

FROM TREE TO END PRODUCT: *construction, deconstruction*

and reconstruction

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CNRS

MeMoWood Conference

Nancy Oct 1-4, 2013





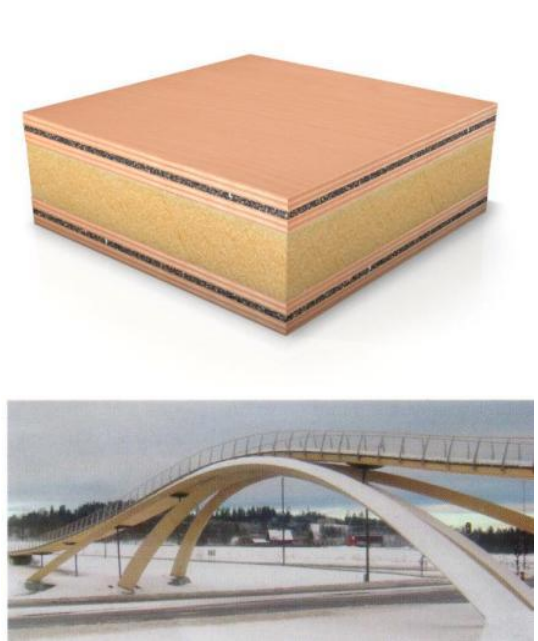
Construction

Tree construction by wood growth



Déconstruction

From tree to timber and fibres



Reconstruction

From components to wooden products

Tree wood compartment

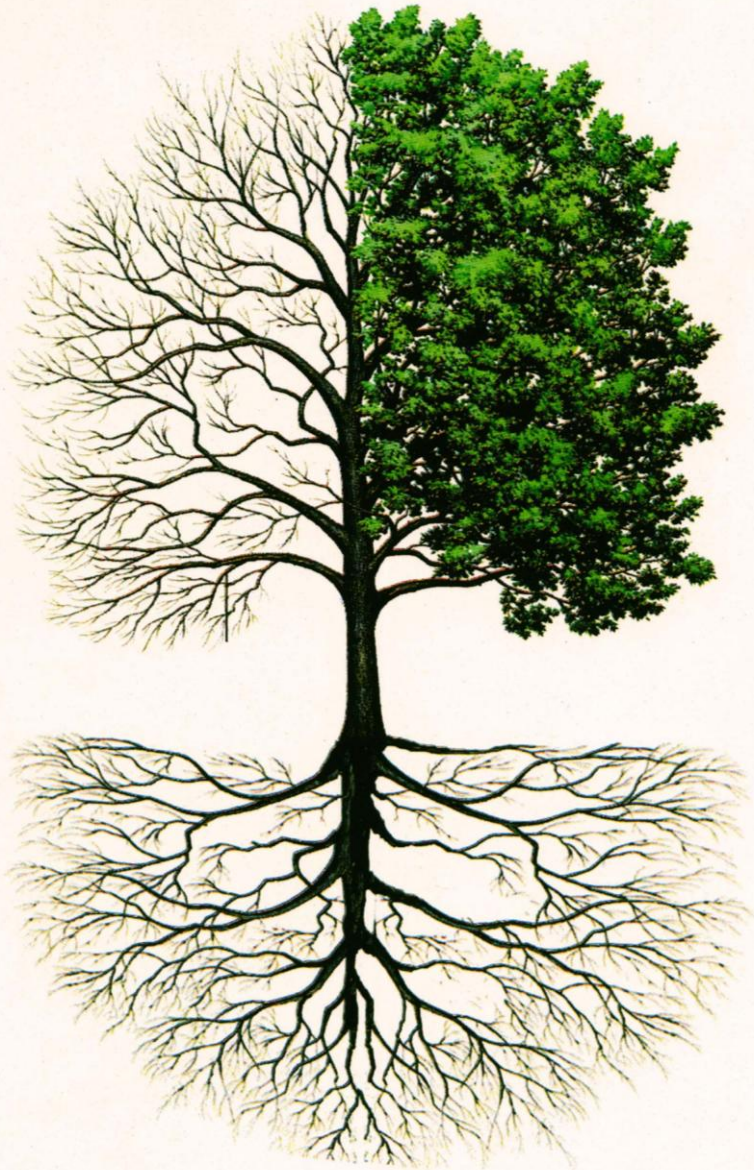
Leaves produce basic components from water, minerals, CO² and solar energy



Terminal and lateral buds are parts of TWC

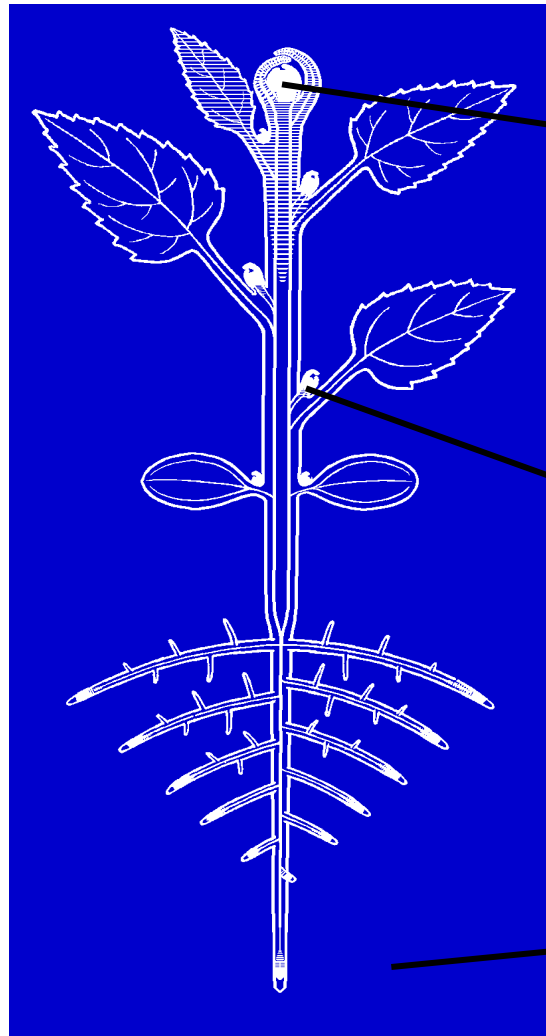
Tree wood compartment is the whole structure connecting tiny roots to leaves

Wood growth builds the tree and creates forces needed for its adaptation to environment



Tiny roots take water and minerals

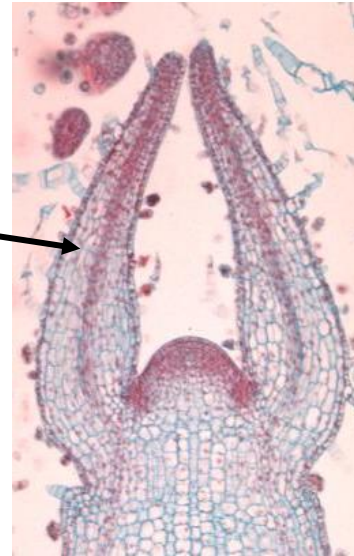
Primary growth



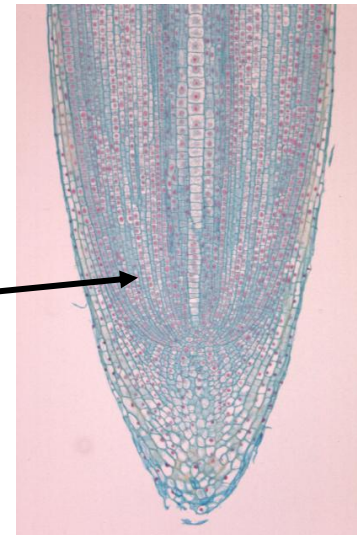
Young tree



Lateral bud

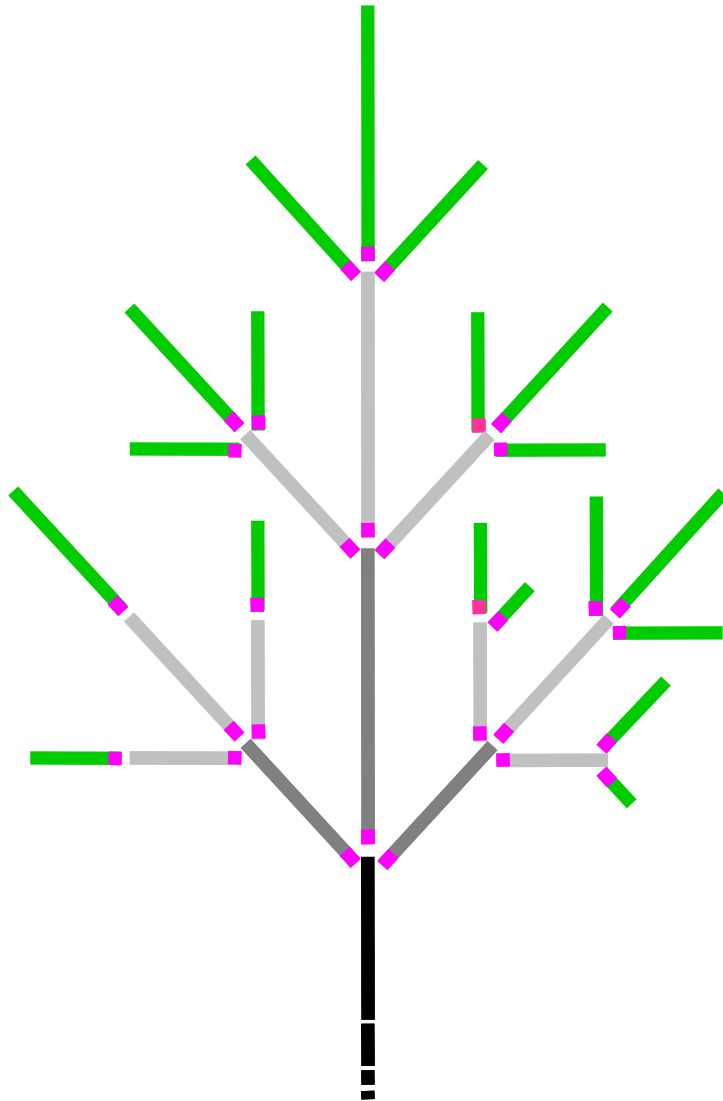


Terminal bud



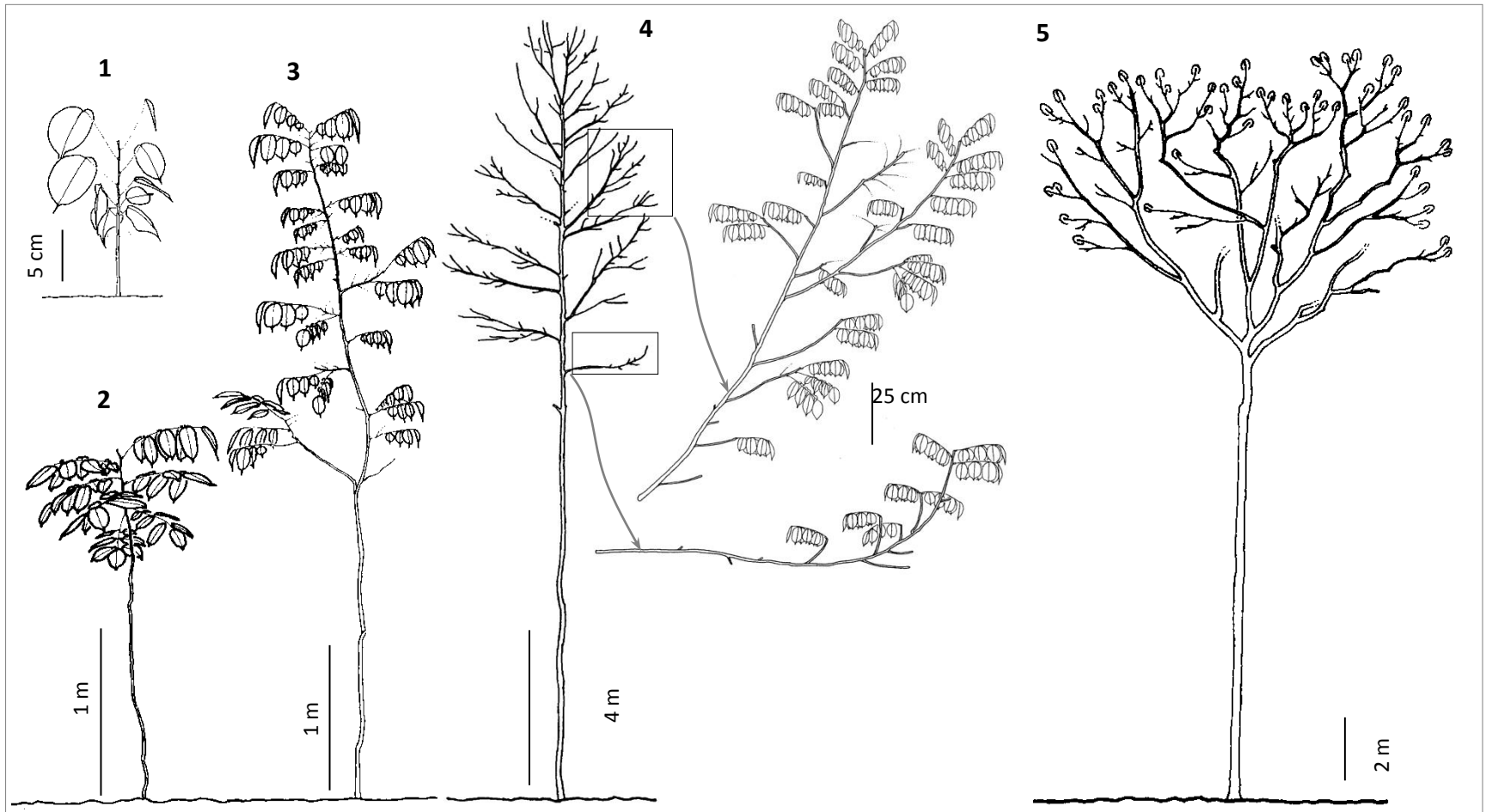
Root apex

Successive growth units



-  Year 4
-  Year 3
-  Year 2
-  Year 1
-  Bud

Aerial wood compartment geometry and primary growth: tree architecture



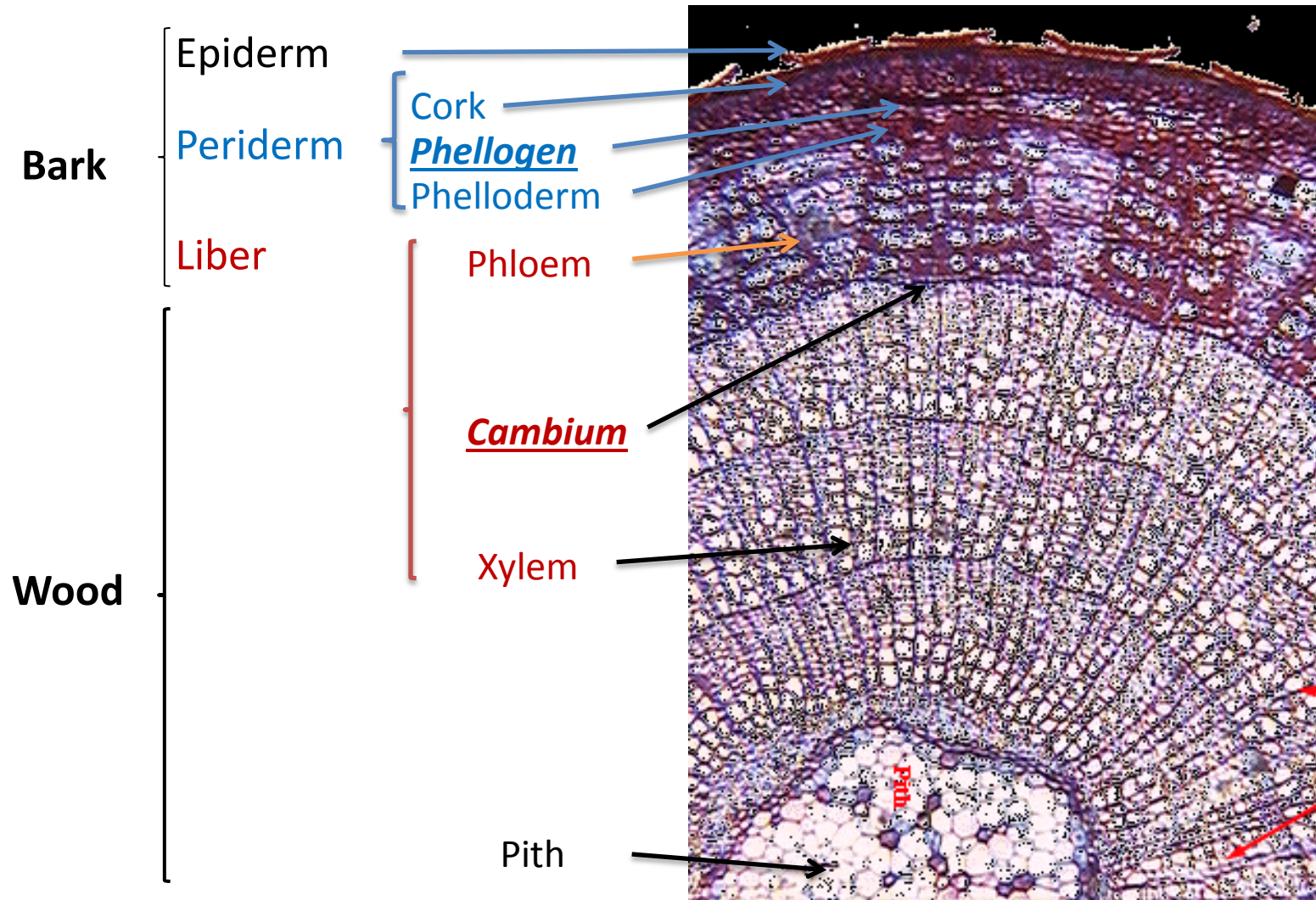
Woody axes are slender cantilever beams connected by their basis
Architectural model is a genetically driven pattern

Modulation of tree construction by primary growth

- Creation of new order axis
- Elongation of existing axis
- Programmed death of existing axis

- 3D distribution of mass
- Centre of gravity, centre of wind pressure
- Damping by branching

Axis anatomy and secondary growth



Cambium → **phloem & xylem**: conduction, mechanical construction & regulation
Phellogen → **phelloderm & cork**: external protection and storage

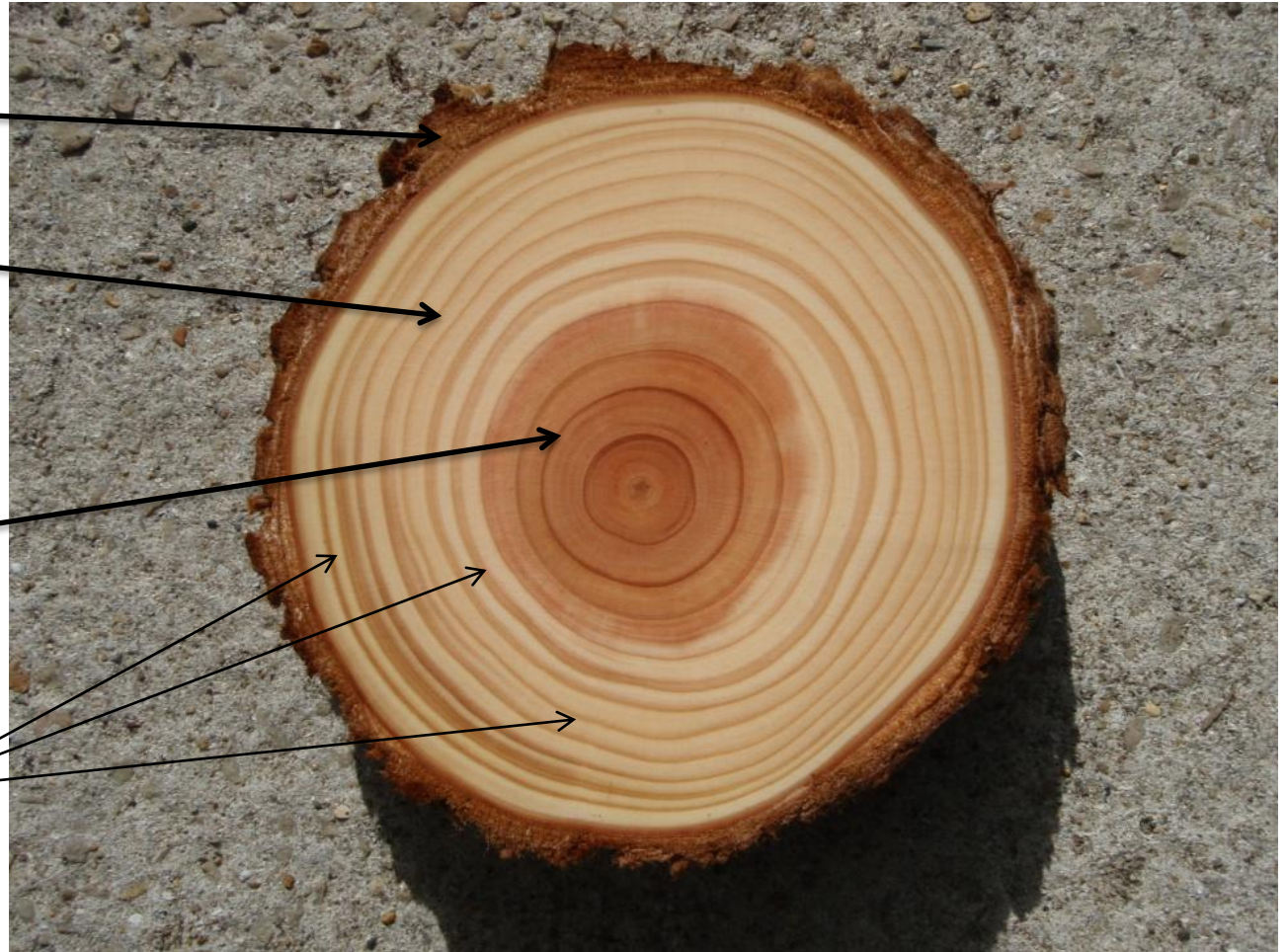
Main parts of a woody axis

Bark

Sapwood

Heartwood

Annual
rings

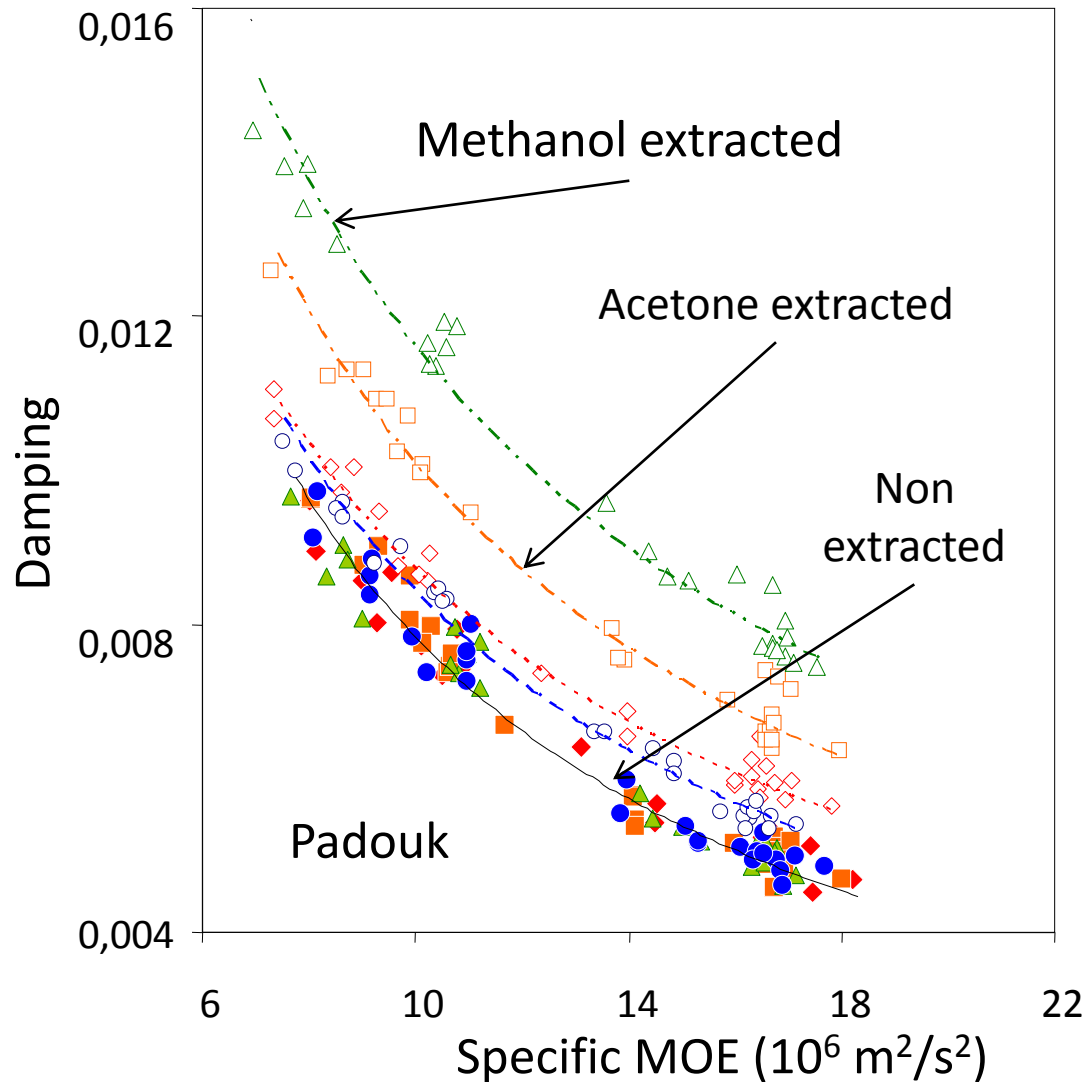


Heartwood: programmed death of xylem



Heartwood
Small molecules: extractives, are synthesized during death of parenchyma cells and embedded inside cell walls in order to protect interior xylem

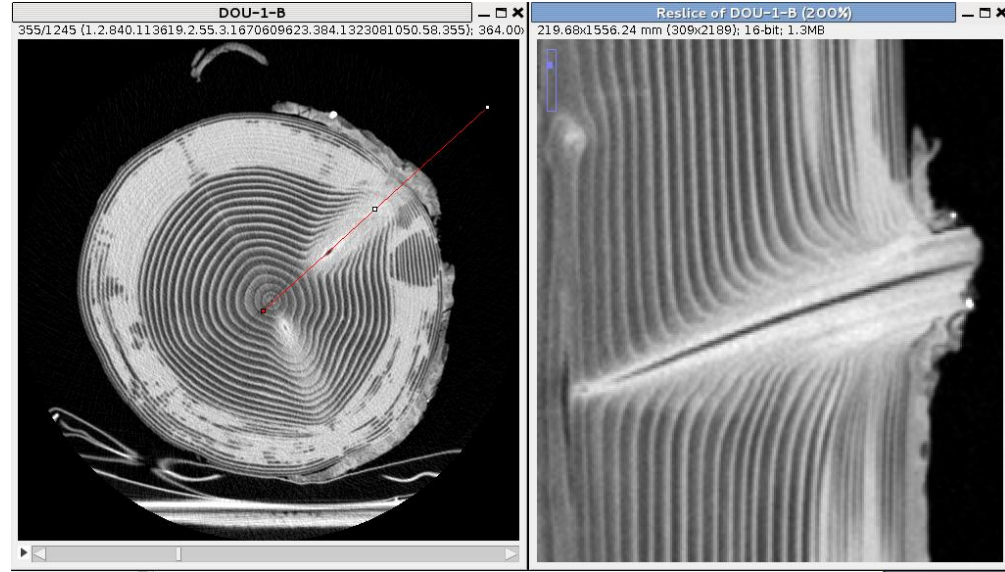
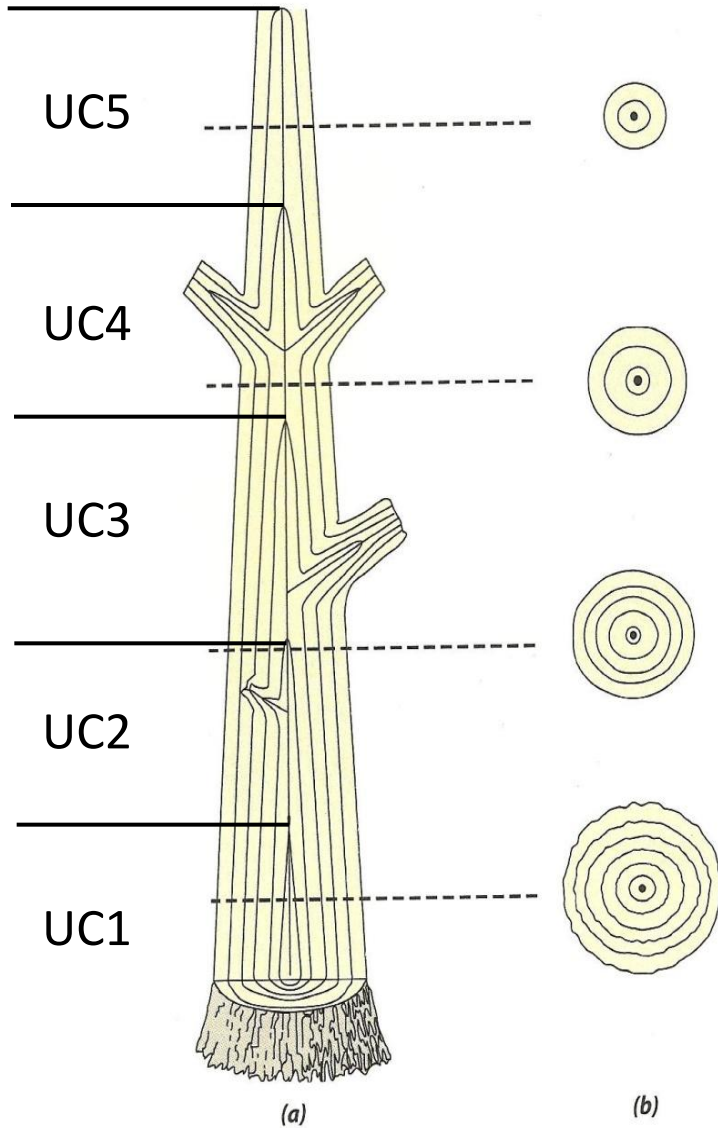
Extractives have a strong impact on xylem damping



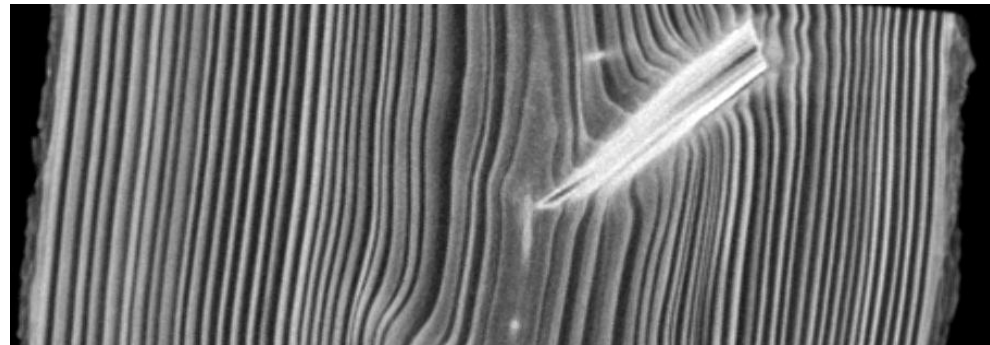
Very weak damping of Padouk Xylem is linked to it's extractives.

Padouk like woods are interesting for xylophone making

3D piling of xylem rings



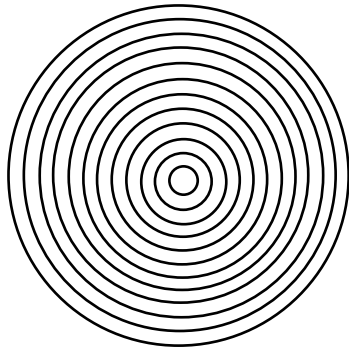
Branch junction



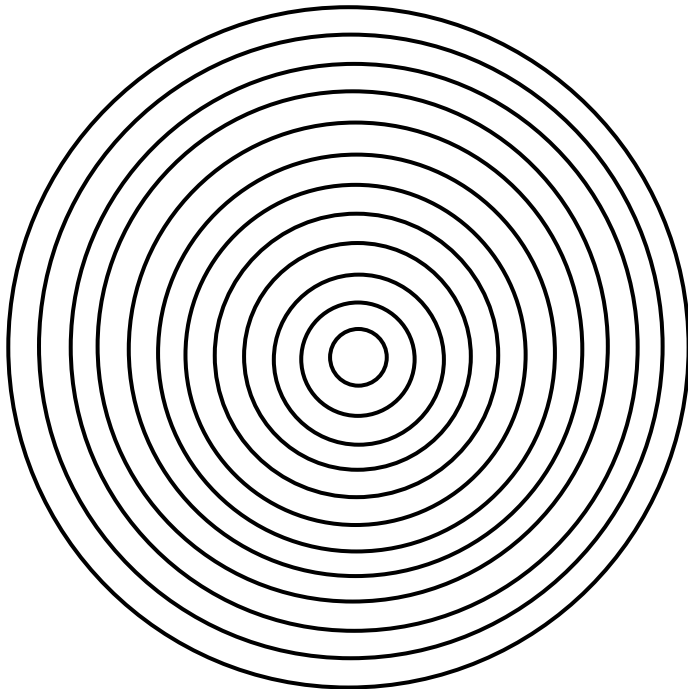
Embedded branch

A way to read history in the xylem

Ring width and axis inertia

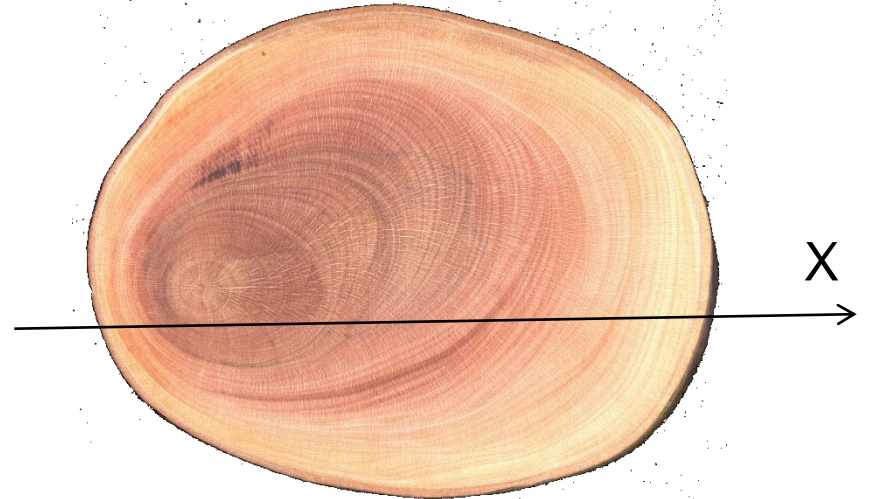


Ring width: 1mm/year



Ring width: 2mm/year

Second moment of inertia
8 times greater for faster growth



Inertia 2 times greater in X direction



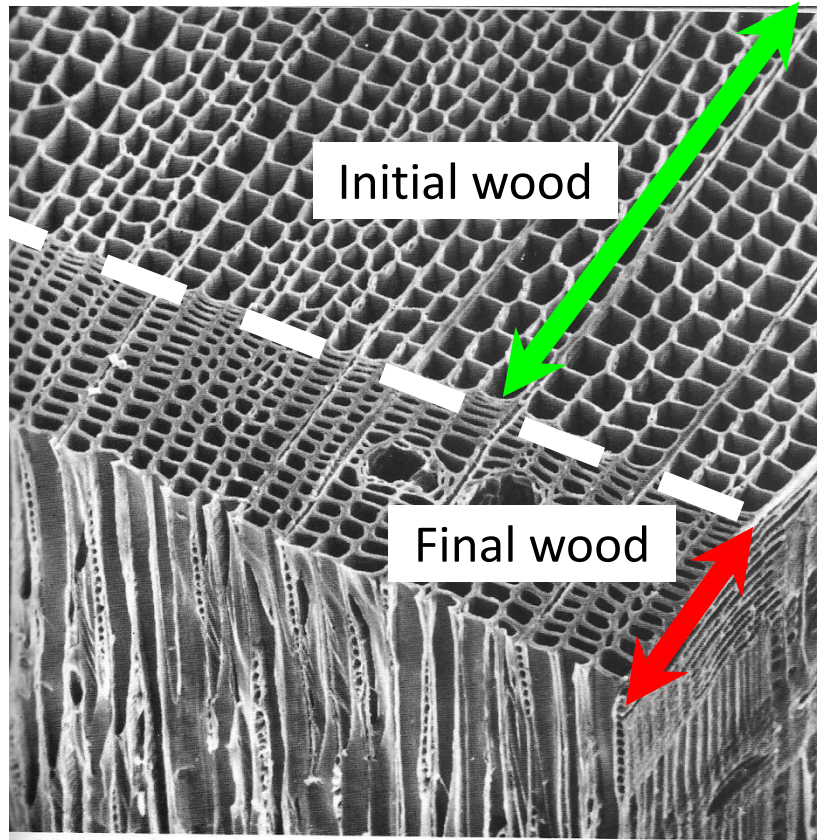
Another way to increase inertia
at constant matter volume

Modulation of tree construction by secondary growth

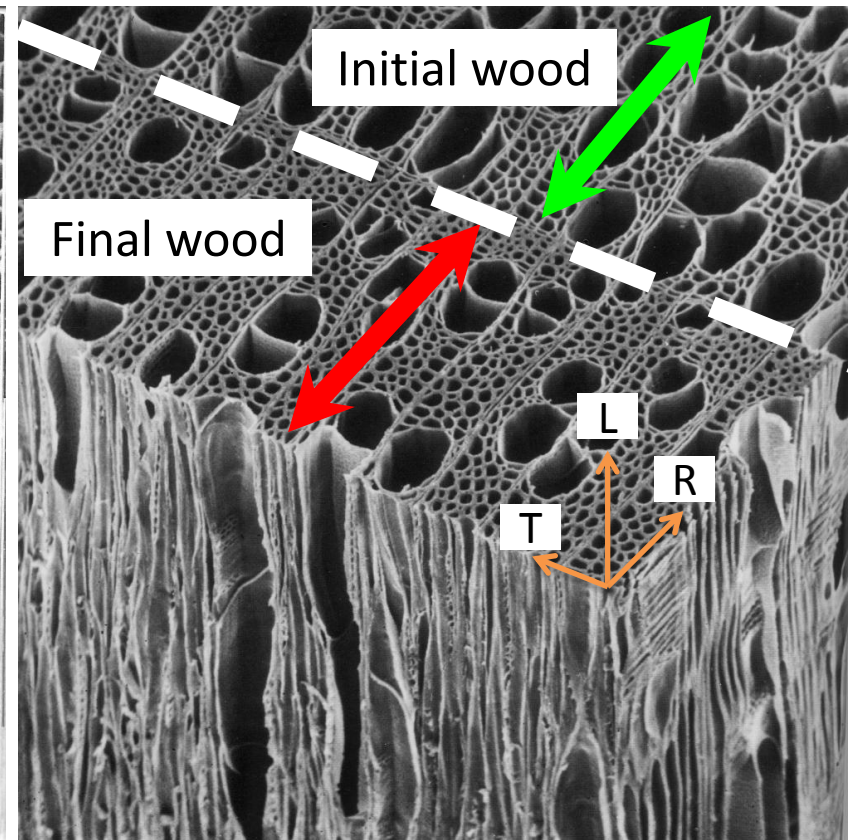
- Axes volume
- Axis second moment of inertia
- Asymmetry of inertia

- Flexure structural stiffness
- Stiffness anisotropy

Xylem anatomy: an anisotropic honeycomb-like material



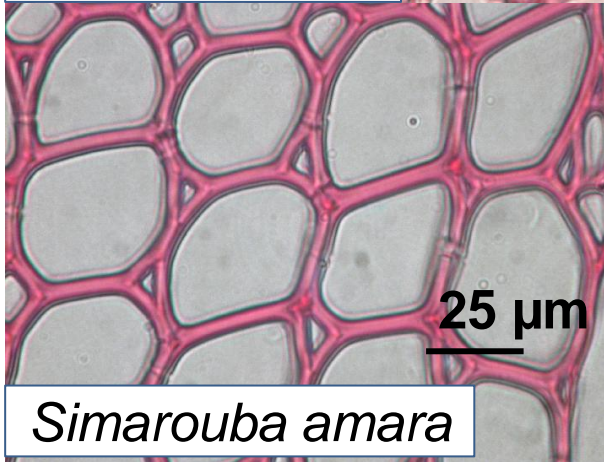
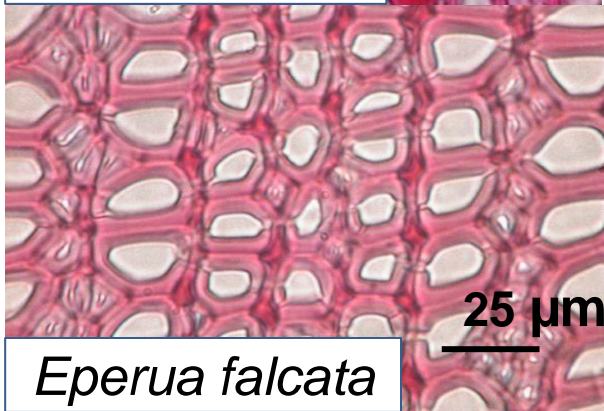
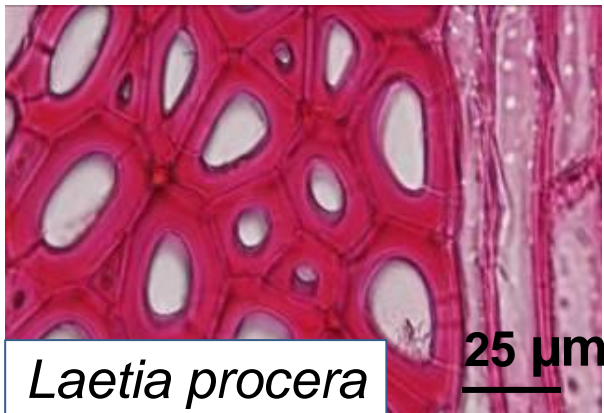
Gymnosperm wood



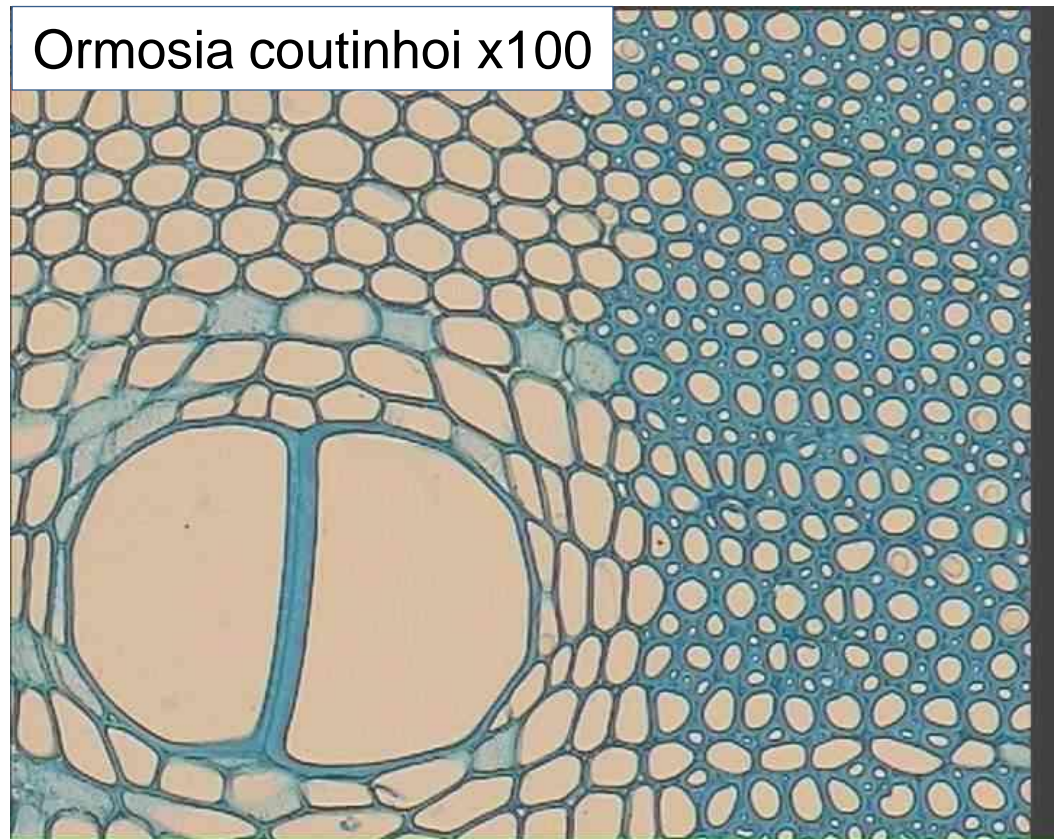
Angiosperm wood

Xylem is made of numerous different cell types which wall thickness can vary strongly

Different wall thicknesses mean different xylem densities

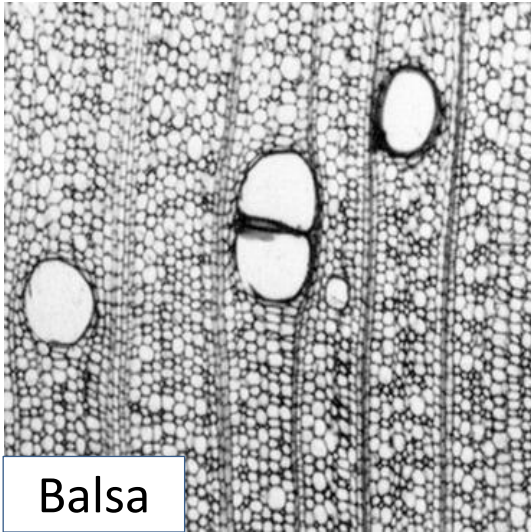


Between species



Inside a single tree

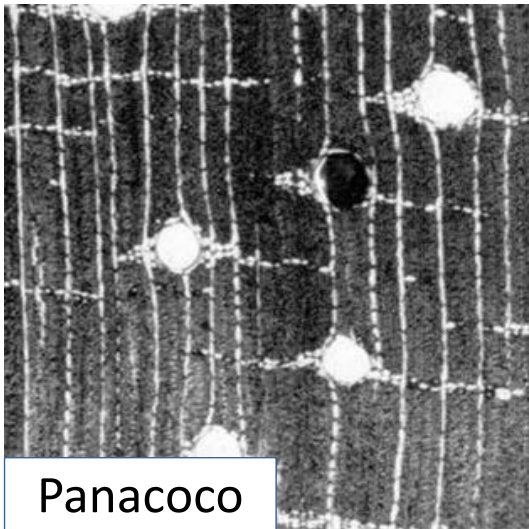
For honeycomb-like material
mechanical strength depends
on density



Balsa

Density = 150 kg/m^3

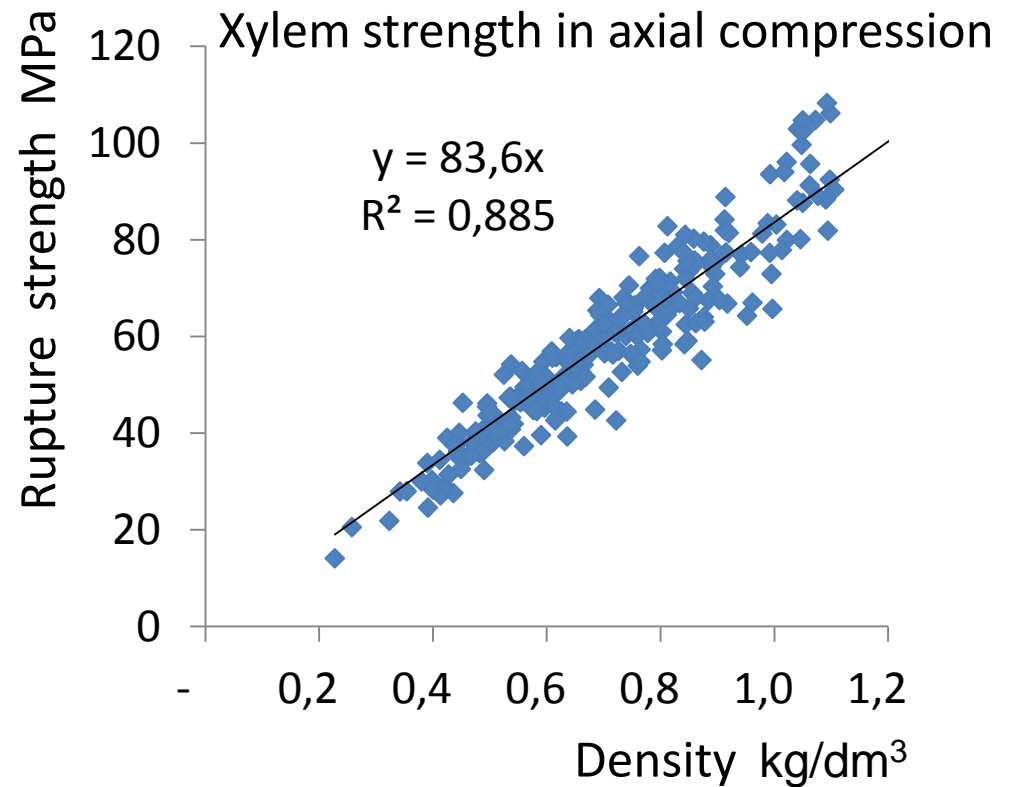
Porosity = 90%



Panacoco

Density = 1200 kg/m^3

Porosity = 20%



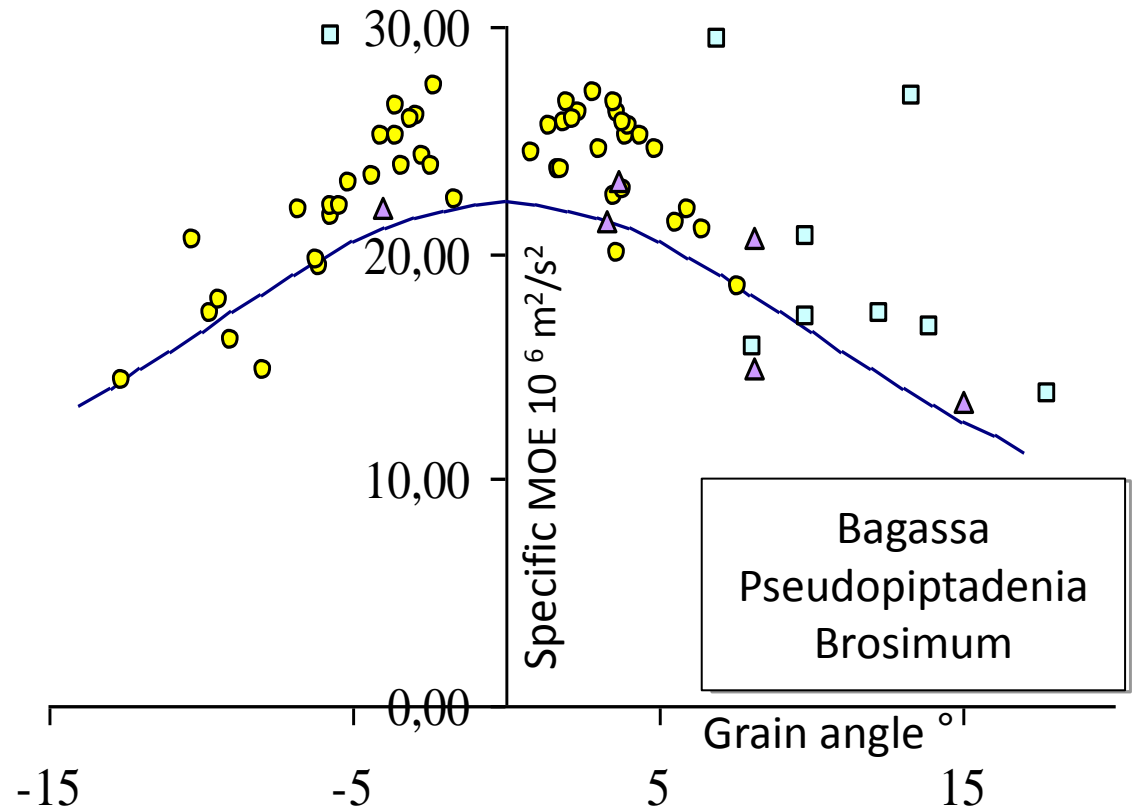
Grain angle influence on xylem stiffness



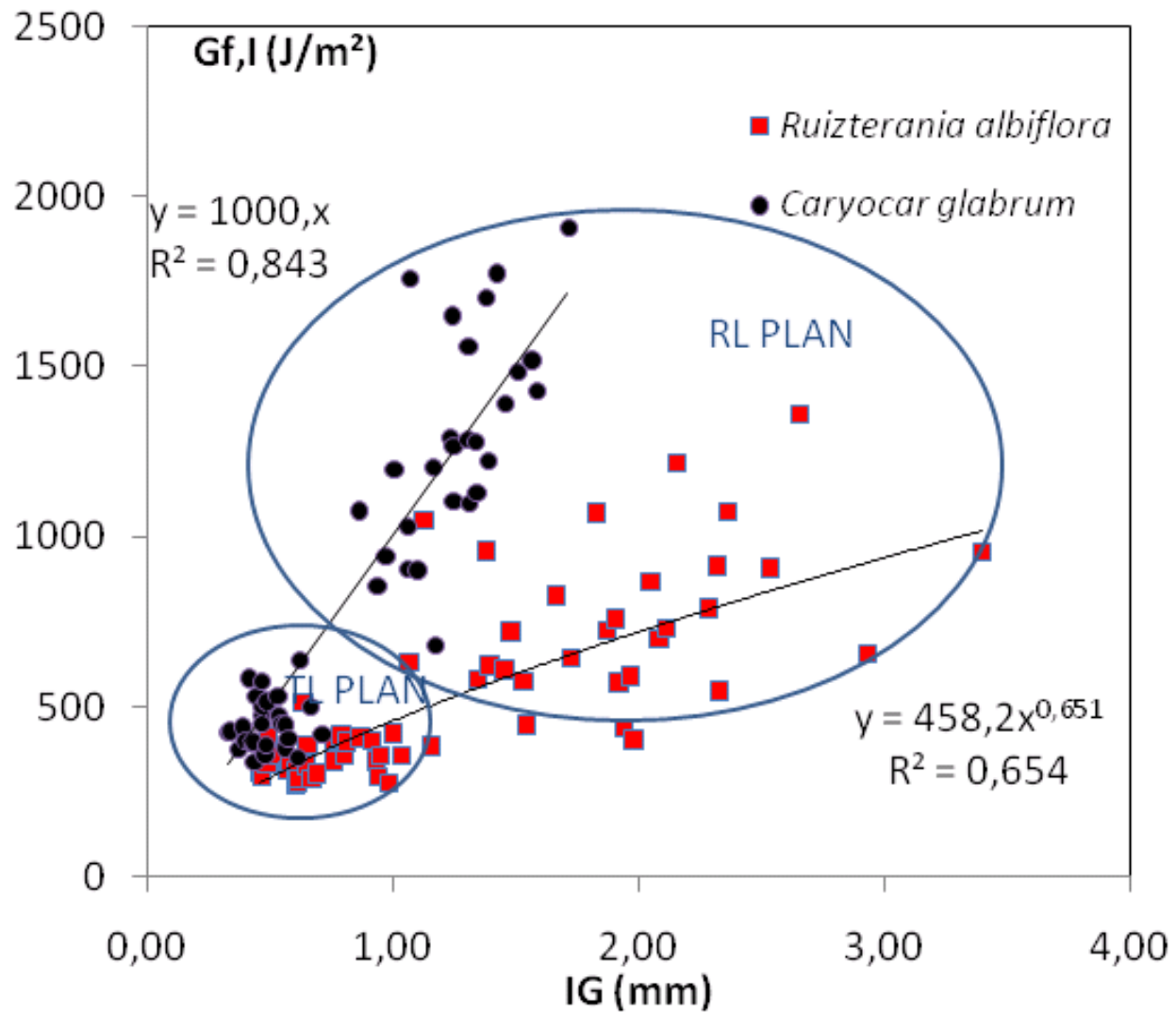
Interlocked grain



Spiral grain



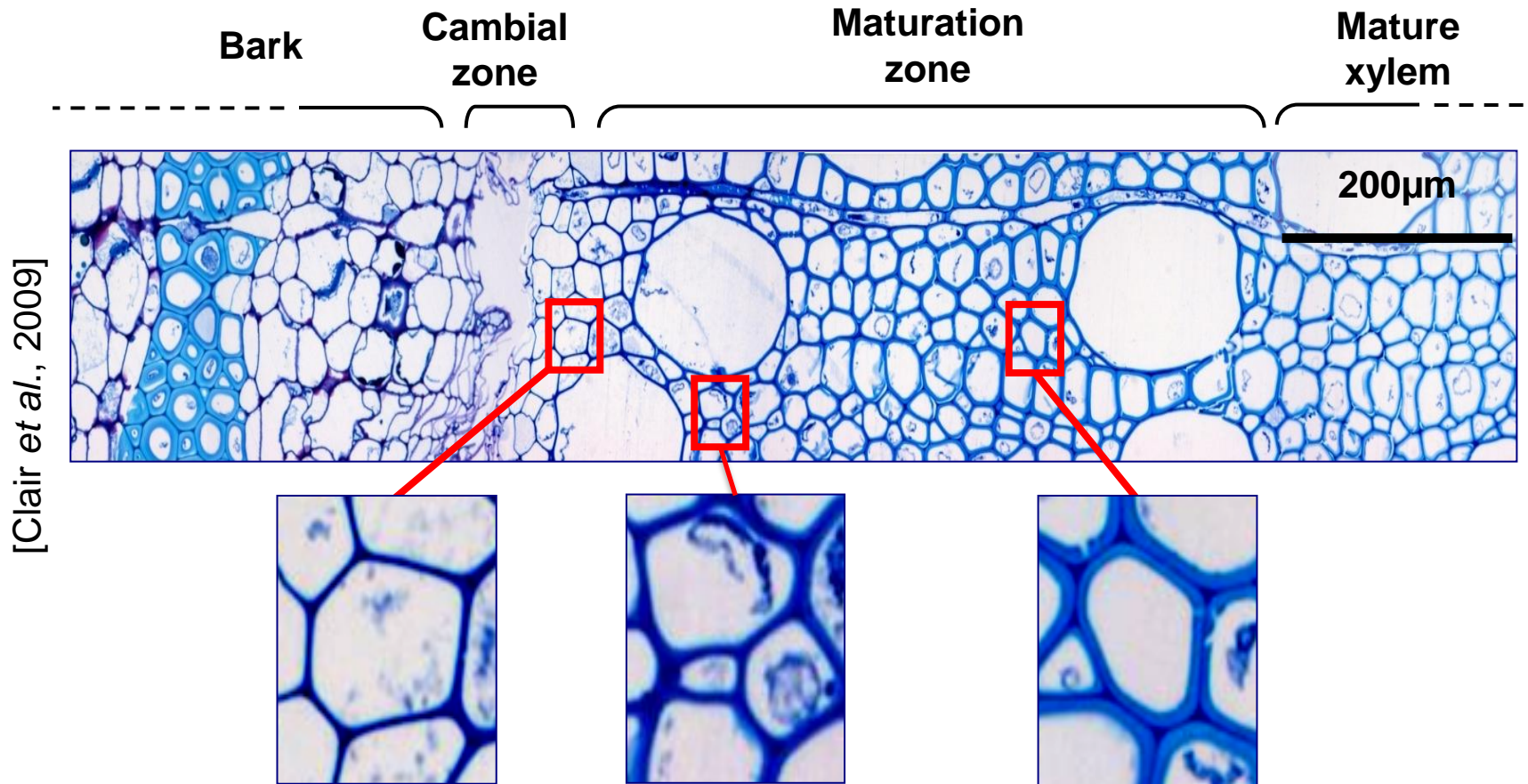
First anisotropy level of xylem



Modulation of tree construction by anatomy

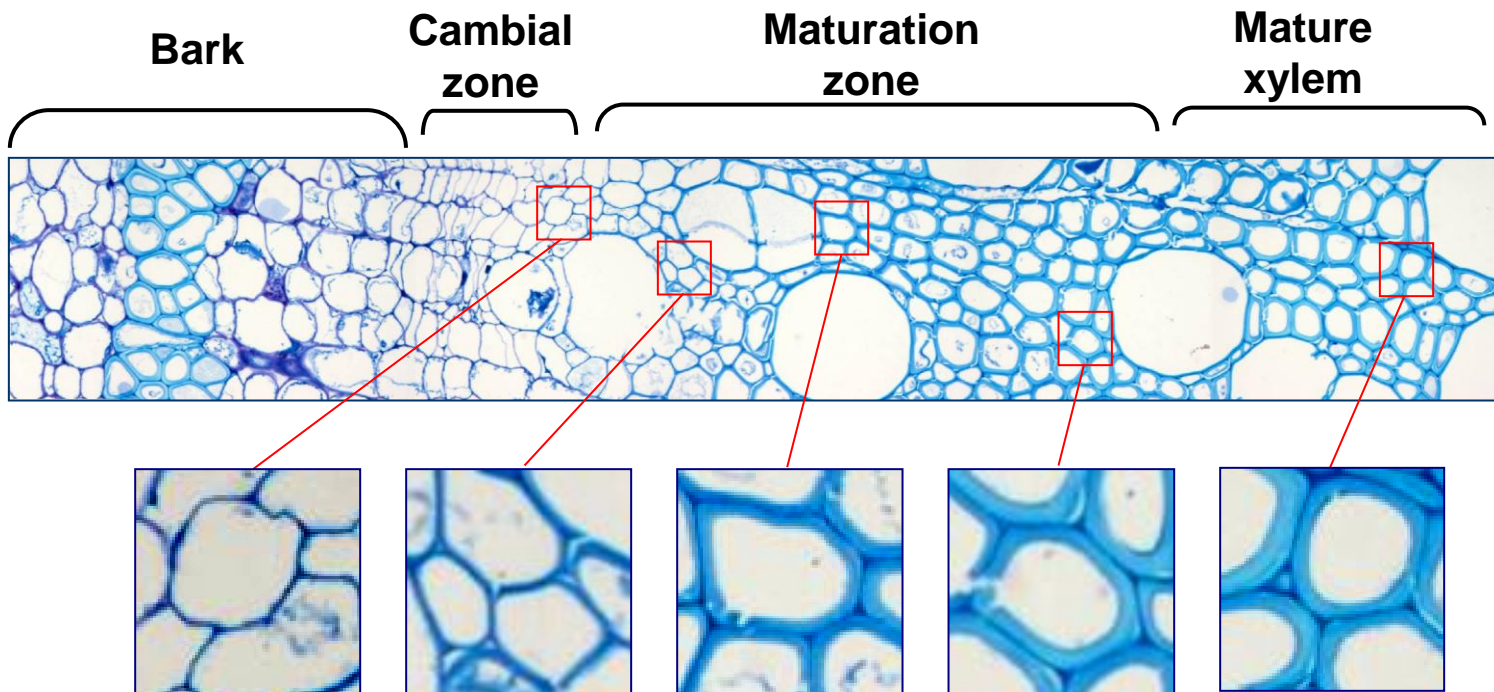
- Axes masses
- Mechanical properties of wooden material
- First anisotropy level (grain angle)

Fibre cell wall thickening (maturation process)

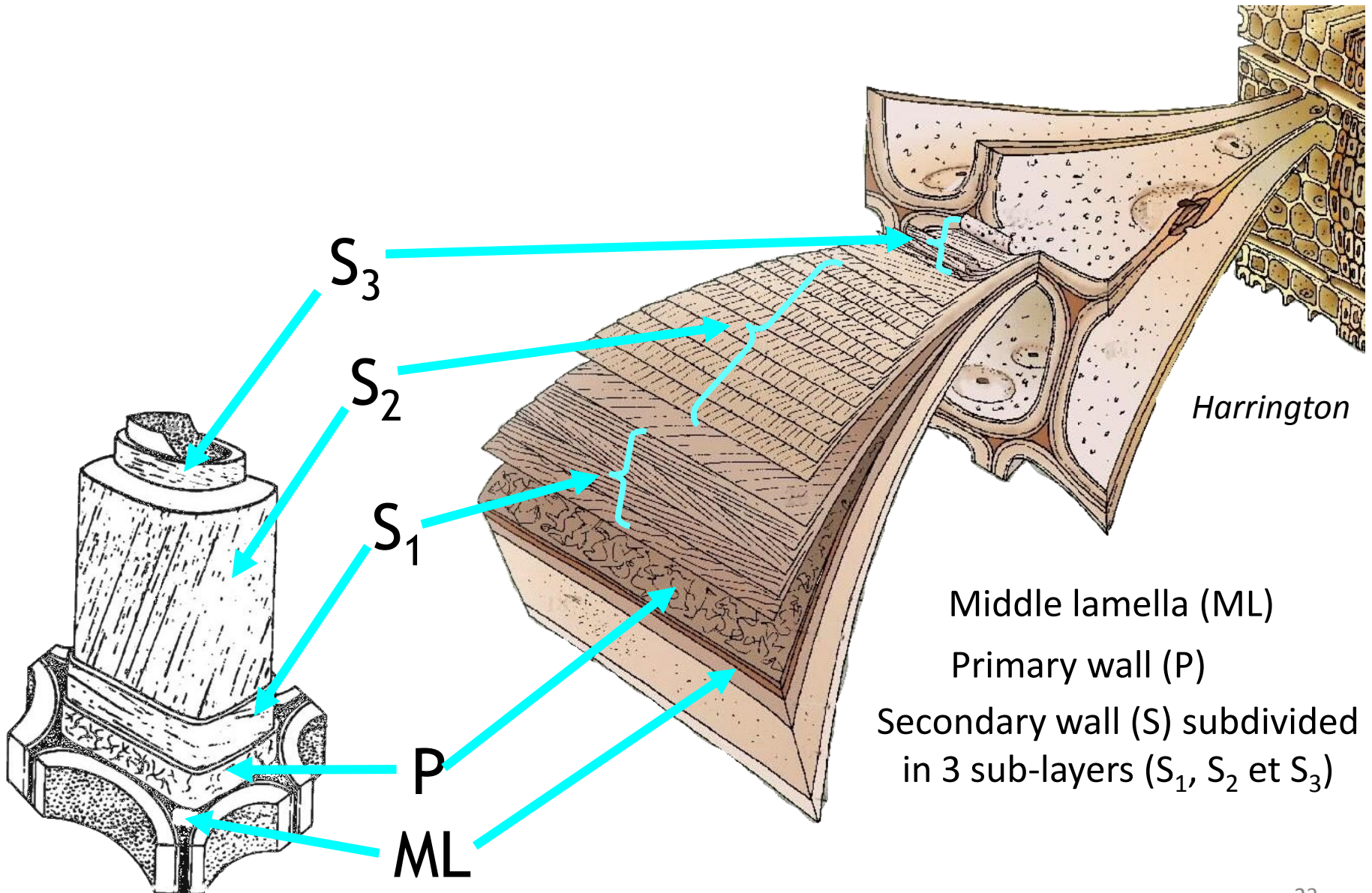


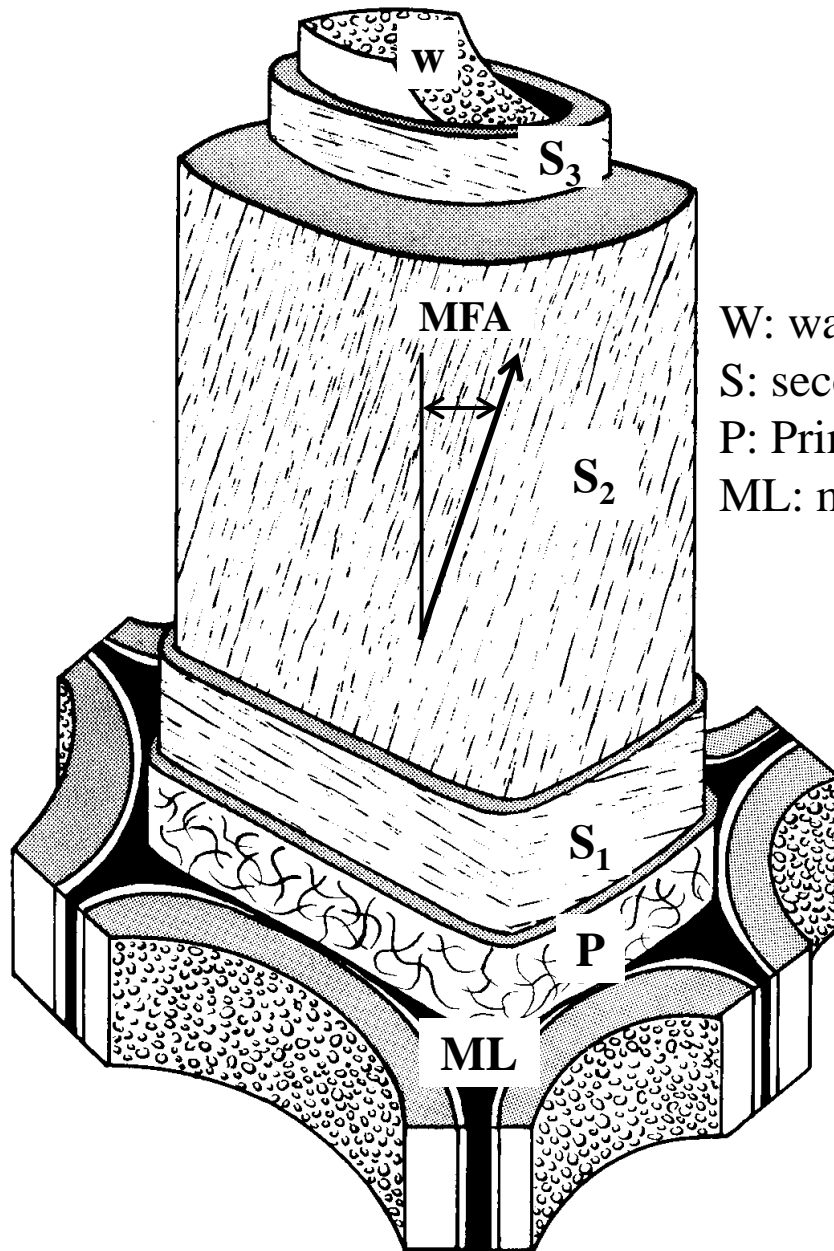
After cell division in the cambial zone cell wall thickening occurs inside the fibre until fibre death

[Clair
et al.,
2011]



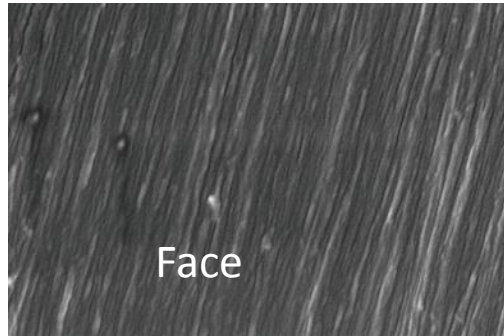
Fibre cell wall ultrastructure





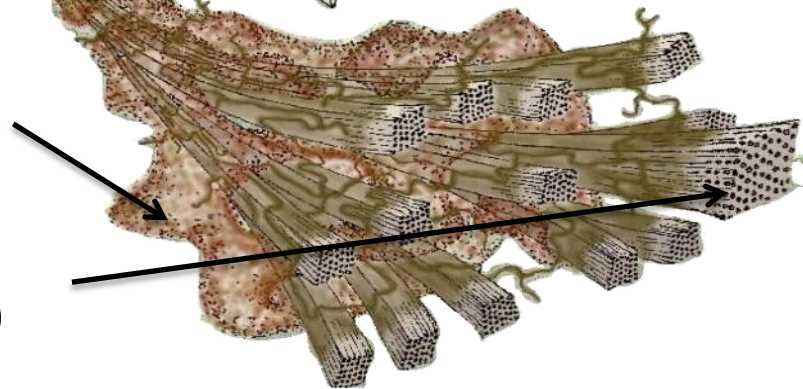
W: warty layer
S: secondary wall
P: Primary wall
ML: middle lamella

Each layer is a fibre composite

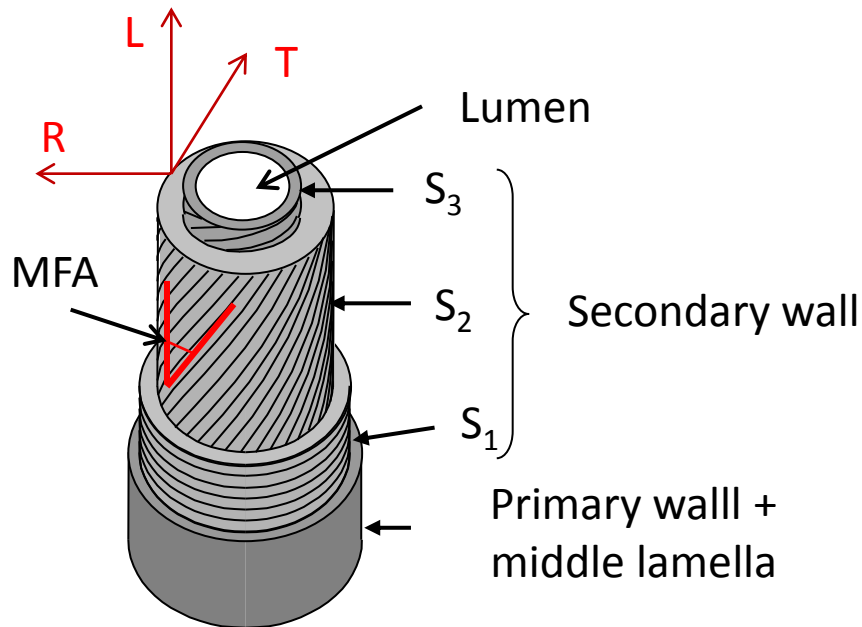


Lignin + hemicellulose matrix

Cellulose nano-fibre aggregates (25nm width)

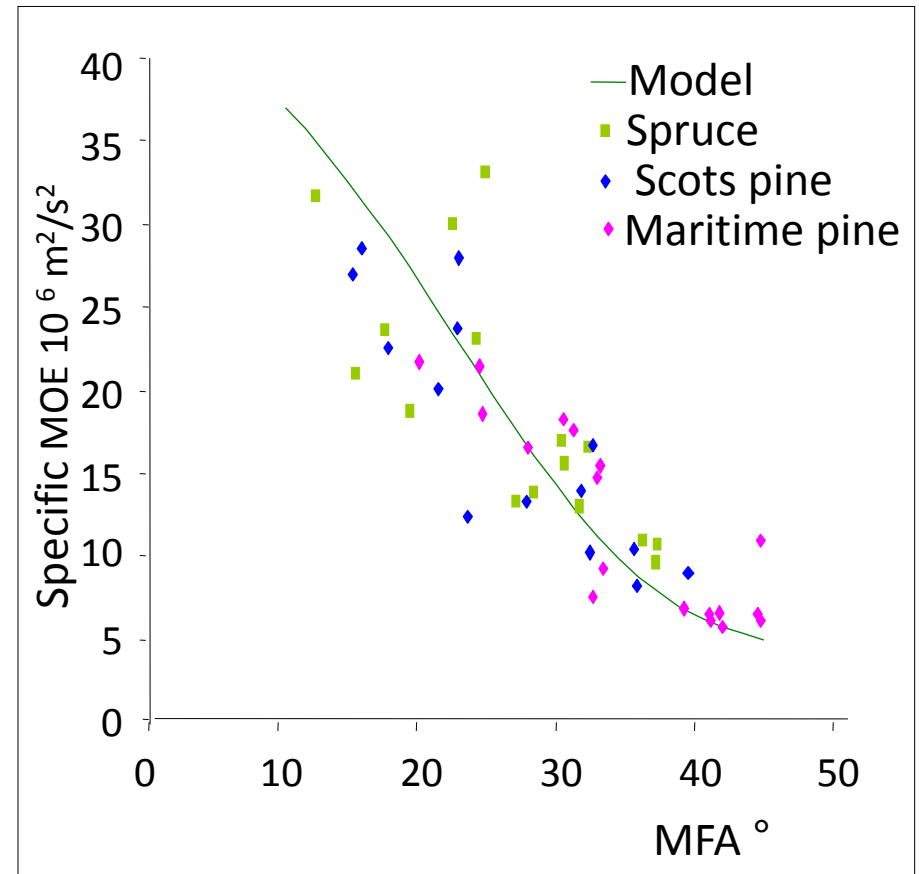


S2 microfibril angle (MFA) is a key factor for elastic properties of cell wall



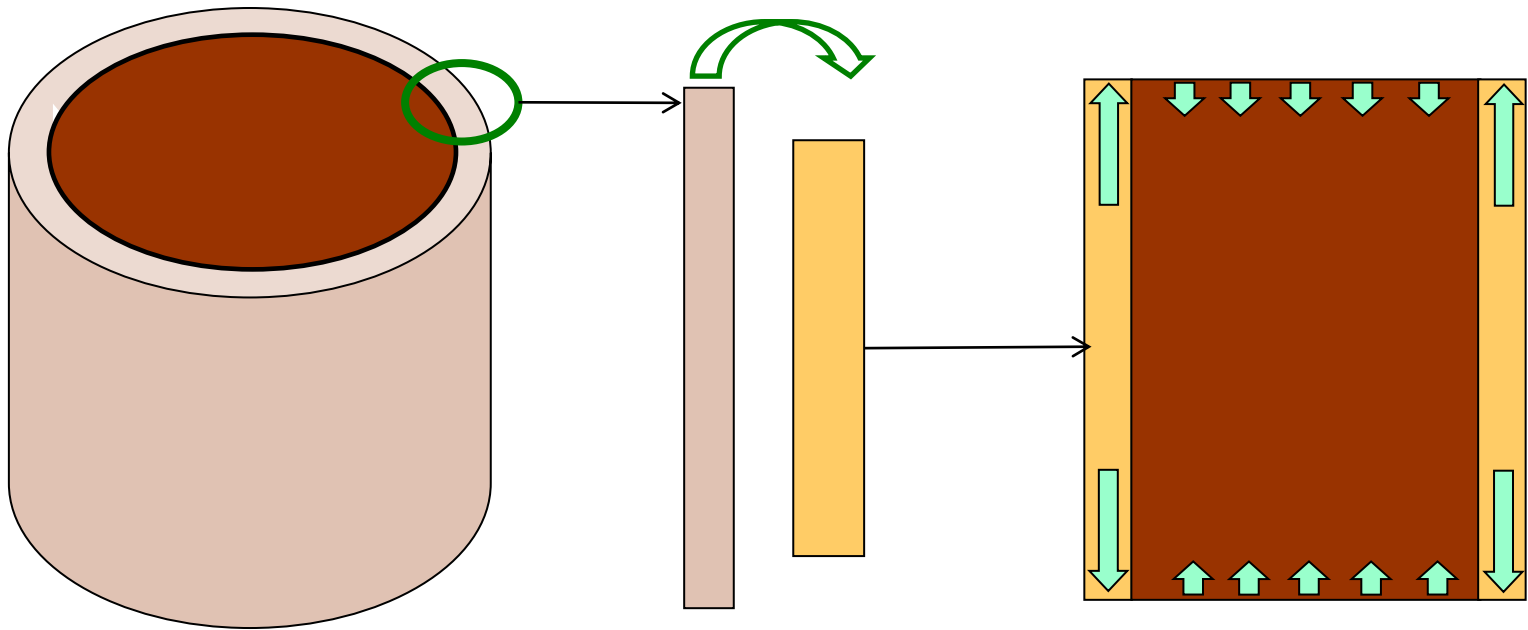
Fibre cell wall composition
S₂ layer is the thickest one

Second anisotropy level of xylem



Specific MOE = MOE / Density

Fibre maturation process generates forces inside an axis

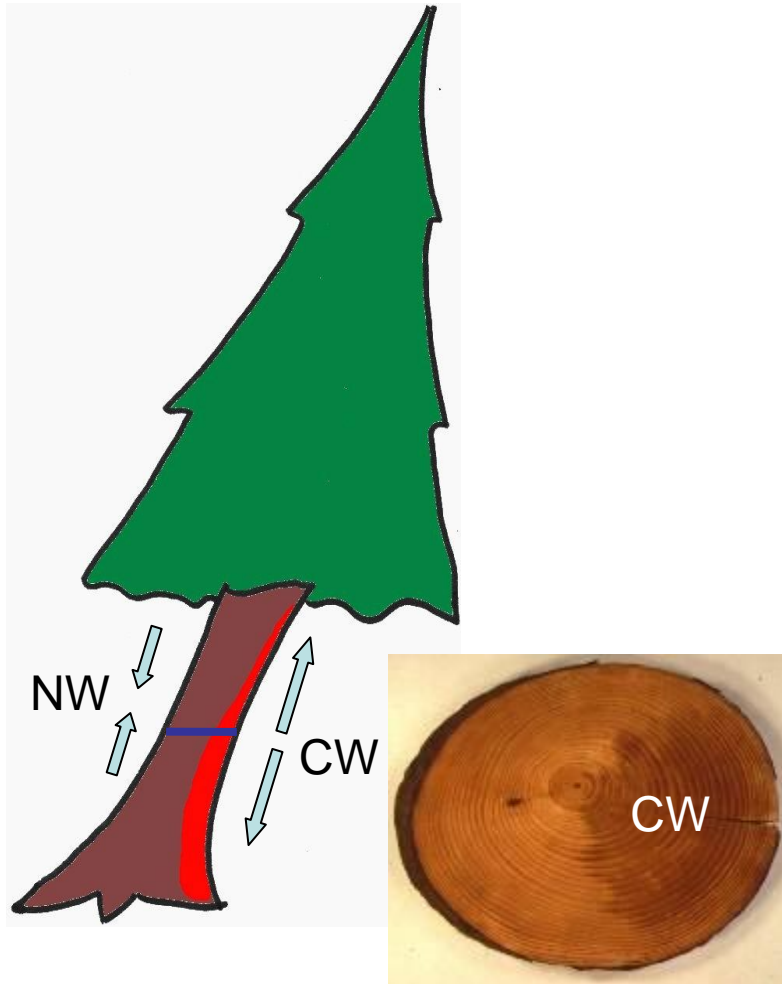


Step 1 Cell division creates a very soft new xylem layer

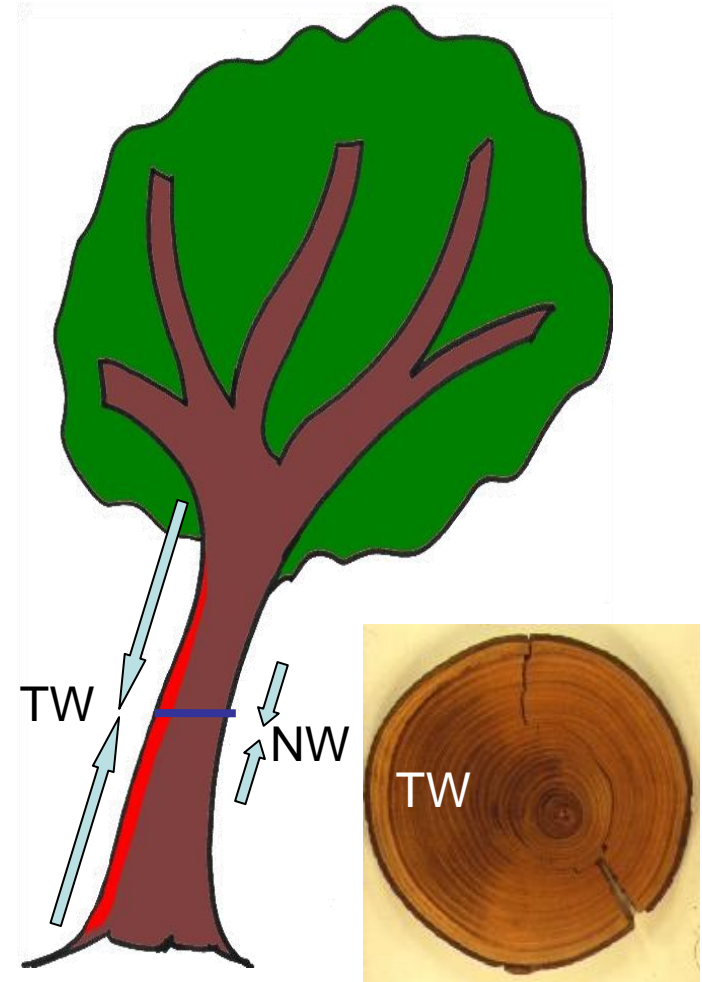
Step 2 Maturation of fibres induces layer shrinkage (*maturation strain*) in L direction while it stiffens

Step 3 Tensile forces created in the new layer are equilibrated by compression in the core xylem

Forces can be very asymmetric

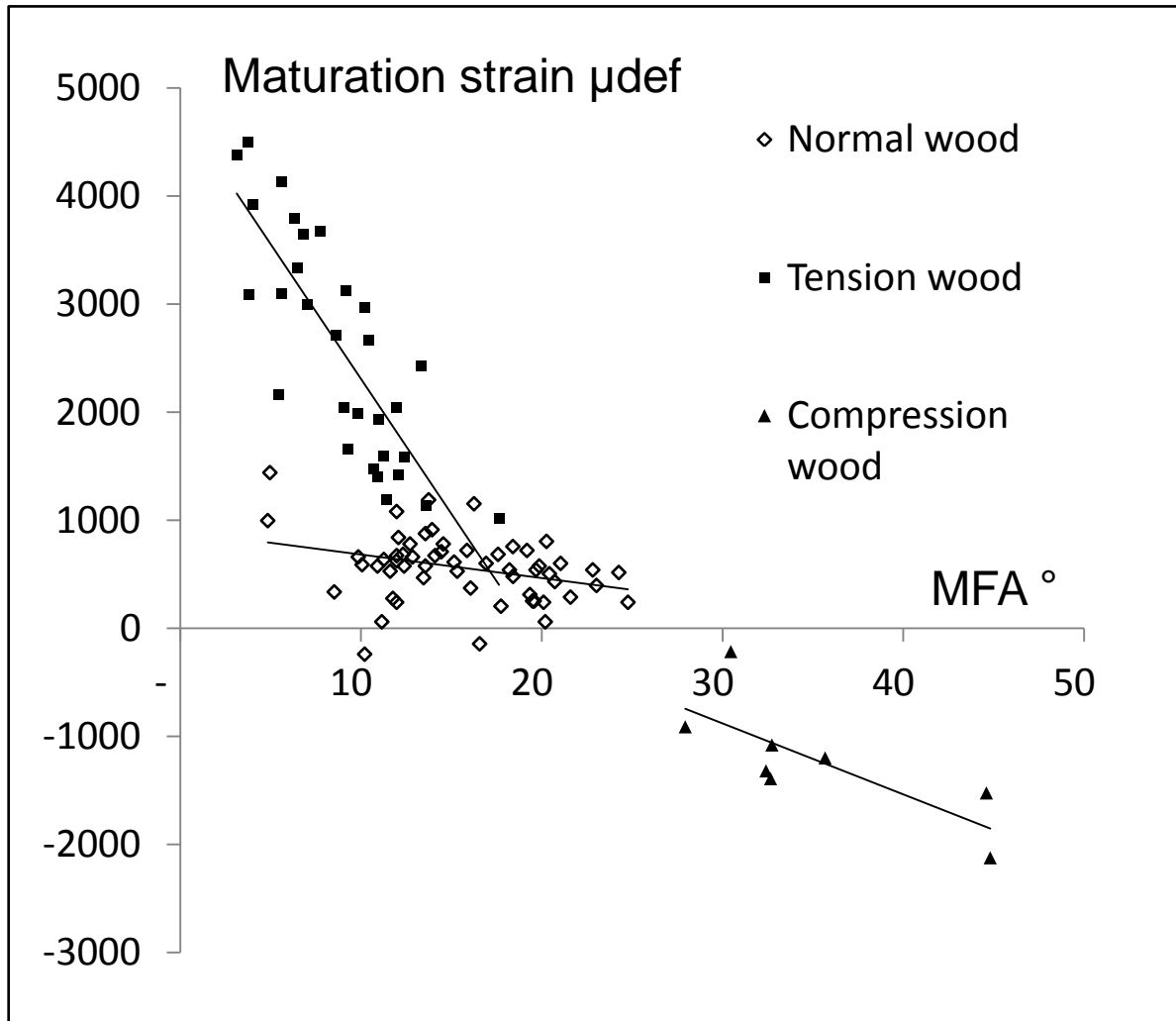


Compression wood in gymnosperms produces compressive forces

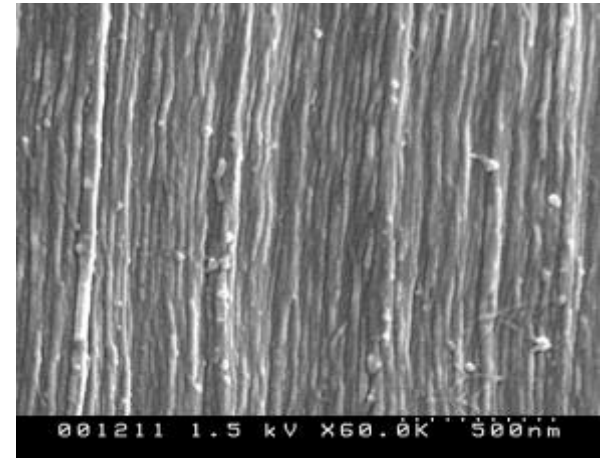


Tension wood in angiosperms produces tensile forces

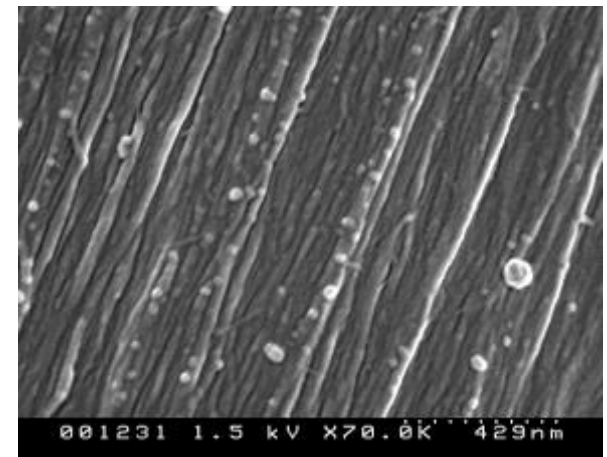
Maturation strain is depending on MFA



Data from 3 angiosperms and 3 gymnosperms



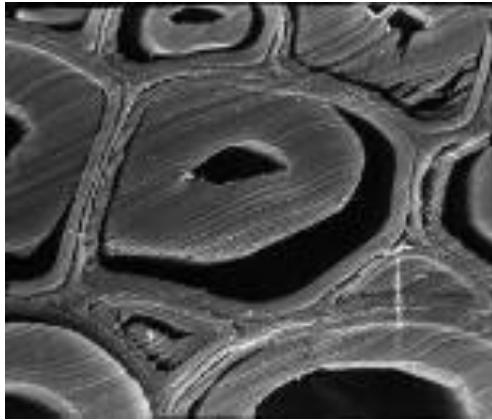
MFA = 4°



MFA = 24°

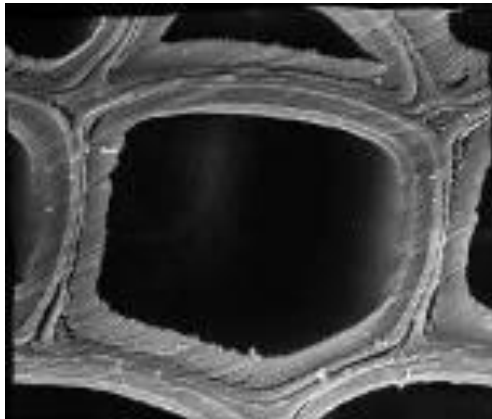
Simarouba

Chemical composition of structural polymers is strongly different for reaction woods



Maturation strain
 $1200/ 5000 \mu\text{def}$

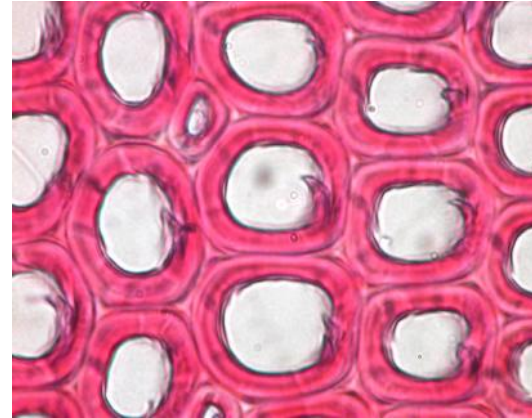
Tension wood



Maturation strain
 $-200/ 1200 \mu\text{def}$

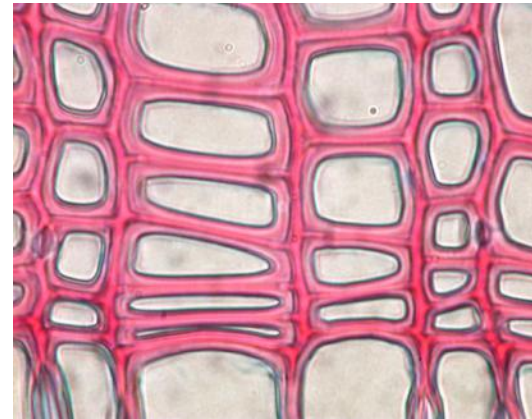
Normal wood

Angiosperms



Maturation strain
 $-2500/ -200 \mu\text{def}$

Compression wood



Maturation strain
 $-200/ 1200 \mu\text{def}$

Normal wood

Gymnosperms

Modulation of tree construction by maturation process

- Second anisotropy level: flexibility
- Level an assymetry of maturation forces

Tree deconstruction



Round-wood



Beams



Boards



Veneers

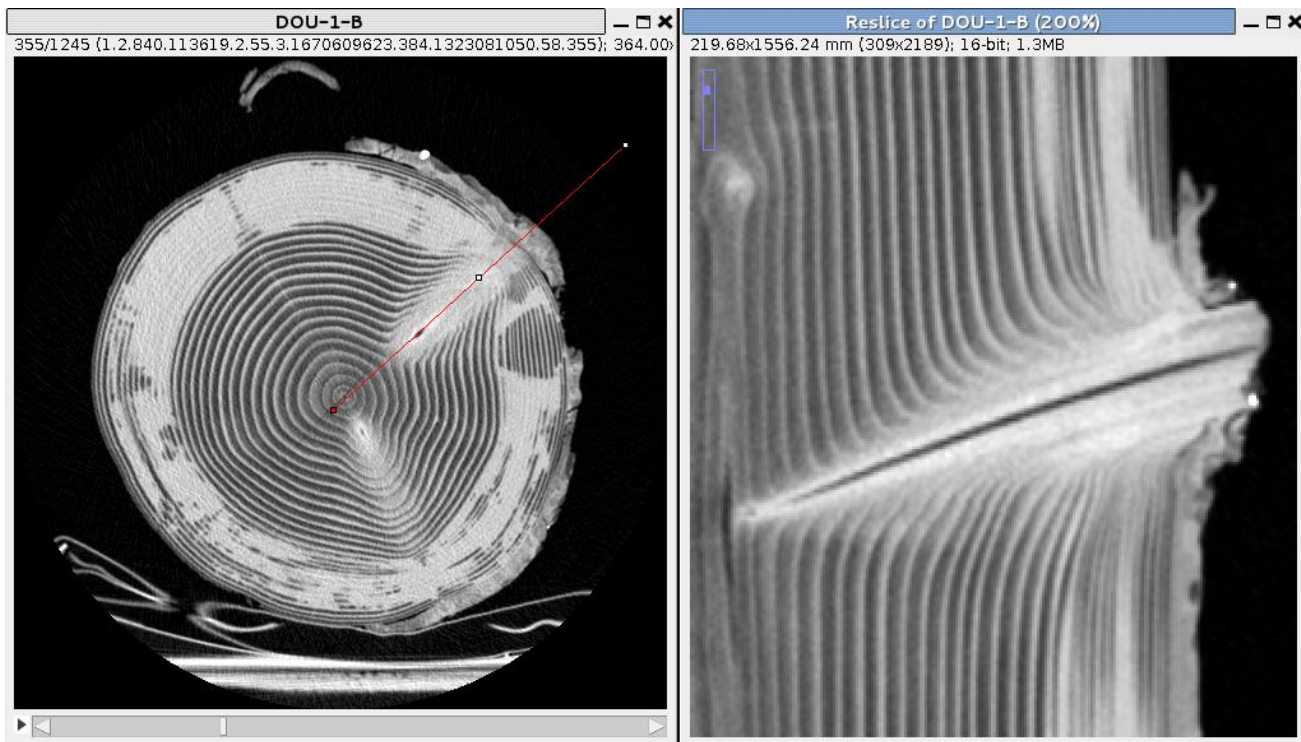


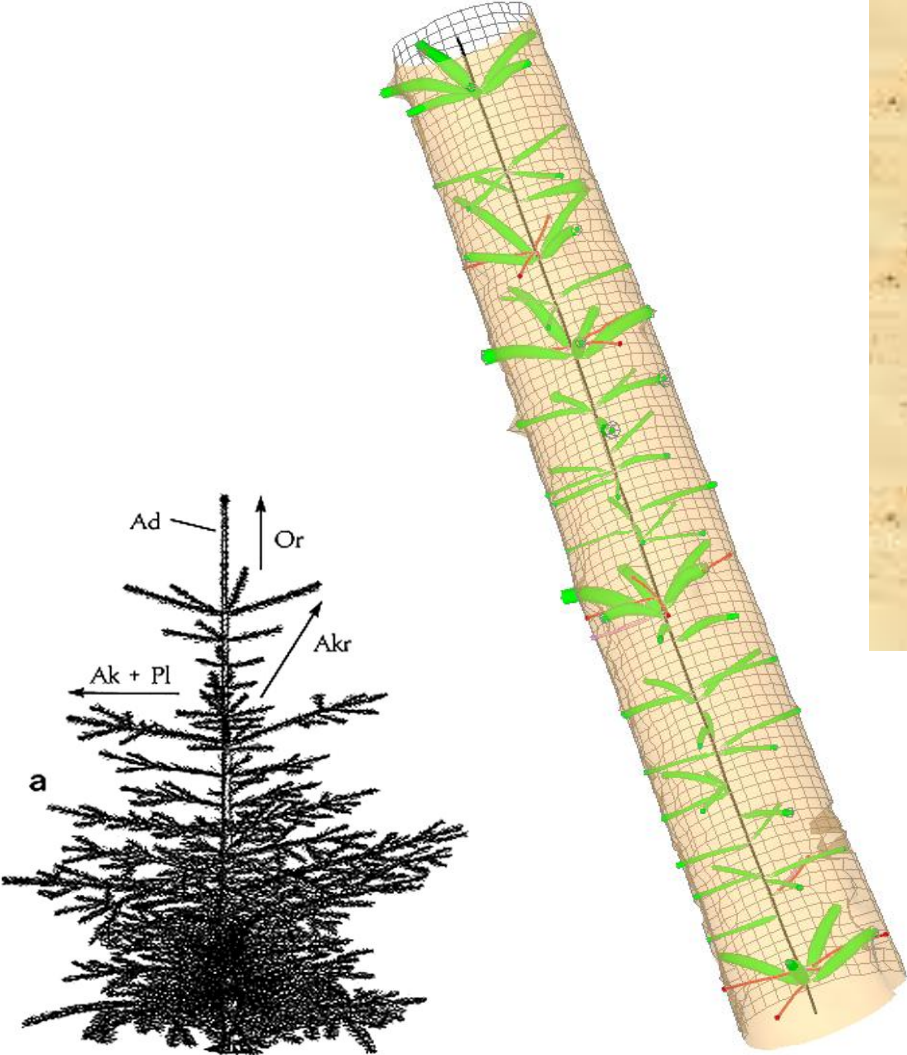
Chips



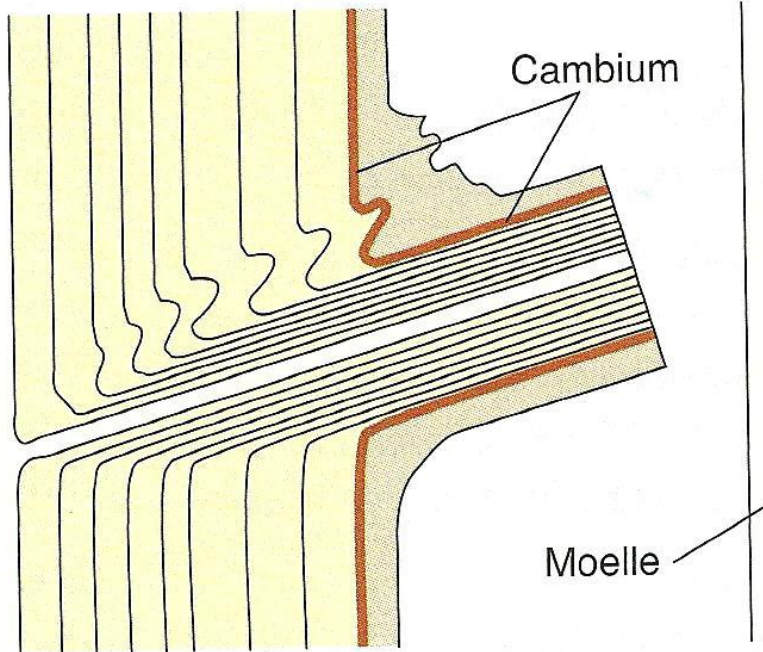
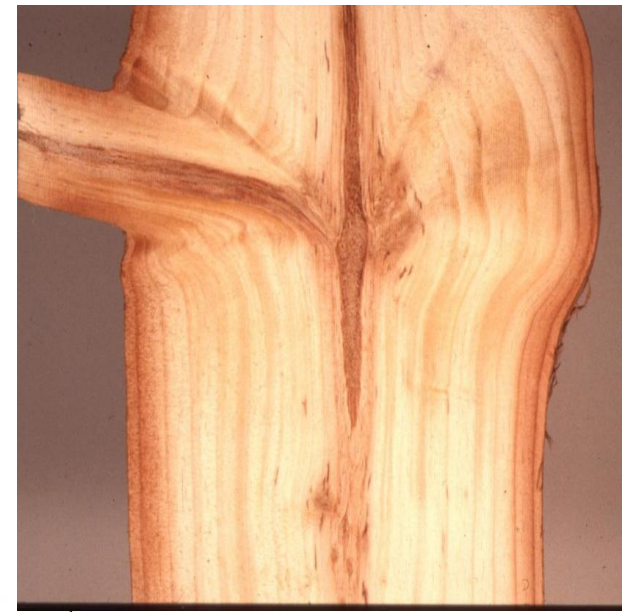
Fibres

***Le bois de l'industriel, de l'architecte, de l'artisan ou du particulier
c'est le résultat de la déconstruction de l'arbre***

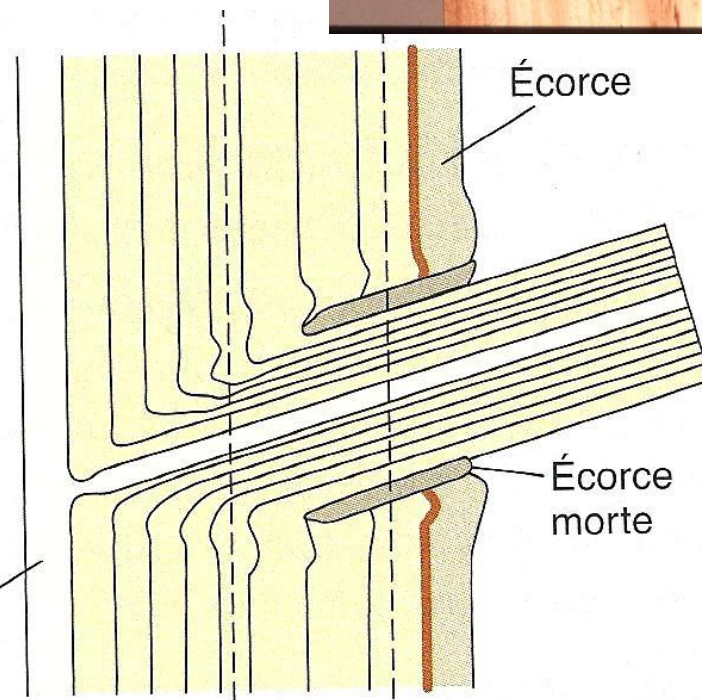




Encastrement des axes



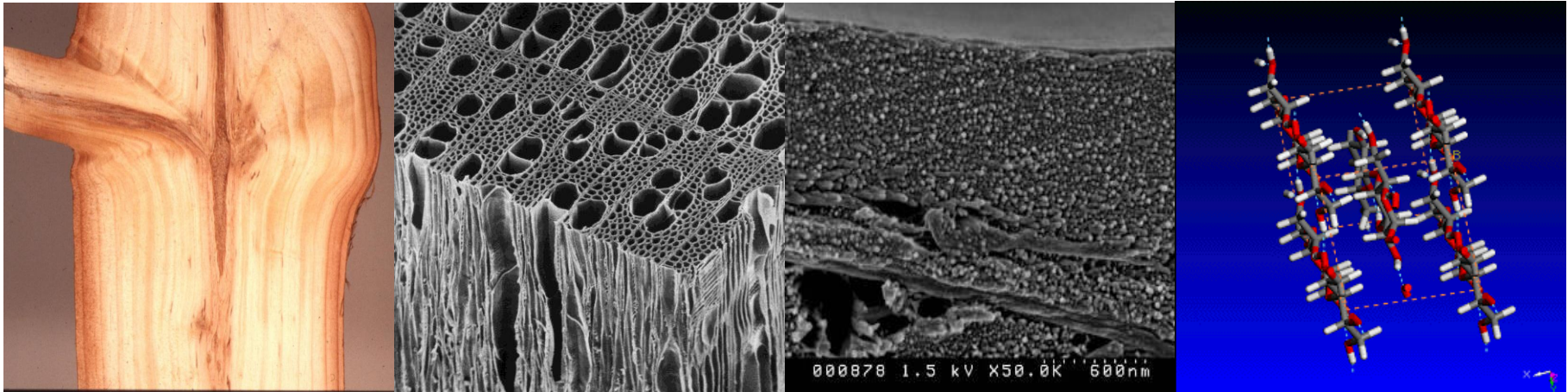
Branche vivante



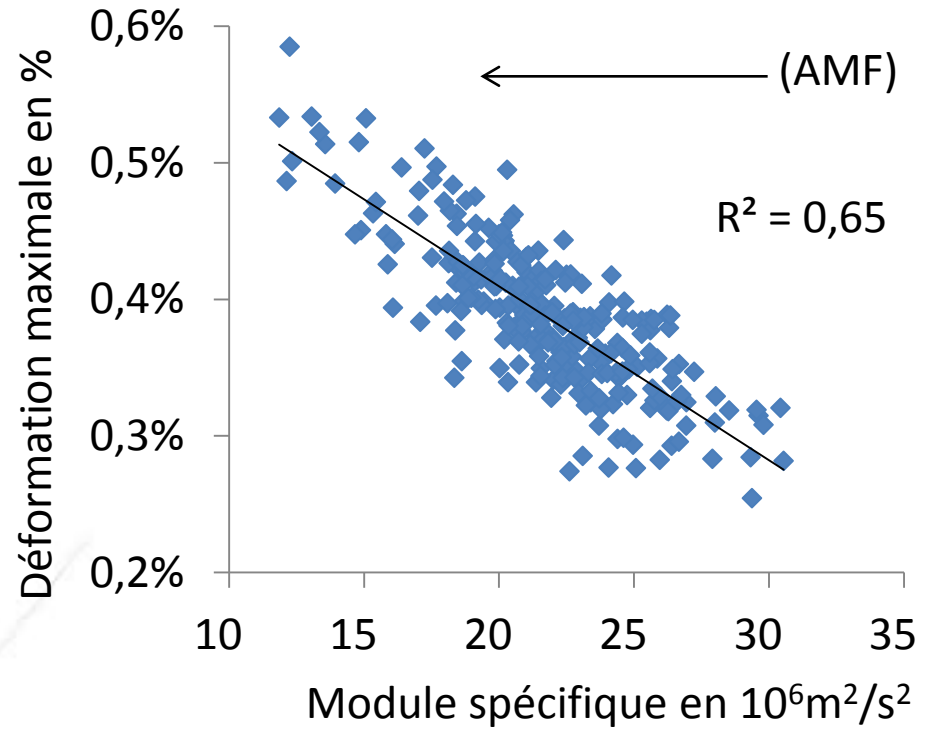
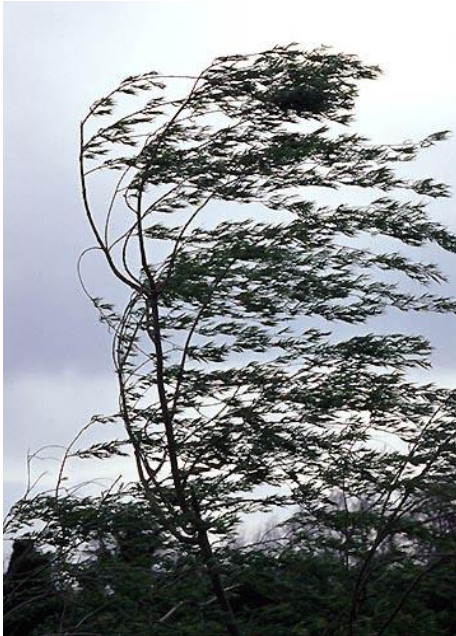
Branche morte

Les échelles de description des bois

- Echelle macroscopique: Architecture et empilement de cernes
- Microstructure: le plan ligneux
- Ultra structure: la paroi cellulaire
- Composition chimique de la paroi: macromolécules, métabolites et minéraux

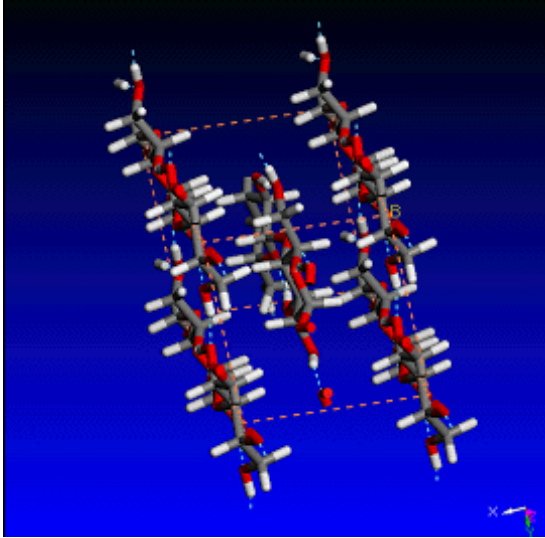


L'angle des microfibrilles facteur d'adaptation au vent

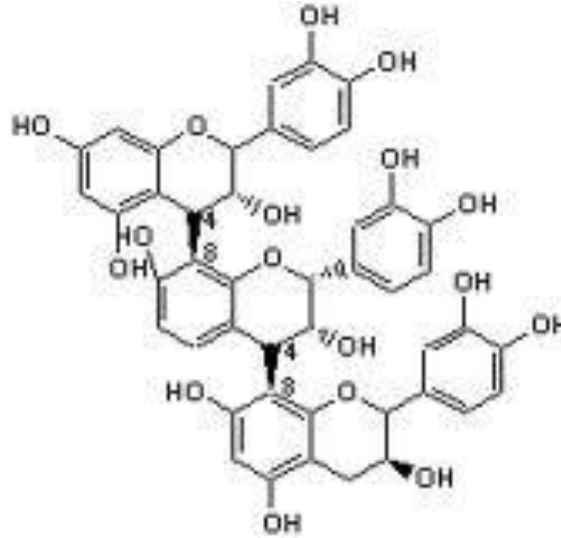


En augmentant l'AMF de 10° à 30° , on divise par 2 le module et on multiplie par 2 la déformation maximale; la flexibilité des axes ligneux est très fortement augmentée

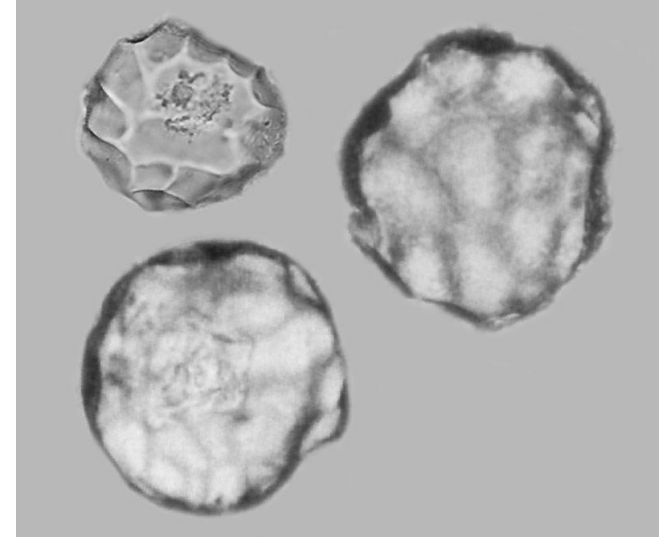
Composition chimique de la paroi: macromolécules, métabolites et minéraux



Cristal de cellulose



Tanin

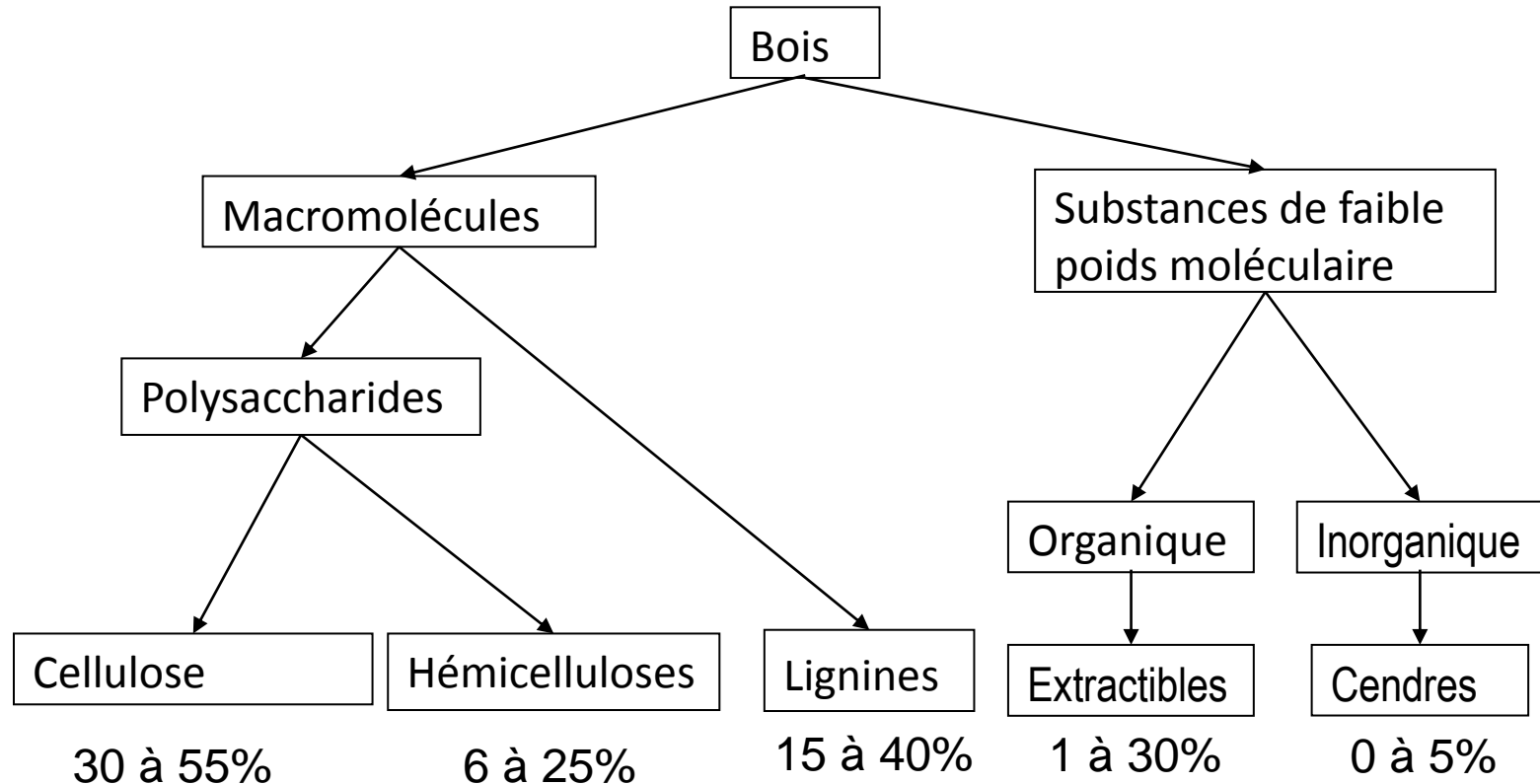


Cristaux de silice

Les outils de description:

Analyse, chromatographie (HPLC, GC/MS ...), spectroscopie (RMN, SPIR, Raman...)

Constituants chimiques du bois



La composition en extractibles est une signature chimique utile pour l'identification



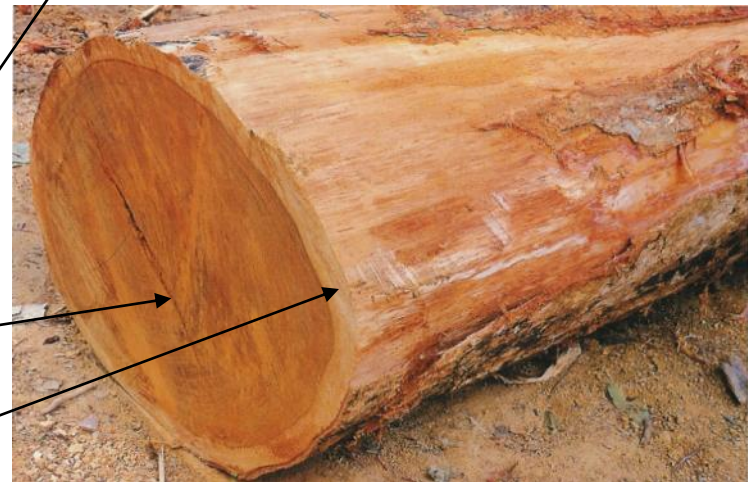
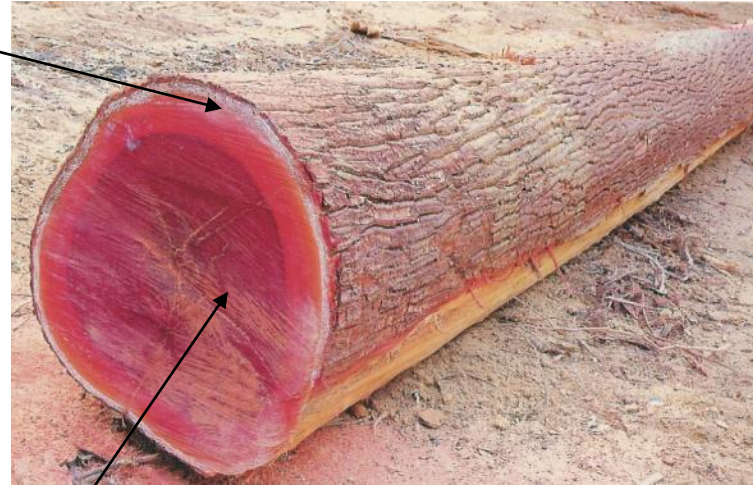
La duraminisation (*duramen* = *bois parfait*)

Aubier



Duramen

Aubier



Conclusion

- C'est la croissance du bois qui fabrique l'arbre
- Le bois de l'arbre est une arborescence avec imbrication de poutres élancées particulièrement résistantes
- Le bois de l'arbre est toujours un remarquable élément de structure
- Le bois parfait est naturellement protégé contre les dégradations biologiques
- Le bois est un éco-matériau qui stocke du carbone
- La diversité des bois est le miroir de la biodiversité et le résultat de l'adaptation de chaque arbre à son histoire

La déconstruction de l'arbre

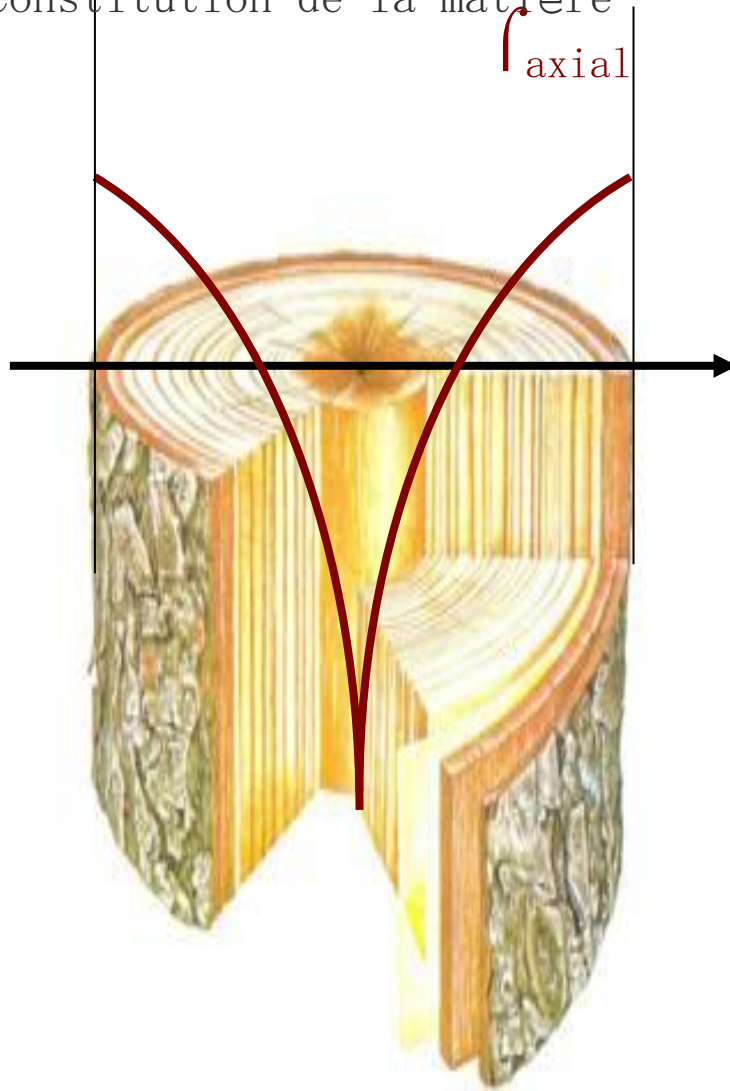
- Avant toute chose il est bon de connaître l'état mécanique de la structure à déconstruire
- La première étape est l'abattage de l'arbre et son tronçonnage en grumes et billons
- La deuxième étape est le débit en profilés
- La troisième étape est le séchage de ces éléments



La formation du bois dans l'arbre

Matériau précontraint

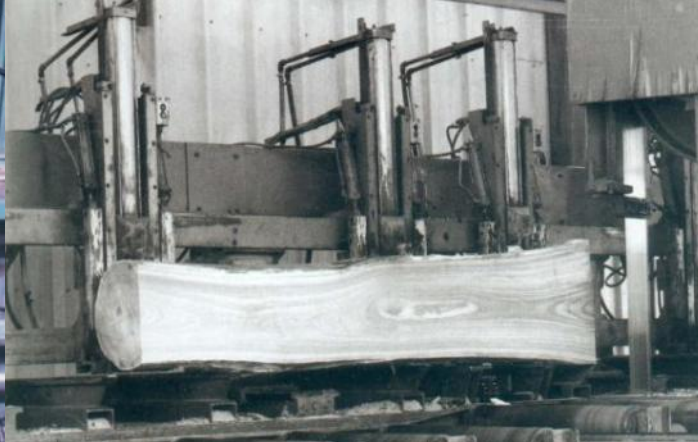
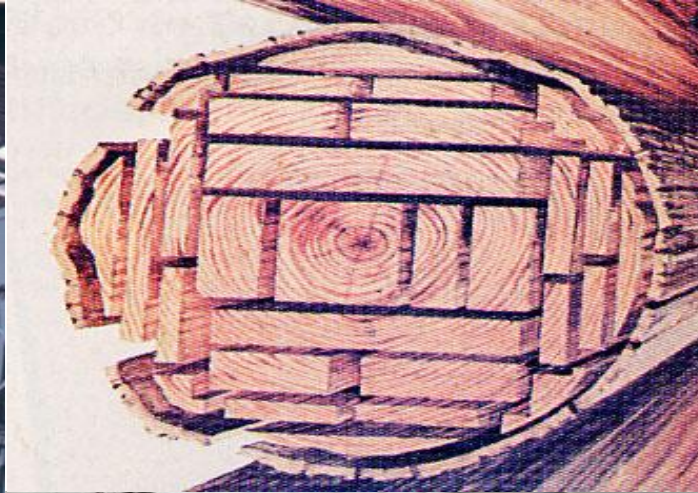
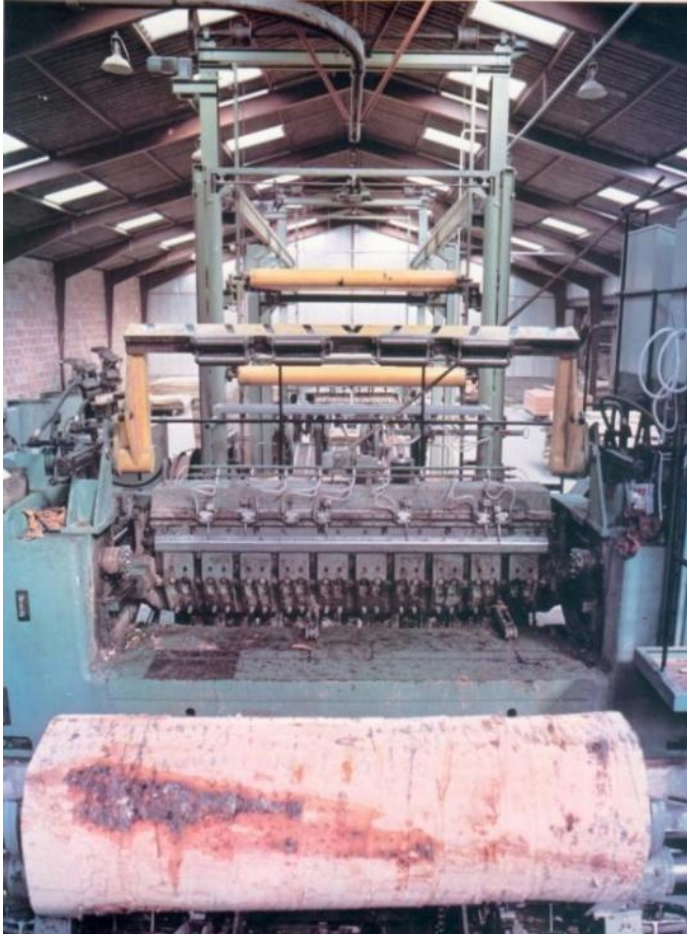
Constitution de la matière



Tension en périphérie
Compression à coeur

Contrainte de croissance
=
contrainte de support
+
contrainte de maturation

Les étapes de la déconstruction



Tronçonnage: grumes et billons

Sciage: profilés bois

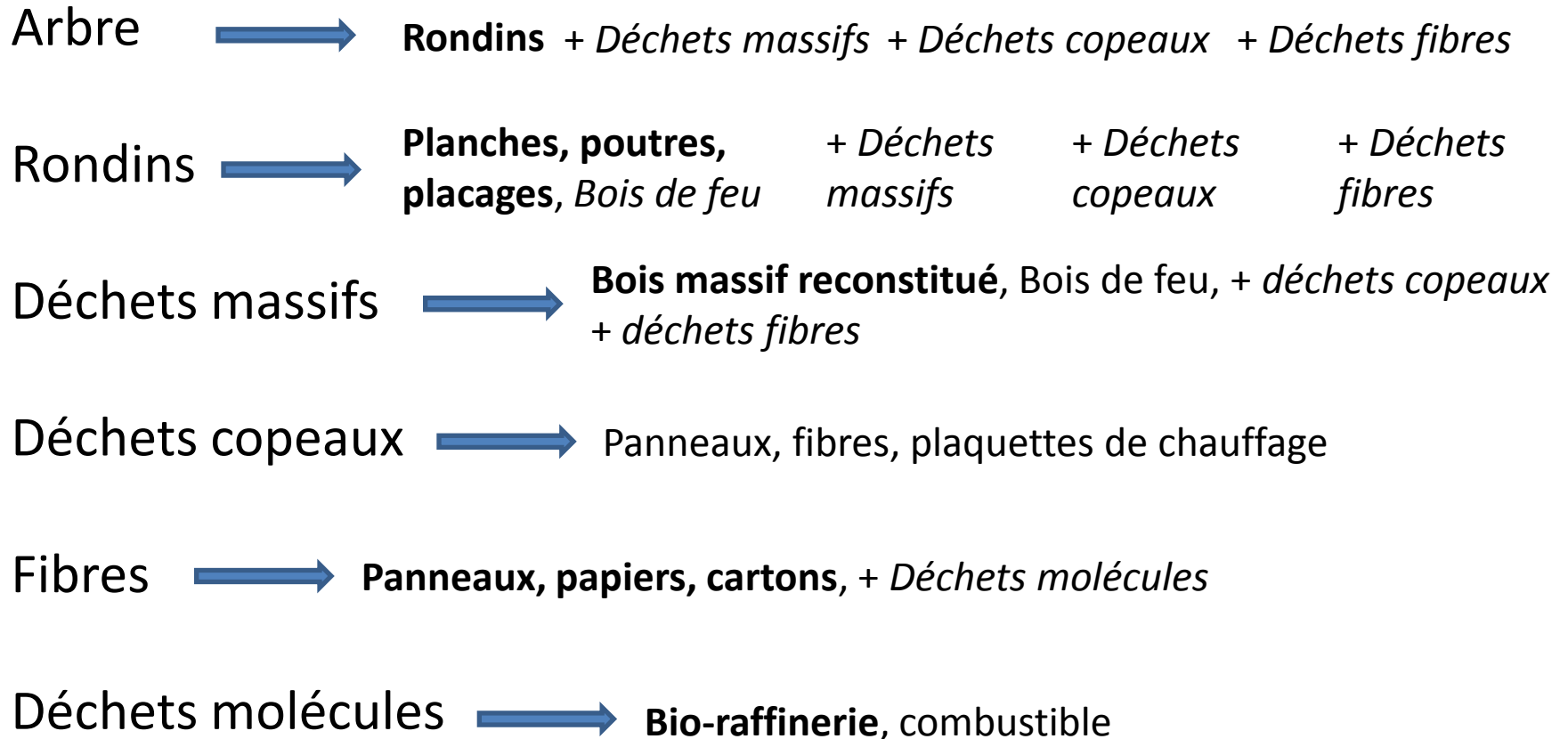
Déroutage et tranchage: feuilles de bois

Fragmentation: plaquettes

Défibrage: fibres

Déconstruction de la paroi: molécules

La cascade des usages du bois



Utiliser toute la cascade maximise la valeur ajoutée, l'emploi le stockage de carbone et l'économie d'énergie

Le bois matériau de l'ingénieur, de l'artisan et de l'artiste

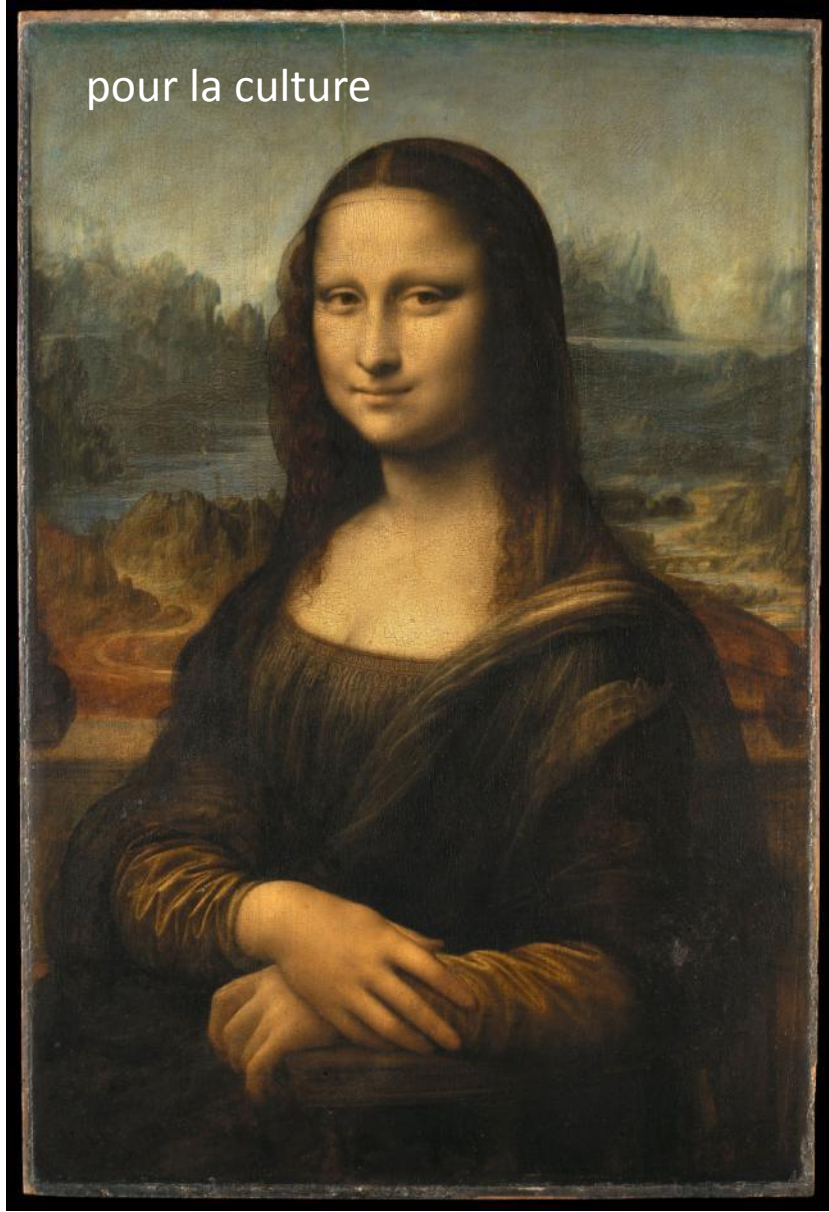


Pour la construction et le génie civil



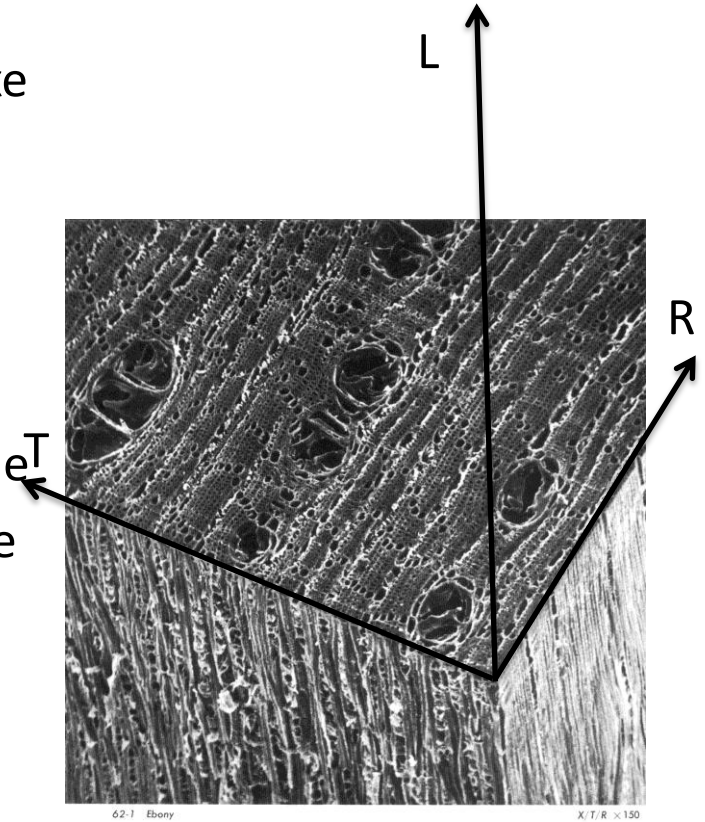
pour l'emballage et le transport





En conclusion: les bois, une grande classe de matériaux du vivant

- Les bois sont des modèles de matériau complexe
 - Anisotropes
 - Cellulaires (donc légers)
 - Composites à fibres nano structurés
 - Polymères thermo et hygro-sensibles
- Ils gardent la signature de leur origine biologique
- Ce sont toujours de bons matériaux de structure
- Ce sont aussi toujours de bons combustibles
- Leur coût énergétique est nul
- Leur utilisation permet de stocker du carbone prélevé dans l'atmosphère
- C'est une ressource renouvelable abondante
- La marge de progression de leur usage en France est énorme

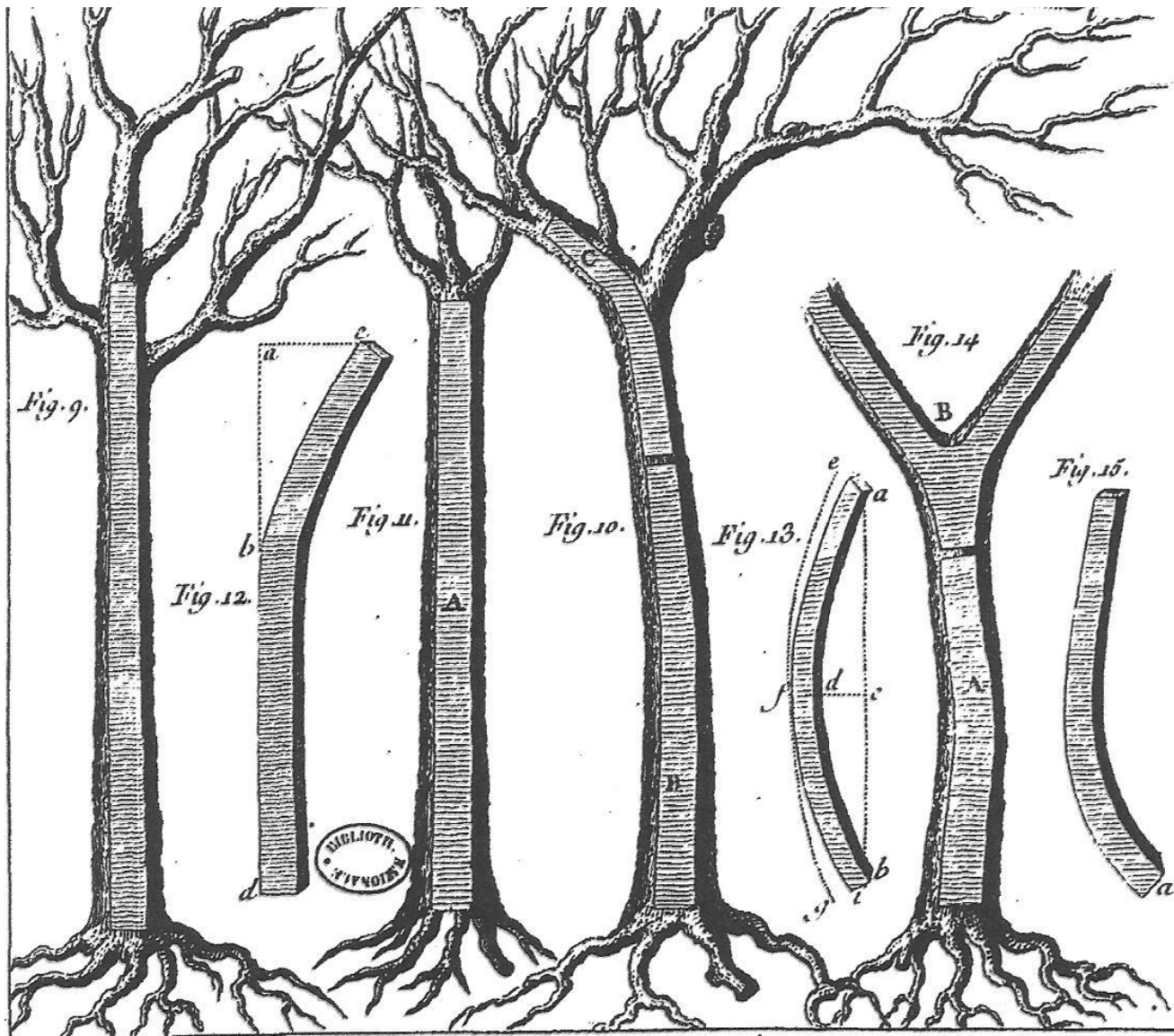


Composition élémentaire du bois: 50% carbone, 45% oxygène + hydrogène

Merci de votre attention









Wooden fork



Clothes tree



Wooden sling





