubs, herbs, succulents, lianas, hydrophytes of any growth form from annual to perennial, with heights from one centimetre to 100 meters from any taxonomic units. Here we present an image-based codification system for xylem, phloem, cortex and periderm anatomy as seen in stems. The list is based on anatomical images from samples we collected from living plants, prepared on double stained slides (safranin and astrablue) which differentiate lignified (red stained) and unlignified (blue stained) cell walls. Plants have been collected in subtropical, arid, temperate, boreal and arctic zones in the northern hemisphere as Sahel, Sahara, Canary Islands, as well as in temperate, boreal arctic zones of Eurasia and North America. The principal xylem features are in accordance with the “IAWA list of microscopic features for hardwood identification”.

In summary, this explanatory list is the base for the combination of anatomical stem features with ecological traits. It is an anatomical base for ecological, taxonomical and physiological studies.

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