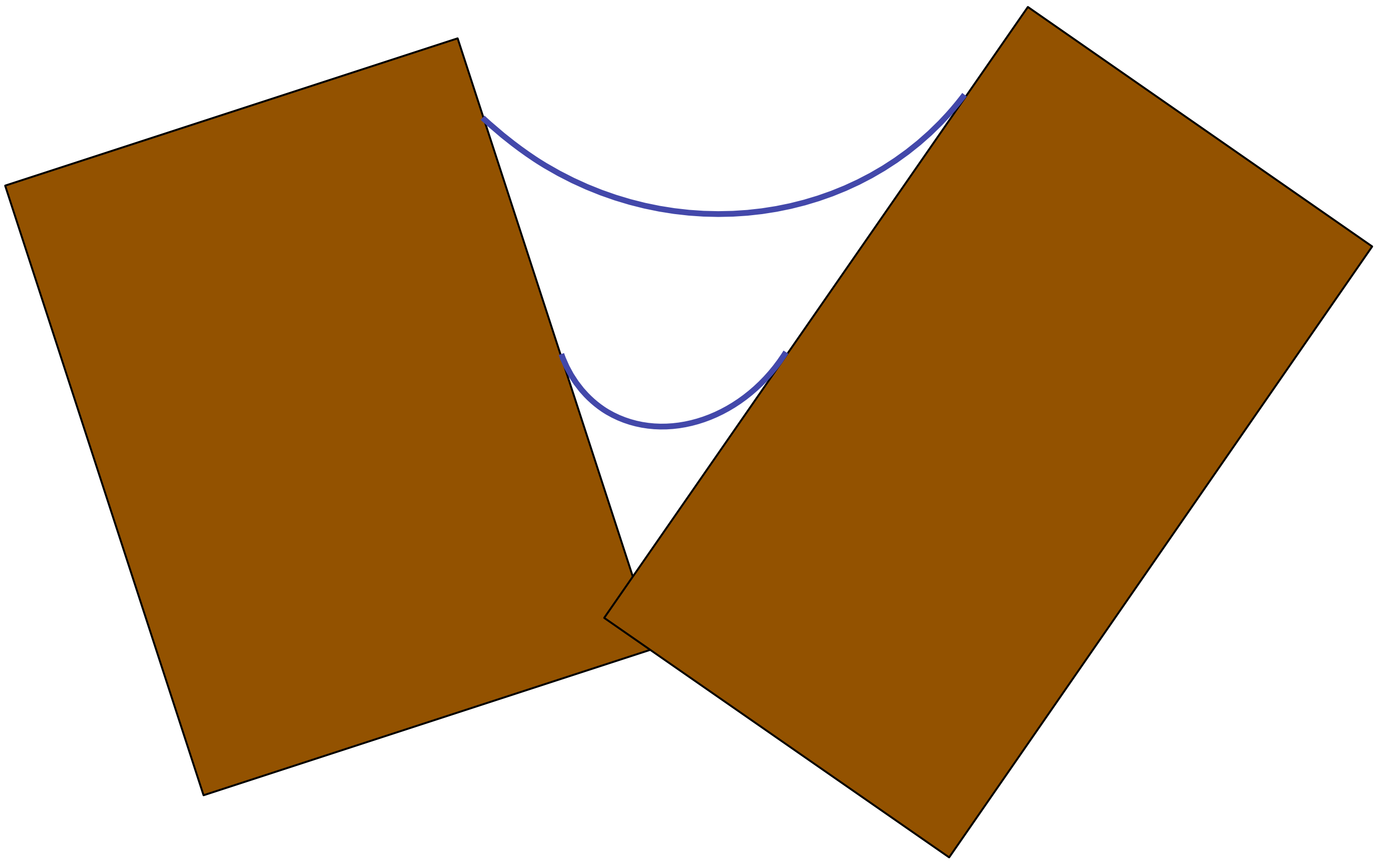
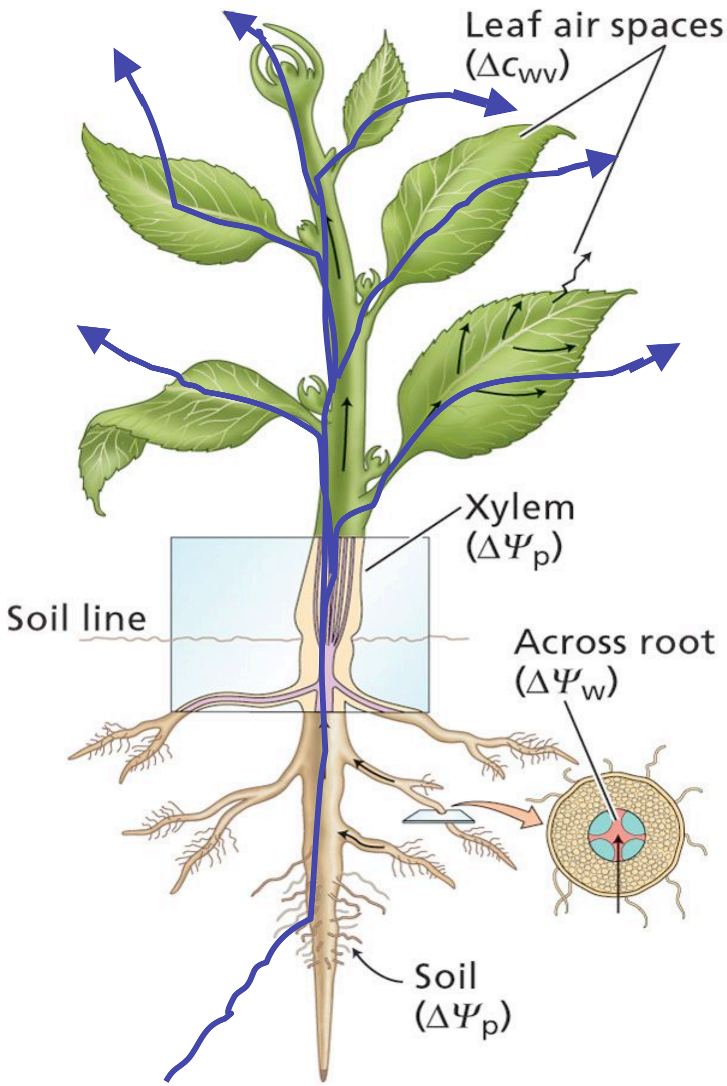
$$\Psi_P = -2T/r$$

Example: calculate Ψ_P for $r = 1 \times 10^{-6}$ m and 1×10^{-7} m.
About -0.15MPa for 1μm, and -1.5 MPa for 0.1 μm



Getting water from the soil into the plant.



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$\Psi_{root} < \Psi_{soil}$

What is the pathway for water movement into the xylem of the roots?

Water can travel from the soil to the root xylem by two distinct pathways - the symplastic and apoplastic pathways.

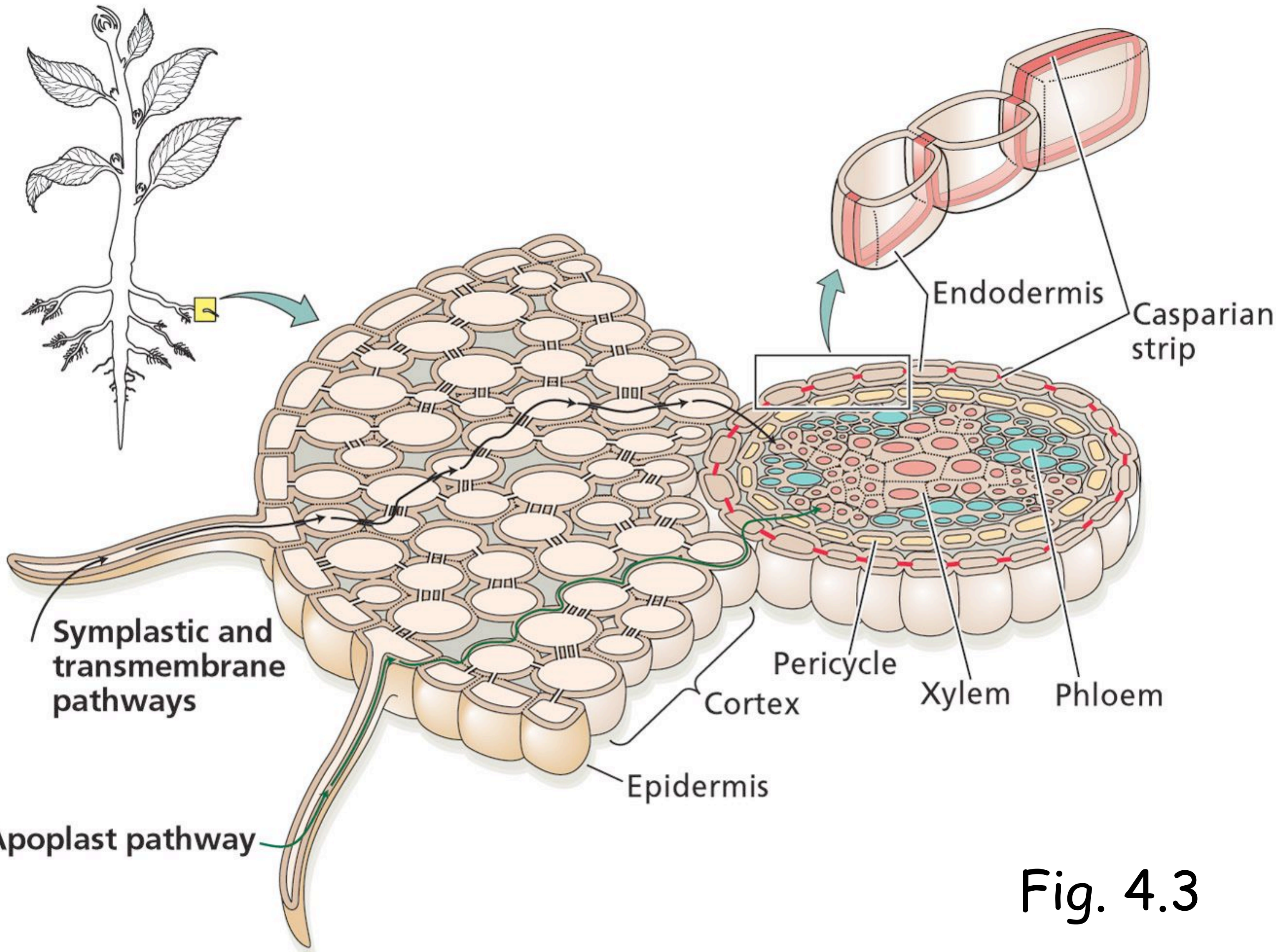

Fig. 4.3

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The less-suberized growing tips of roots have higher water uptake rates than older portions of the root.

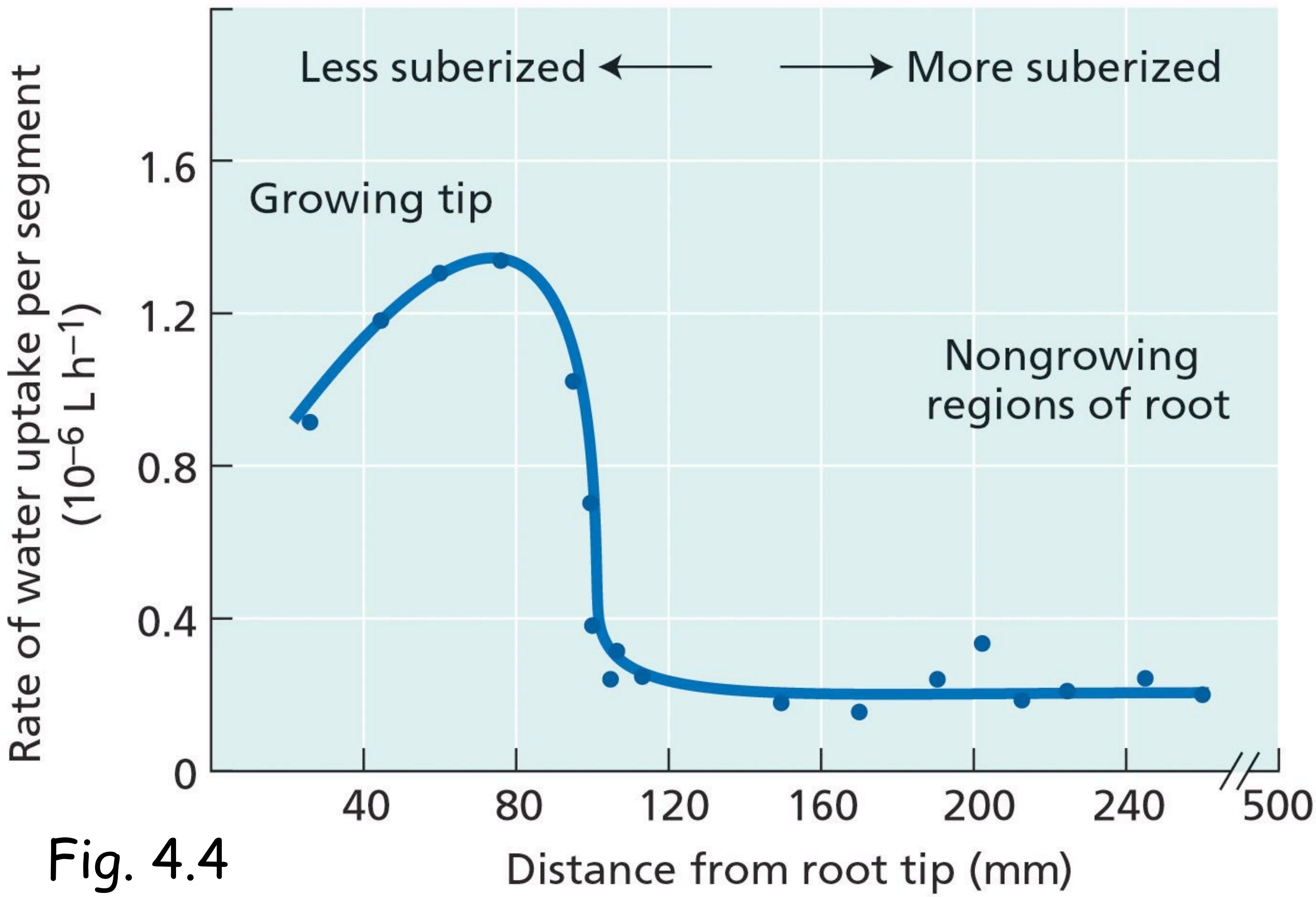

Fig. 4.4

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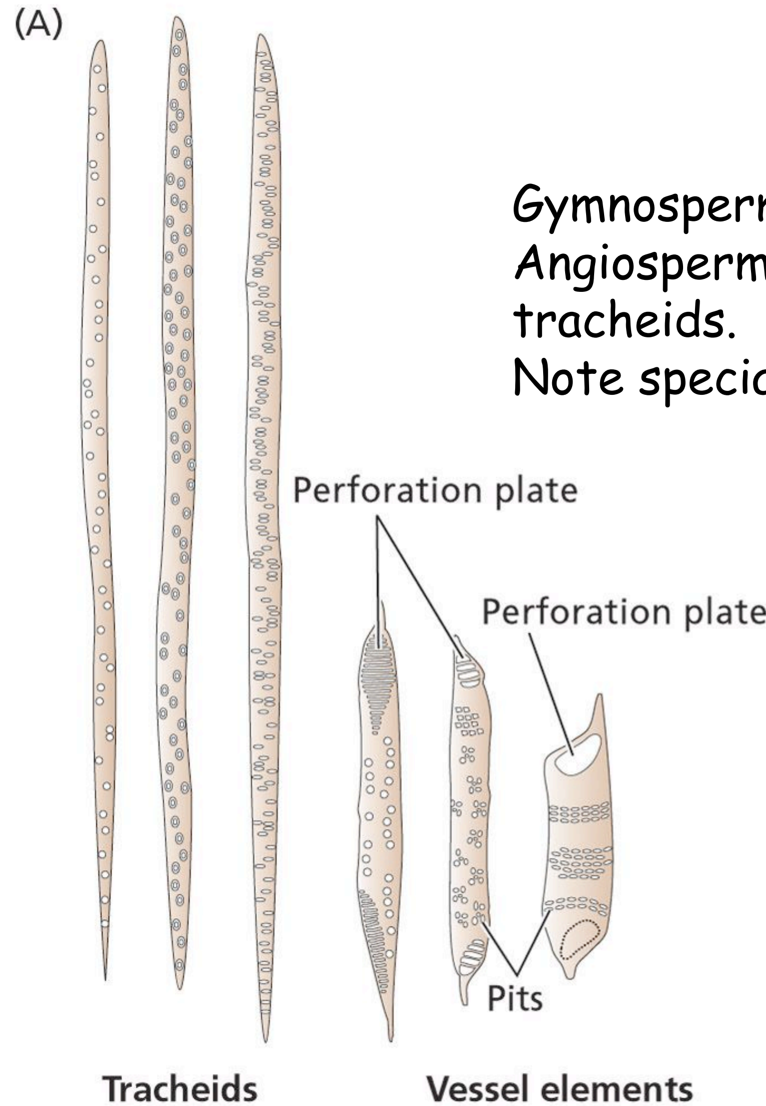
What is the pathway for water movement from roots to leaves?

Water flows from roots to leaves via the xylem, a network of specialized cells called tracheary elements.



Gymnosperms have tracheids.
Angiosperms have vessel elements & sometimes tracheids.
Note special anatomical features.

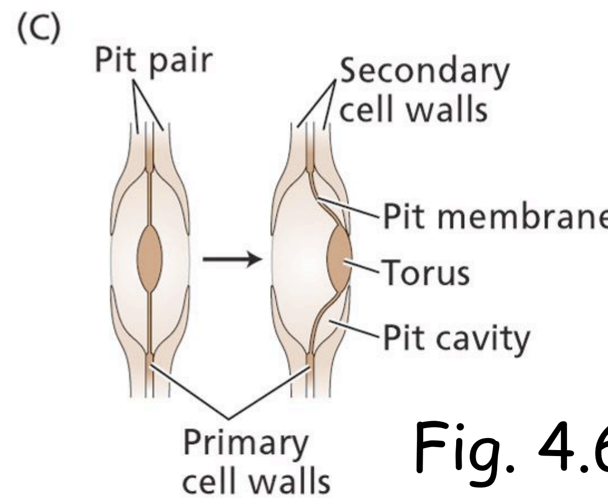


Fig. 4.6

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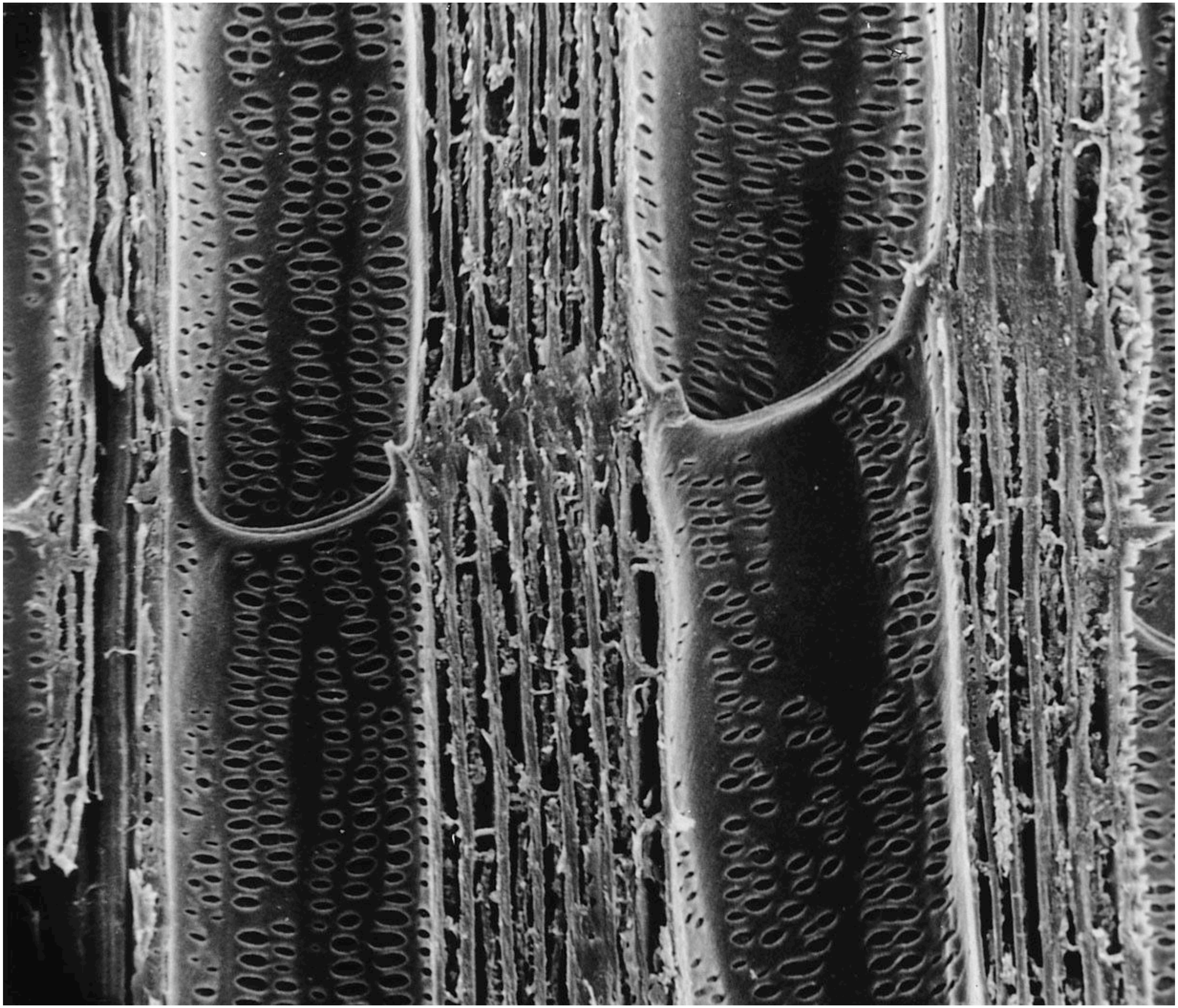

Xylem cavitation

Embolisms that stop water transport can form in tracheary elements when xylem pressure is sufficiently negative to pull in air through a pit.

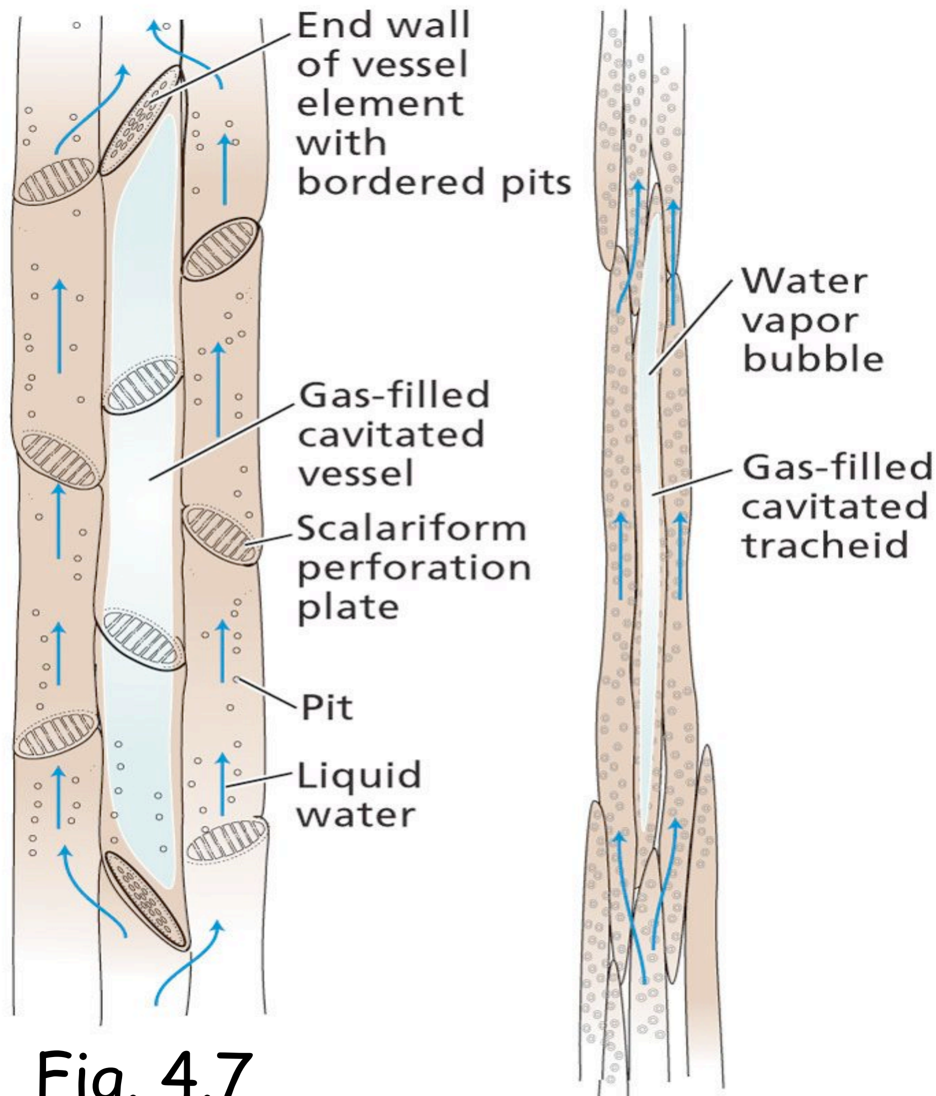

Fig. 4.7

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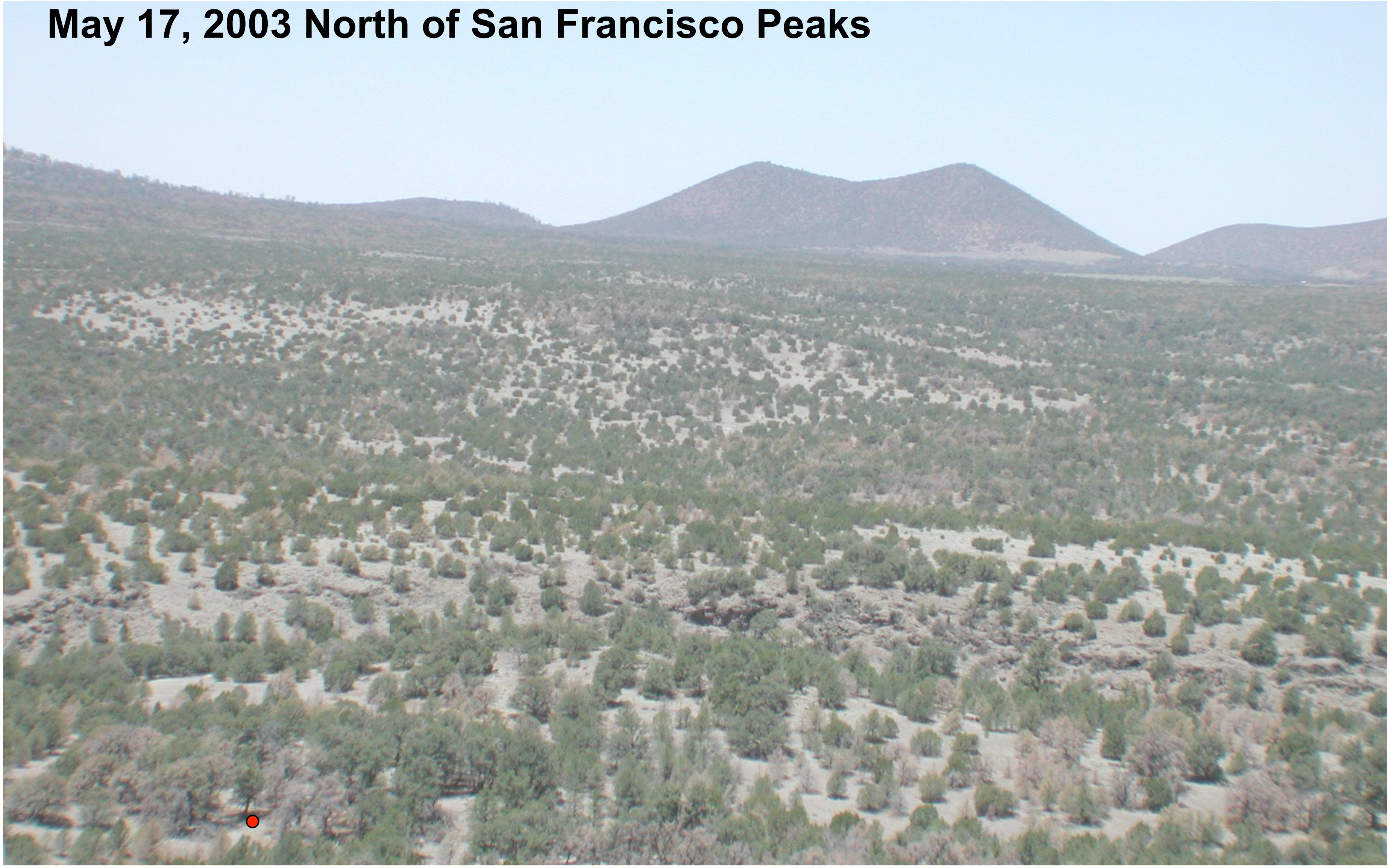
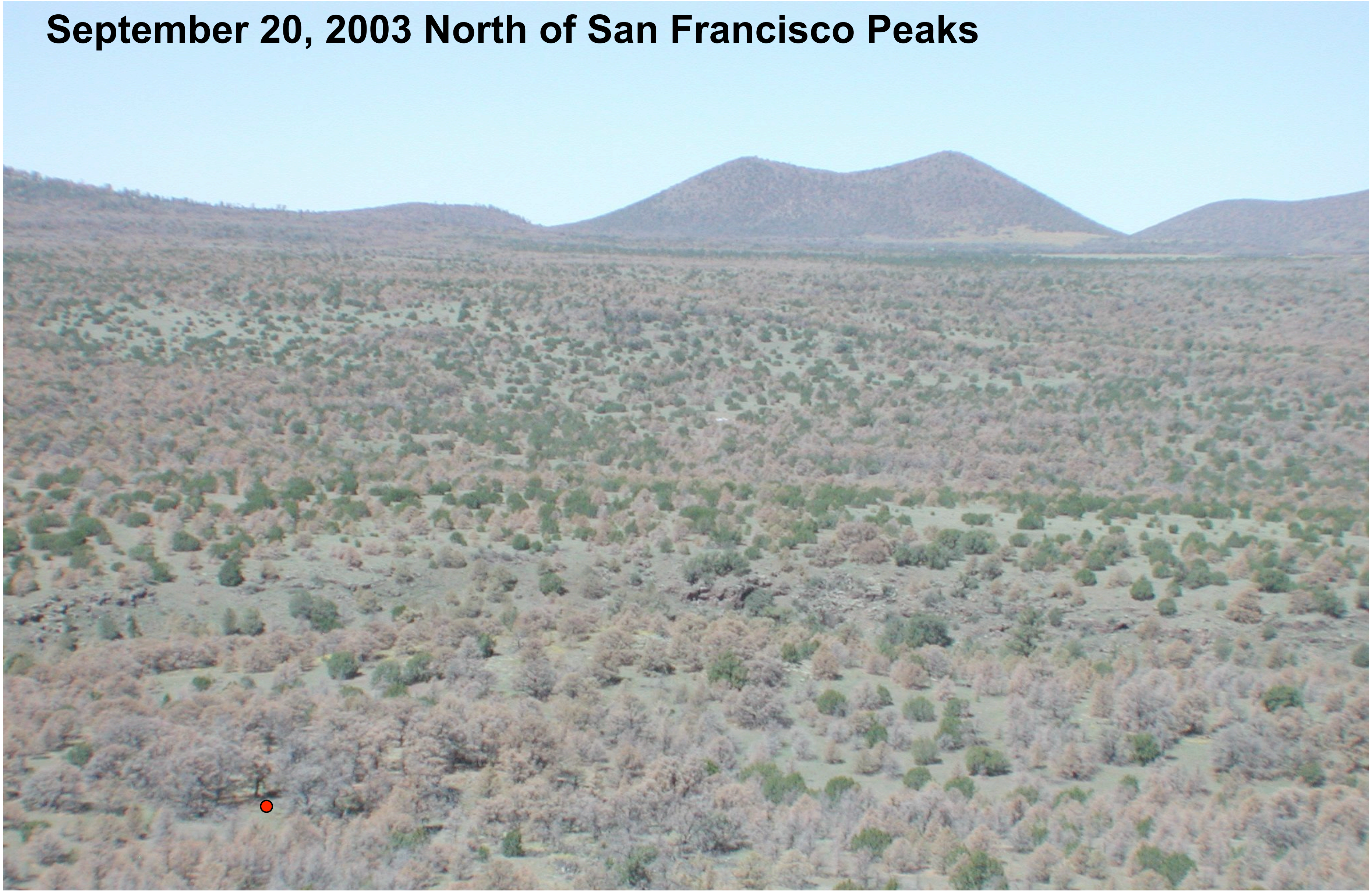
May 17, 2003 North of San Francisco Peaks



September 20, 2003 North of San Francisco Peaks



PJ Woodland → Juniper Woodland

The xylem network is extremely intricate in leaves.

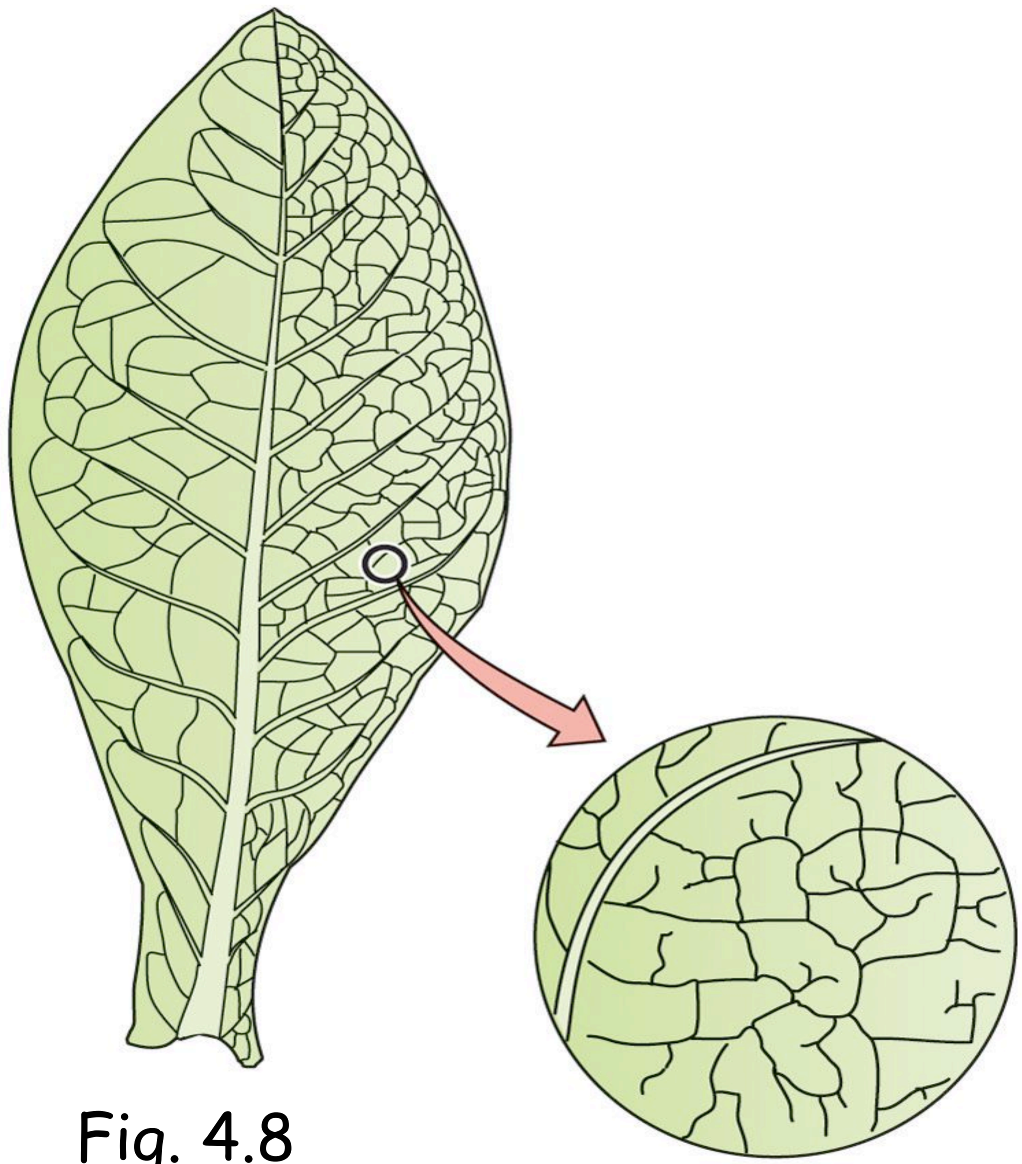


Fig. 4.8

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OK, we've got water from the soil, into the roots, and up to to the leaves.

Where does water evaporate inside leaves?

How does water at sites of evaporation have a lower water potential than xylem "upstream"?

The wet walls of leaf cells are the sites of evaporation.

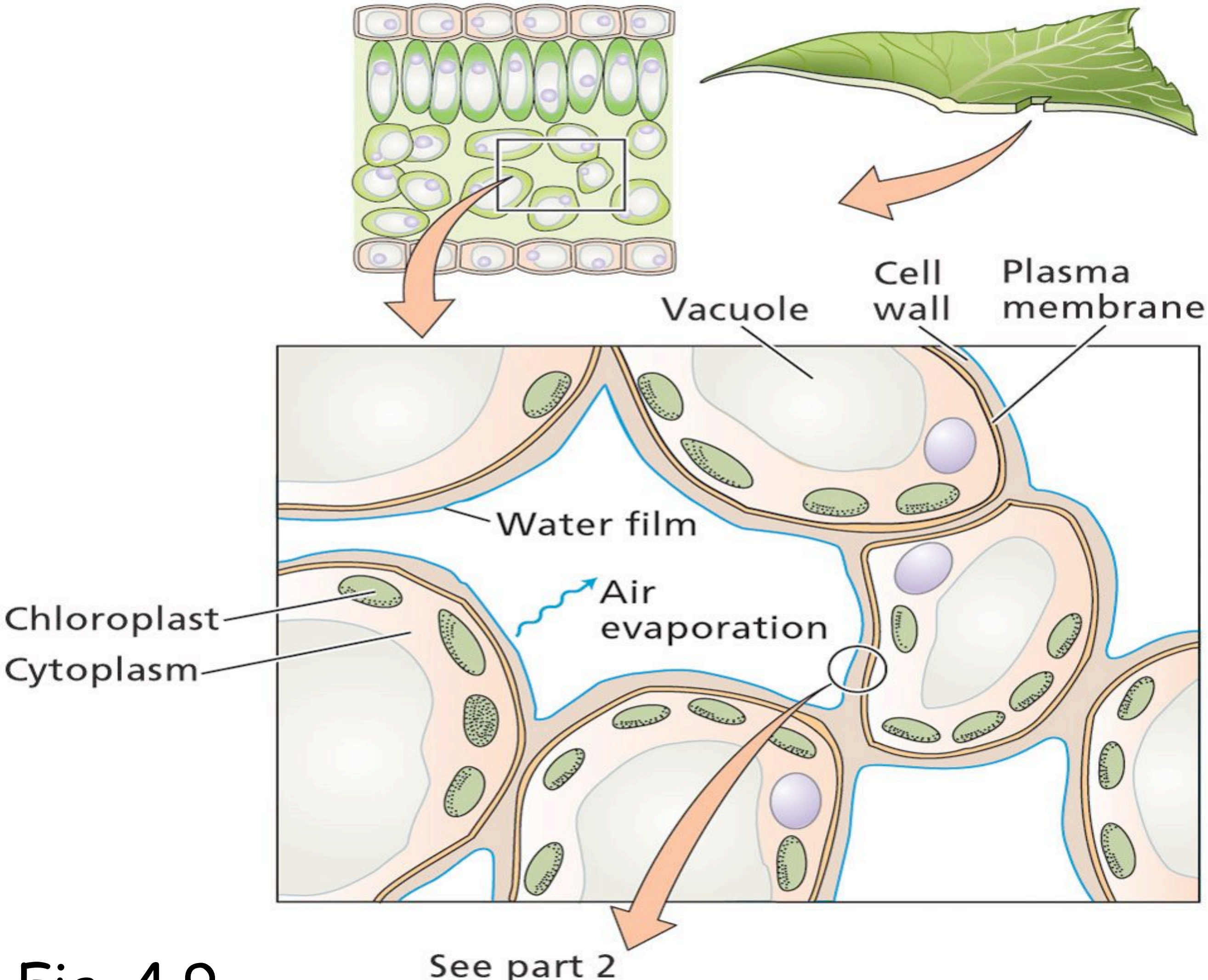

Fig. 4.9

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As for soils, a more negative Ψ_p develops as leaf cell walls dehydrate and water is held in smaller pore spaces.

$$\Psi_p = -2T/r$$

	Radius of curvature (µm)	Hydrostatic pressure (MPa)
(A)	0.5	−0.3
(B)	0.05	−3
(C)	0.01	−15

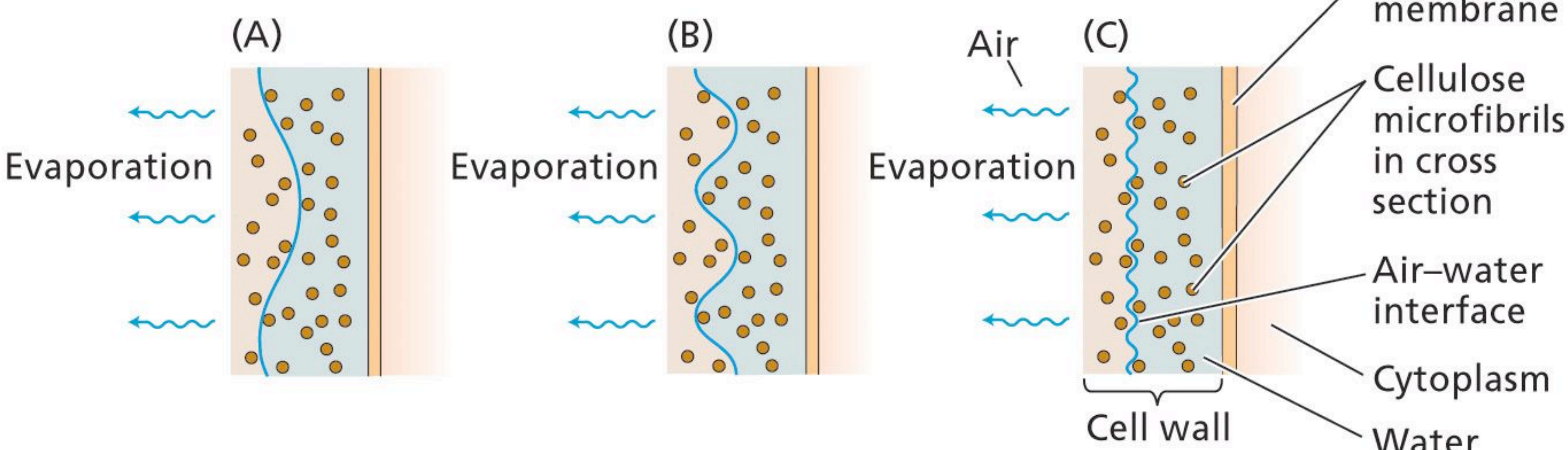

Fig. 4.9

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Putting it all together

A model for water movement through the plant.

The Cohesion-Tension (CT) Model
of xylem transport
(dates to Dixon and Joly, 1896)

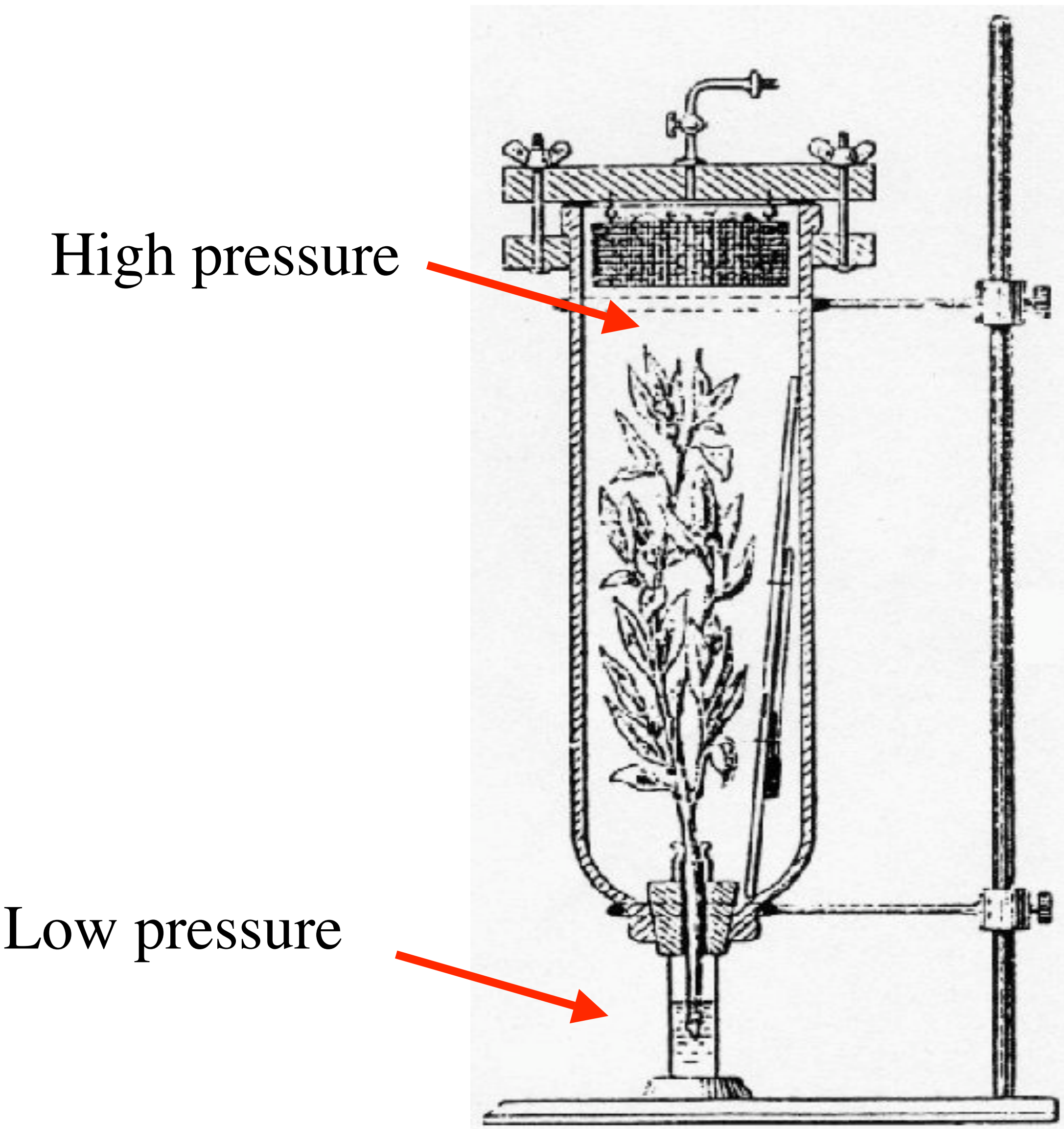
The CT is the most widely accepted model of water transport through the xylem (read the web essay!)

1. A negative pressure or tension is generated in leaf cell walls by evaporation (transpiration).

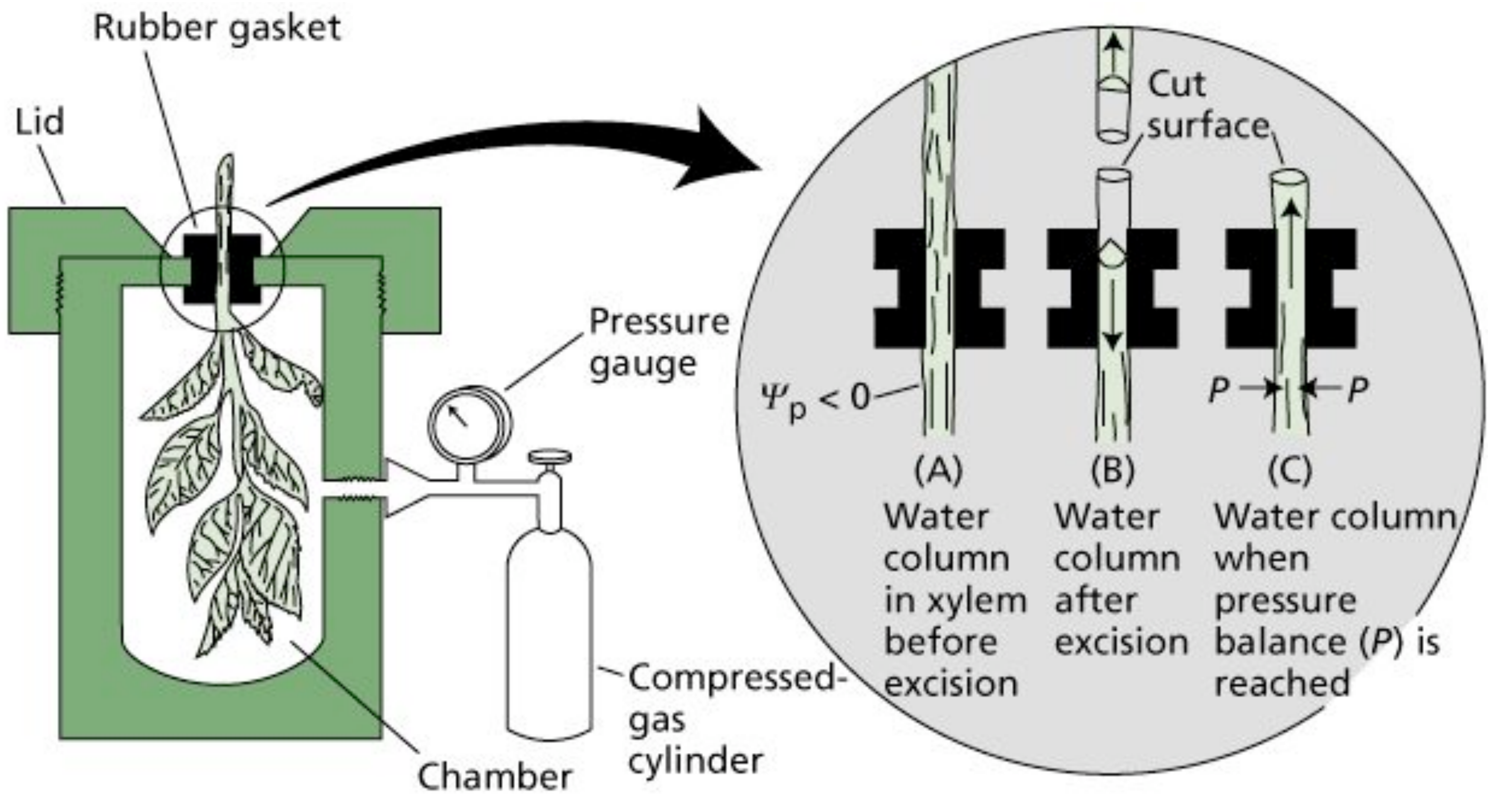
2. The cohesive property of water means this tension is transmitted to water in adjacent xylem and throughout the plant to the roots and soil.

Dixon & Joly, ca. 1894

A leafy branch subjected to a pressure of 0.3 MPa could draw up water from an external vessel that was at atmospheric pressure.



The negative pressure (tension) in the xylem can be measured indirectly with a Scholander pressure “bomb”.



Cohesion-Tension Theory of water transport (Web Essay 4.2)

Essential elements

1. **Water within the whole plant forms a continuous network of liquid columns from the absorbing surfaces of roots to the evaporating surfaces.**

2. **This hydraulic continuity transfers instantaneously the variations of tensions or pressure throughout the plant.**

3. **Hydraulic continuity is highly dependent on the tensile strength of water.**

4. **The driving force for water movement in the system is generated by surface tension of the menisci of water at the evaporating surfaces within leaves.**

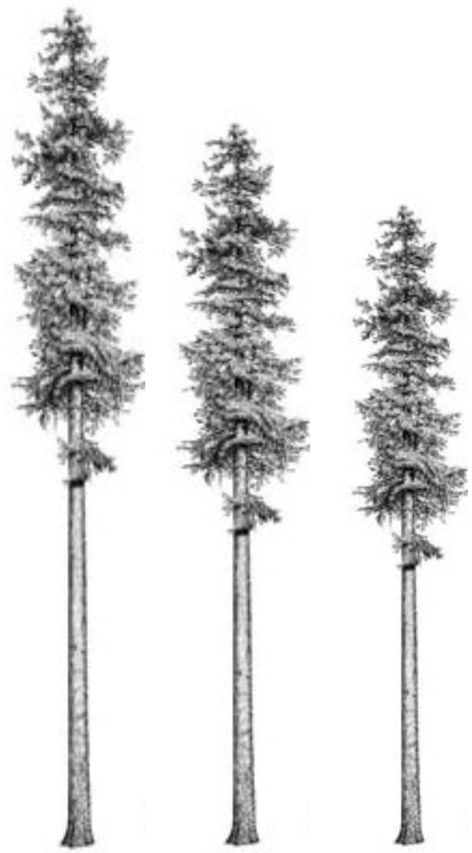
5. **In this way, transpiration establishes gradients of negative pressure or tension along the pathway in transpiring plants. This causes an inflow of water from the soil to the transpiring surfaces.**

6. **Due to the fact that transpiration "pulls" the sap from the soil to the leaves, water in the xylem is in a metastable state of tension. In this state, the water column is susceptible to cavitation, (i.e., to the appearance of a vapor phase within the liquid phase).**

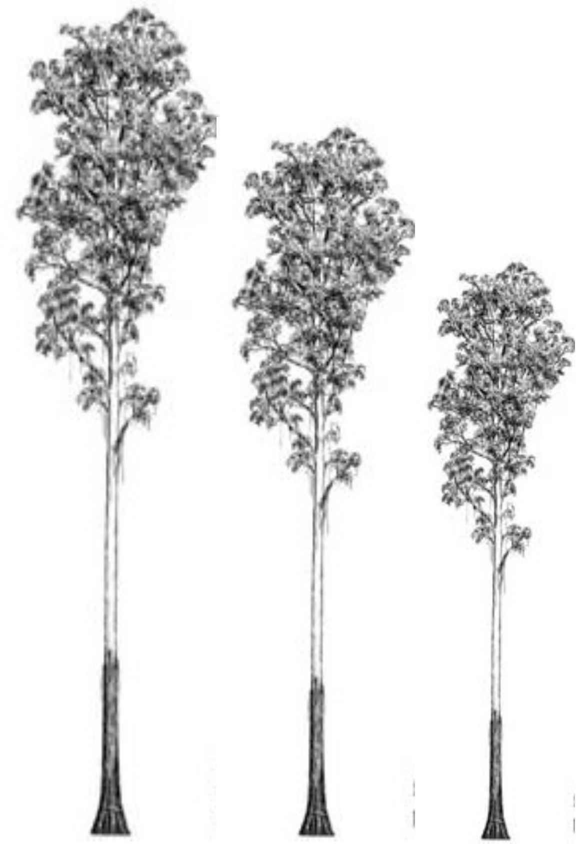
Water relations of tall trees

Redwood

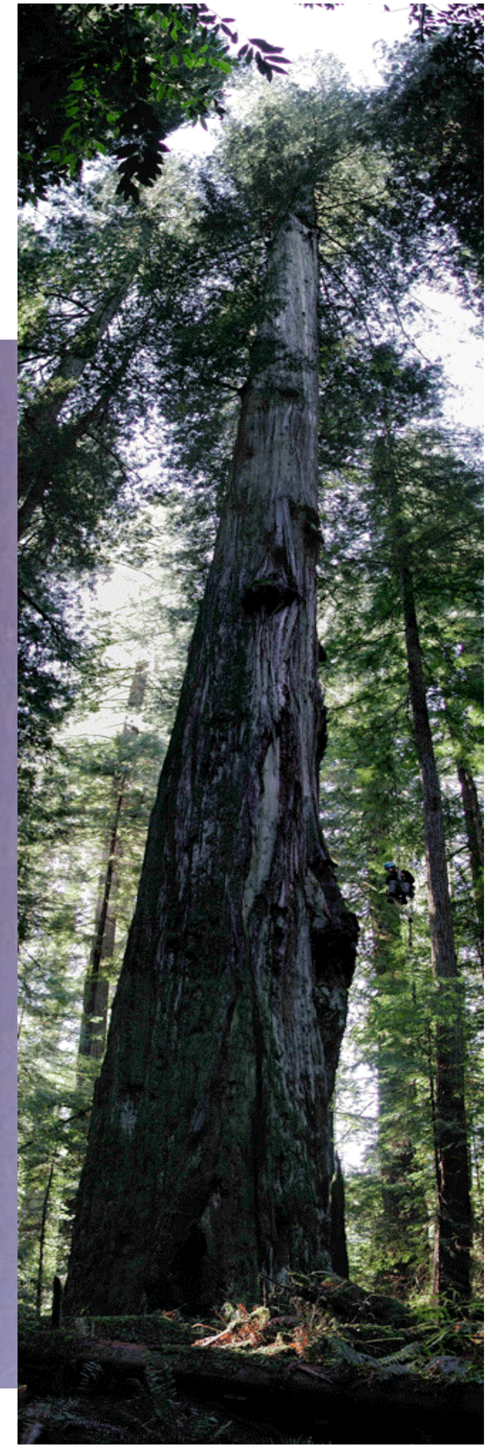
Douglas-fir



mountain ash



Redwood, *Sequoia sempervirens*

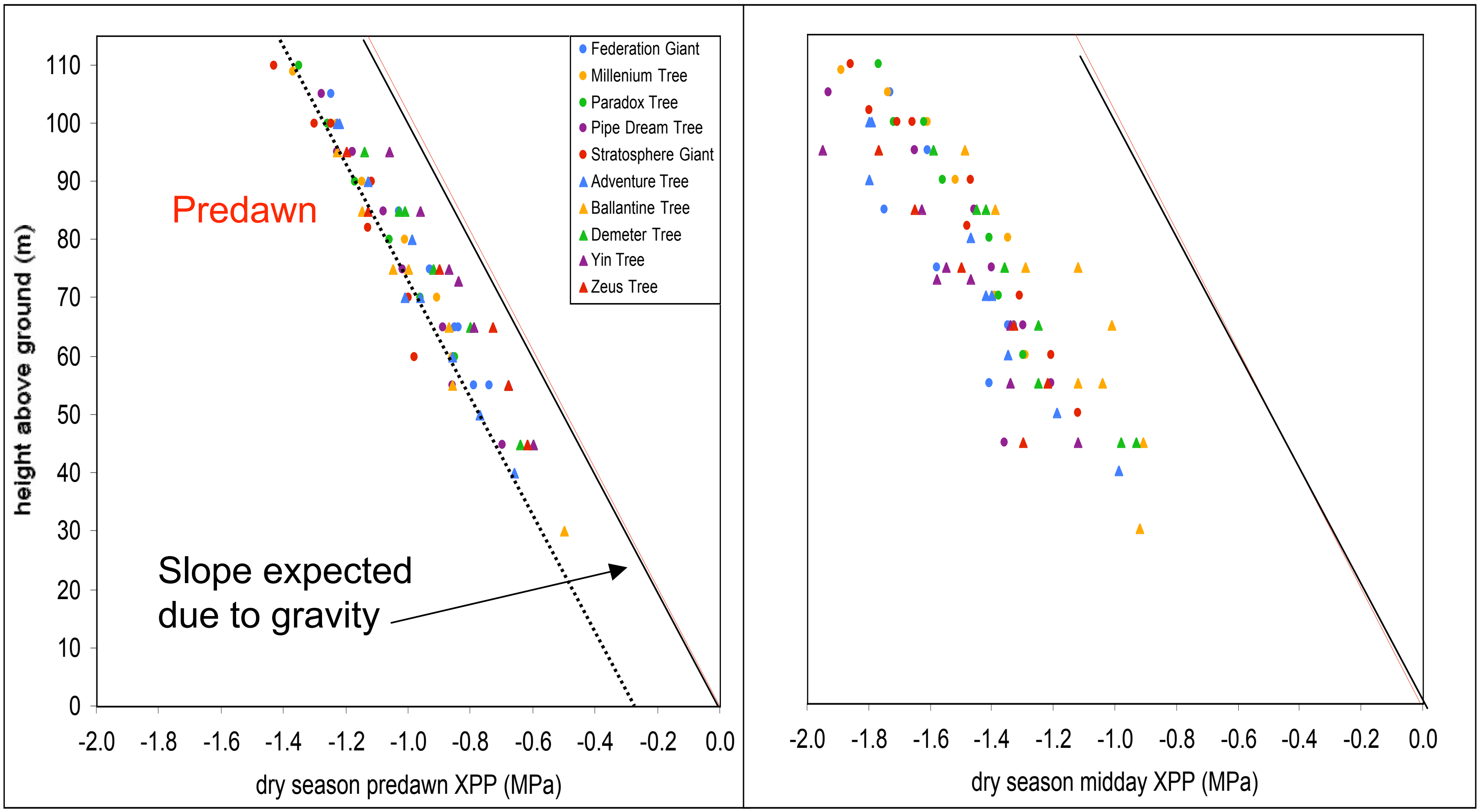


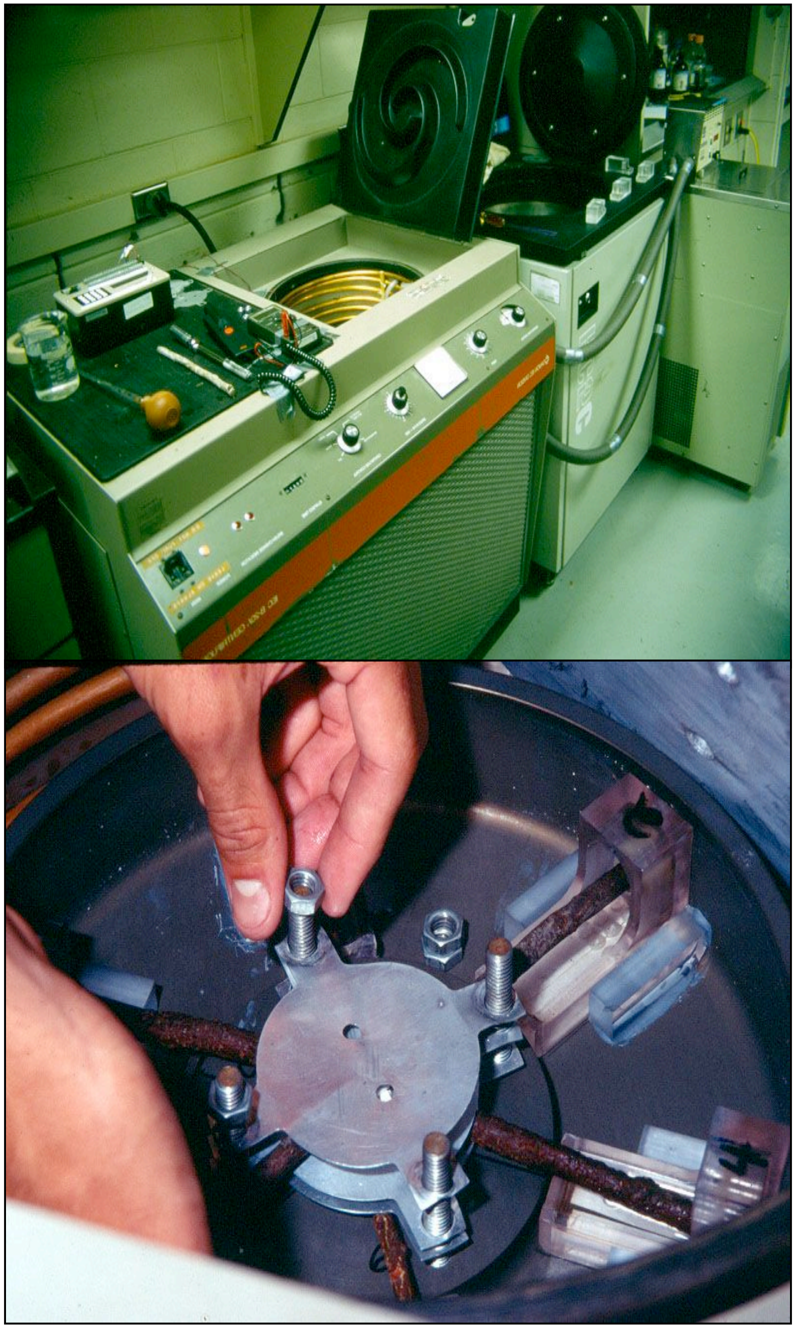
Mountain ash
Eucalyptus regnans
Victoria, Australia

Giant sequoia
Sequoiadendron giganteum

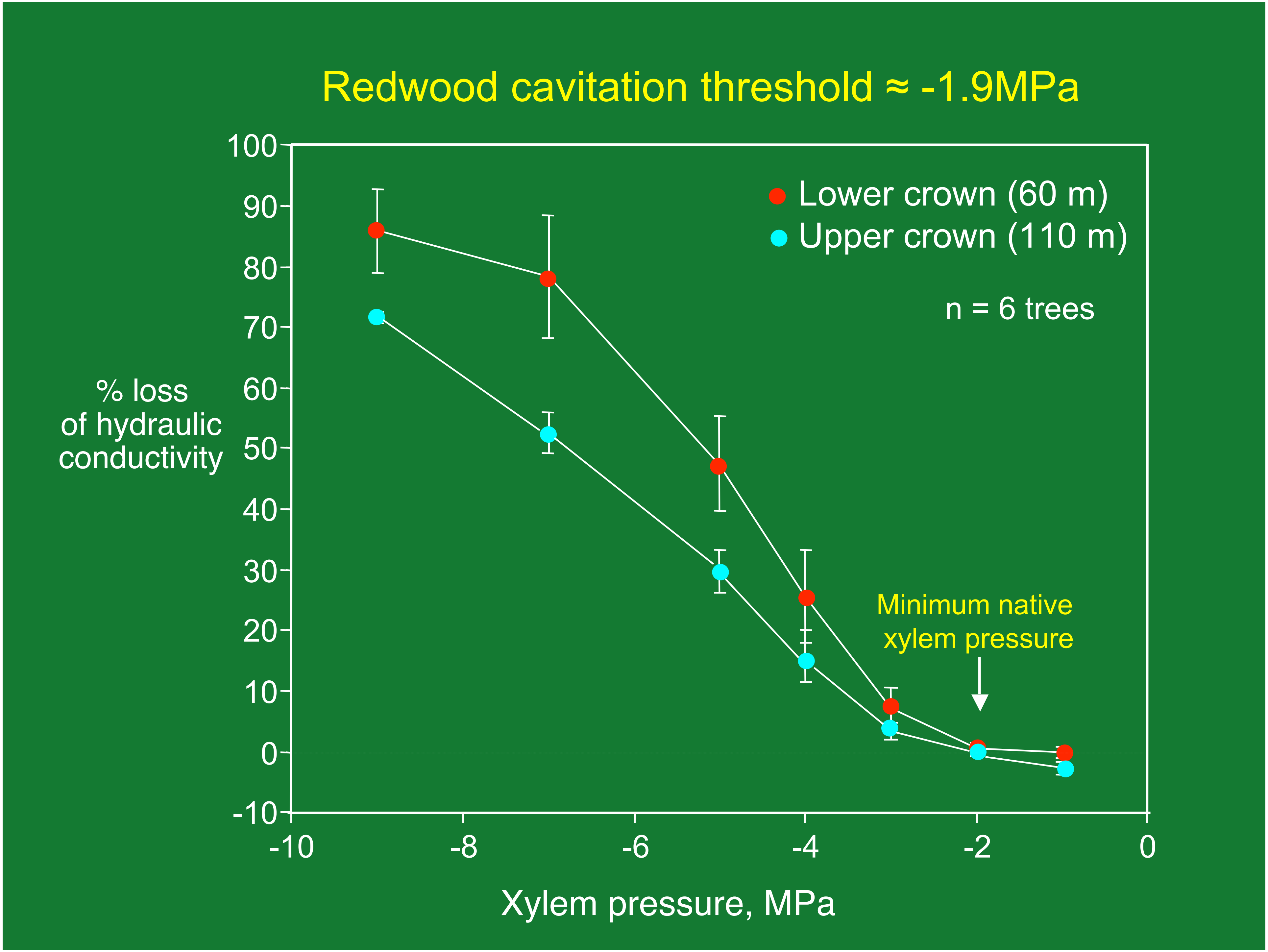
Xylem pressure decreases with height as predicted by the cohesion-tension model. Gravity rules!

slope = -0.0096 ± 0.0007 MPa m^{-1}
$R^2 \geq 0.97$, $p < 0.0001$





Creating known xylem tensions in stem segments using a centrifuge. (Alder *et al.* 1997)



Redwood cavitation threshold ≈ -1.9MPa
Lower crown (60 m)
Upper crown (110 m)
n = 6 trees
Minimum native
xylem pressure
% loss
of hydraulic
conductivity
100
90
80
70
60
50
40
30
20
10
0
-10
-10
-8
-6
-4
-2
0
Xylem pressure, MPa

Transpiration -
the diffusion of water vapor from the internal air spaces of leaves out through the stomatal pore.

- Hugely important to local and global hydrological cycles.

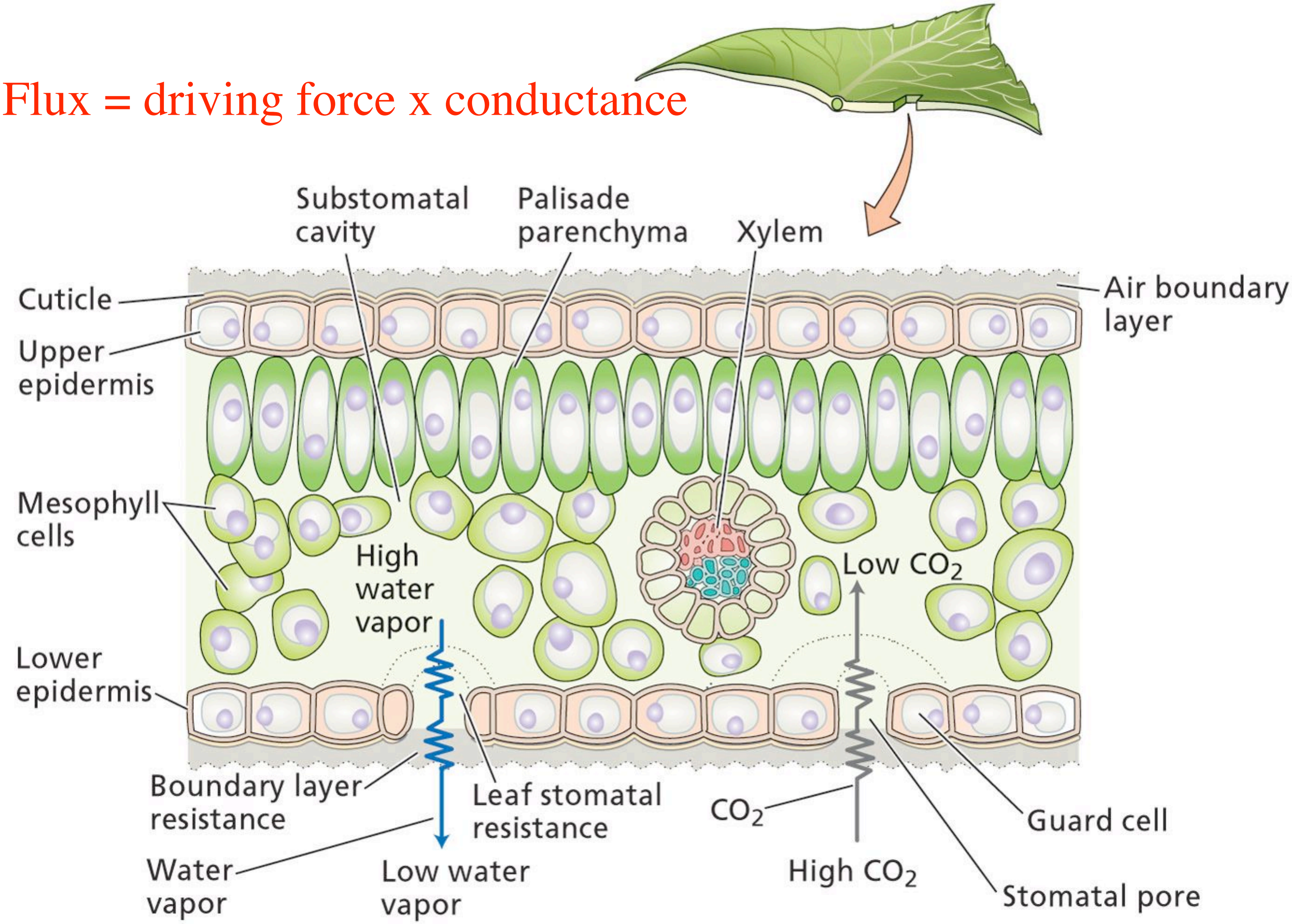
- Moves vast quantities of water from soils back to atmosphere

- Influences energy balance via the cooling effect of evaporation (latent heat of vaporization)

    - How plants regulate transpiration is vital to survival and growth in a desiccating environnment

• Transpiration rate (a flux) is a function of the water vapor diffusion gradient (the driving force) and stomatal aperture (the conductance of the pathway).

Flux = driving force x conductance



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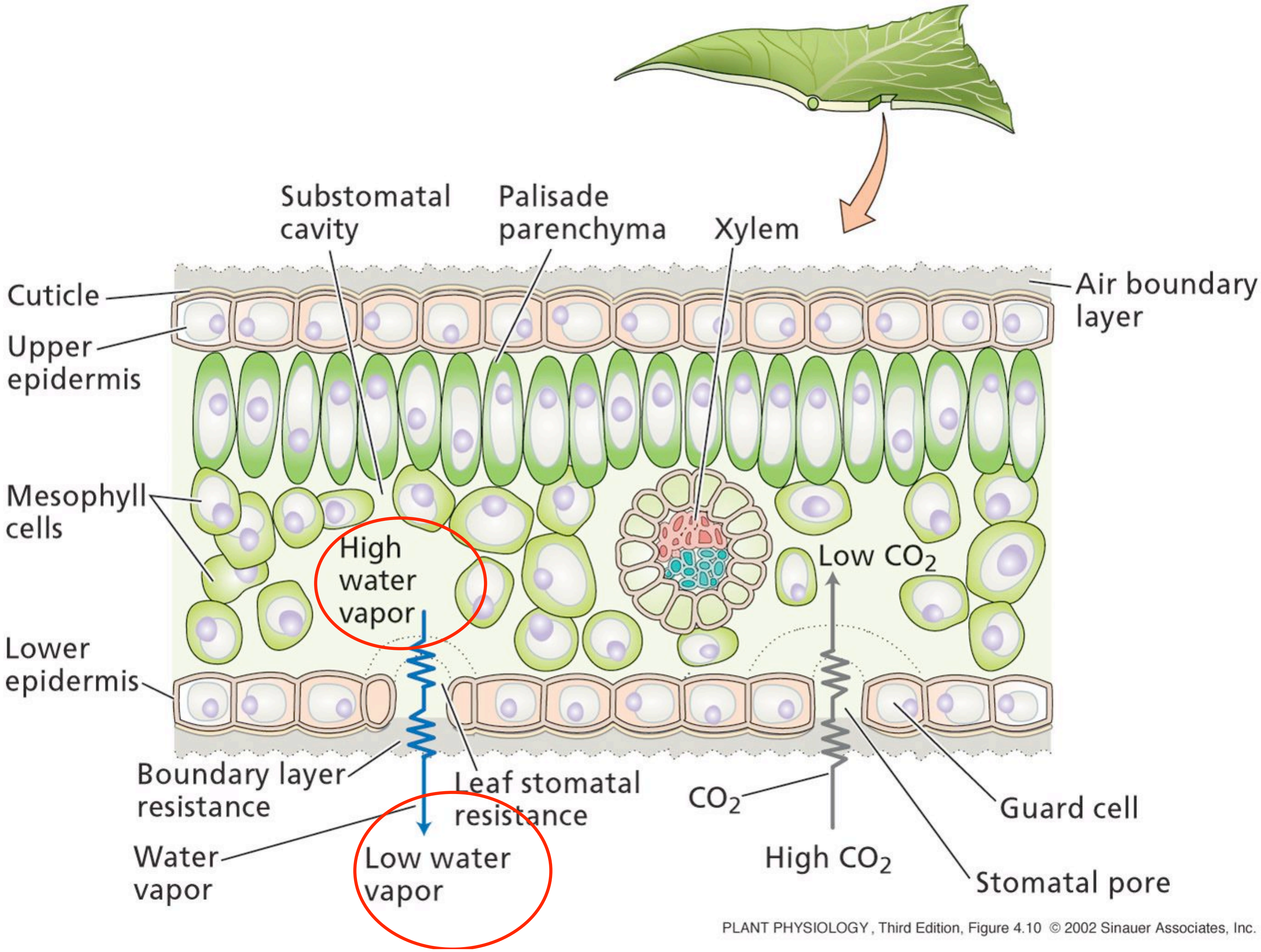
The driving force for transpiration is the H_2O conc. gradient from inside to outside the leaf.



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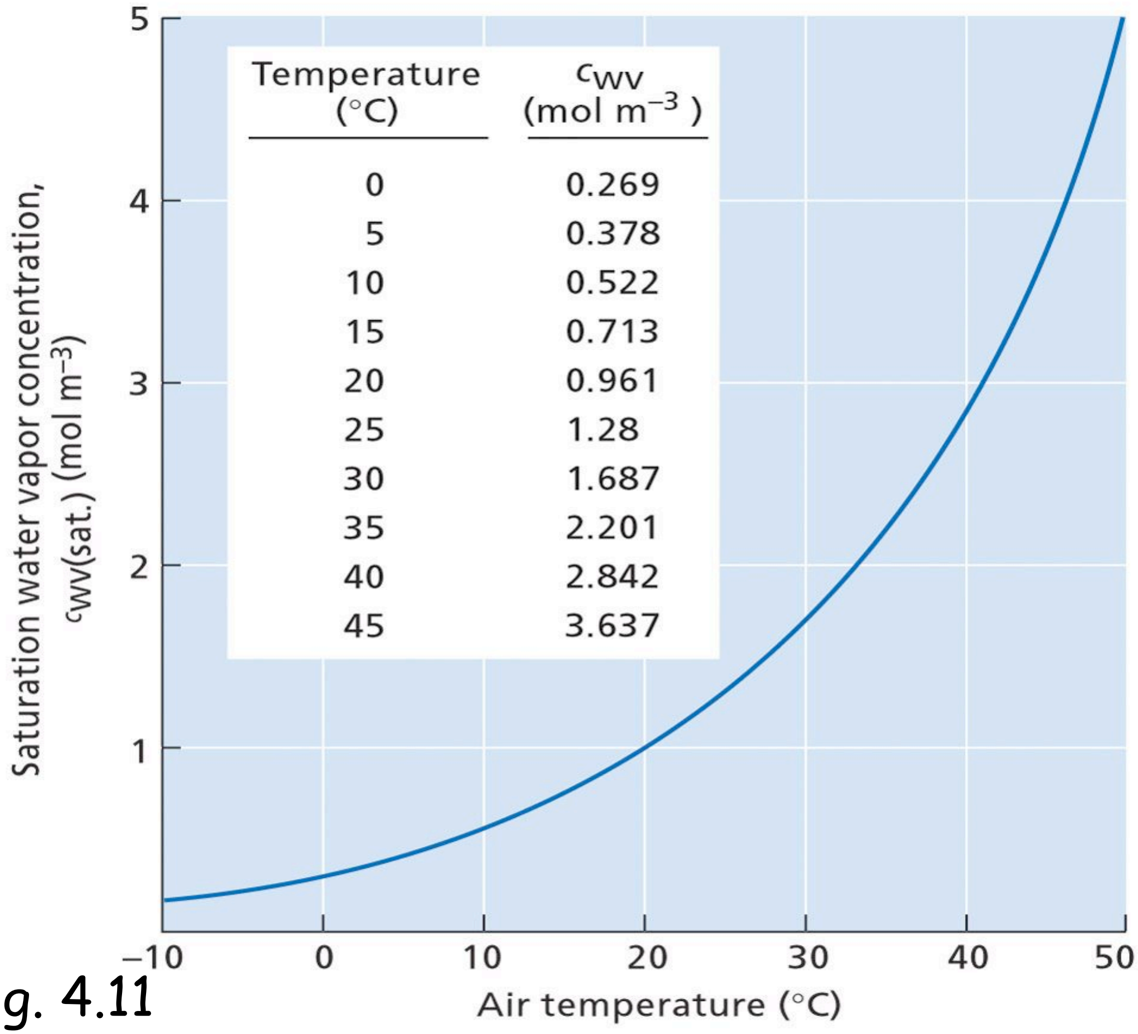
How can we know the [H_2O] inside a leaf?

How can we know the [H_2O] inside a leaf?

The air inside leaves is saturated with water vapor.

The [H_2O] of saturated air is a strong function of temperature.

Warmer air can hold more water vapor than cooler air.



Temperature (°C)	c_{wv} (mol m^{-3})
0	0.269
5	0.378
10	0.522
15	0.713
20	0.961
25	1.28
30	1.687
35	2.201
40	2.842
45	3.637

Fig. 4.11

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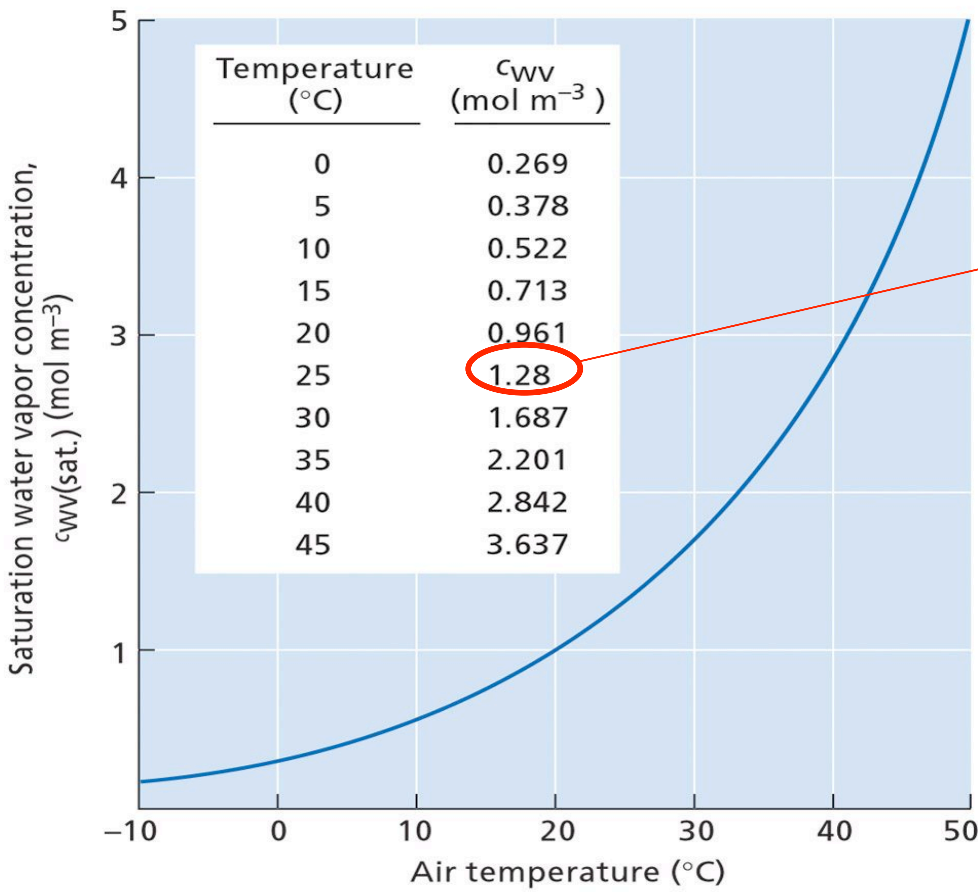
How can we know the $[H_2O]$ of the air outside the leaf?

The $[H_2O]$ of the air outside the leaf can be measured.

<u>Relative humidity</u> expresses the fraction of the saturation water vapor concentration.

Relative humidity = $[H_2O] / [H_2O]_{sat'n}$ * 100%



Temperature (°C)	c_{wv} (mol m^{-3})
0	0.269
5	0.378
10	0.522
15	0.713
20	0.961
25	1.28
30	1.687
35	2.201
40	2.842
45	3.637

50% RH at 25 °C

$0.5 \times 1.28 = 0.64$ mol m^{-3}

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The water vapor concentration gradient from inside to outside a leaf.

TABLE 4.2
Representative values for relative humidity, absolute water vapor concentration, and water potential for four points in the pathway of water loss from a leaf

Location	Relative humidity	Water vapor	
		Concentration (mol m^{-3})	Potential (MPa)[a]
Inner air spaces (25°C)	0.99	1.27	–1.38
Just inside stomatal pore (25°C)	0.95	1.21	–7.04
Just outside stomatal pore (25°C)	0.47	0.60	–103.7
Bulk air (20°C)	0.50	0.50	–93.6

Source: Adapted from Nobel 1999.
Note: See Figure 4.10.
[a]Calculated using Equation 4.5.2 in Web Topic 4.5; with values for $RT/\overline{V}_w$ of 135 MPa at 20°C and 137.3 MPa at 25°C.

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