



THE 1ST INTERNATIONAL SUMMER SCHOOL ON ADVANCED SOIL PHYSICS

MODELING WATER FLUXES IN THE SOIL-PLANT SYSTEM

MODELLING ROOT ANATOMY & HYDRAULICS

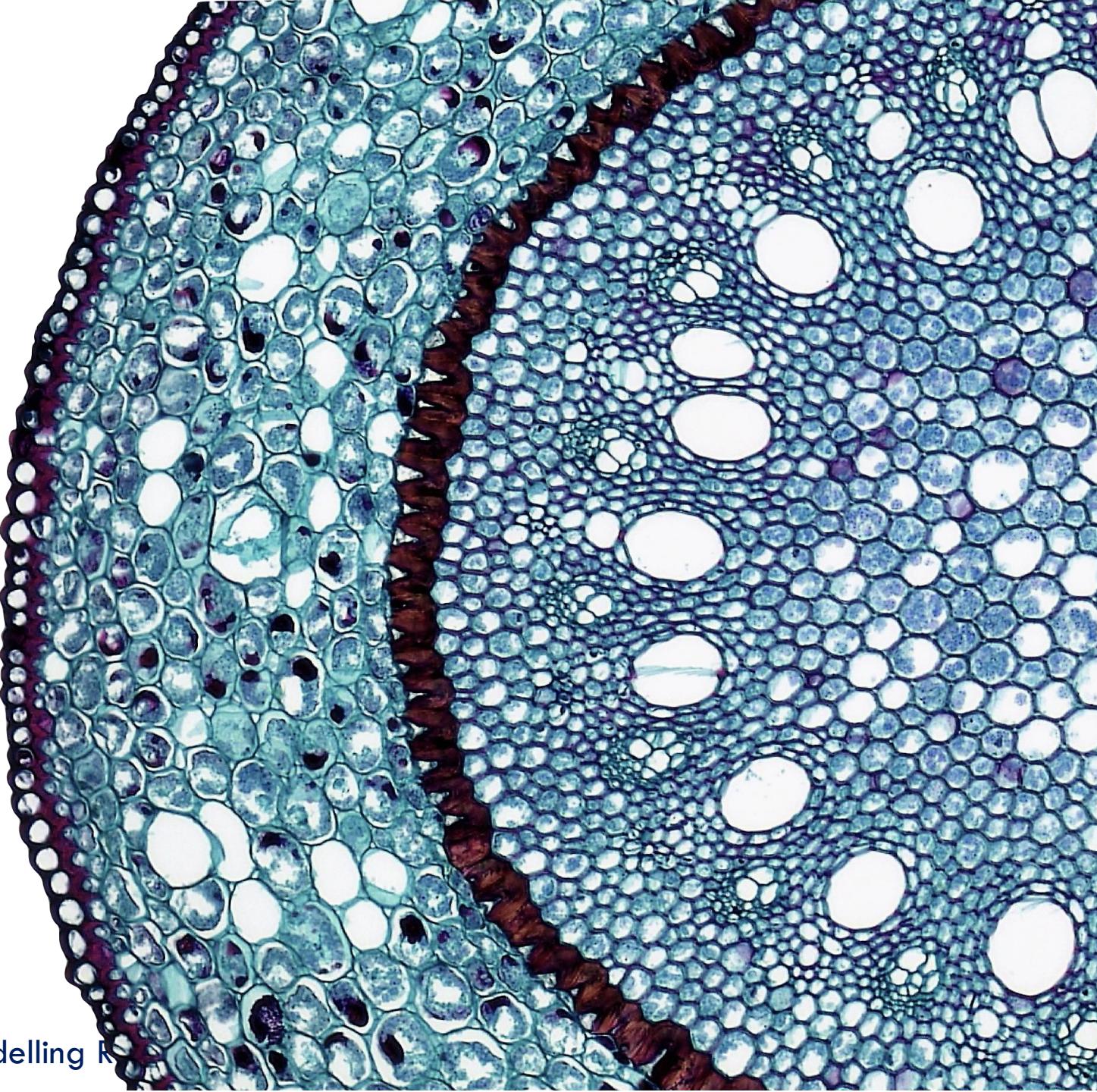
GUILLAUME LOBET & VALENTIN COUVREUR

 UCLouvain

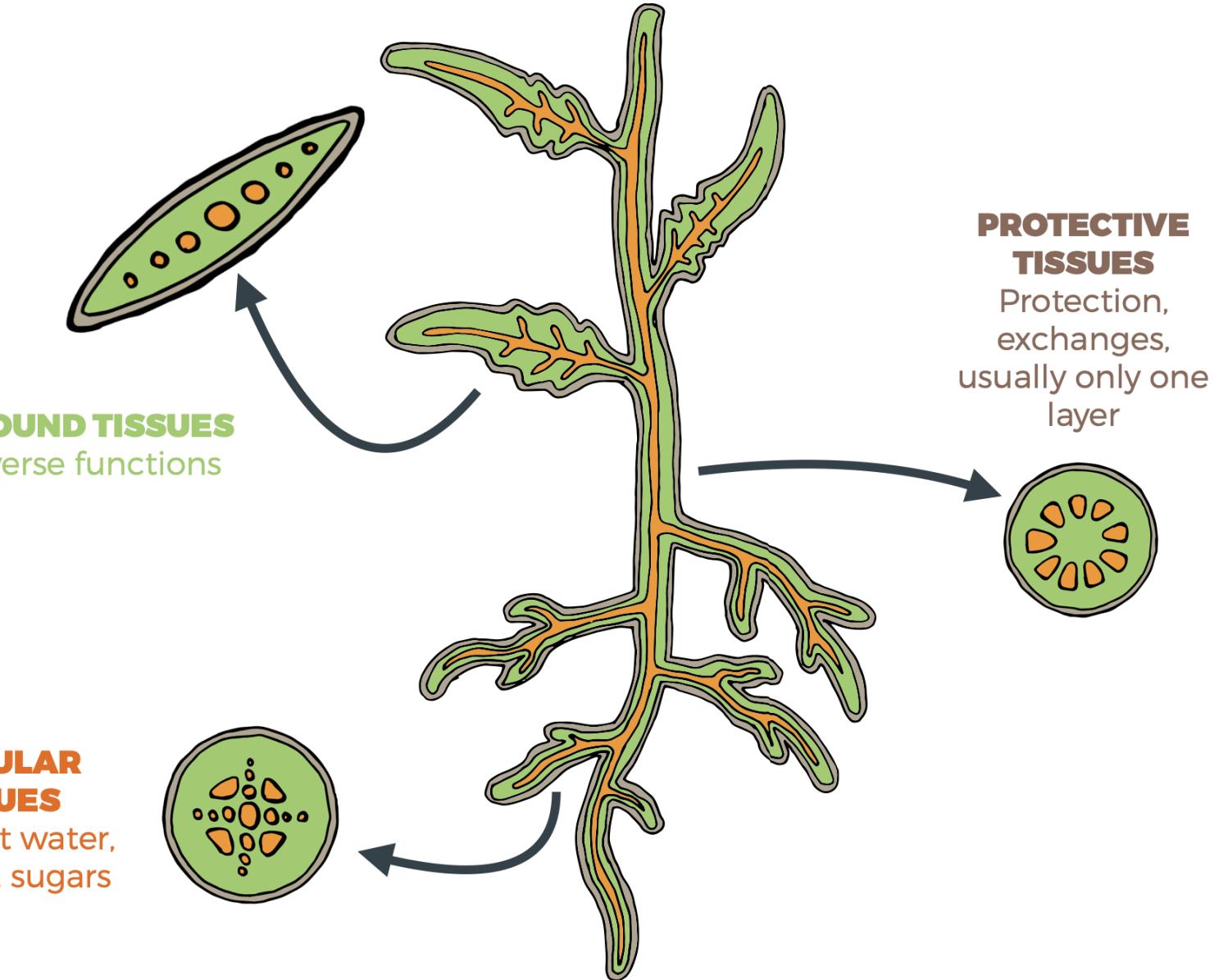


ENVITAM

ROOT ANATOMIES THE BIOLOGY



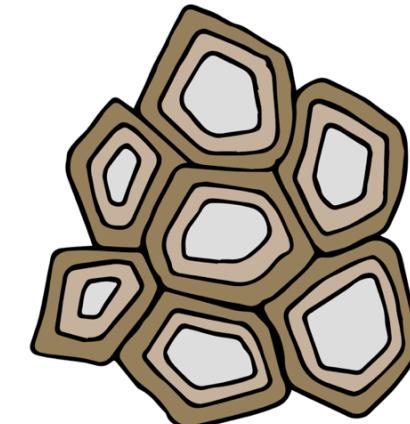
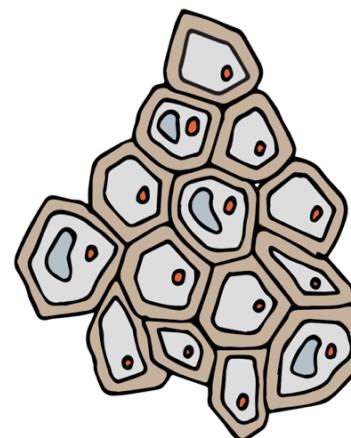
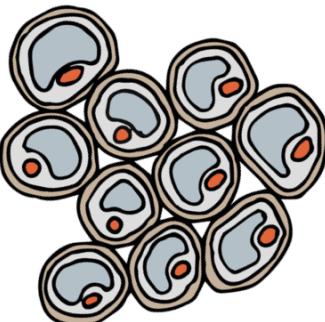
PLANTS HAVE THREE TYPES OF TISSUES



PLANTS HAVE THREE TYPES OF CELLS

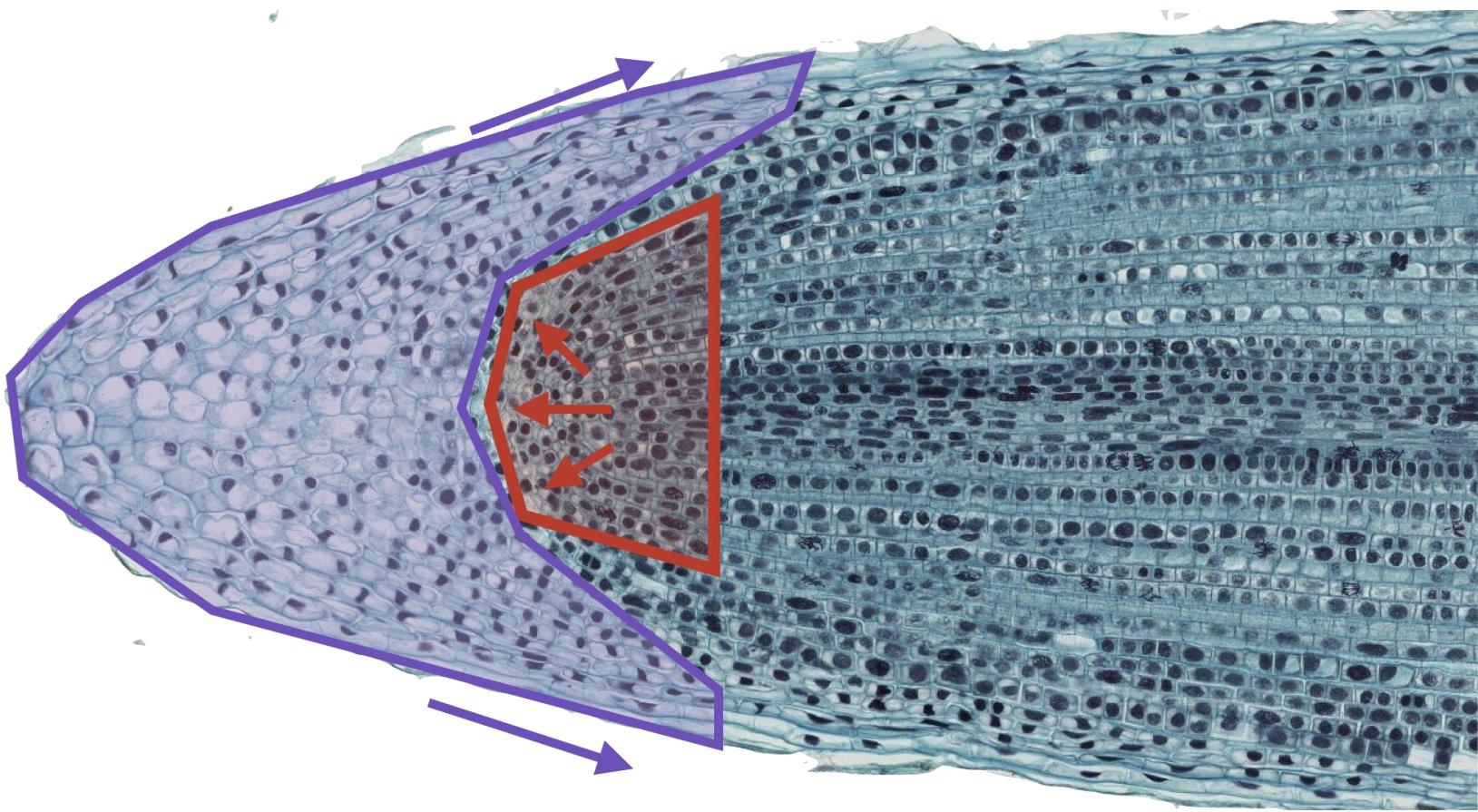
Parenchyma Collenchyma Sclerenchyma

Vacuole
Nucleus
Cytoplasm
Primary walls
(cellulose)
Secondary walls
(Sometime
lignin)

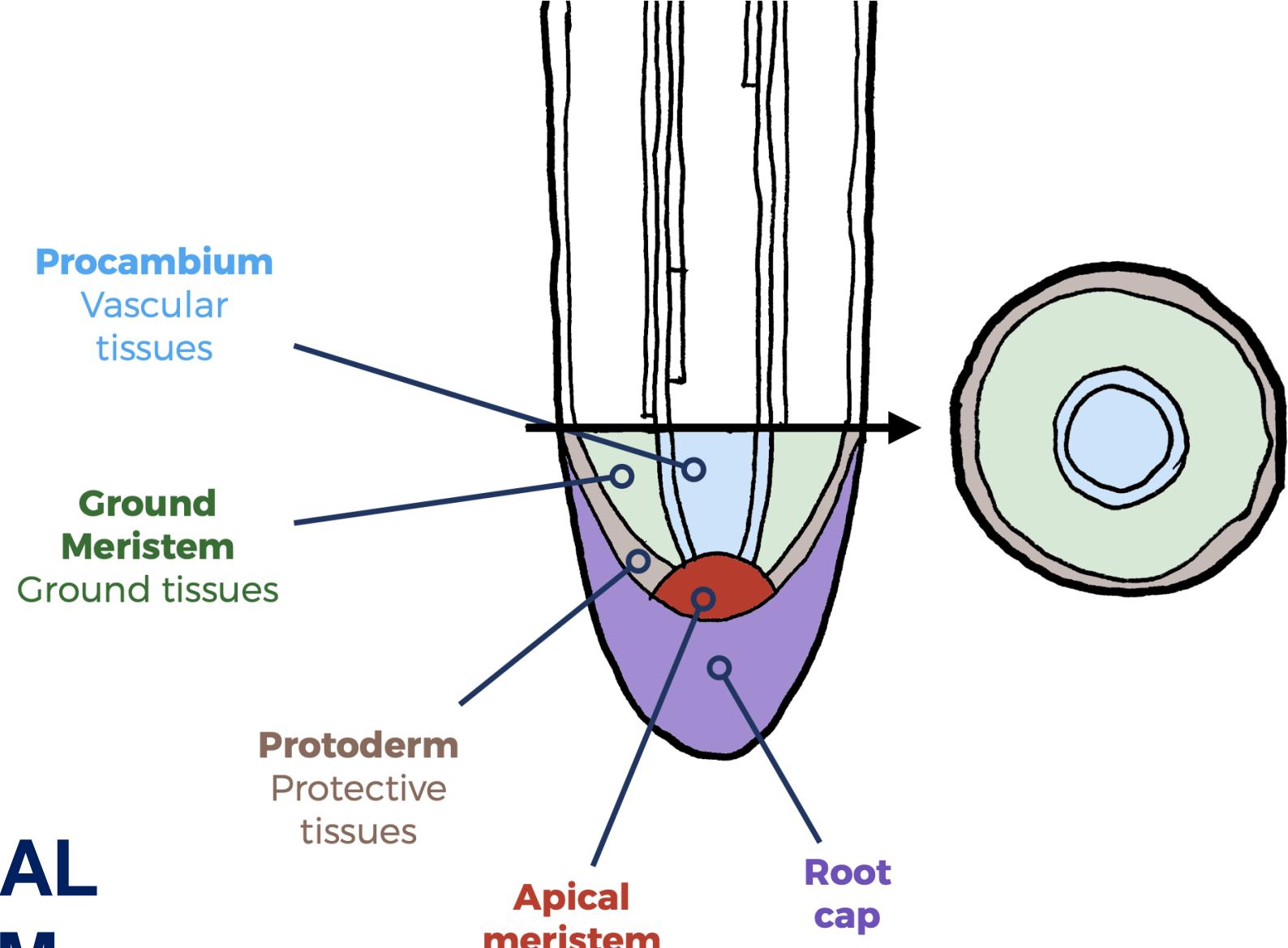


	Parenchyma	Collenchyma	Sclerenchyma
Walls	Thin primary	Thick primary	Primary + secondary
Cytoplasm	Abondant	Present	Absent
Nucleus	Present	Present	Absent
Vacuole	Large	Present	Absent
Intercellular spaces	Present	Absent	Absent
Fonctions	Diverses	Flexible support	Rigid support

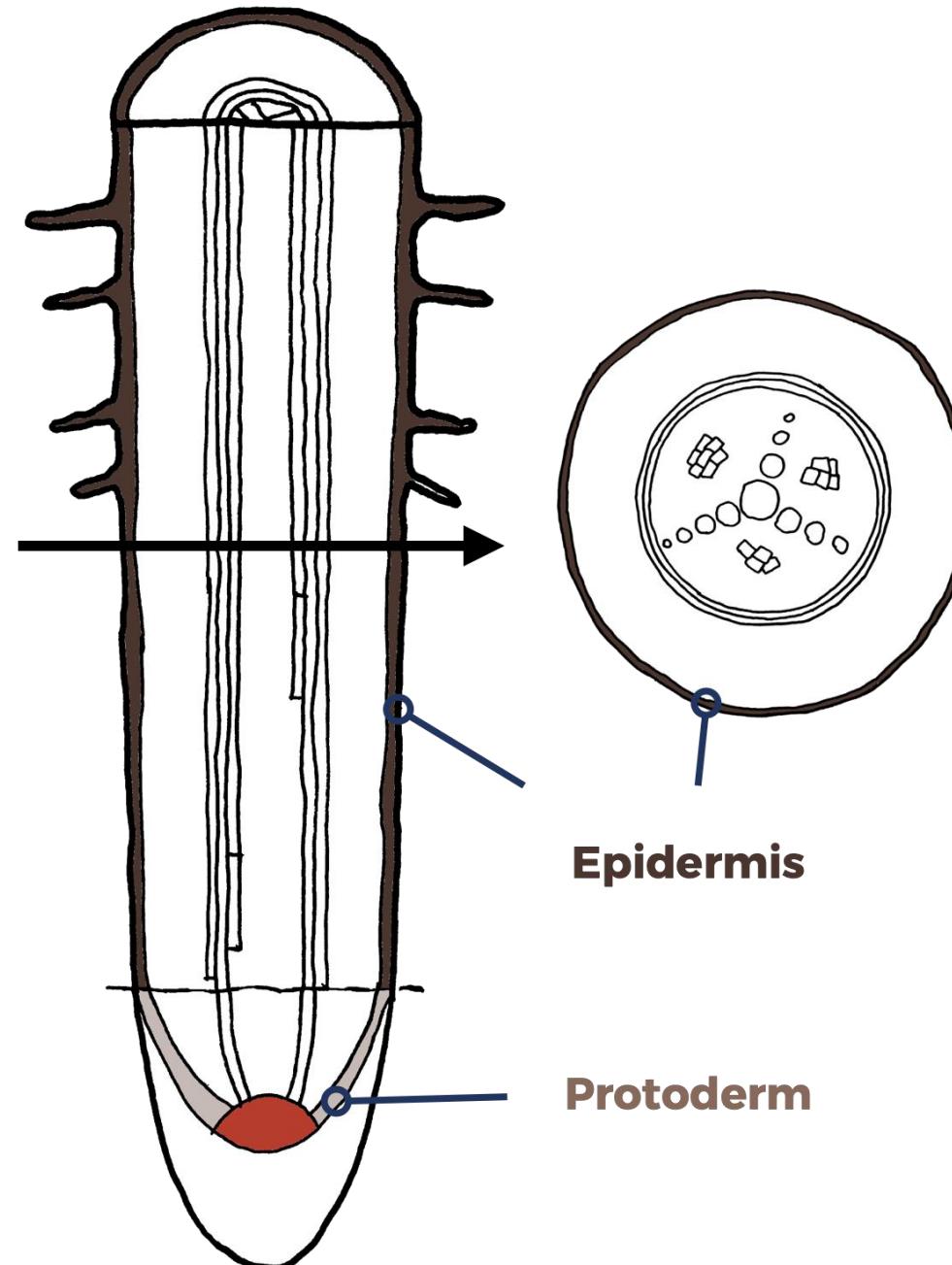
ROOT APICAL MERISTEM



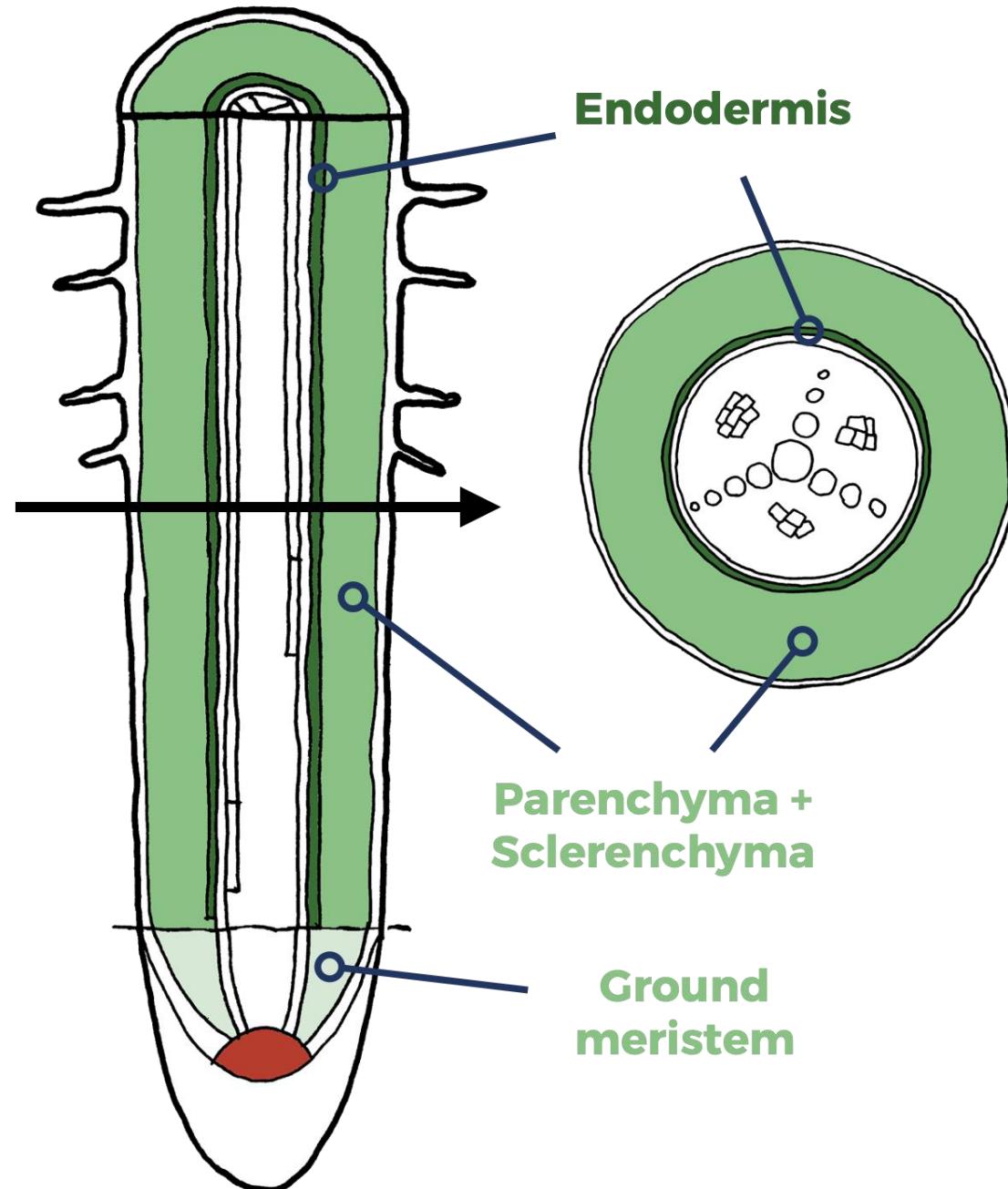
ROOT APICAL MERISTEM



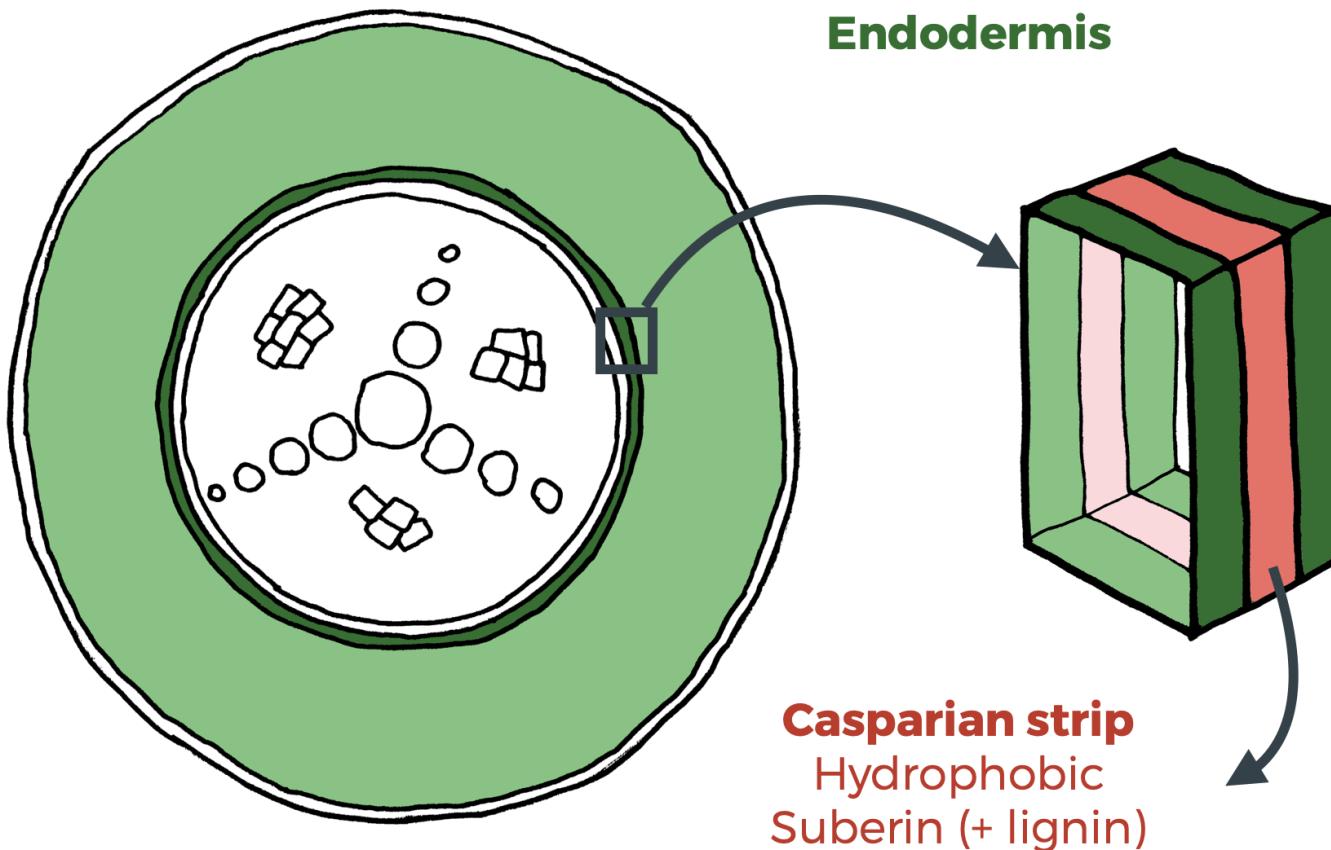
EPIDERMIS



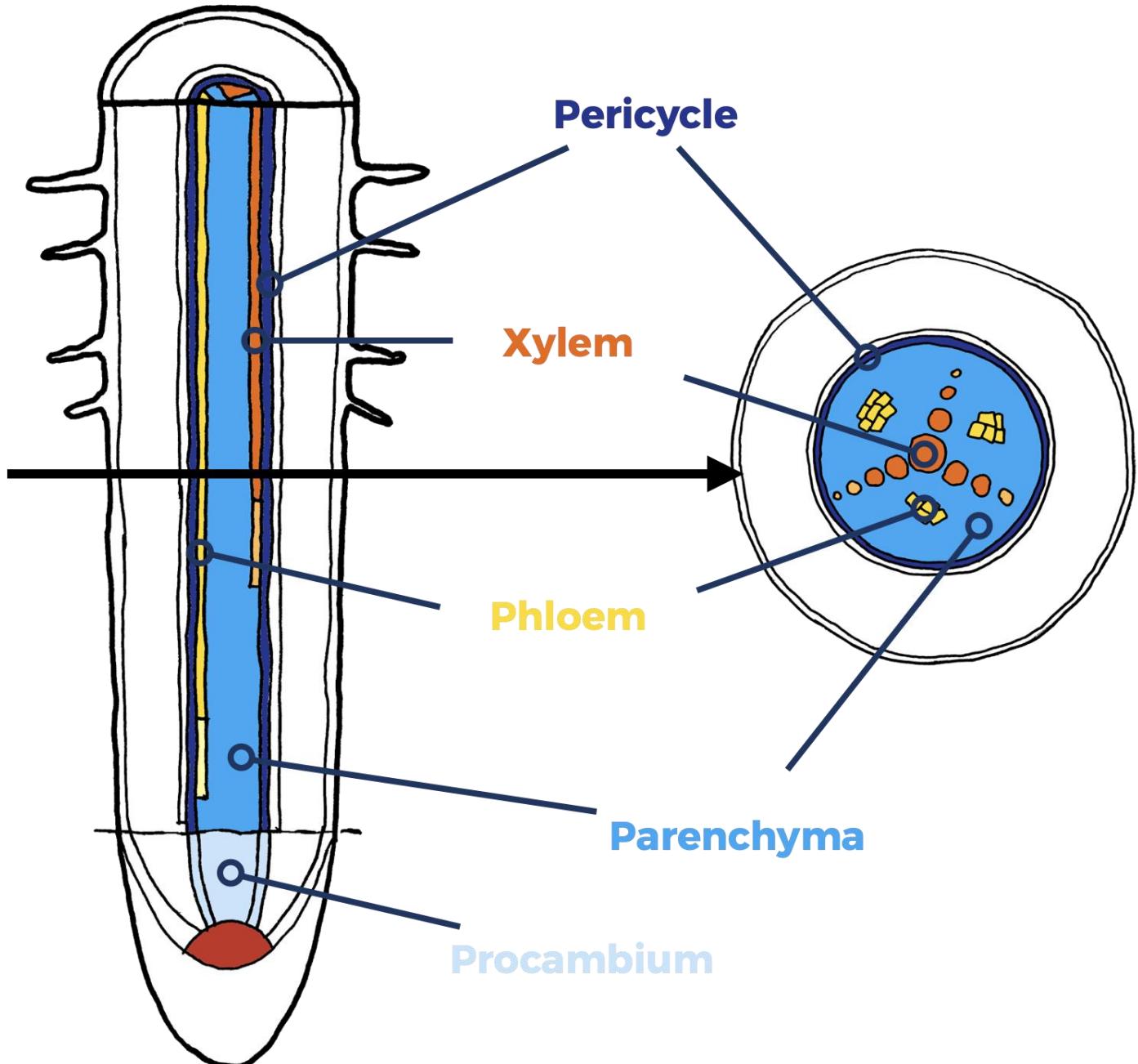
CORTEX



CASPARIAN STRIP

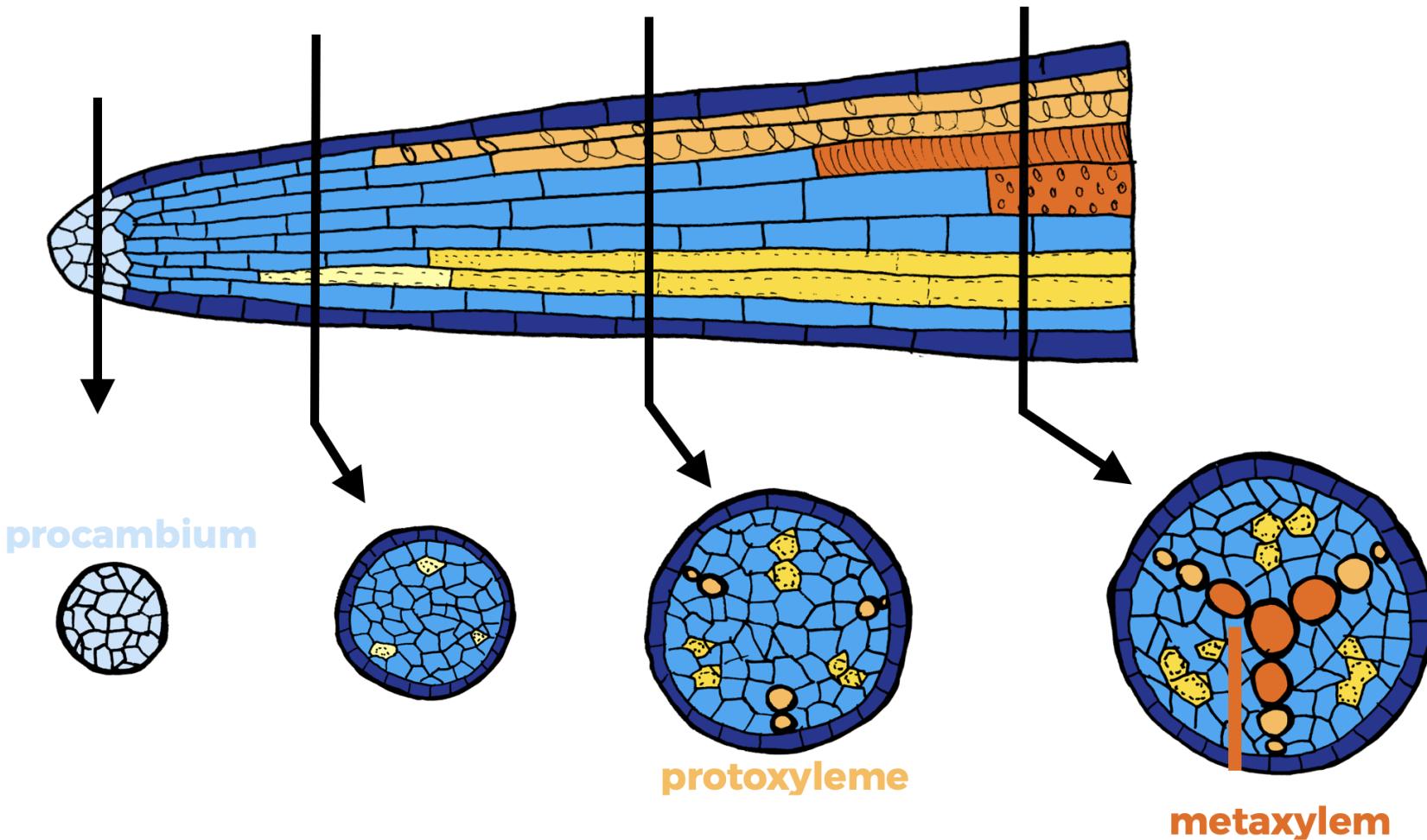


STELLE

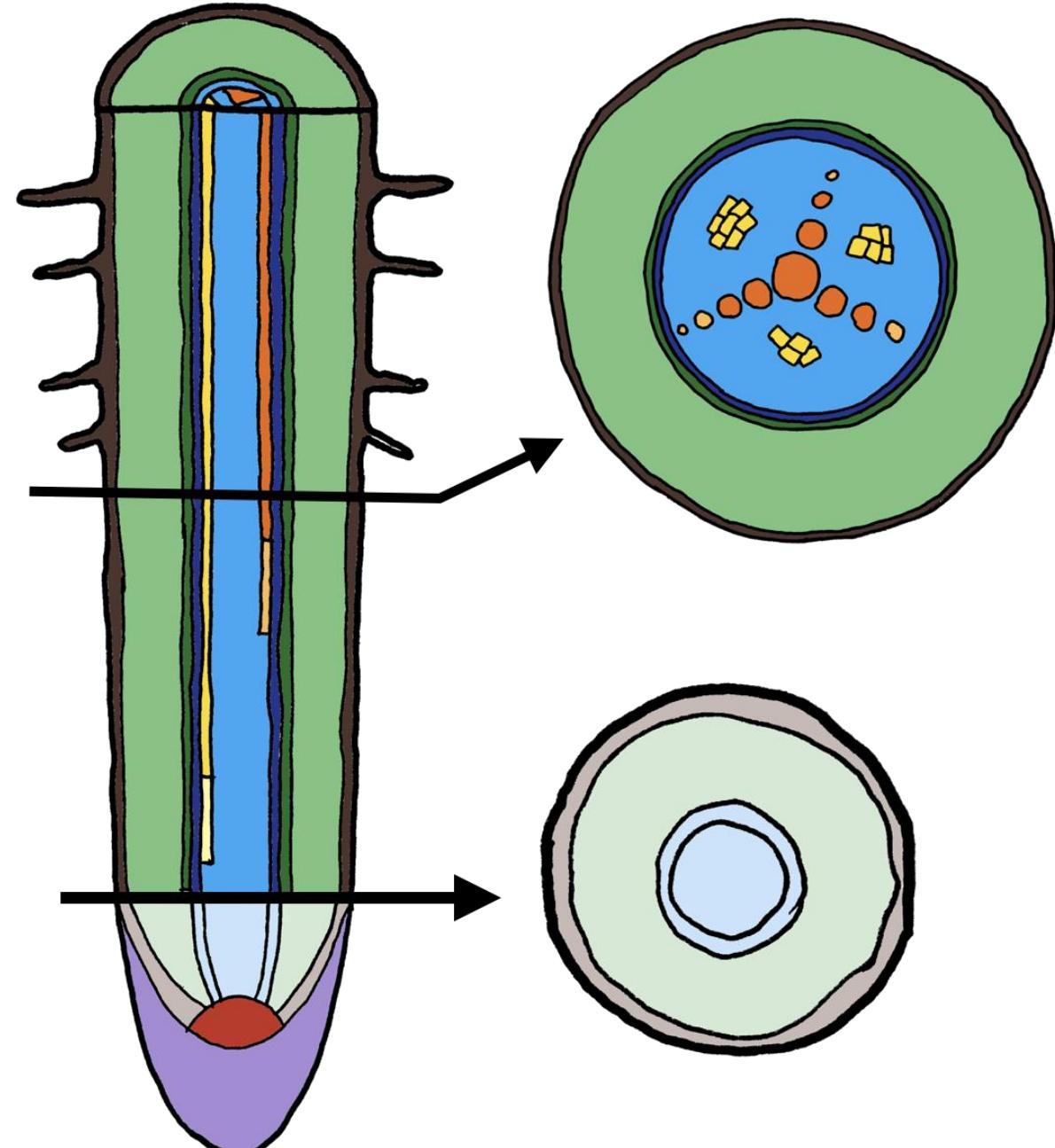


- Modelling Root Anatomy & Hydraulics -

STELLE



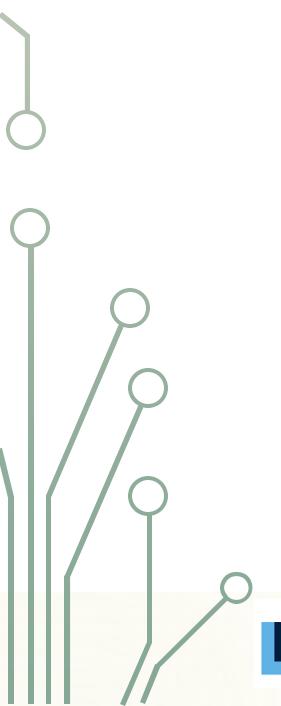
ROOT TISSUES



- Modelling Root Anatomy & Hydraulics -



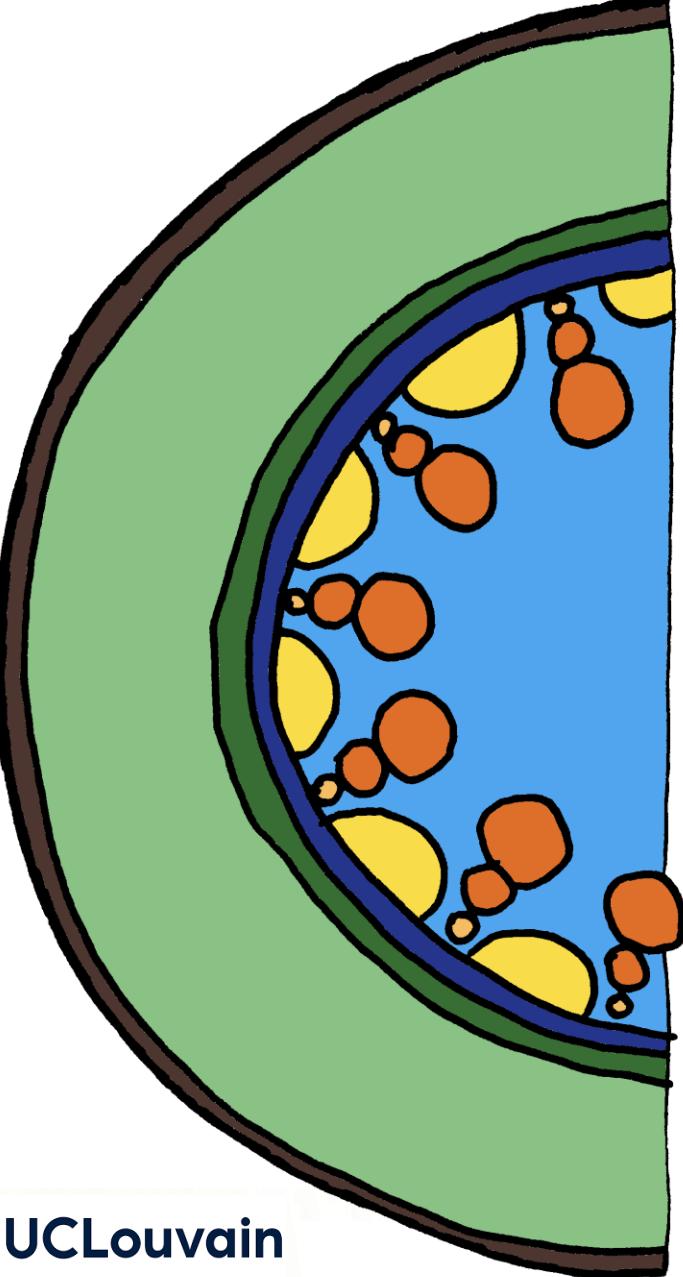
WOOLAP



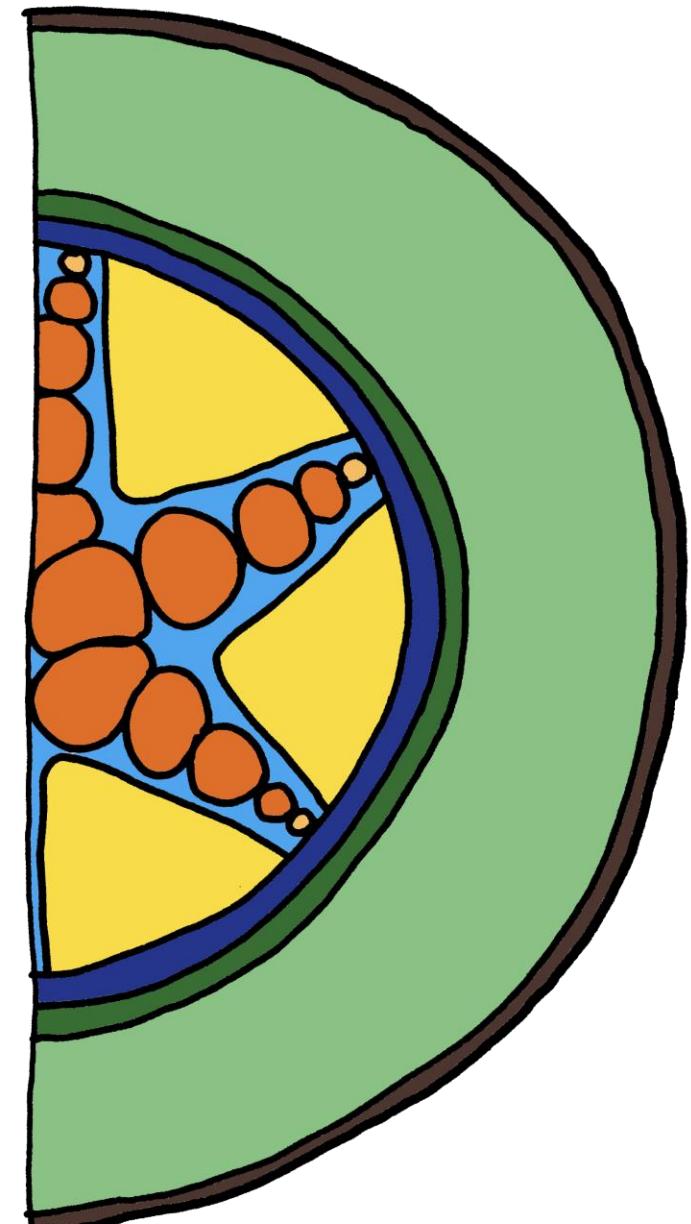
UCLouvain

THE 1ST INTERNATIONAL SUMMER SCHOOL ON ADVANCED SOIL PHYSICS "MODELING WATER TRANSPORT IN THE SOIL-PLANT SYSTEM"

MONOCOT ROOT



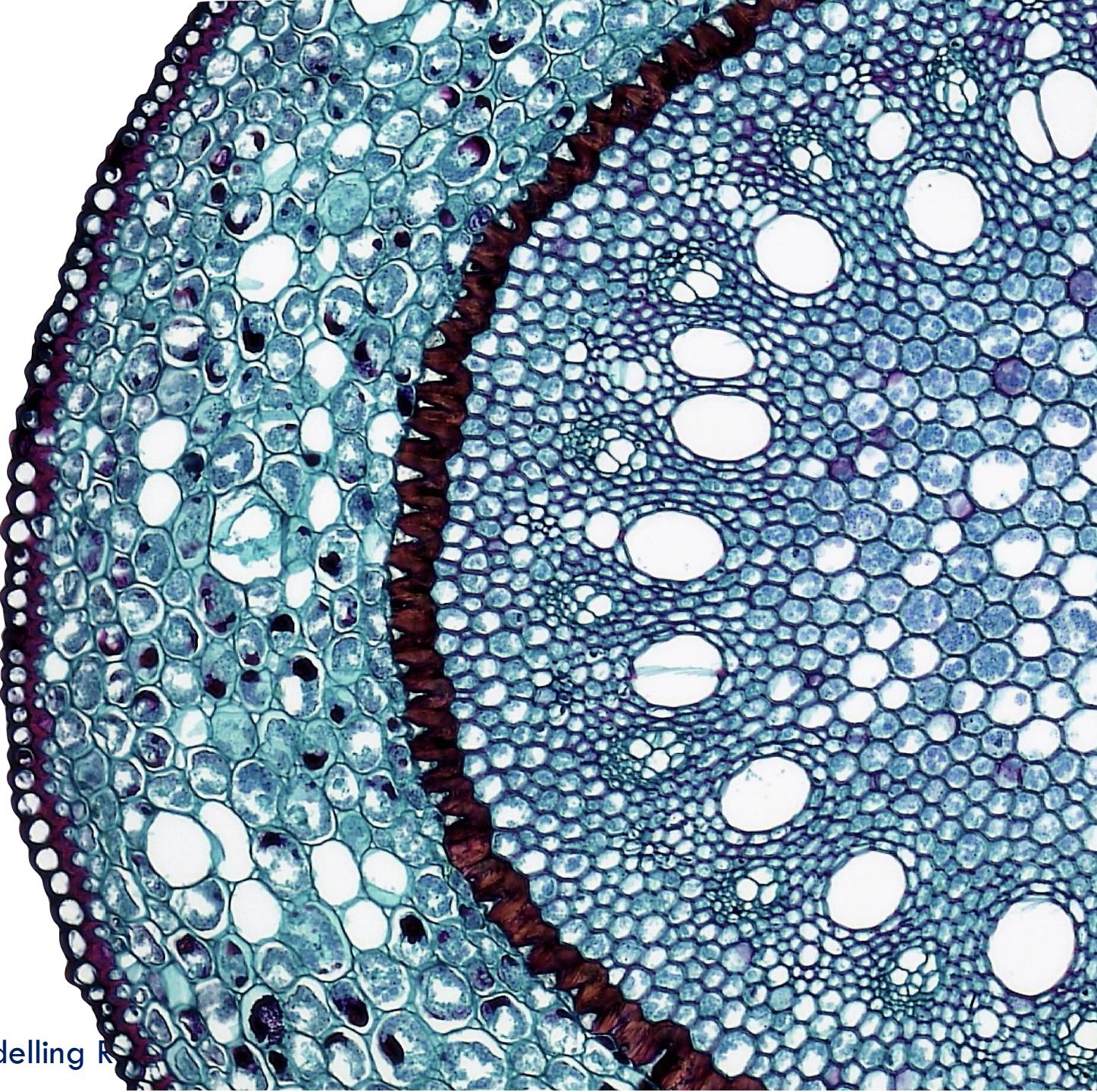
DICOT ROOT



MONOCOT ROOT ANATOMY



MONOCOT ROOT ANATOMY



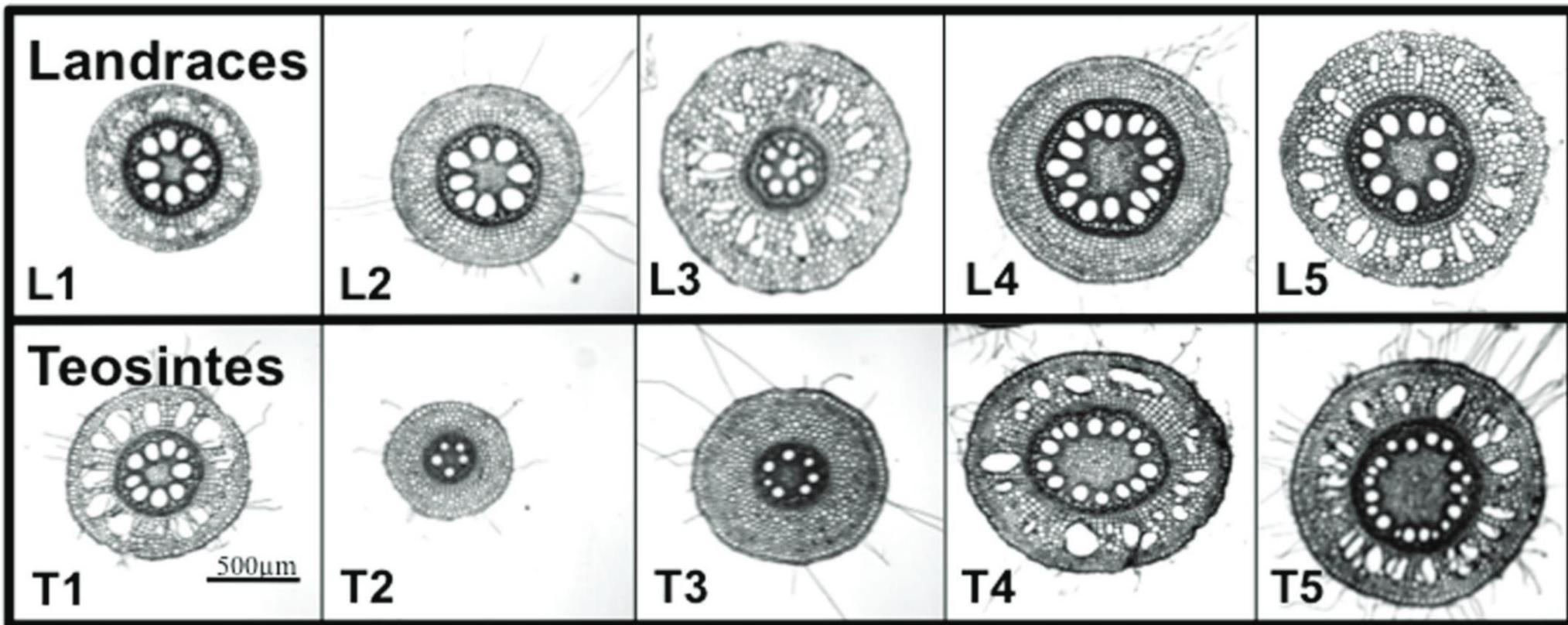
- Modelling R

DICOT ROOT ANATOMY



- Mod

VARIATIONS IN ROOT ANATOMIES



Burton et al, 2013

VARIATIONS IN ROOT ANATOMIES

XYLEM VESSELS

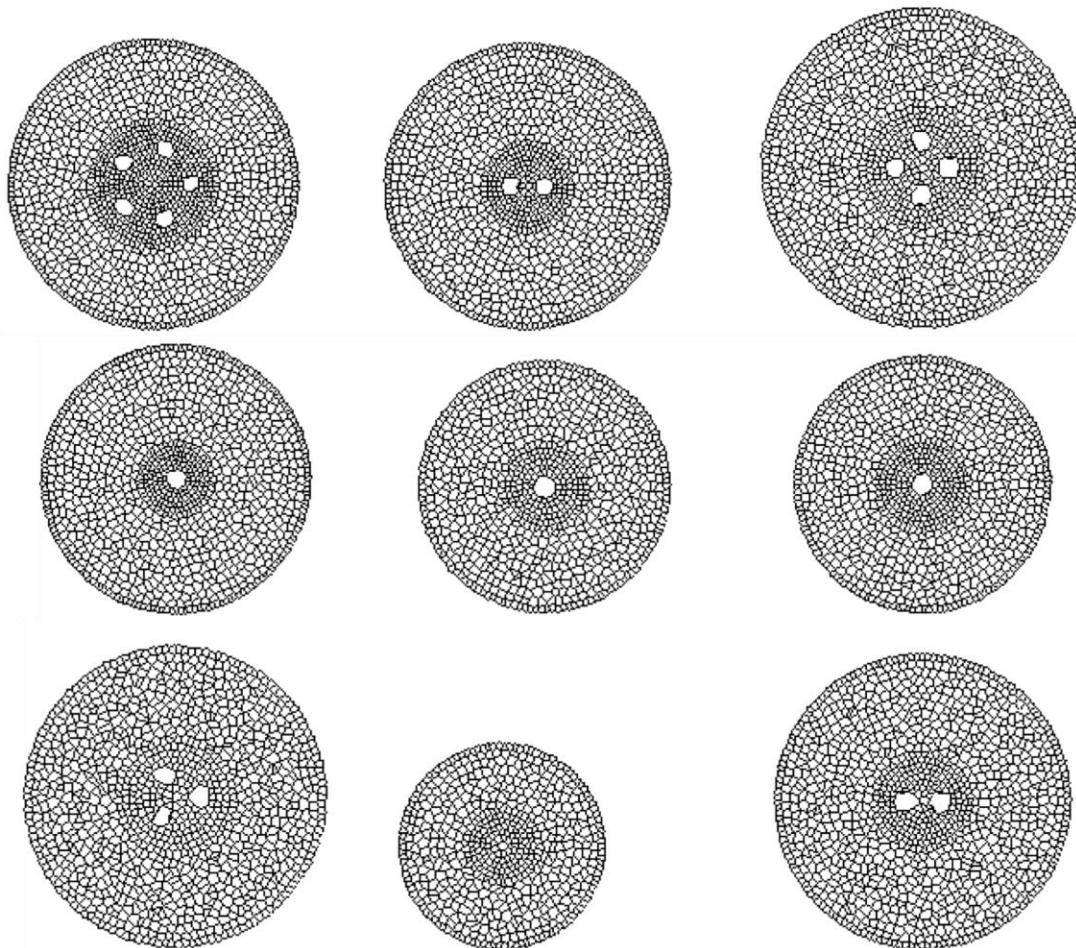
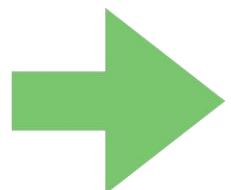
Ø XYLEM VESSELS

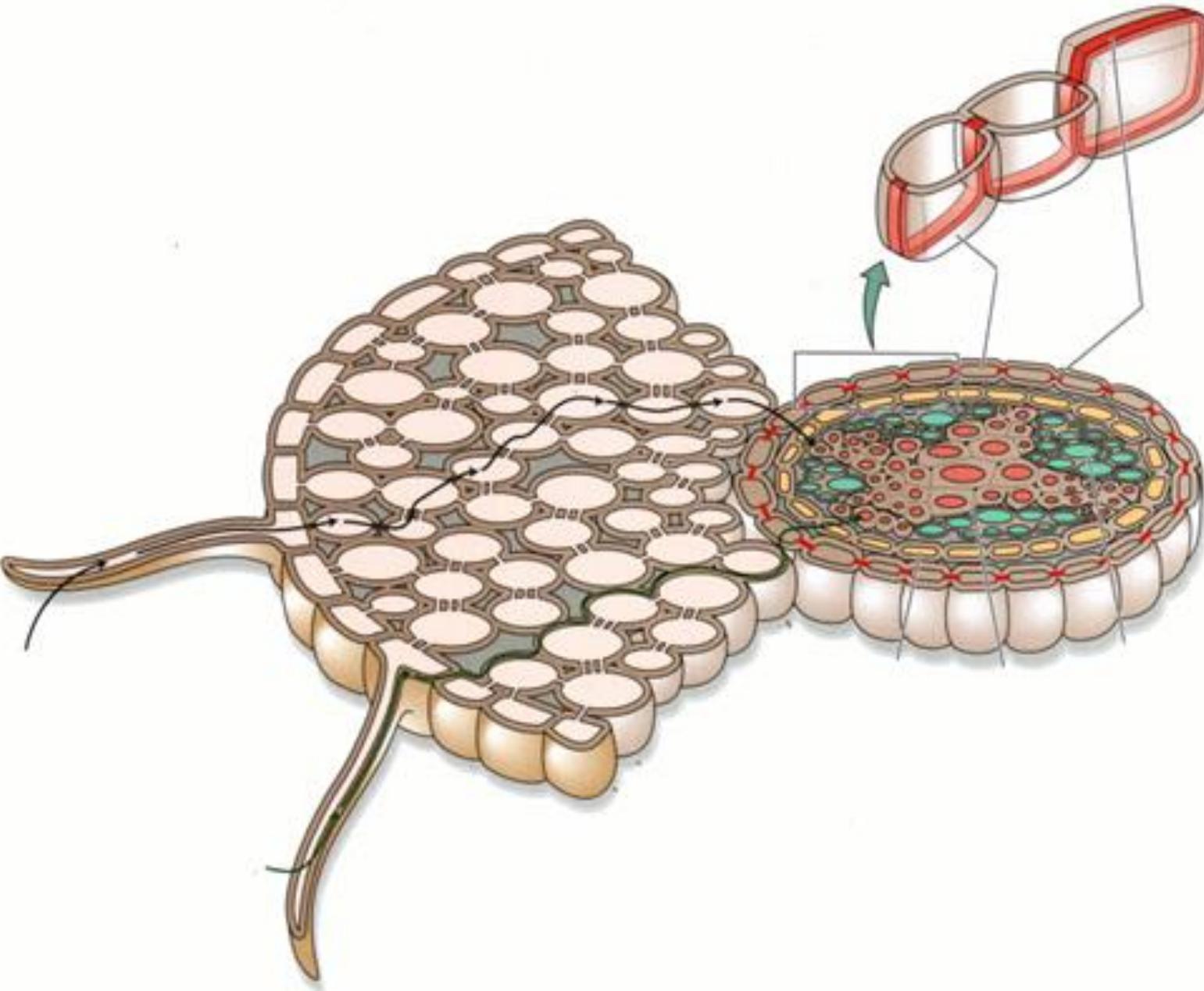
CORTEX LAYERS

Ø CORTEX CELLS

Ø STELE

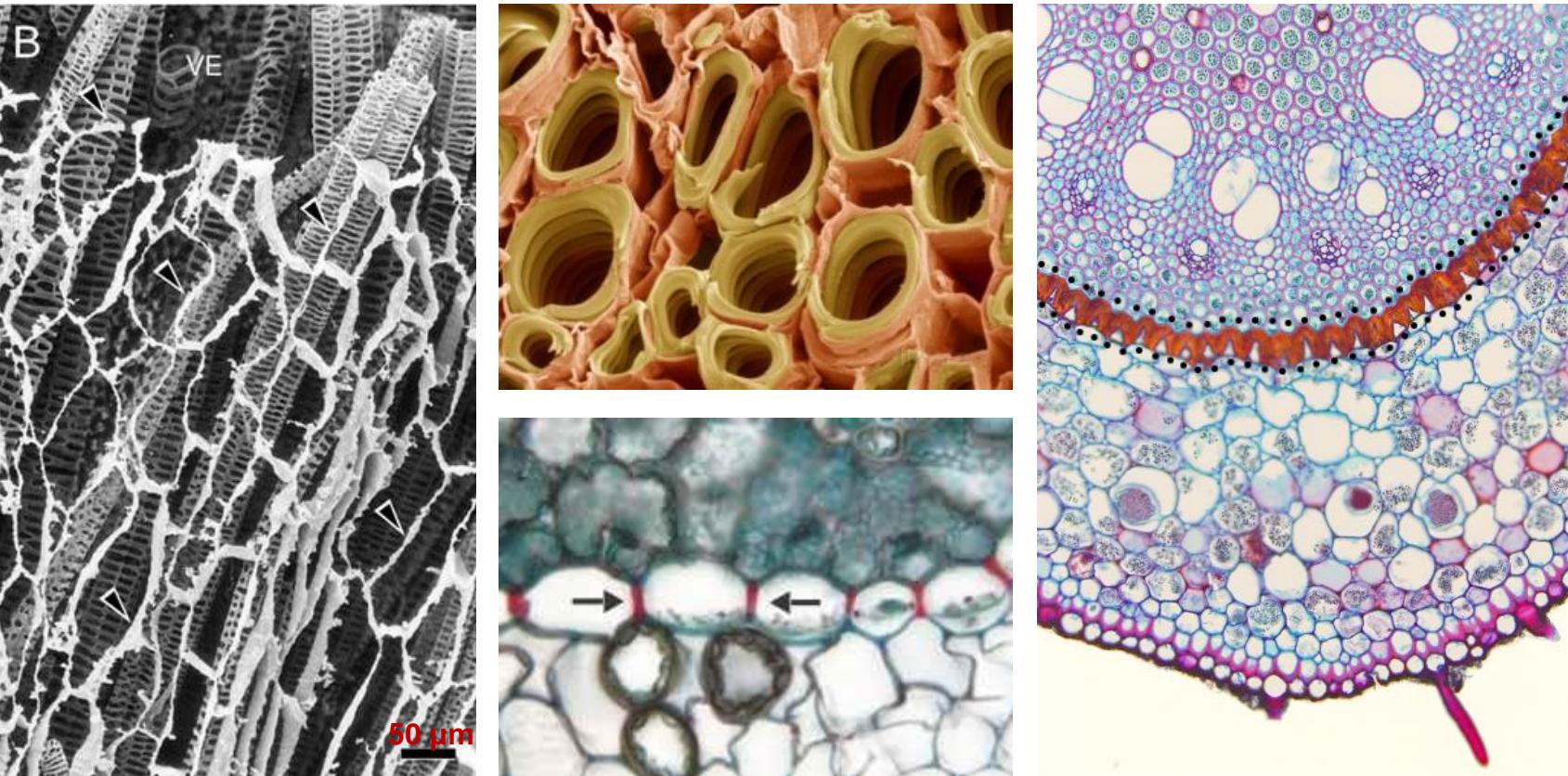
% AERENCHYMA





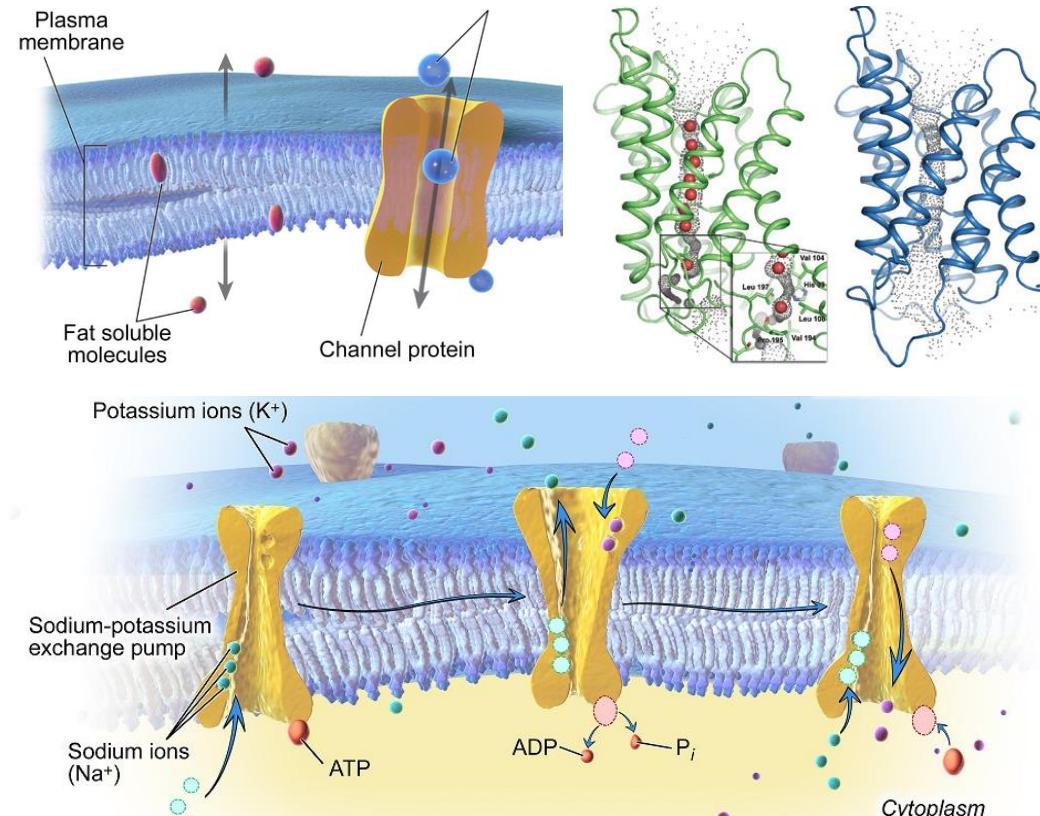
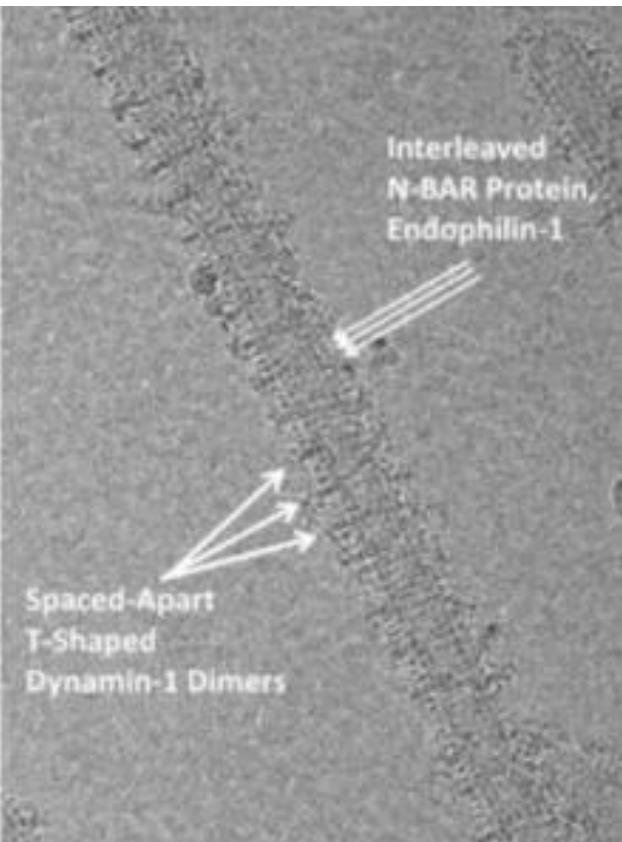
Apoplastic structures

- Scaffolds: Physical **separation** of compartments
- Thickening: Physical **support** against implosion / explosion
- Pipes: Long distance water **transport**



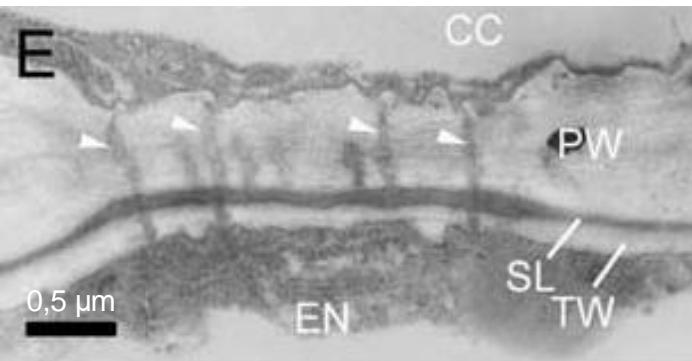
Transmembrane structures

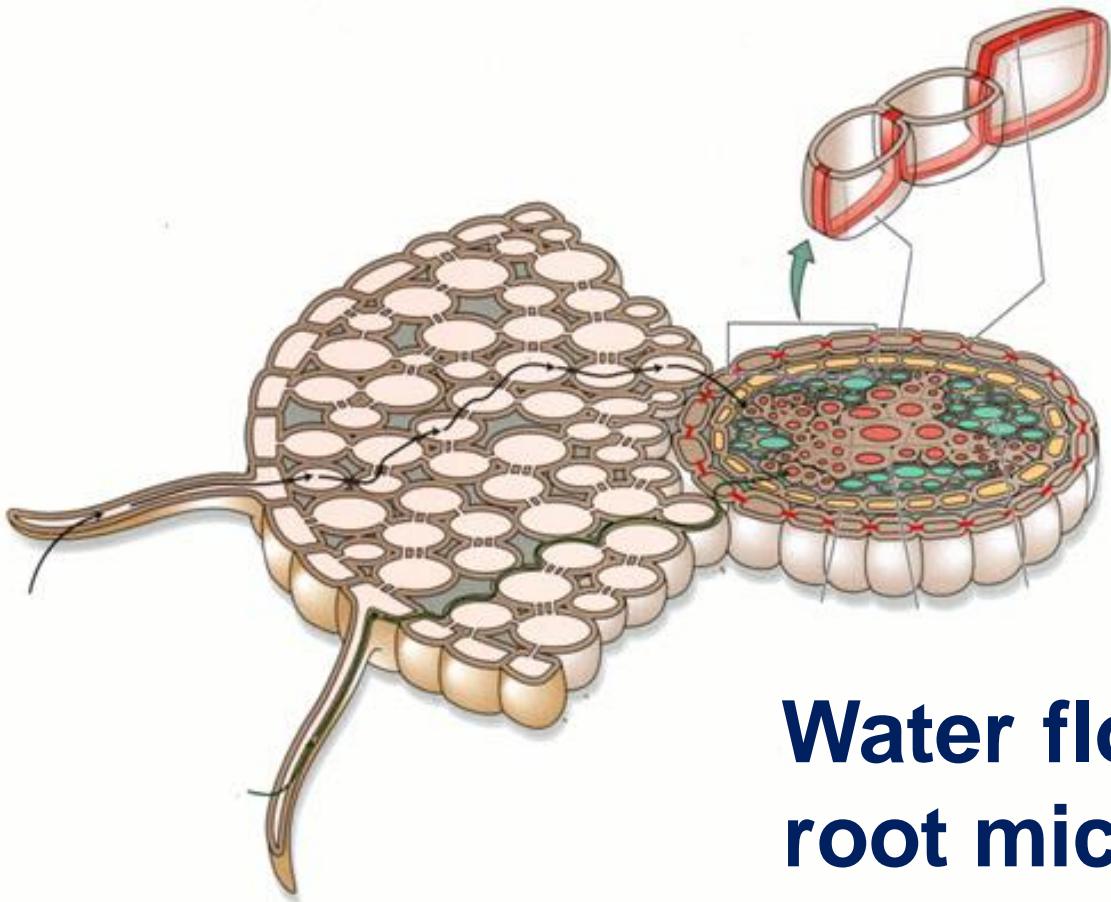
- Pumps: Active **accumulation** of ions / molecules
- Channels: Passive **diffusion** of ions / molecules



Symplastic structures

- Plasmodesmata: Passive **diffusion** of ions / molecules

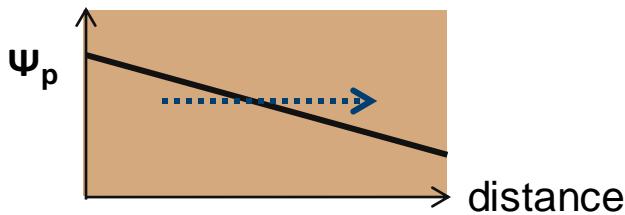




Water flow across root micro-structures

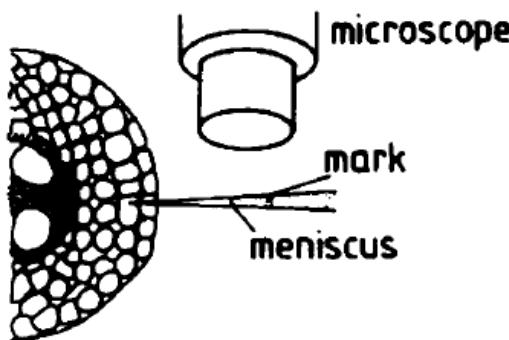
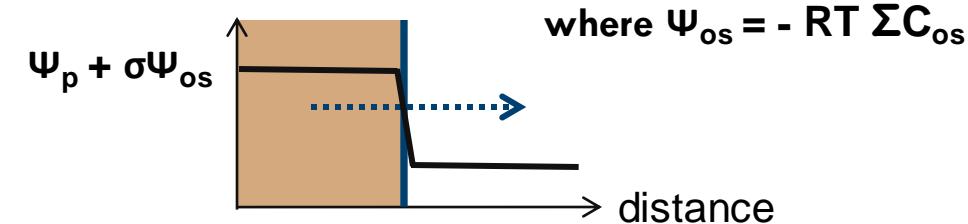
Cell level hydrological principles

Porous media (cell wall):

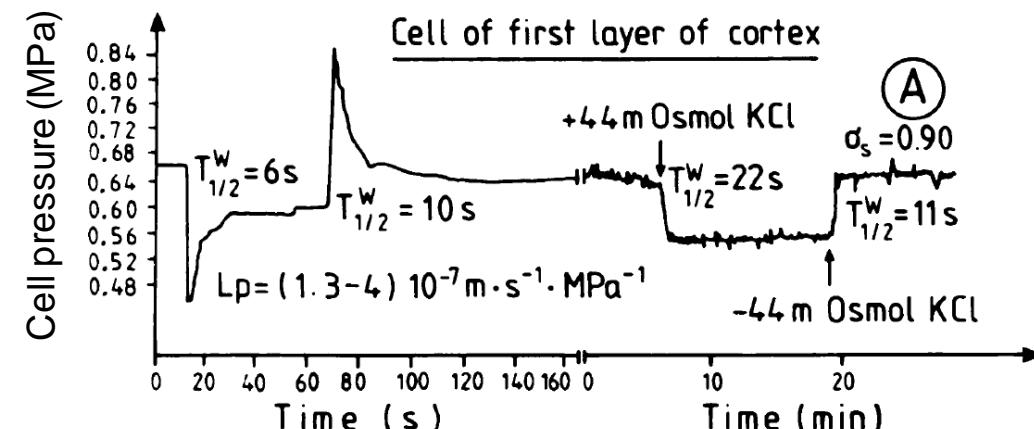


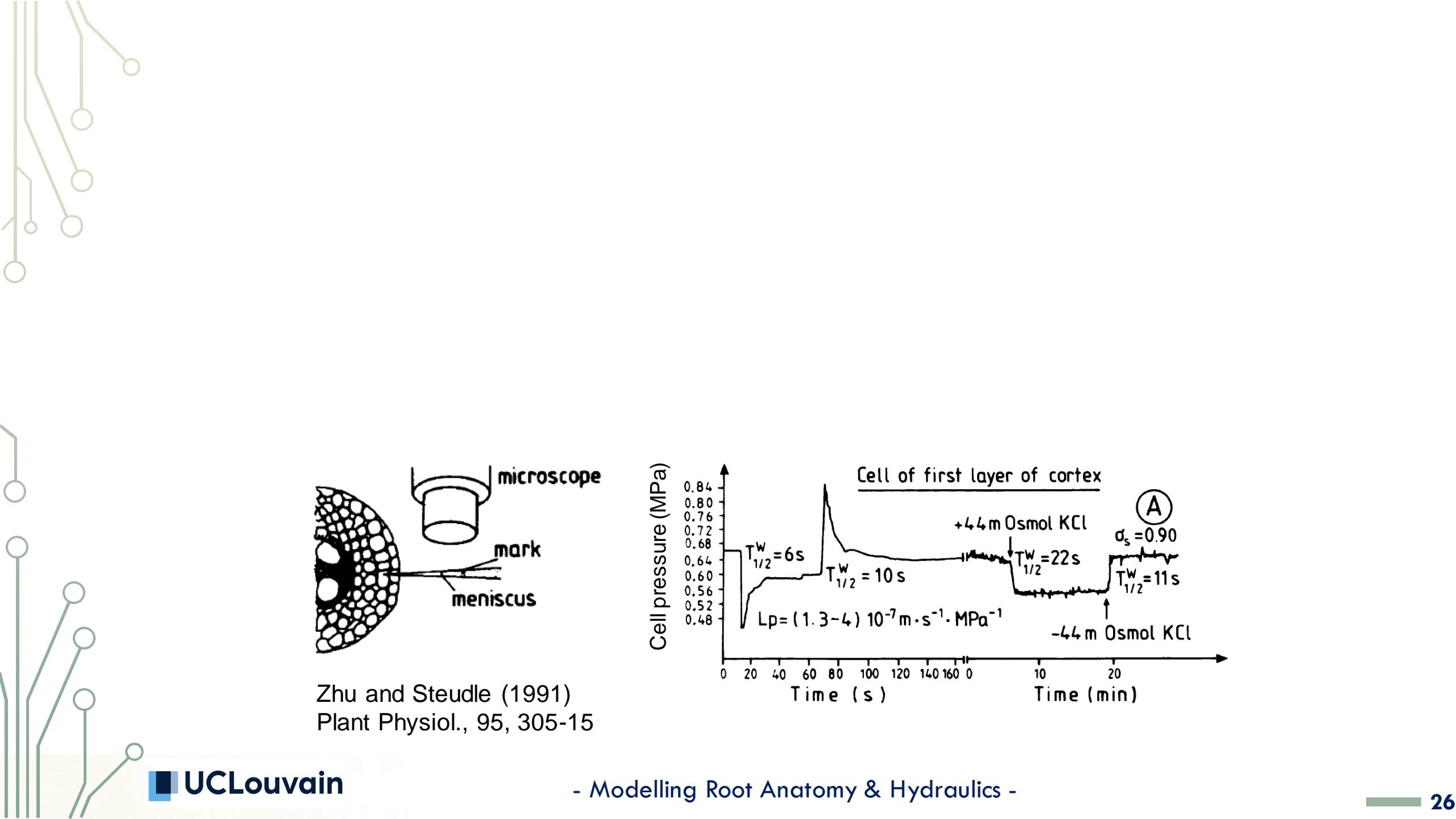
Semi-permeable membrane:

$$\text{Flux} = L_p (\Delta \Psi_p + \Delta \sigma \Psi_{os})$$

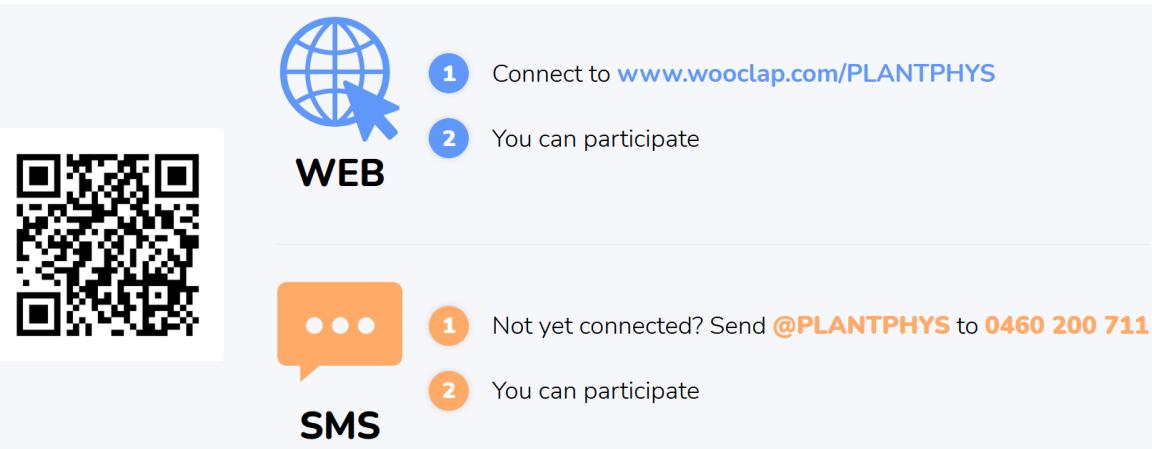
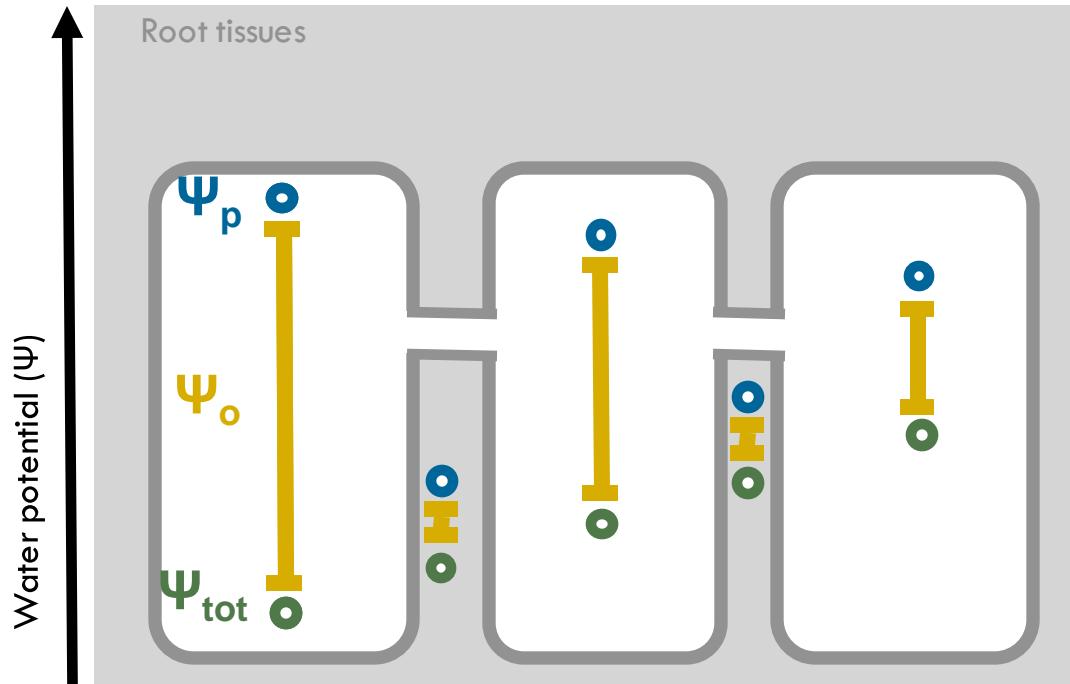


Zhu and Steudle (1991)
Plant Physiol., 95, 305-15



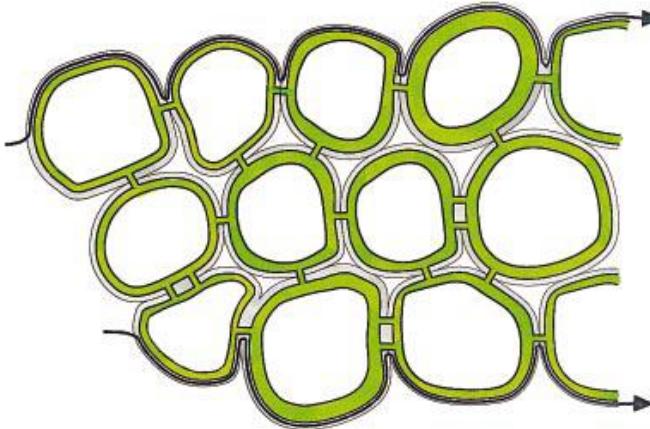


Where to does water flow ?

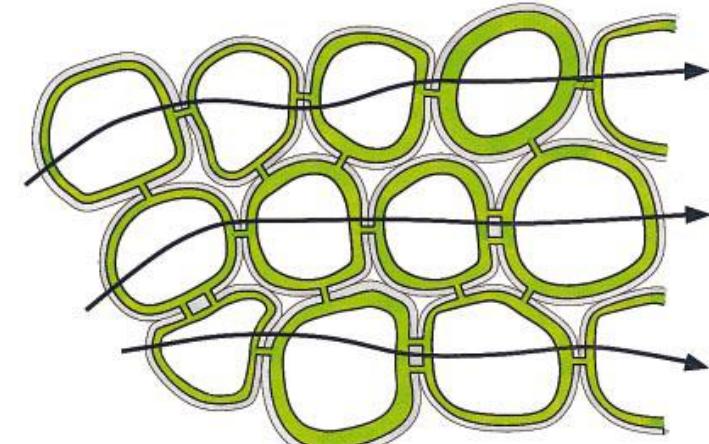
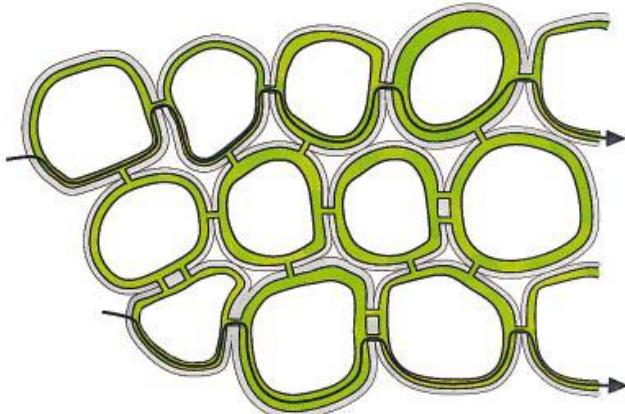




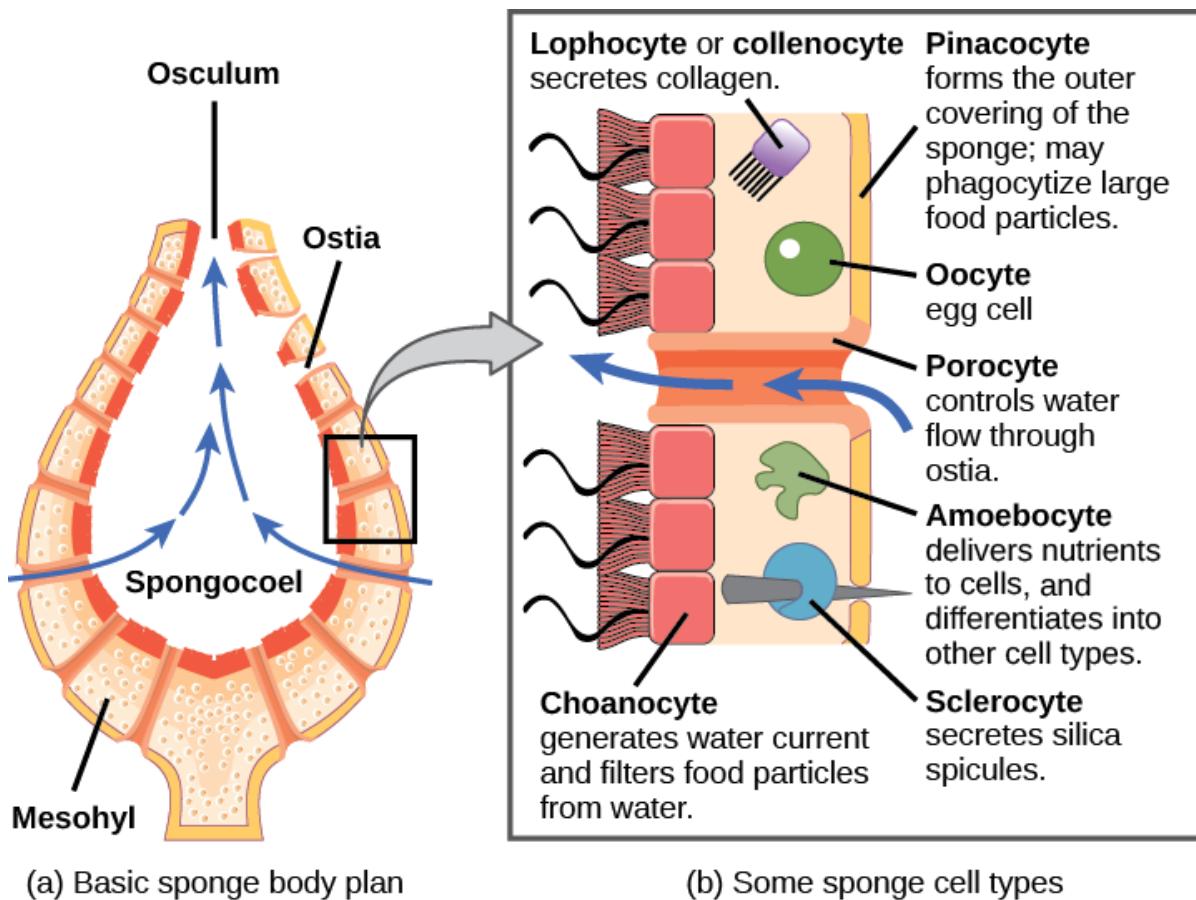




Setting hydraulic principles on a biological layout

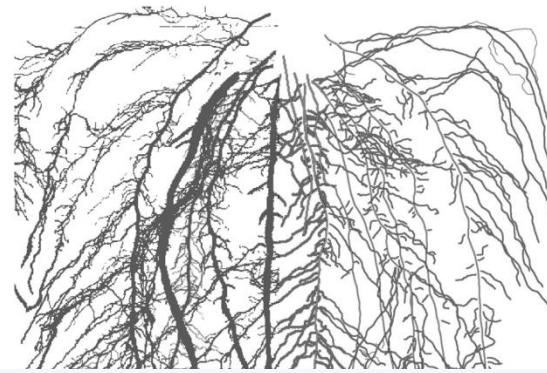
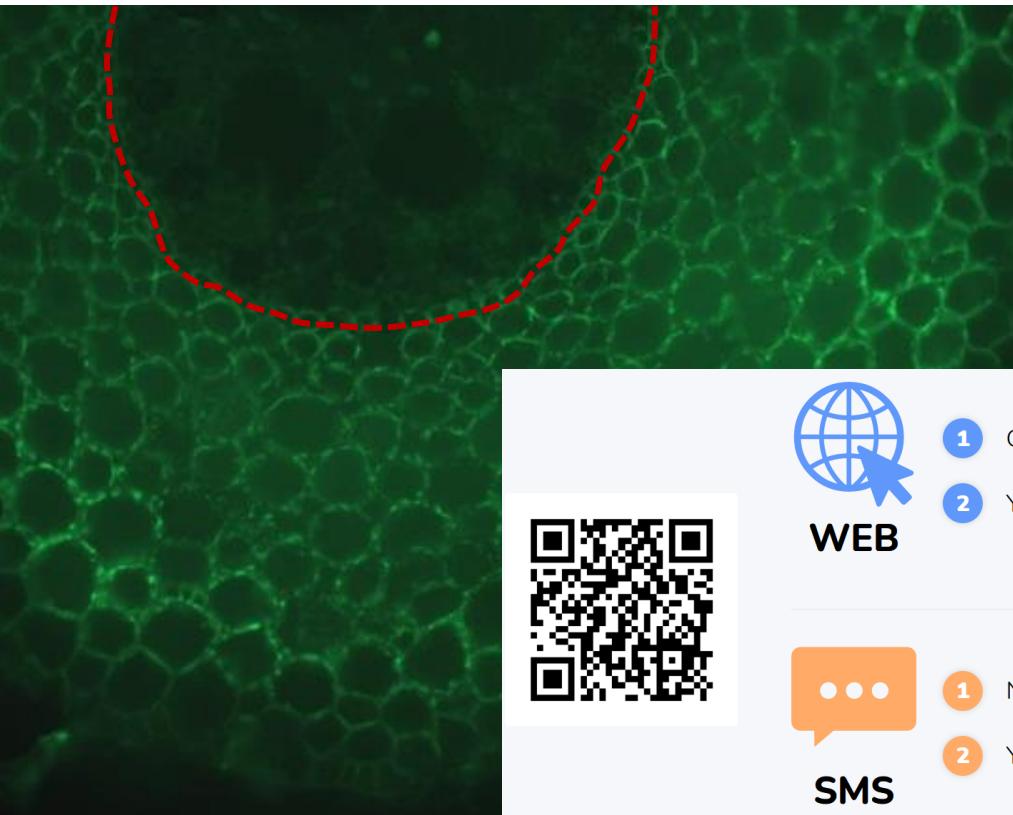


Function emergence: water / nutrients filtering



Emergence: “Arising of novel and coherent structures, patterns and properties during the process of self-organization in complex systems” (Goldstein, 1999)

Function emergence



WEB

- 1
- 2

Connect to www.wooclap.com/PLANTPHYS

You can participate



SMS

- 1
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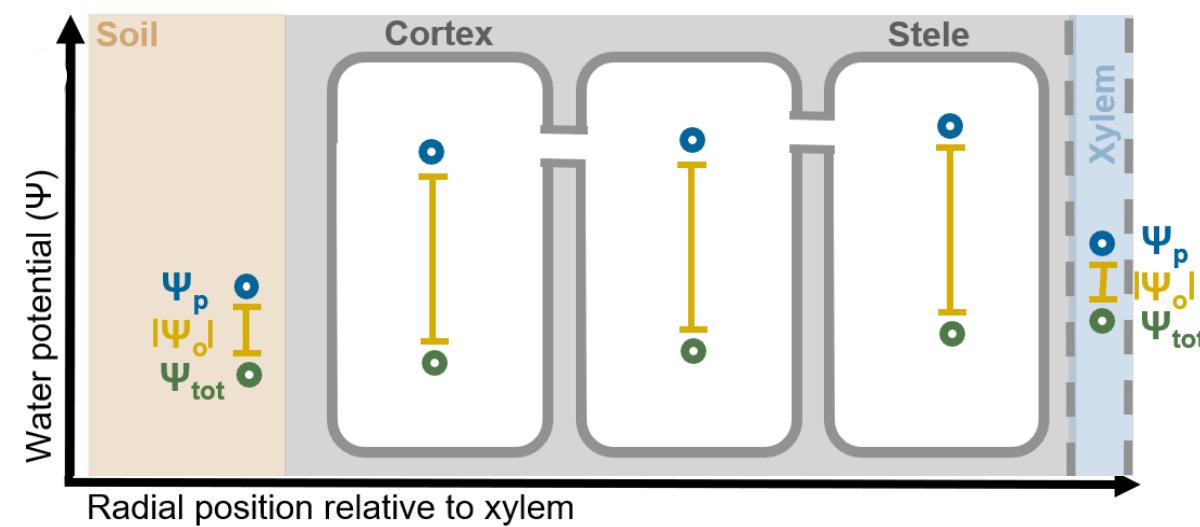
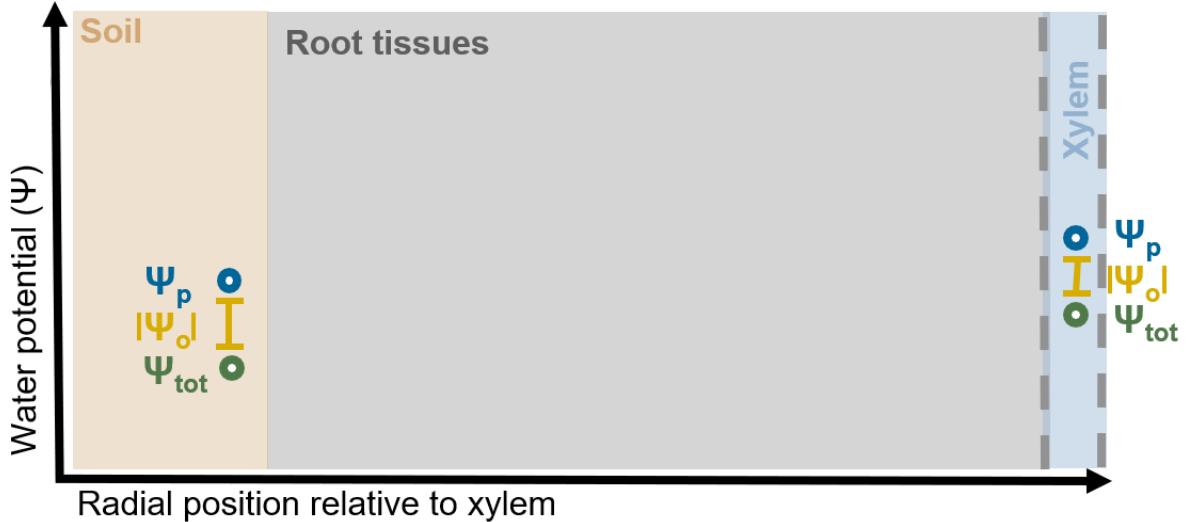
You can participate



Disorienting dilemma...



Where does water flow to?



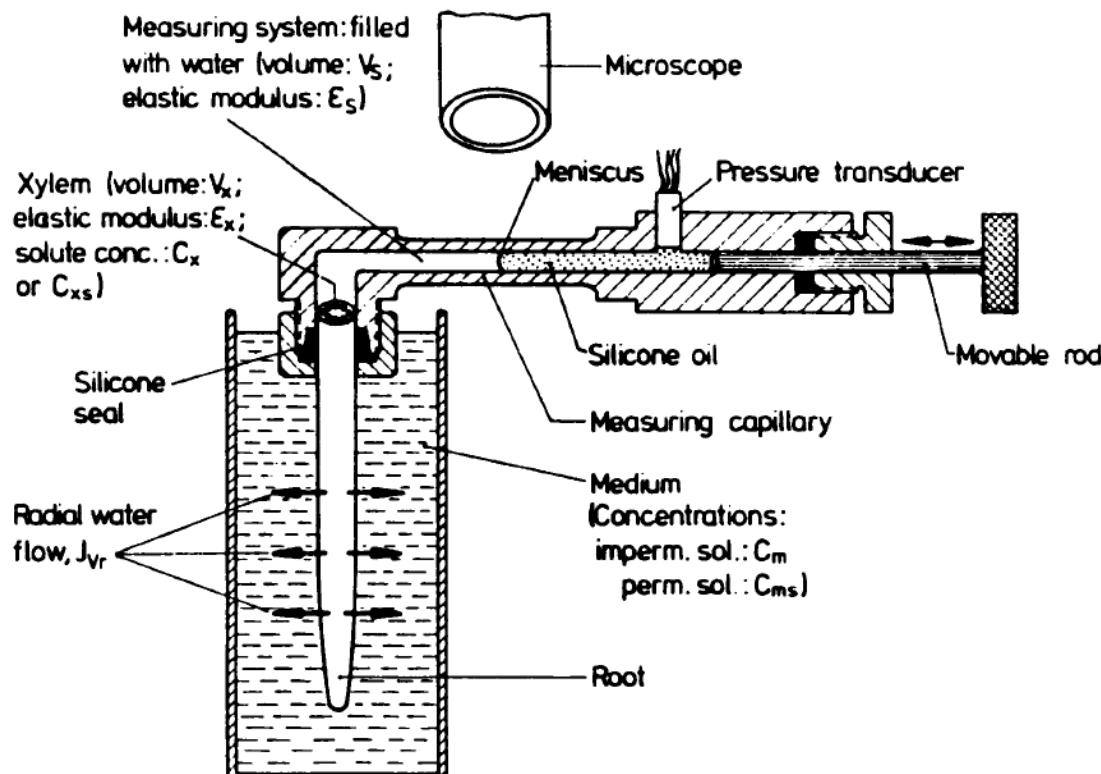
Check out the printed version when you have time ;)

Root level hydrological principles

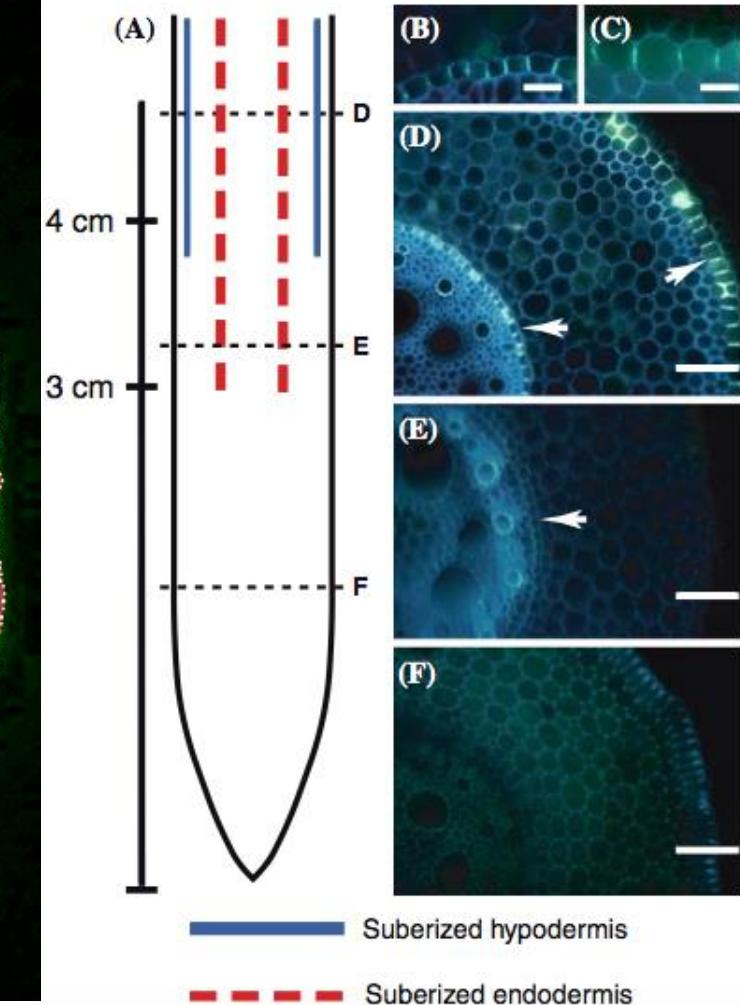
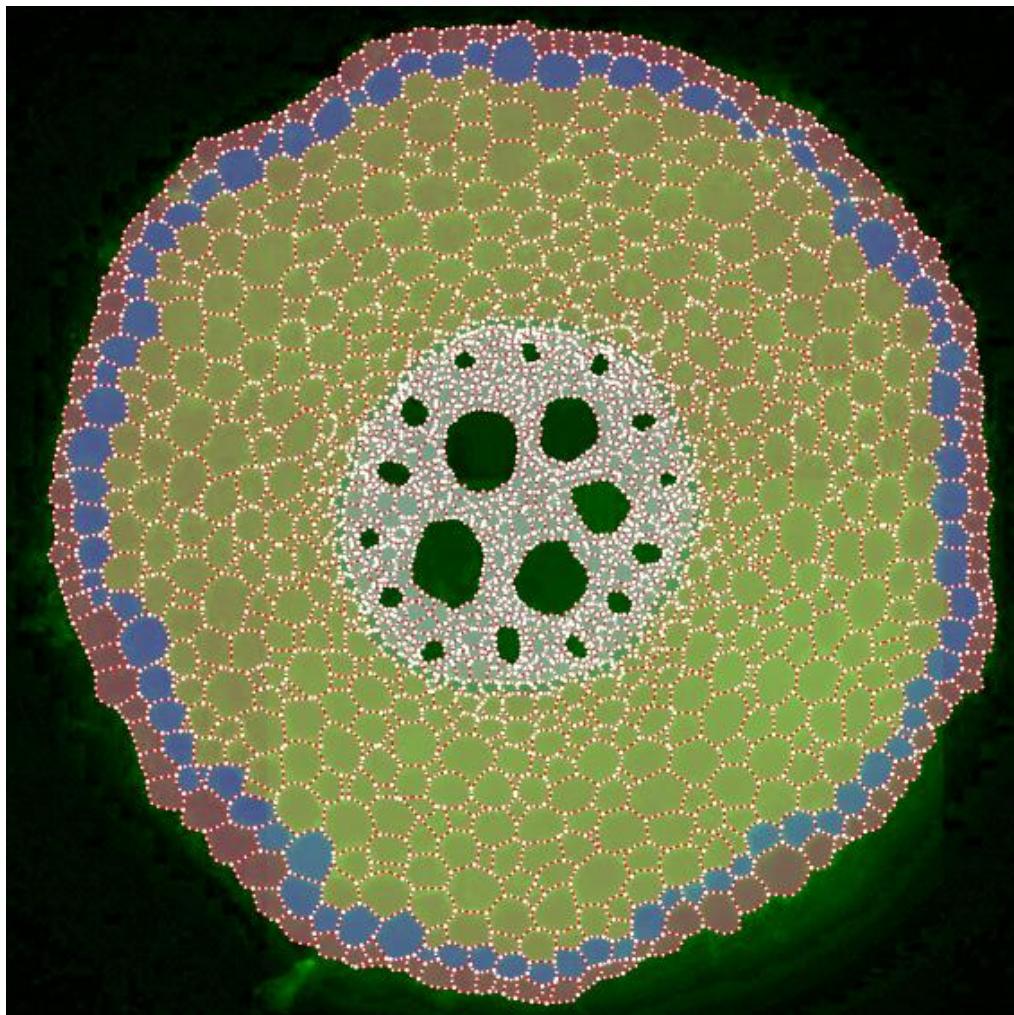
$$\text{Flux} = L_{pr} (\Delta \Psi_p + \Delta \sigma \Psi_o, \text{apo})$$

$$\text{where } \Psi_o = -RT \sum C_o$$

Fiscus and Kramer (1975) PNAS, 72, 3114-8

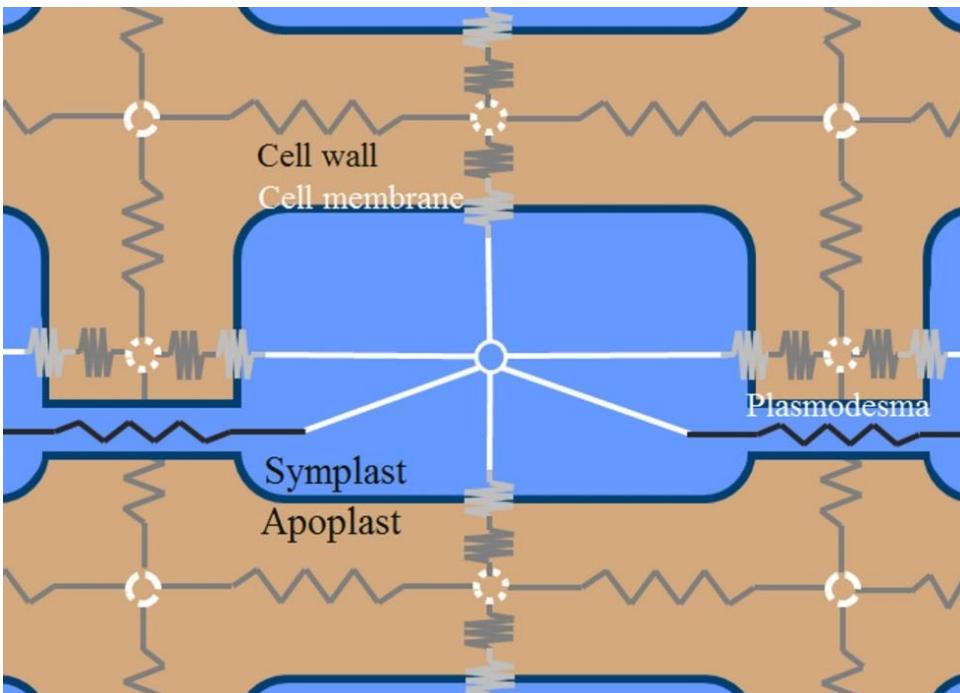


Root anatomy and location of apoplastic barriers



Cell level hydraulic model

- Root anatomy
- Apoplastic barriers
- Permeability of cell walls (Steudle and Boyer, 1985), membranes (Elhert et al., 2009), and plasmodesmata (Bret-Hart and Silk, 1994; Warmbrodt, 1985; Clarkson et al., 1987)



Flow principles:

- Ψ_p driven in walls and plasmodesmata
- Ψ_{tot} driven flow across membranes

Plasmod.: $2.0 \cdot 10^{-4} \text{ cm hPa}^{-1} \text{ d}^{-1}$

Membrane: $5.0 \cdot 10^{-4} \text{ cm hPa}^{-1} \text{ d}^{-1}$

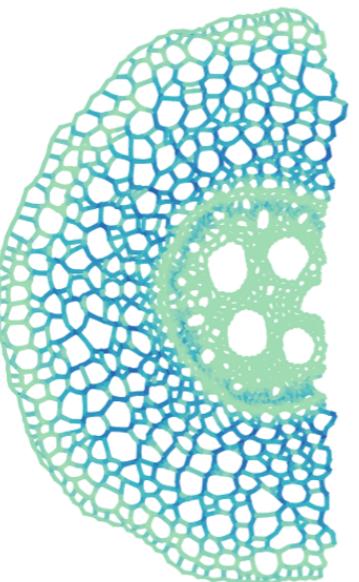
Young root: $1.0 \cdot 10^{-4} \text{ cm hPa}^{-1} \text{ d}^{-1}$

Cell wall: $0.005 \text{ cm}^2 \text{ hPa}^{-1} \text{ d}^{-1}$

Silty clay: $0.5 \text{ cm}^2 \text{ hPa}^{-1} \text{ d}^{-1}$

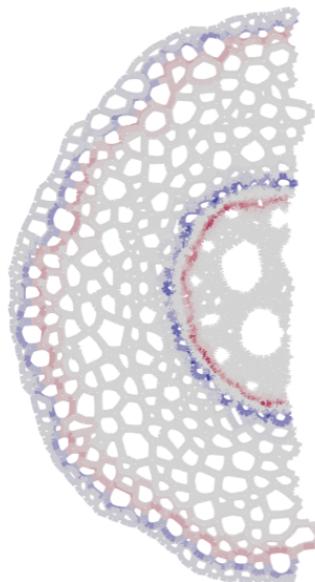
MODELLING WATER FLOW AT THE ORGAN SCALE

- MECHA -



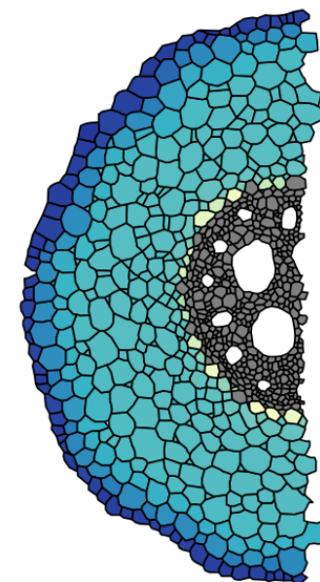
Wall
fluxes
 $[1e6*m/s]$

0.8
0.6
0.4
0.2
0.0



Trans-
membrane
flux
 $[1e7*m/s]$

2
1
0
-1
-2



Cell
pressure
 $[hPa]$

8000
7800
7600
7400



Open Source



mecharoot.github.io



Couvreur et al, 2018

Going with the Flow: Multiscale Insights into the
Composite Nature of Water Transport in Roots^{1[OPEN]}



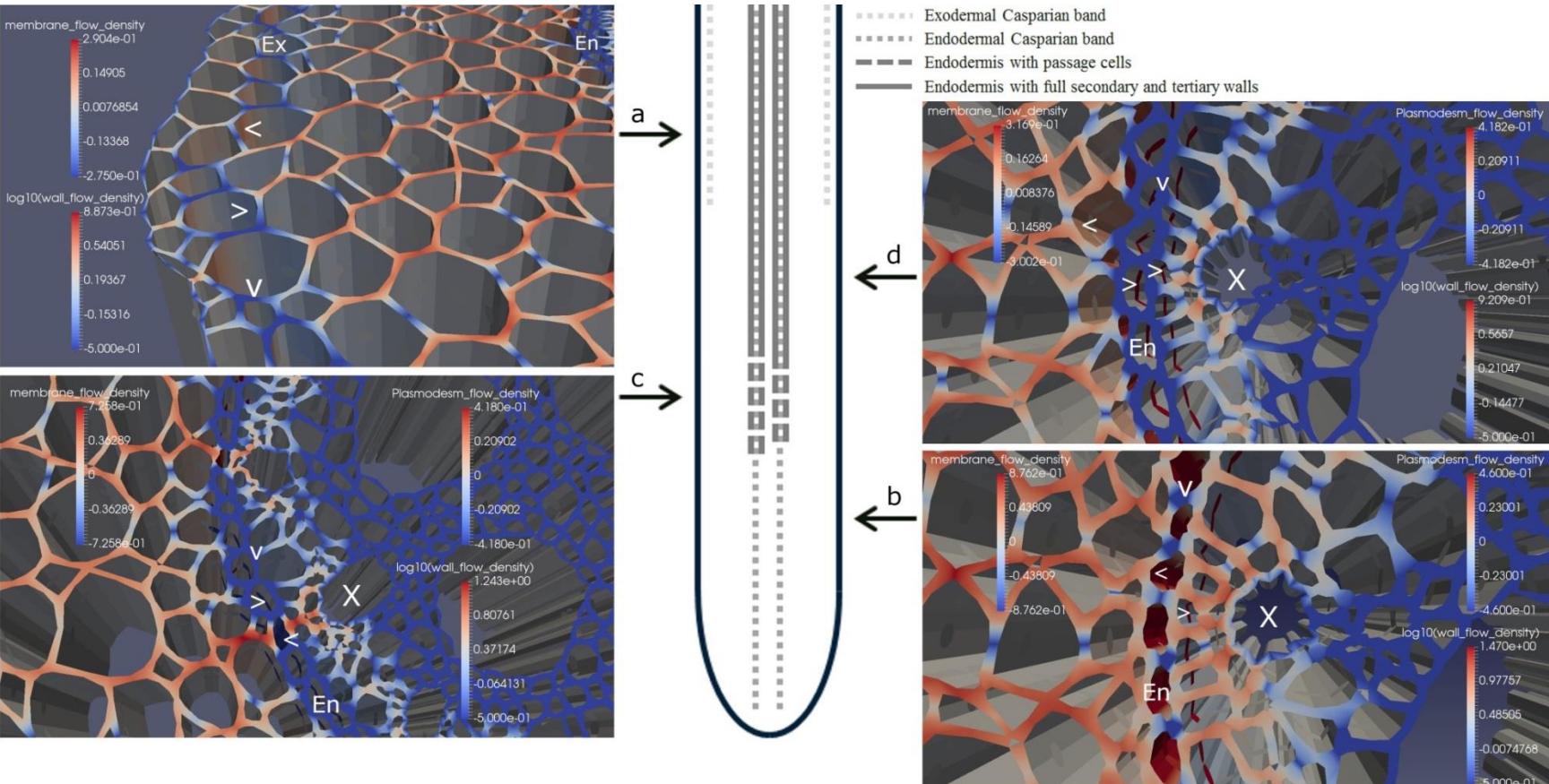
RADIAL CONDUCTIVITY



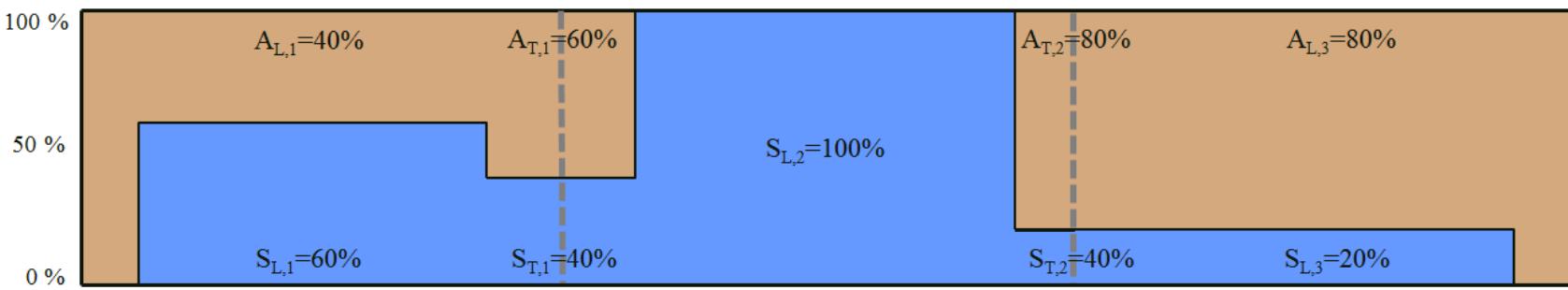
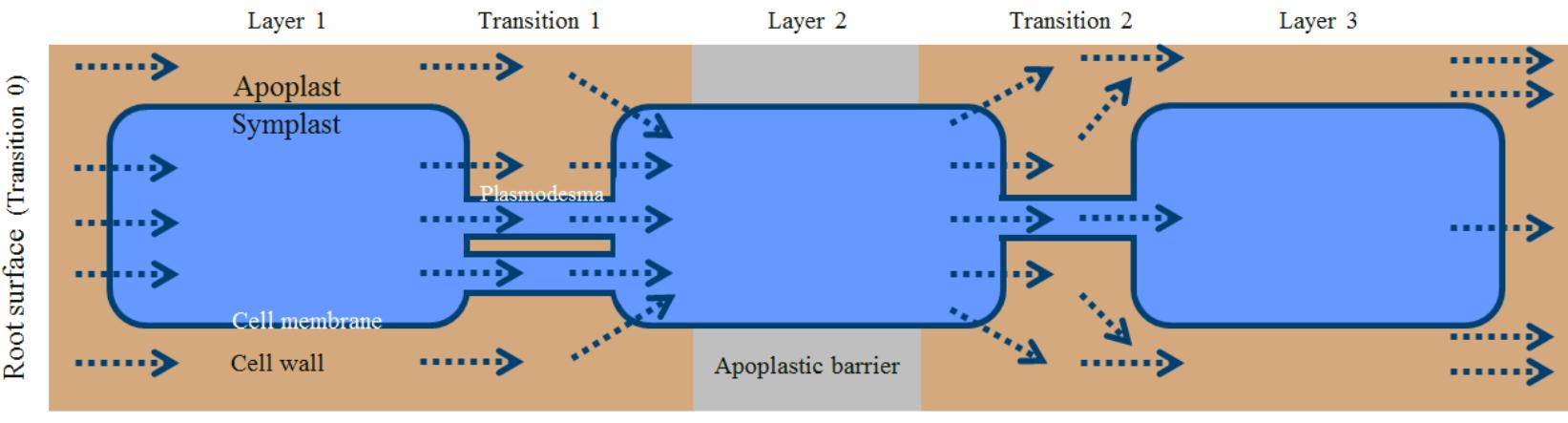
AXIAL CONDUCTIVITY

12

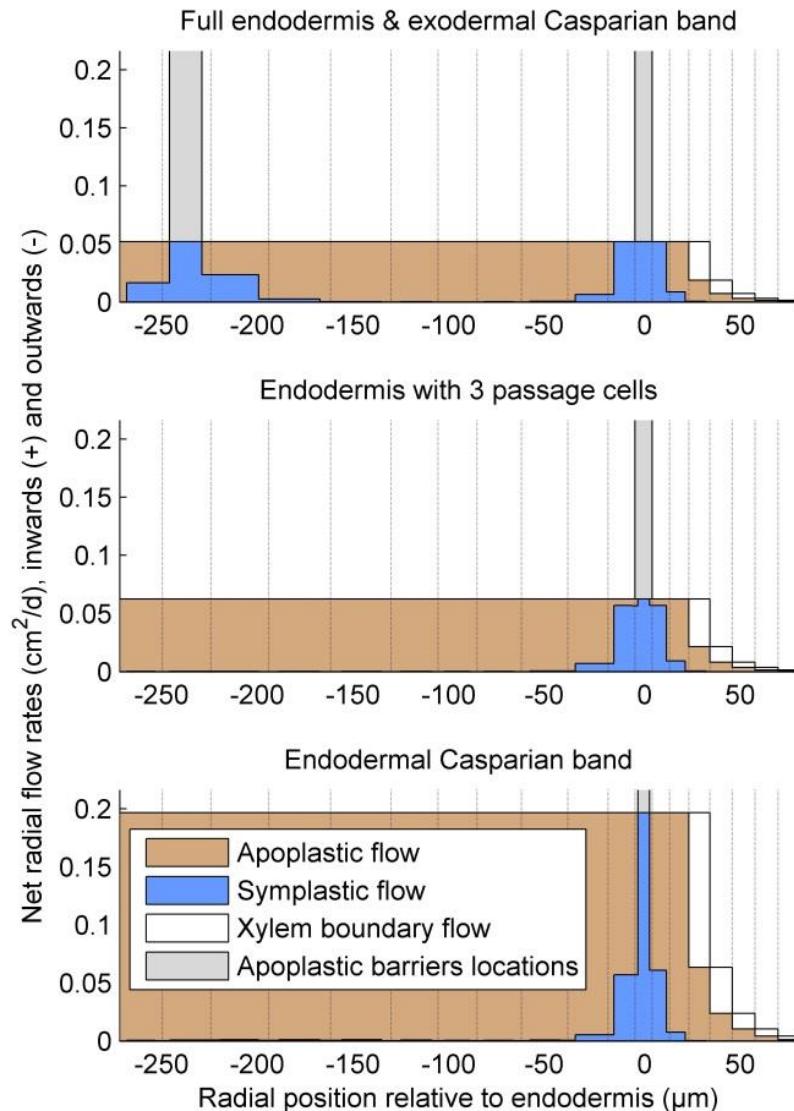
Behavior of the connected hydraulic network



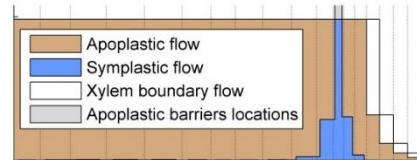
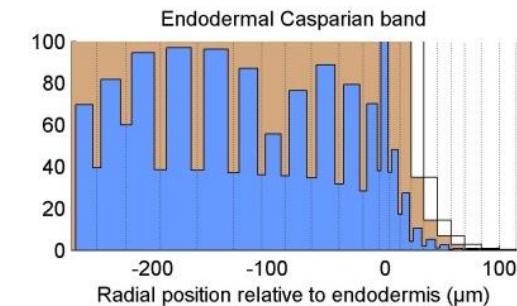
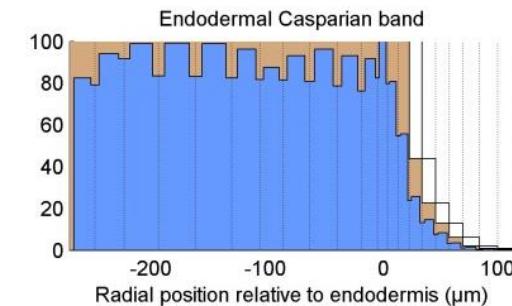
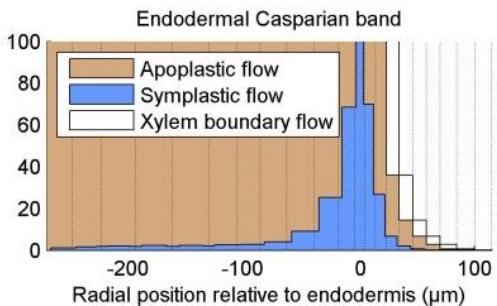
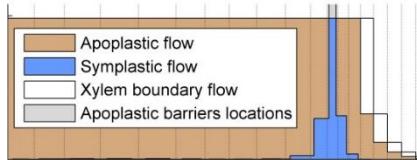
From flow rates to pathway quantification



From flow rates to pathway quantification

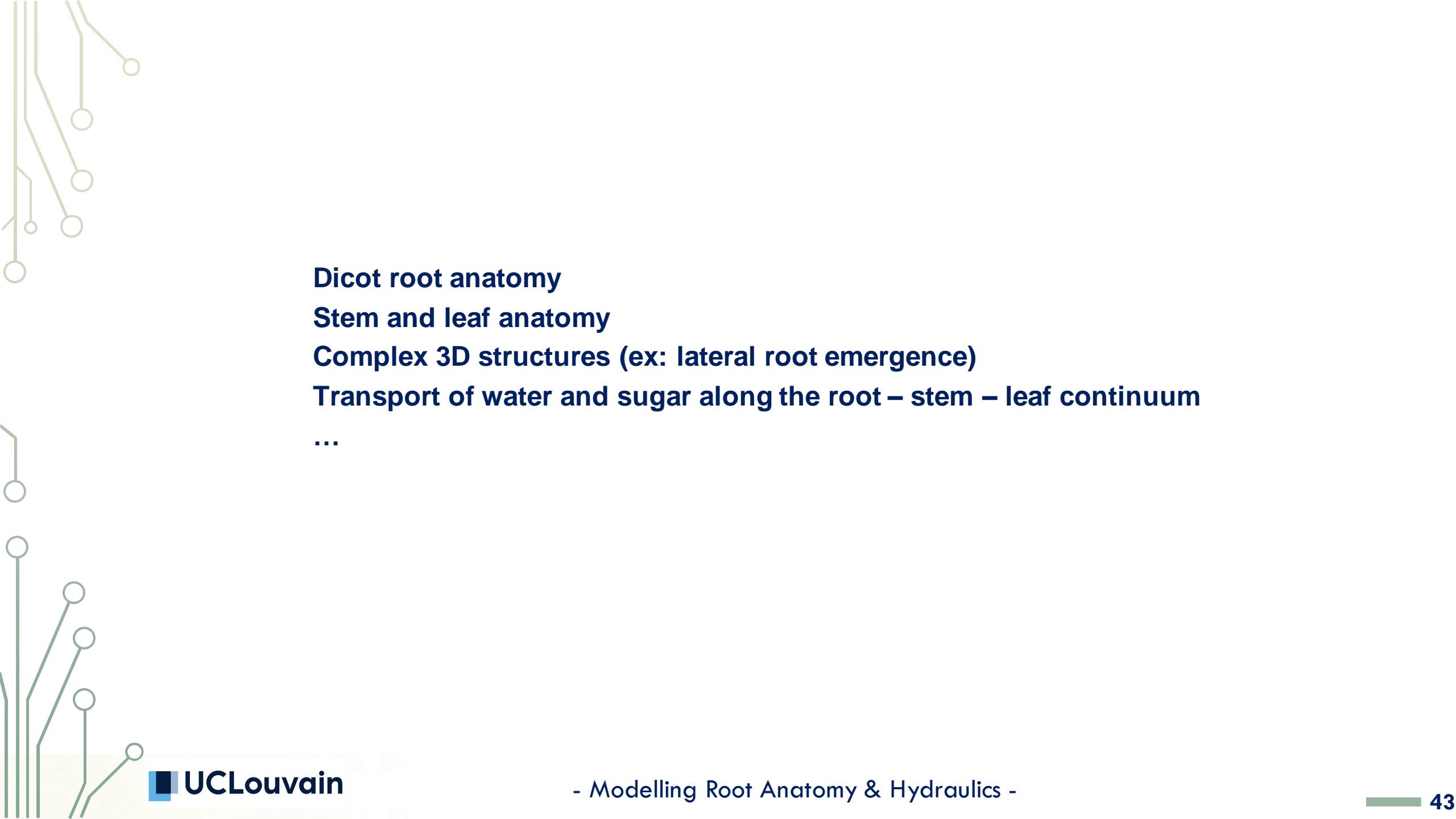


How sensitive are water pathways to cell properties?





Perspectives & applications



Dicot root anatomy
Stem and leaf anatomy
Complex 3D structures (ex: lateral root emergence)
Transport of water and sugar along the root – stem – leaf continuum

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Watching plants drink

