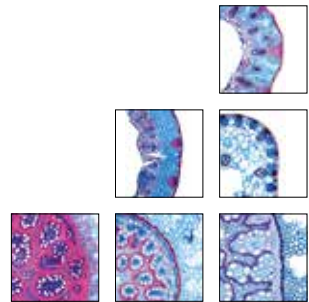


Anatomy of culms and rhizomes of Sedges

Atlas of Central European Cyperaceae (Poales)

Vol. II



**Fritz H. Schweingruber
Hugo Berger**

Coverphoto
Schoenus ferrugineus

Species on the cover
Top: *Carex curvula*
Middle (left to right): *Schoenus nigricans*, *Cyperus flavescens*
Base (left to right): *Carex elata*, *Carex flava*, *Carex gracilis*

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Content

1 Introduction	5
2 Basics	6
2.1 Material and methods	6
2.2 Taxonomic and ecological classification	6
3 Definition of anatomical features	7
3.1 Definition of culm features	7
3.2 Definition of rhizome features	31
4 Monographic presentation	45
4.1 Structure of the monographic presentation of culms	45
4.2 Characterisation of 120 species	46
5 Results	286
5.1 Frequency of anatomical culm features within the family of Cyperaceae	286
5.2 Frequency in relation to ecological factors	287
5.2.1 Relation culm length to humidity	287
5.2.2 Aerenchyma in relation to humidity of locality	288
5.3 Culm features in relation to taxonomy	289
5.3.1 Outline circular or oval, vascular bundles in 1 row	289
5.3.2 Outline circular or oval, vascular bundles in 2-3 rows	290
5.3.3 Outline triangular acutely or obtusely, vascular bundles in 1 row	291
5.3.4 Outline triangular acutely or obtusely, vascular bundles in 2-3 rows	292
6 Anatomical features in relation to taxonomy	293
7 Conclusion	293
8 Acknowledgements	294
9 References	294
10 Index	295

1. Introduction

All books about plant systematics for regions or even continents (Tutin et al. 1964-1980) describe the morphology of Cyperaceae in detail. Taxonomic differences between taxa within the whole family are characterized for flowers as well as for sterile parts of the plants and growth forms. Since macroscopic features of the flowers and the vegetative parts differentiate species in detail it was not necessary to use anatomical features for systematic studies (Judd et al. 2002). The anatomy of most species presented here have never been shown and described before. Most of the species described by Schulze-Motel in Hegi 1980 made unstained hand drawings from culms of most European *Carex* species. The pictures clearly show the form of the circumference and the distribution of vascular bundles, sclerenchyma and parenchyma and partially the presence of the assimilating part. However, the drawings have a very low resolution. Drawings had low priority for the taxonomic characterization neither in the introduction nor in the monographic part. Since an overview and a comparison is missing the taxonomic value of the presentation is limited.

Metcalf and Gregory 1971 created an anatomical base for anatomical culm. Before characterizing hundreds of species they defined the anatomical characteristics of the culm structure on longitudinal and transverse sections. Principally we follow their classification. After sectioning with a Reichert sledge microtome they double stained the sections with safranin. The anatomy of each species has been described in detail of all species and presented in drawings for a few individuals. Only the end-wall structure (scalariform perforations) have been evaluated for taxonomic purposes. The taxonomic value of tracheal longitudinal elements seems to be limited.

Dolezal et al. 2018 made an attempt to relate morphological and anatomical structures of Monocotyledons to phylogeny and to environmental gradients in the Himalaya above timberline. In focus are water- and air conducting elements structures and stabilizing elements. Taxonomic differences between Poaceae 117 and Cyperaceae 35 species in the huge topographic intensively structured geographical area are obvious and encouraged us to do the same for the European region. They presented described and classified the microscopic structure of 300 herbarium specimens of Poaceae from the alpine region (Schweingruber and Berger 2017).

The anatomical structure of rhizomes of a very few species has been described by Neumann 1952. We resign of mentioning a few isolated anatomical studies (see Gregory in Metcalf 1971) because none of them intends to relate many species to a large taxonomic spectrum or to ecological conditions.

Schweingruber et al. are preparing more than 300 stems of wetland plants. Some transverse sections of the plants described there have been used in the present compendium.

Based on the studies from all the approaches mentioned we followed the following concept: Evaluation and presentation of major characteristics within the family of Sedges (Cyperaceae) and describing the anatomical structures of culms and rhizomes of a large number of species of, double stained microscopic slides (Safranin/Astrablue) within the family of Cyperaceae in

the region of the Alps. Because rhizomes play by Cyperaceae an important role for the macroscopic species identification we decided to study their anatomical structures. Finally we relate important macroscopic features as humidity, site conditions to plant size and some microscopic features. The present study is part of an anatomical study about all stem anatomical features of Angiosperms (Schweingruber et al, 2011 and 2013, Crivellaro and Schweingruber 2015).

2. Basics

2.1 Material and methods

Since anatomical structures collapse during drying processes (see *Carex baldensis*) we had to section primarily fresh material collected in nature. Culms were sectioned in the upper half of the flower stalk and rhizomes close to the basal origin of the culm.

After collection significant parts of the plant they were labeled and stored in ethanol 40%. The detailed technique is described by Gaertner and Schweingruber 2013. All sections are stained with a one to one mixture of Safranin/Astrablue for a few minutes. Staining and dehydration with ethanol 96% and xylene occurred directly on the glass. Permanent slides are embedded in Canada Balsam. Photographs have been made in transmitting light with an Olympus BX51 microscope. Sections are documented by 100 times (objective 10, eyepiece 10) and 400 times (objective 40, eyepiece 10).

We analyzed 89 of 114 *Carex* species of the alpine zone and 37 non *Carex* species (Aeschimann et al. 2005).

2.2 Taxonomic and ecological classification

Most important features for Cyperaceae is the correct taxonomic name. The determination is primarily based on Aeschiman et al. 2005, on comparative material of the Herbarium of the Institute of Botany at the University of Bern and the floras of Binz 1986 and Graf 2015. Since plant size, the occurrence of the individual on specific sites influent the anatomy we made the following classification:

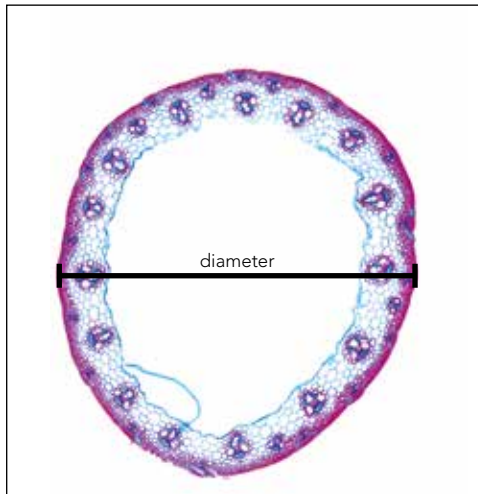
Length of culm	0-15 cm, 15-40 cm and >40 cm
Vegetations zones	higher altitudes: alpine, alpin/subalpine, subalpine/mountain lower altitudes: mountain and colline (hill zone)
Humidity of the site	very dry, dry, medium, moist, wet

3. Definition of anatomical features

3.1 Definition of culm features

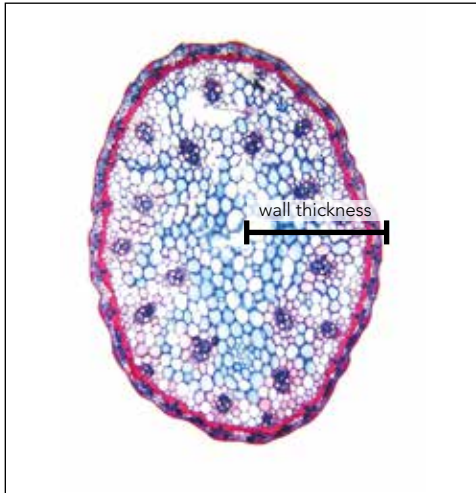
Anatomical key traits for culms have primarily been defined by Metcalfe 1971. The present material however allowed a more specific classification. Some features are already defined by Dolezal et al. 2018 and Schweingruber and Berger 2017. However some additional features are defined in this volume. E.g. triangular culms, papillouse epidermis, peripheral sclerenchymatic beams (girders) and the form and occurrence of chlorenchyma. All details are described on page 7-30.

Culm-diameter

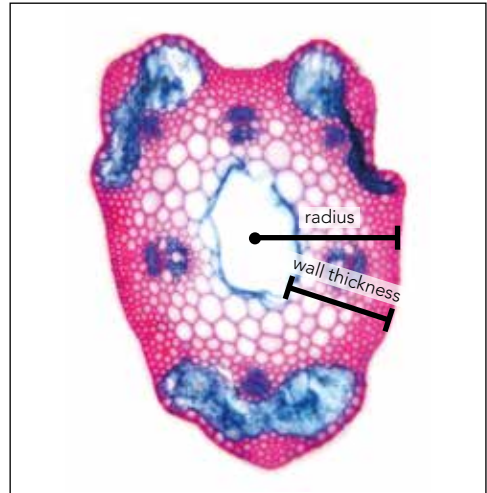


- 4a** Culm-diameter < 0.5 mm
- 4b** Culm-diameter 0.5-1 mm
- 5** Culm-diameter 1-2 mm
- 6** Culm-diameter 2-5 mm
- 7** Culm-diameter 5-10 mm
- 8** Culm-diameter > 10 mm

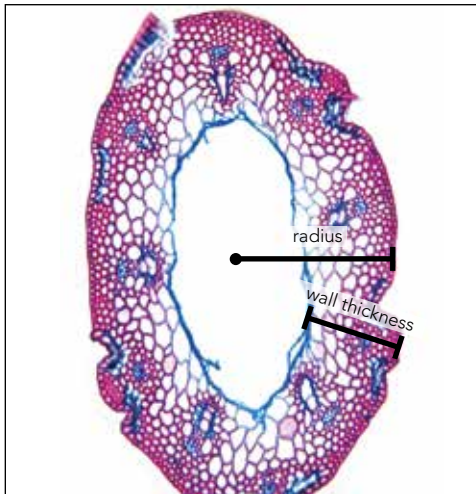
Culm-radius in relation to culm-wall



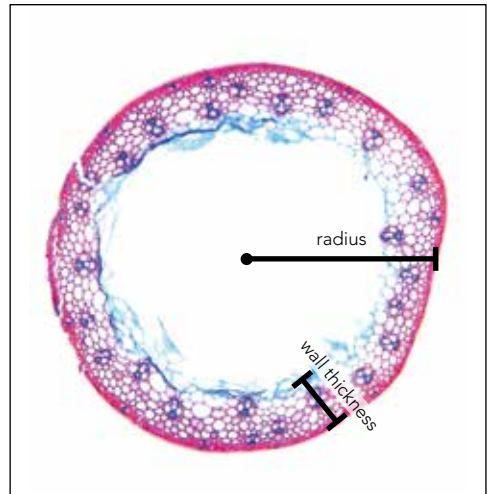
9a Center full, radius of culm in relation to wall thickness 1:1.



9b Wall very large, radius of culm in relation to wall thickness approximately 1: 0.75.

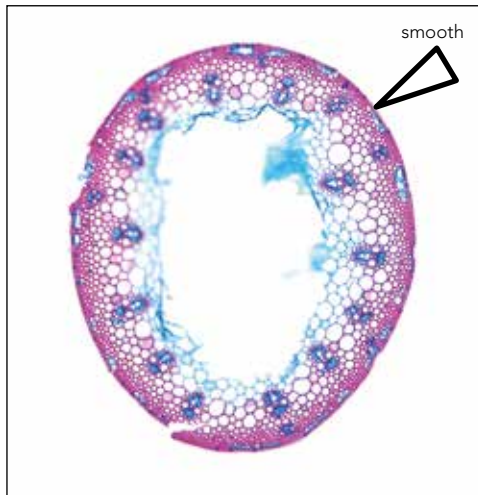


9c Wall large, radius of culm in relation to wall thickness approximately 1: 0.5.

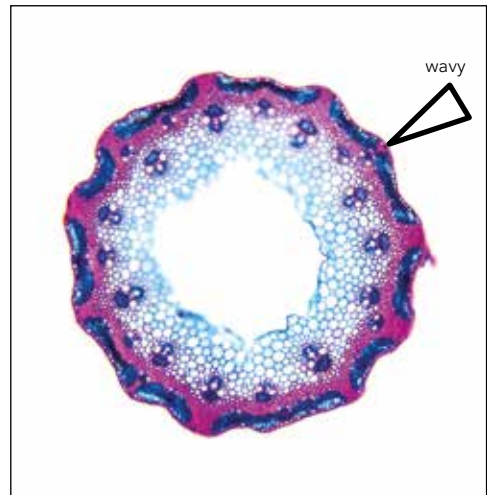


9d Wall thin, radius of culm in relation to wall thickness approximately 1: 0.25 or < 0.25.

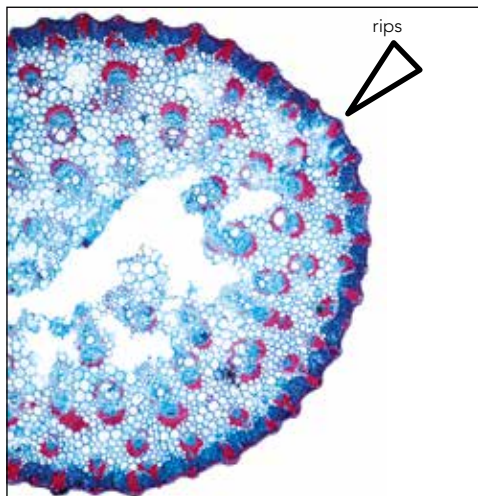
Form of outline



10 Outline circular with a smooth surface.



11 Outline circular wavy.



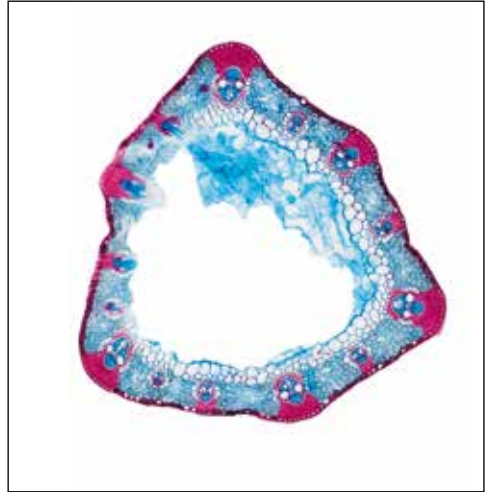
12 Outline circular, with ribs.



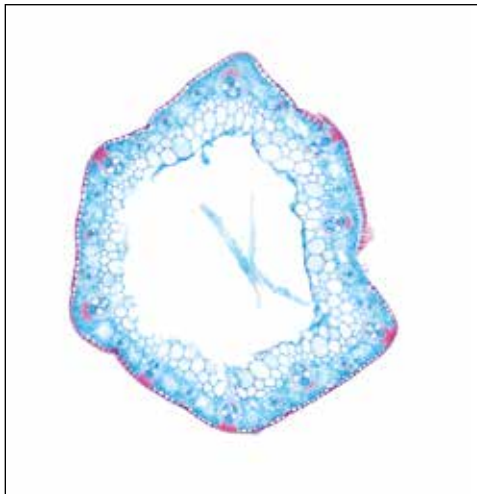
13 Outline oval.



14 Outline triangular, acutely.

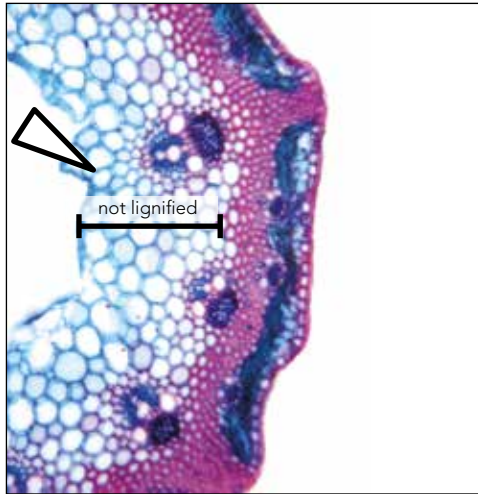


15 Outline triangular, obtusely.

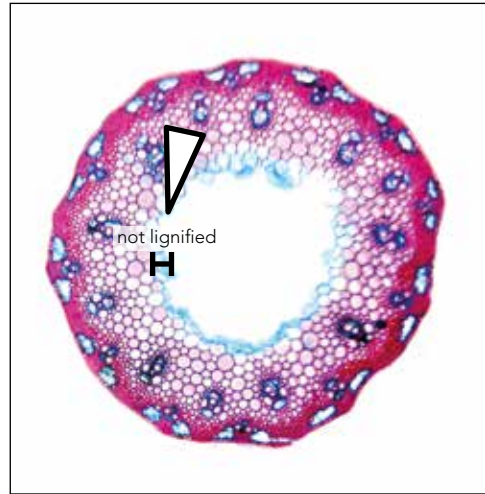


16 Outline pentagonal or hexagonal.
Corresponds with feature 16 in
Vol. III + IV.

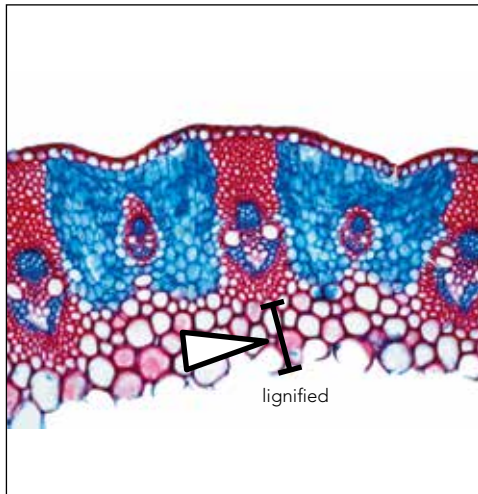
Construction of culm center



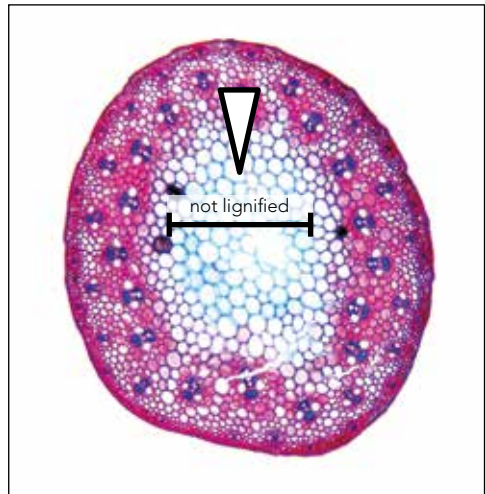
19a Culm-center hollow and surrounded by many large thin-walled, not lignified cells.



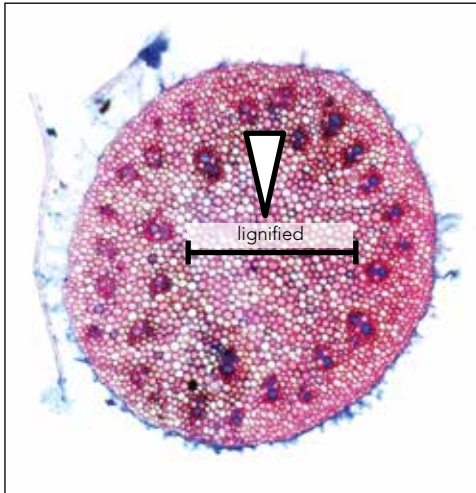
19b Culm-center hollow and surrounded by a few thin-walled, not lignified cells.



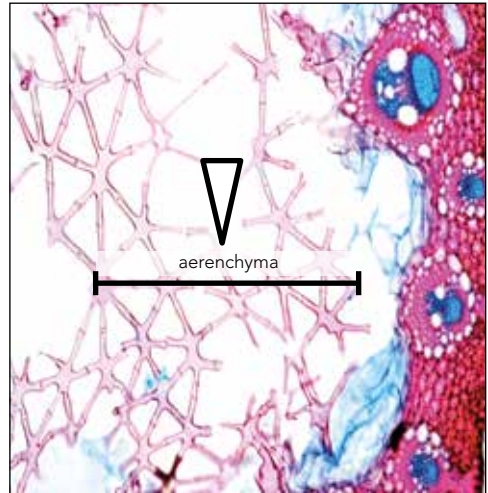
19c Culm-center hollow, surrounded by thin-walled lignified cells.



20a Culm-center full, containing unligified cells.



20b Culm-center full, containing lignified cells.



21 Culm-center with net-like aerenchyma (stellate).

Separation within the culm, flower stalk or stem

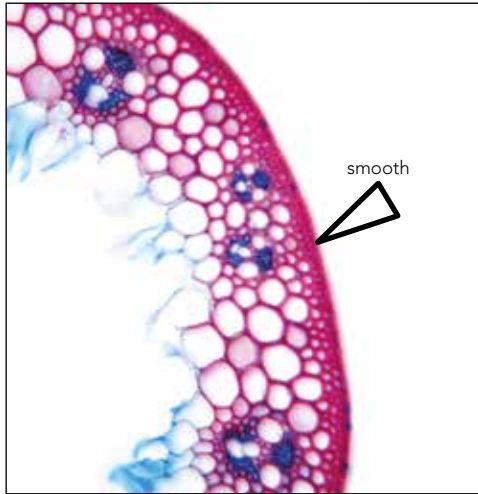


25 Without cortex/central cylinder separation. Endodermis absent.

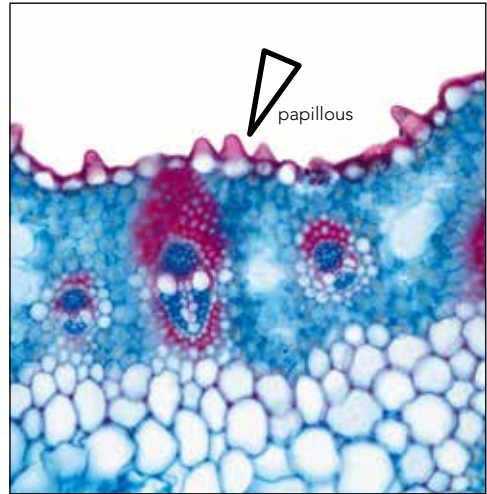


27 With cortex/central cylinder separation. Endodermis present.

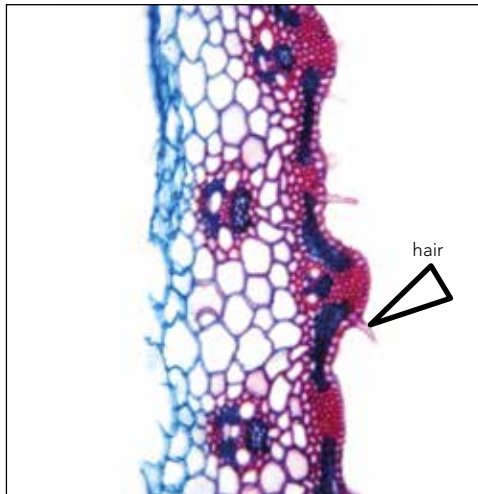
Epidermis



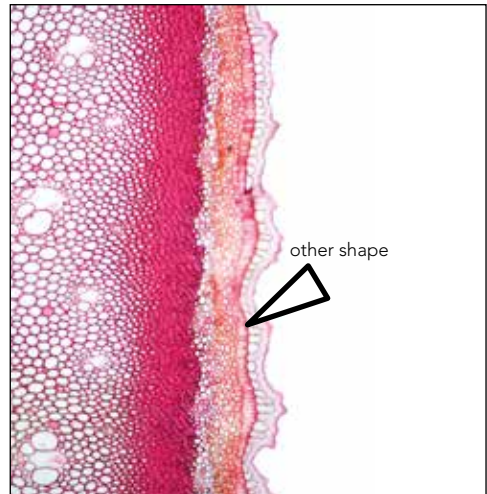
30 Epidermis smooth.



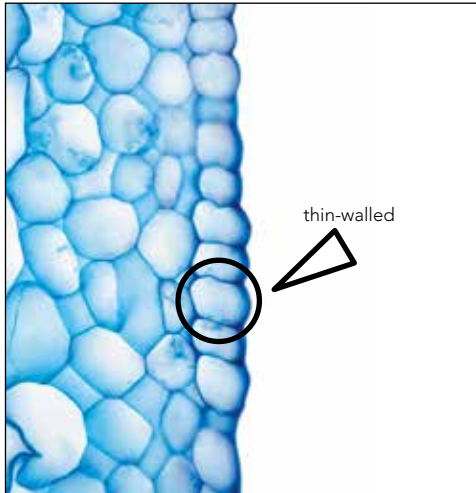
31 Epidermis papillous (bulliform).



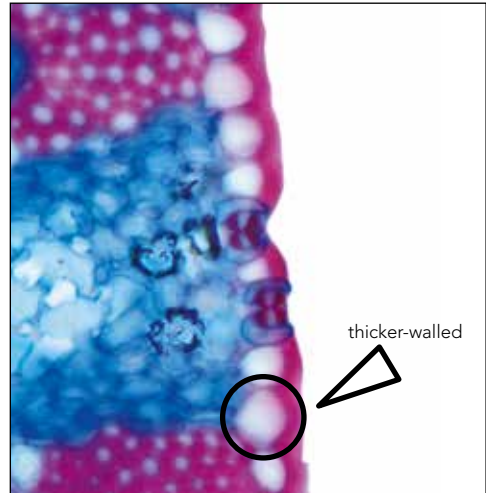
32 Epidermis with hairs.



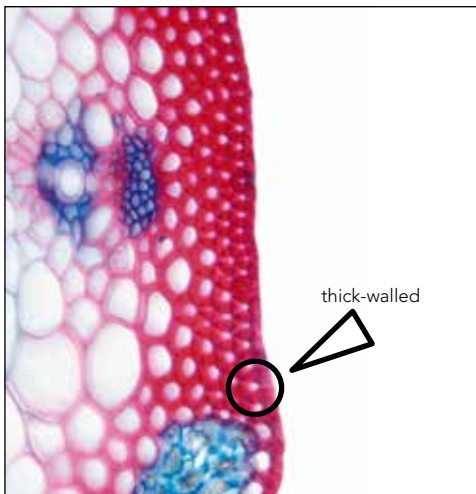
33 Epidermis with other shape.



34 Epidermis cells thin-walled all around.



35 Epidermis cells inside thin-, peripheral thicker-walled (lignified).



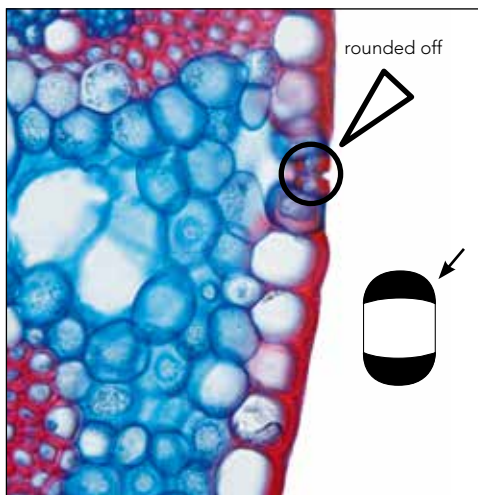
36b Epidermis cells thick-walled all around.

Cuticula

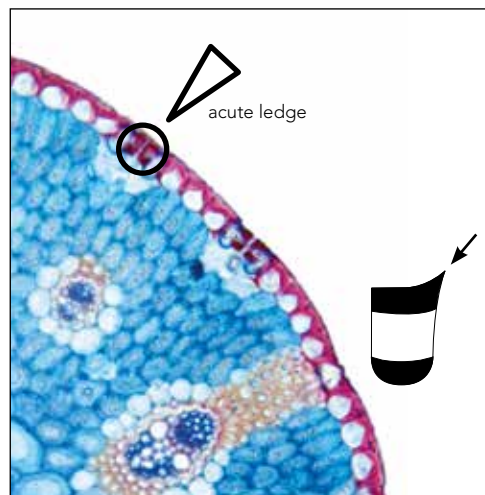


36d Cuticula very thick.

Construction of stomata

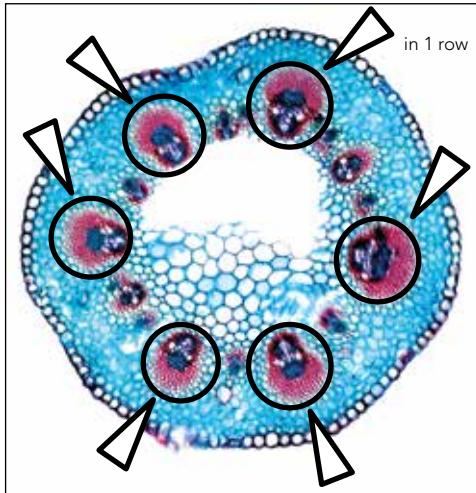


36g Guard cells of stomatas externally rounded off.

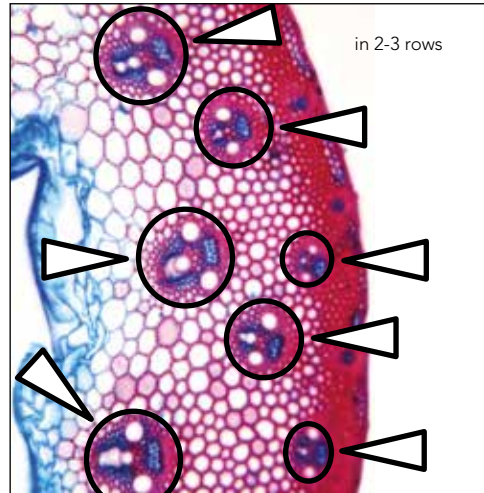


36h Guard cells with and externally acute ledge. Difficult to recognize (see also feature 101h).

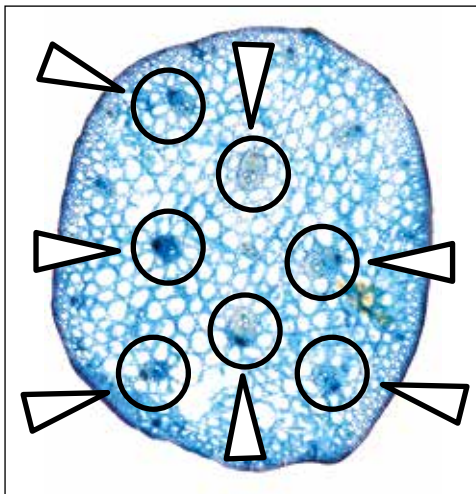
Arrangement of large vascular bundles



41 Large vascular bundles arranged in one peripheral row.



41a Large vascular bundles arranged in 2-3 peripheral rows.

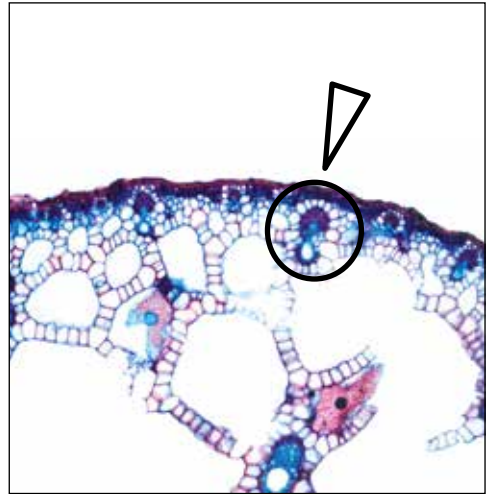


42 Large vascular bundles distributed in the whole culm.

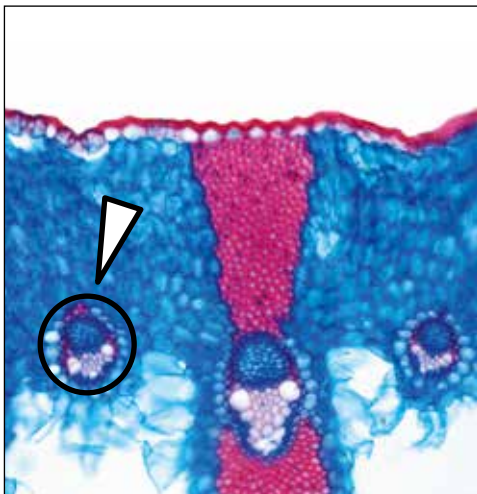
Arrangement of small or rudimentary vascular bundles



43 Groups of fibers in the epidermis and hypodermis. Probably rudimentary vascular bundles.



44a Small or rudimentary vascular bundles, mainly at the periphery.

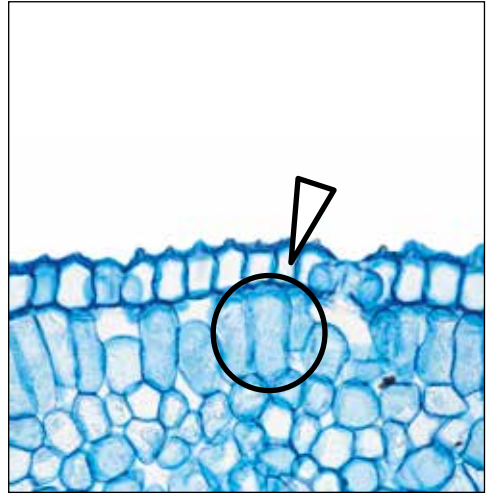


44b Small or rudimentary vascular bundles within in the chlorenchyma.

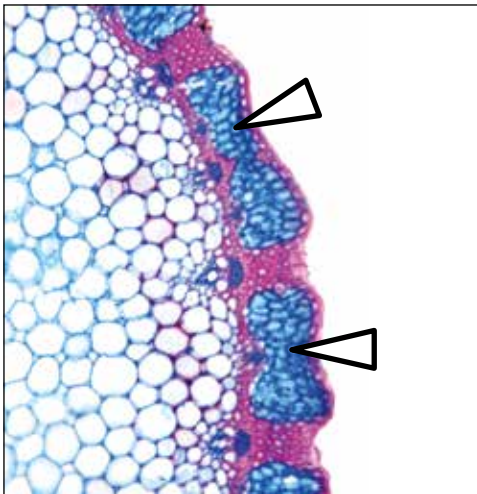
Chlorenchyma



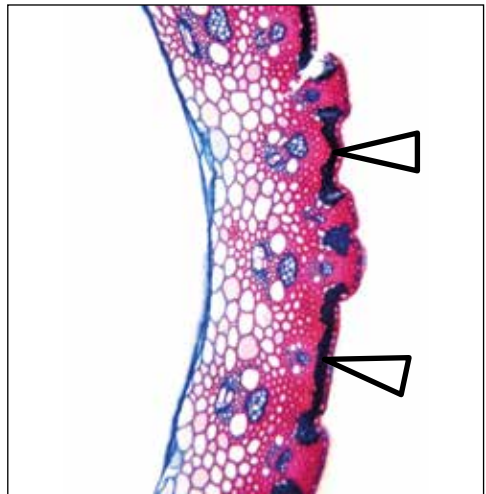
46 Chlorenchyma in a continuous peripheral belt with unignified, round cells (like a large cortex).



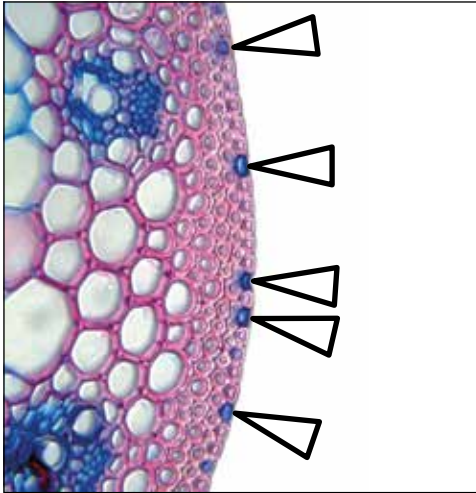
47 Chlorenchyma in form of unignified thin-walled palisade-like cells.



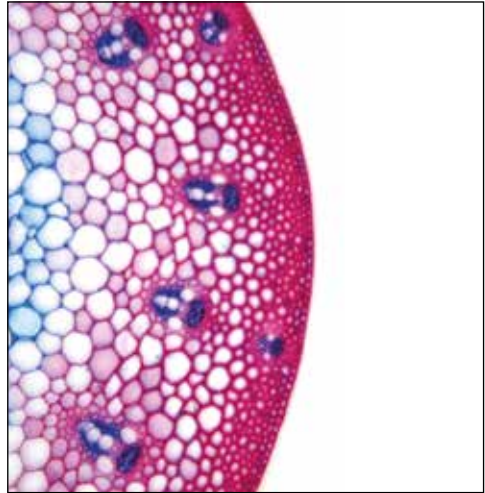
48a Chlorenchyma in round, oval, square or rectangular groups.



48b Chlorenchyma in tangentially enlarged groups.

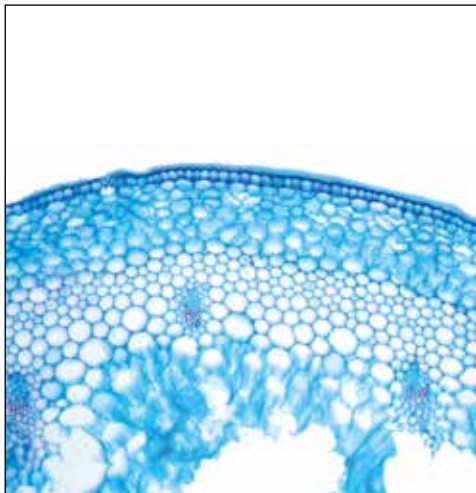


49a Chlorenchyma very small in 1-3 lined up cells.

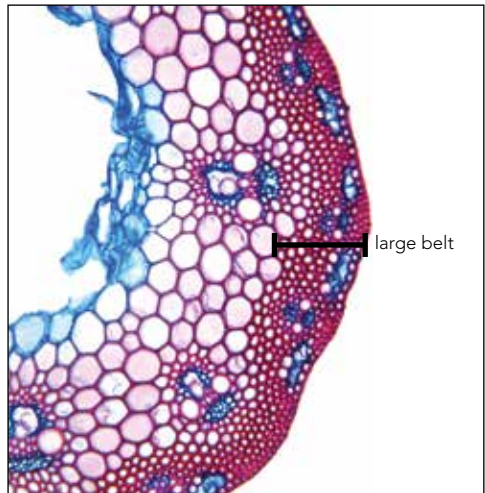


49b Chlorenchyma absent.

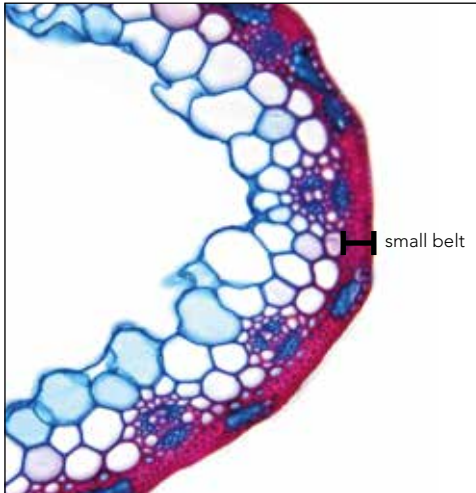
Peripheral sclerenchyma belt



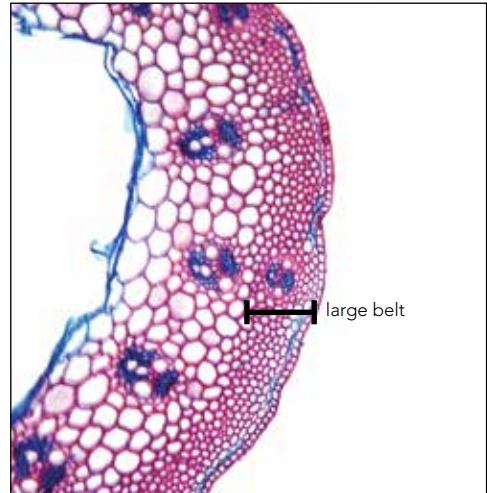
51 Sclerenchyma belt absent but sometimes with a belt of unligified cells.



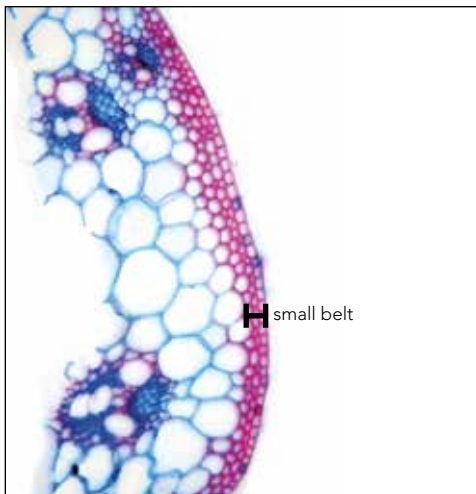
52a Sclerenchyma in a large, peripheral continuous belt (>3 cells), cells thick-walled.



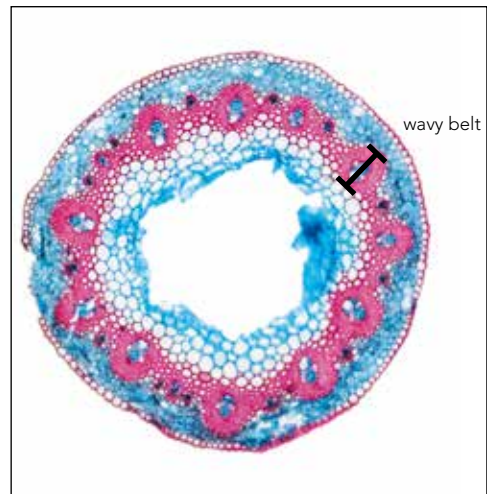
52b Sclerenchyma in a small, peripheral continuous belt (< 4 cells), cells thick-walled.



52c Sclerenchyma in a large, peripheral continuous belt (> 3 cells). Cells medium thick-walled.

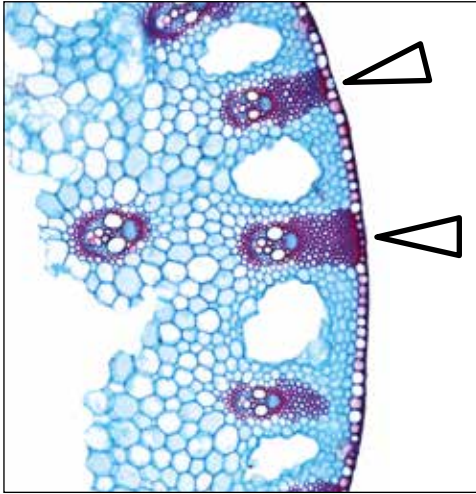


52d Sclerenchyma in a small, peripheral continuous belt (< 4 cells). Cells medium thick-walled.

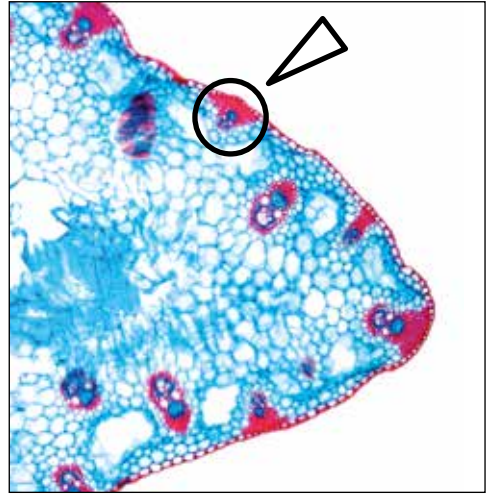


53b Sclerenchyma in a wavy continuous belt centripetal of the chlorenchyma.

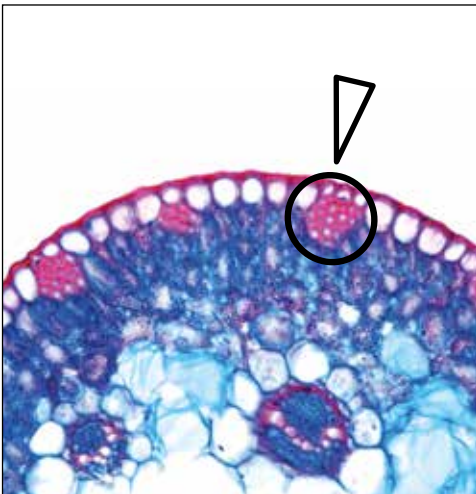
Sclernchyma girders



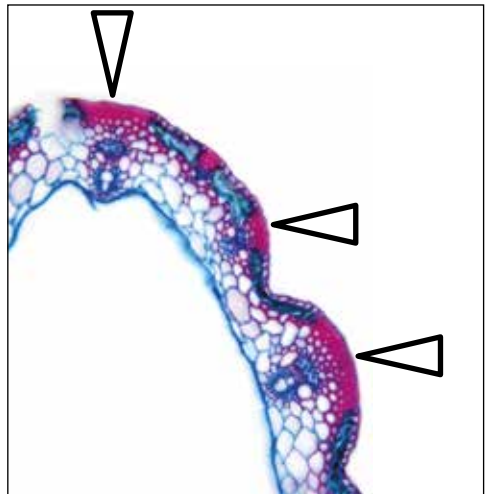
55a Girders square or rectangular.



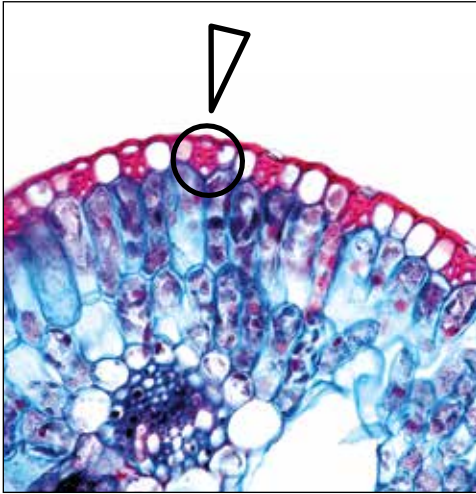
55b Girders conic.



55c Girders at the periphery round.

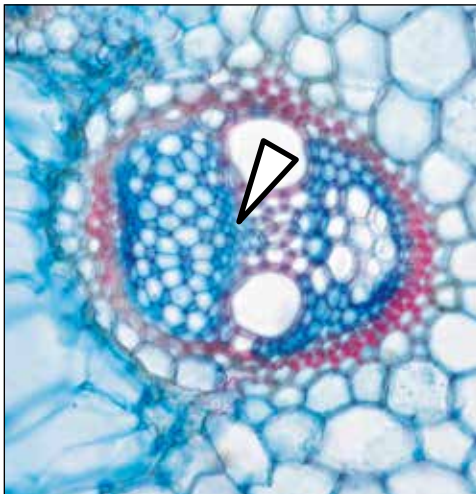


55d Girders tangentially enlarged.



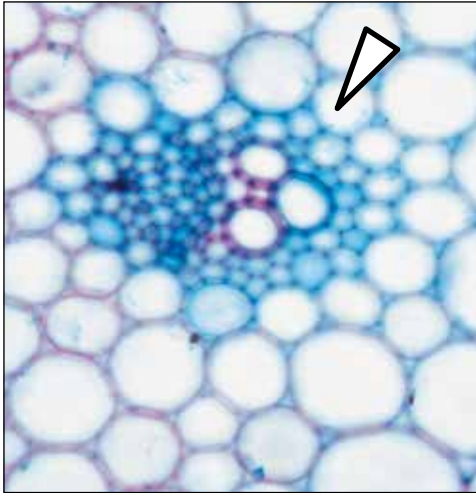
55f Groups of sclerenchyma (girders) small within the epidermis (see also feature 43).

Types of vascular bundles

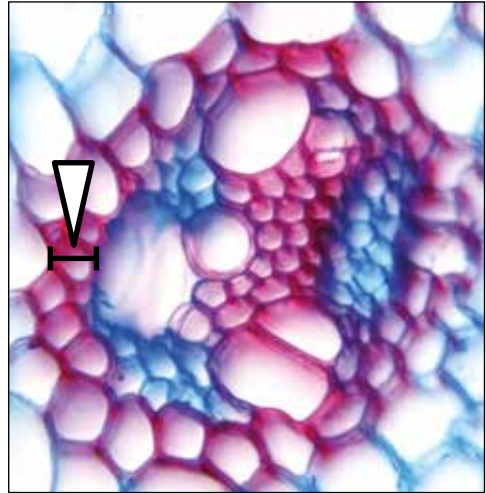


78 Vascular bundles collateral closed (absent cambium).

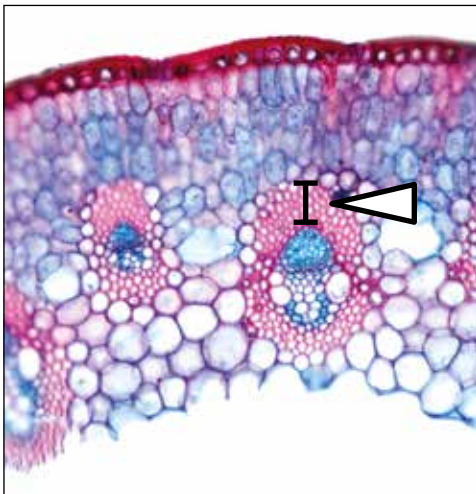
Sclerenchymatic sheath around vascular bundles



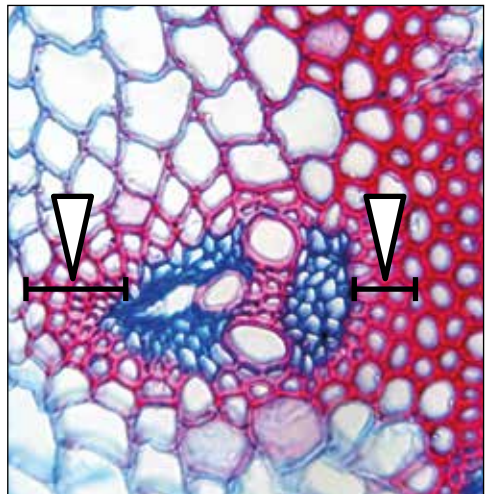
81 Sclerenchymatic sheath around vascular bundles absent or not lignified.



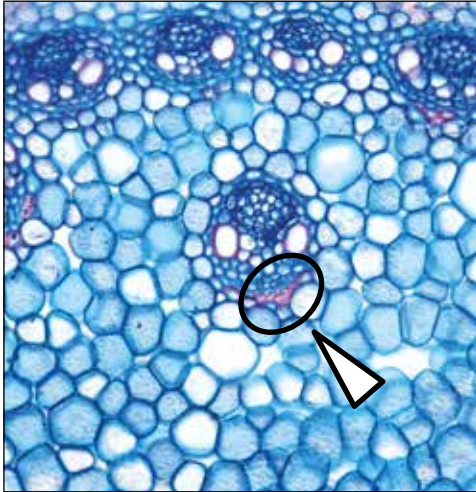
82 Small sclerenchymatic sheath around vascular bundles with 1-2 cells.



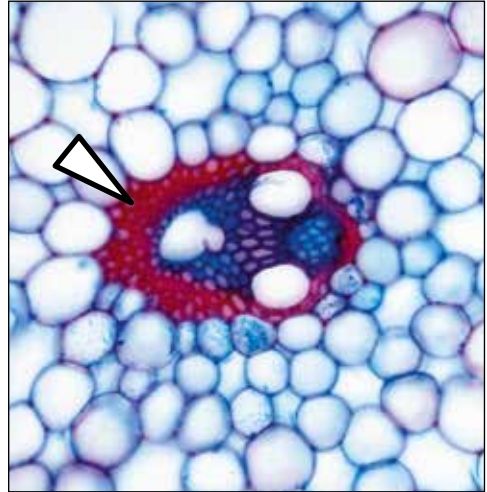
83 Sclerenchymatic sheath around vascular bundles circular large, 3 to x cells.



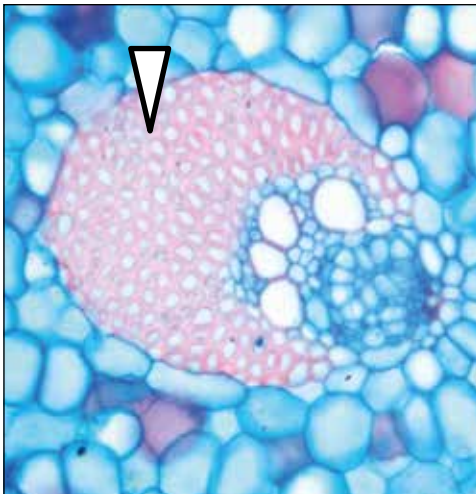
84 Sclerenchymatic sheath bilateral, large at both radial ends of vascular bundles.



85a Sclerenchymatic sheath around vascular bundles one-sided small, 1-2 cells.

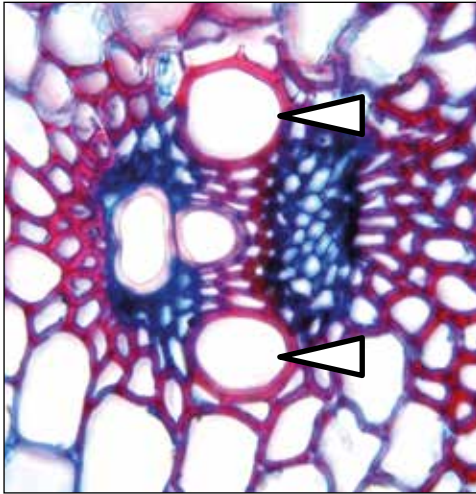


85b Sclerenchymatic sheath around vascular bundles one-sided large 2-4 cells, centripetal.

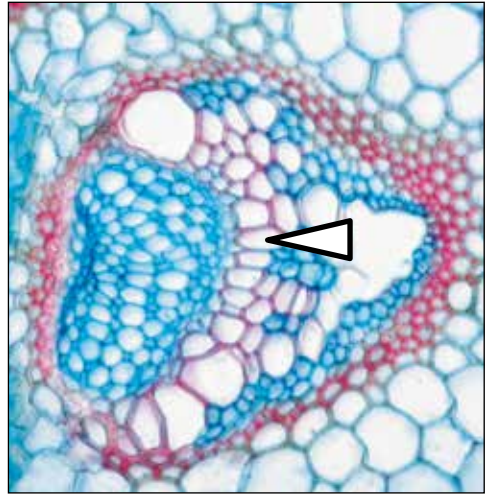


86 Sclerenchymatic sheath around vascular bundles one-sided large. Drop-like at the centripetal side (Typha-type).

Vessel arrangement in vascular bundles

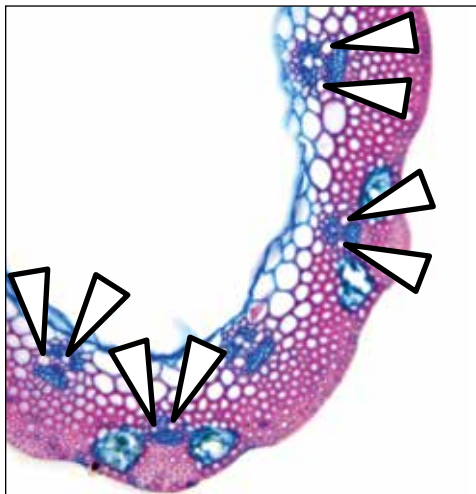


90a Vessel arrangement in vascular bundles in lateral position.



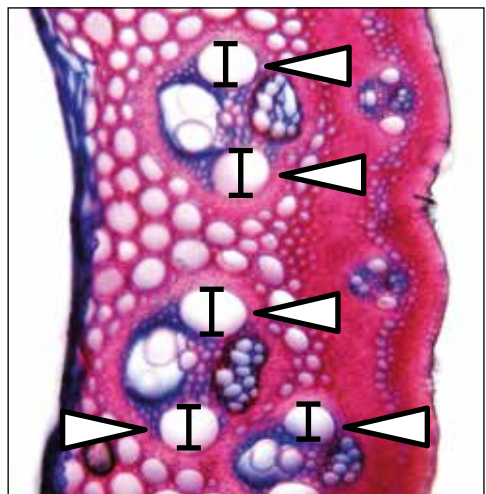
91 Vessel arrangement in vascular bundles horseshoe like.

Vessel size



95 Largest vessel in the bundle small, < 20 μm

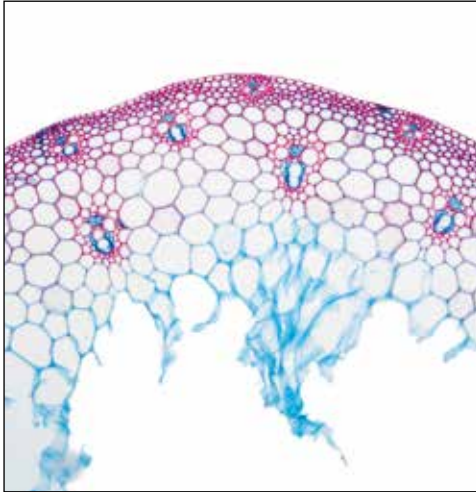
96 Largest vessel in the bundle 20-50 μm



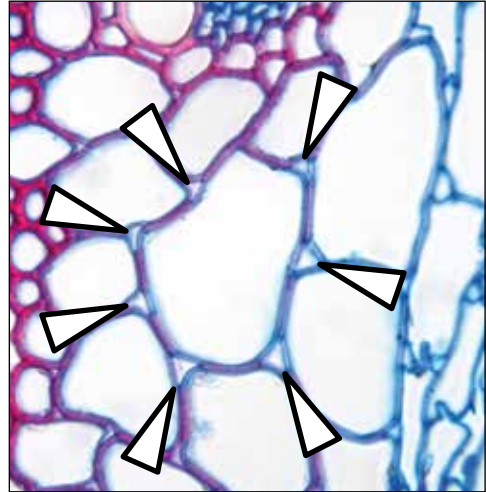
97 Largest vessel in the bundle 50-100 μm

98 Largest vessel in the bundle > 100 μm

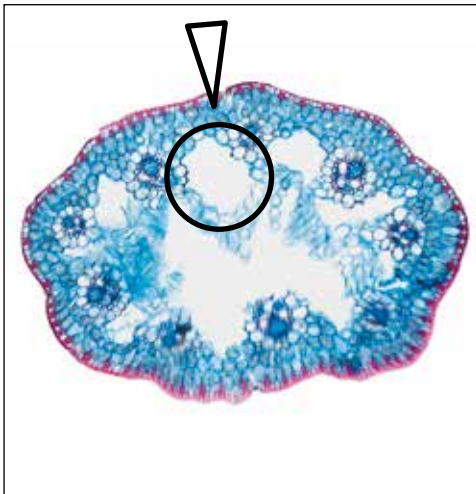
Cavities (intercellulars) and aerenchyma between parenchyma cells



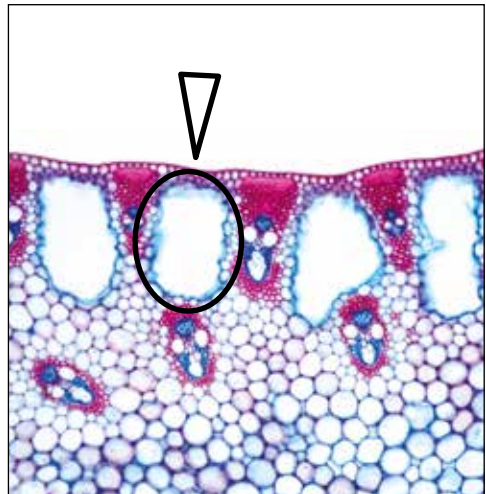
100 Cavities (intercellulars) between parenchyma cells absent.



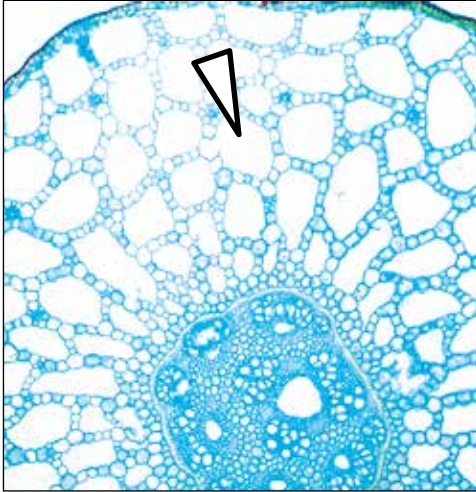
101a Cavities (intercellulars) between parenchyma-cells small, often triangular.



101b Aerenchyma (intercellulars) between parenchyma cells irregular and large (lysigenous).



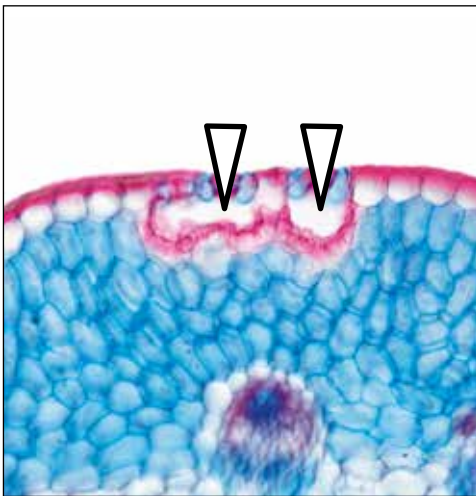
101c Aerenchyma (intercellulars) between parenchyma cells round, oval to radial (lysigenous).



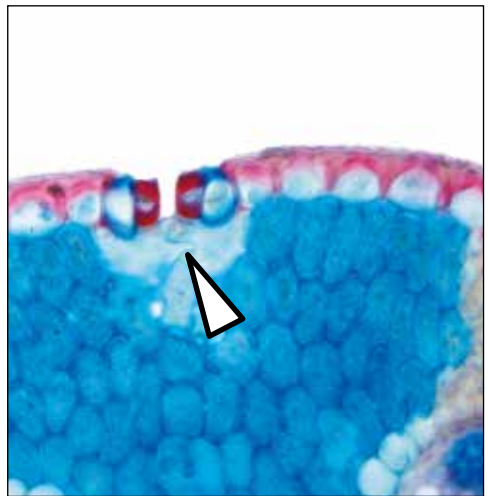
101d Aerenchyma (intercellulars) between parenchyma cells net-like. Honeycumb (schizogenous).



101e Aerenchyma (intercellulars) between parenchyma cells stellate (schizogenous).

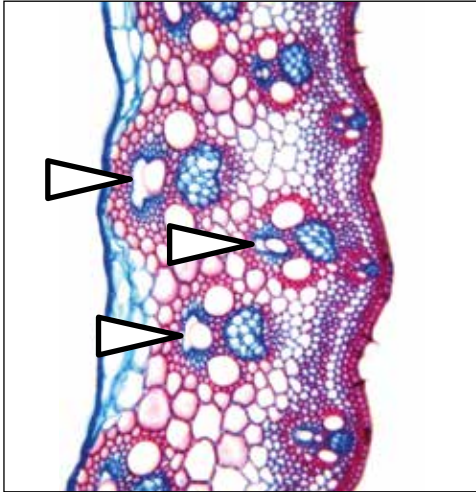


101f Substomatal cavities surrounded by small cells.



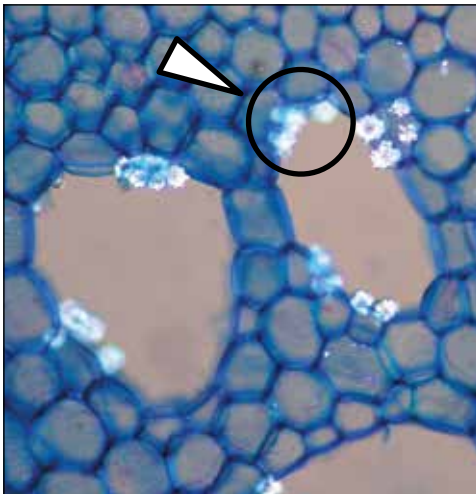
101h Substomatal cavities irregular formed by normal parenchyma cells.

Cavities in vascular bundles

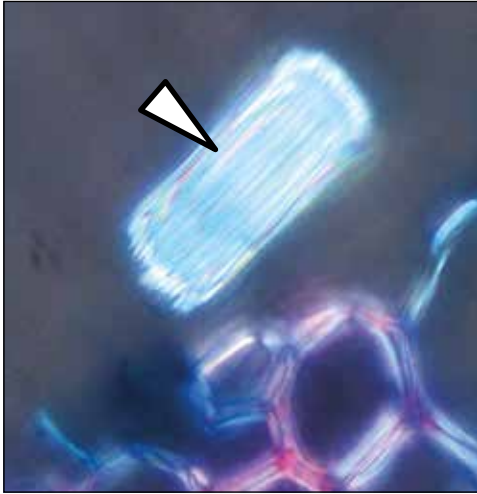


110a Distinct cavities (intercellular) in the protoxylem area of vascular bundles.

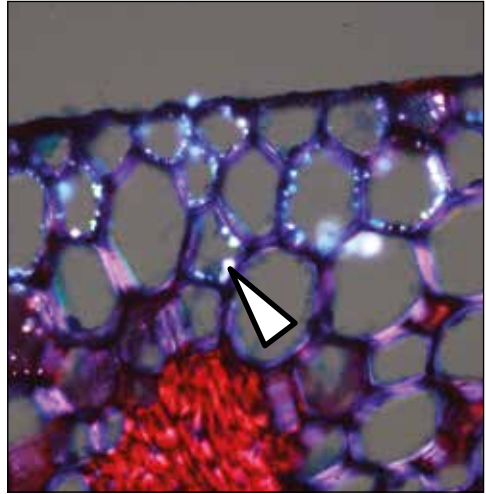
Crystals



117a Crystals as druses.

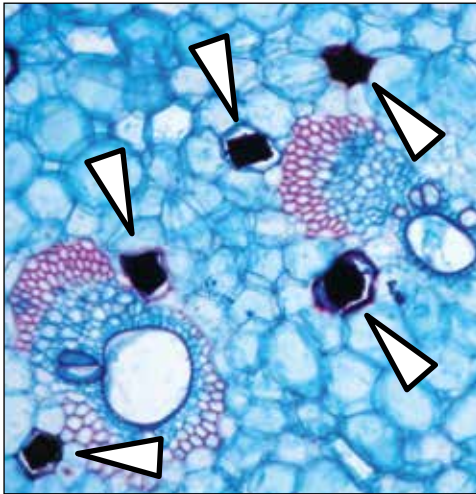


118 Crystals as raphids in bundles.

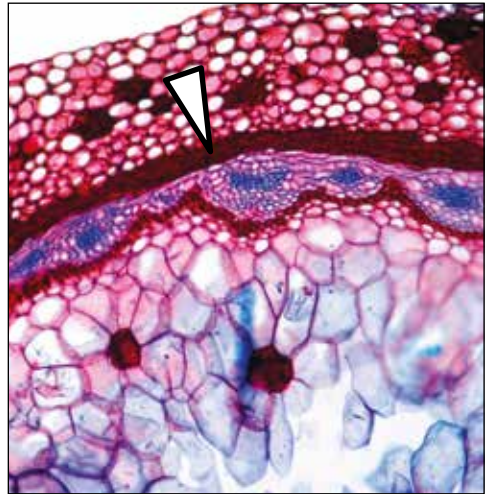


119 Crystals as sand.

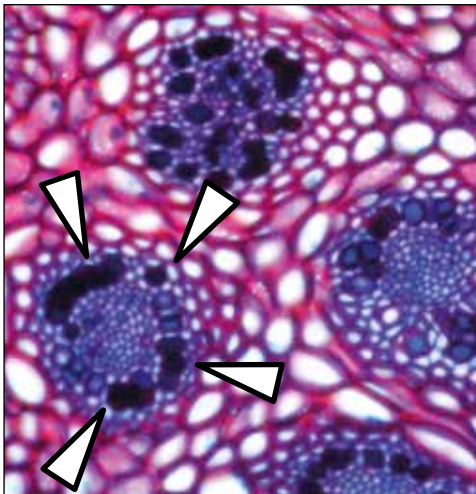
Cell contents: slime, phenols



125a Cell contents as slime or phenols in isolated cells.



125b Cell contents as slime or phenols in layers.



125c Cell contents as slime or phenols in vascular bundles.