Fiber morphology and its impact on paper manufacturing

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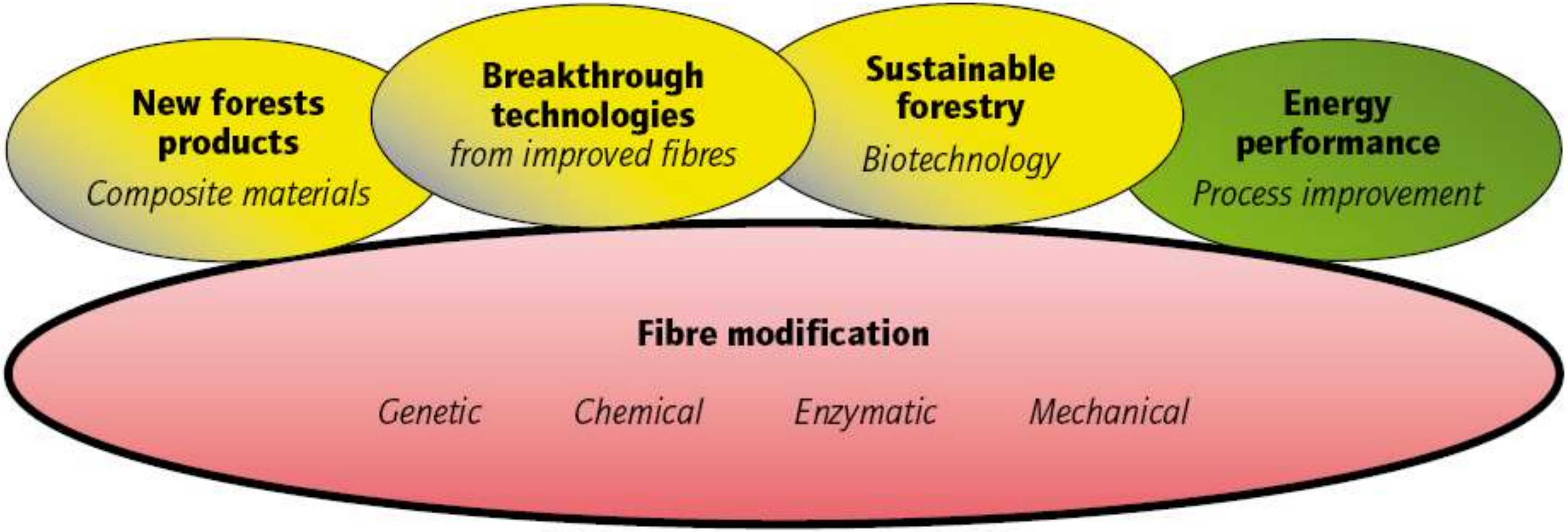
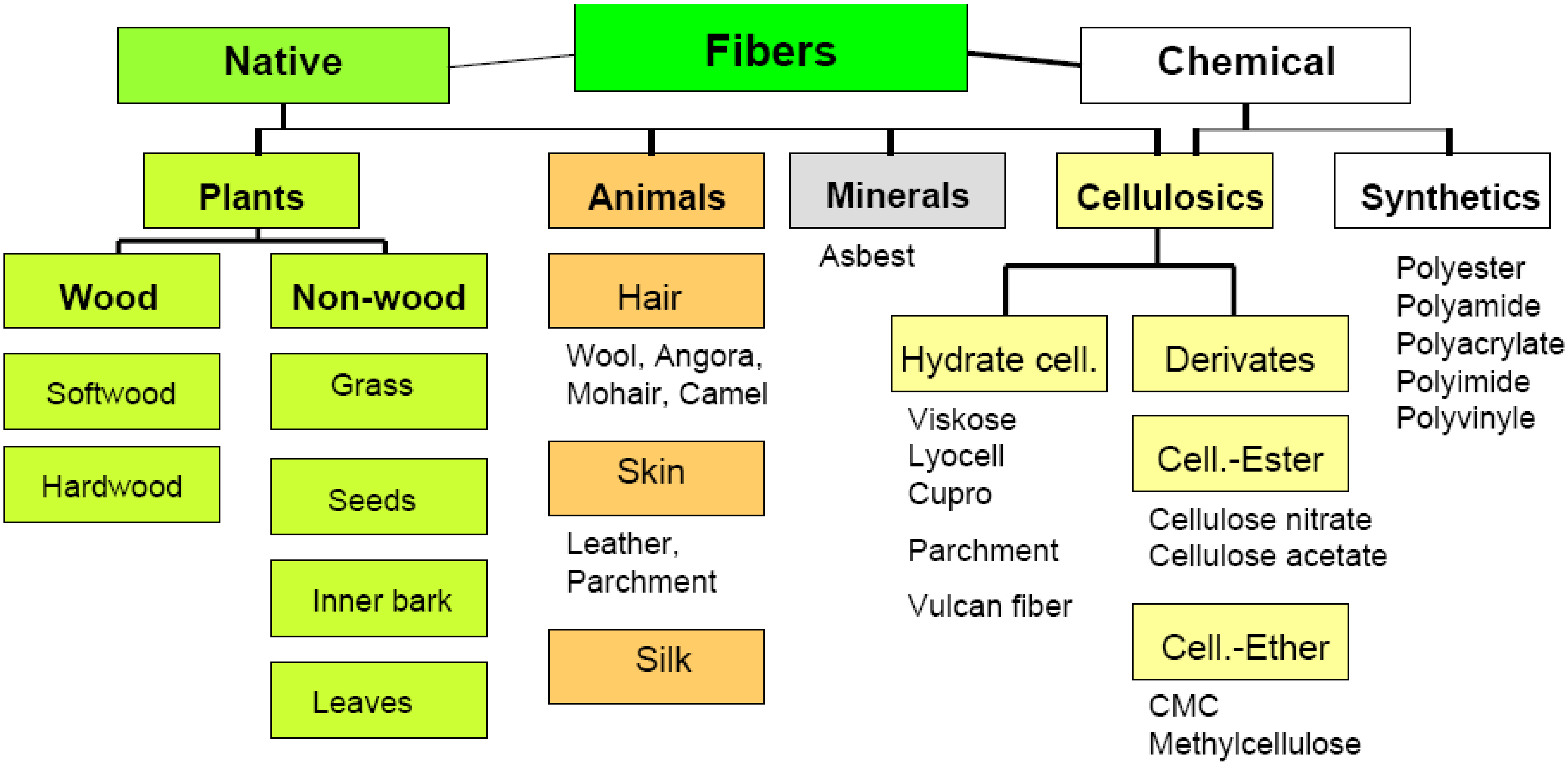
- ✓Introduction
- ✓Woody Plant Body
- ✓Wood anatomy and fiber morphology
- ✓Wood and fiber properties
- ✓Chemical composition of wood
- ✓Wood, fiber and paper properties
- ✓Final thoughts

Fibre engineering provides a platform for enhanced products, sustainability and energy utilization

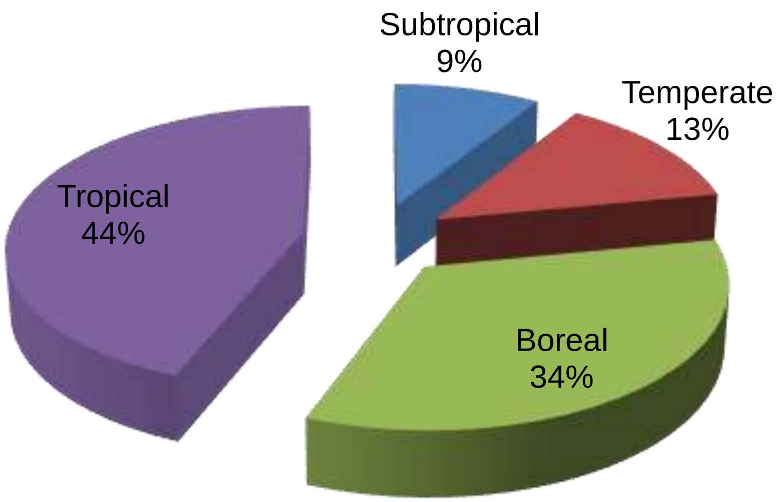


Fibre Classifications

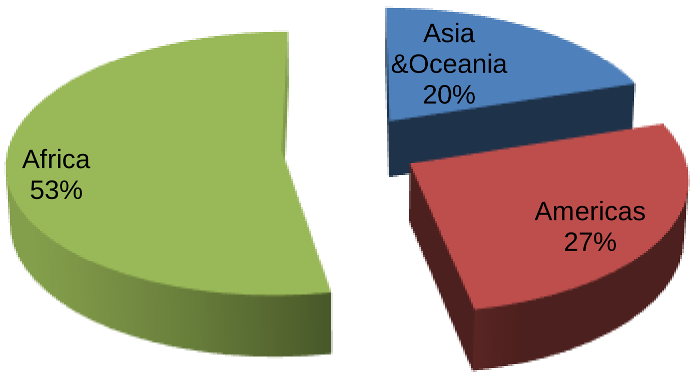


Global Forest Cover

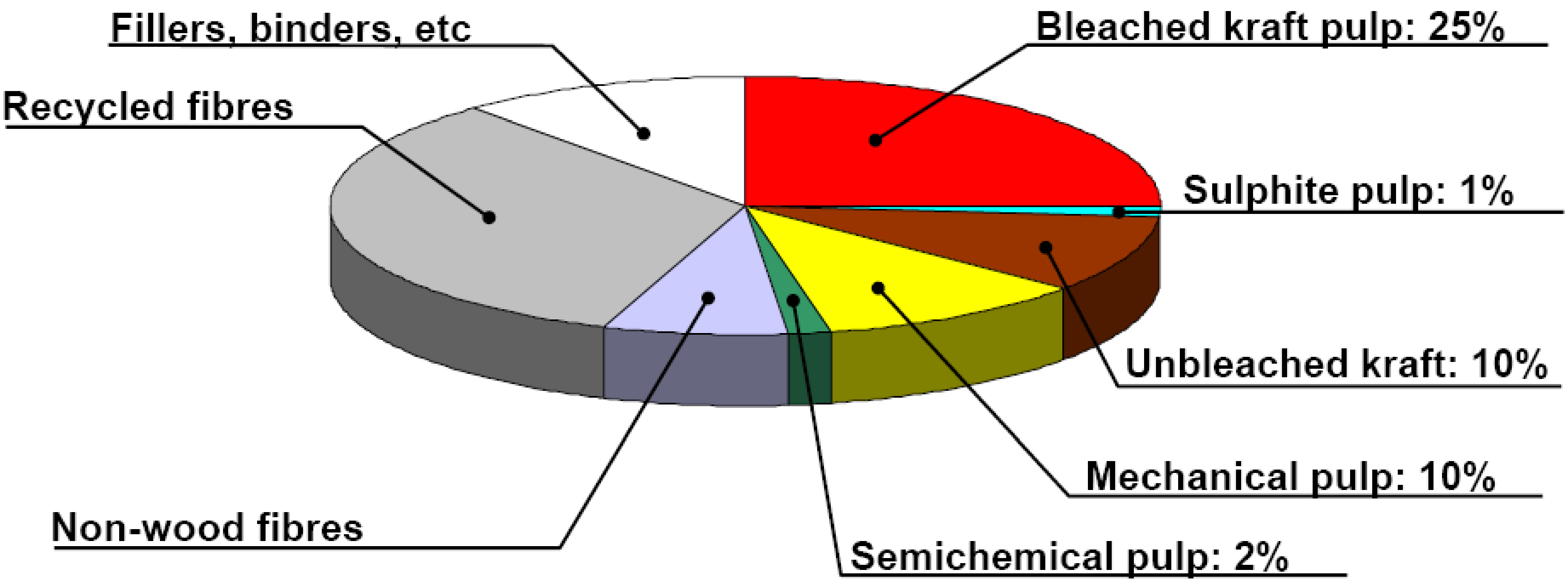
Forest covered by climatic domain



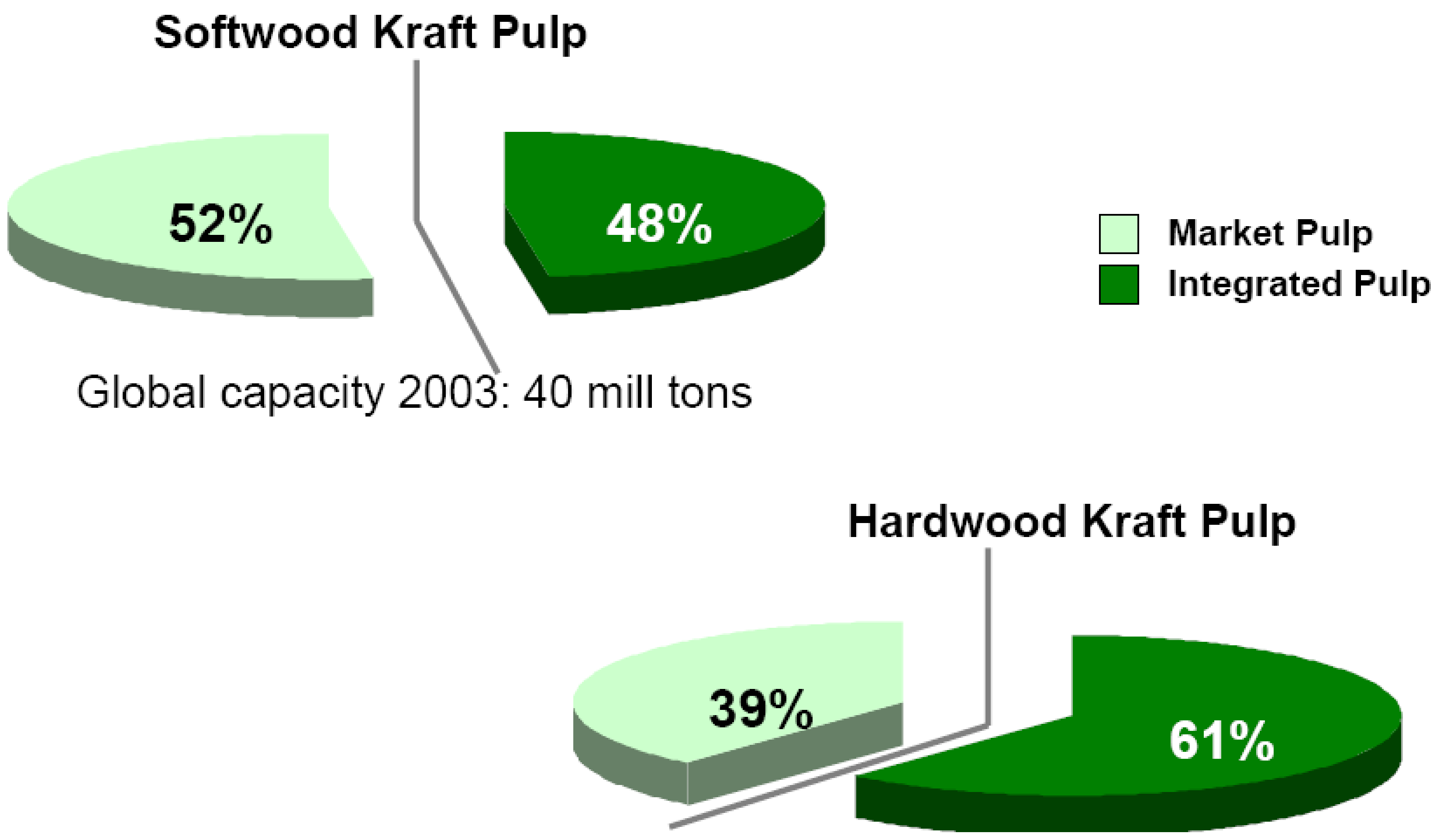
Tropical forest covered by Reason



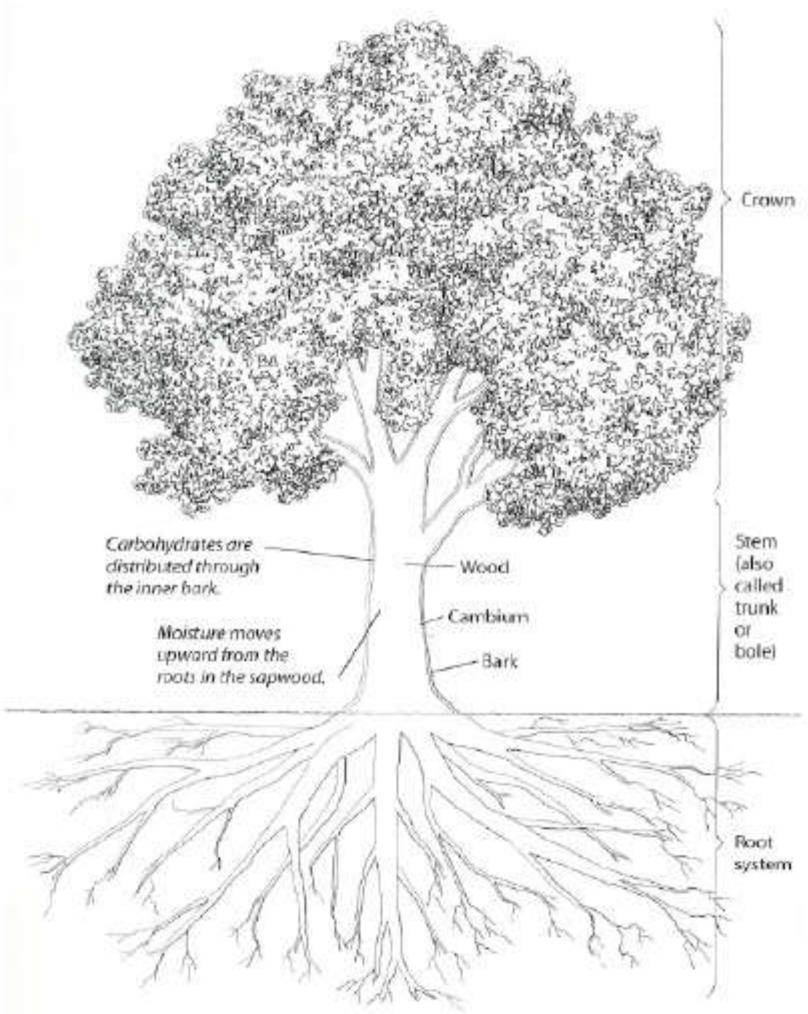
Global fibre furnish for paper and board



World supply of SW and HW Kraft Pulp



Woody Plant Body



❖**Crown characteristics**

✓ Influencing the rate of plant growth and in such expressions of growth as increase in stem diameter and production of fruits, cones, and seeds.

❖ **Leaf structure**

✓ Affecting the photosynthesis and transpiration, which influenced by environmental stress.

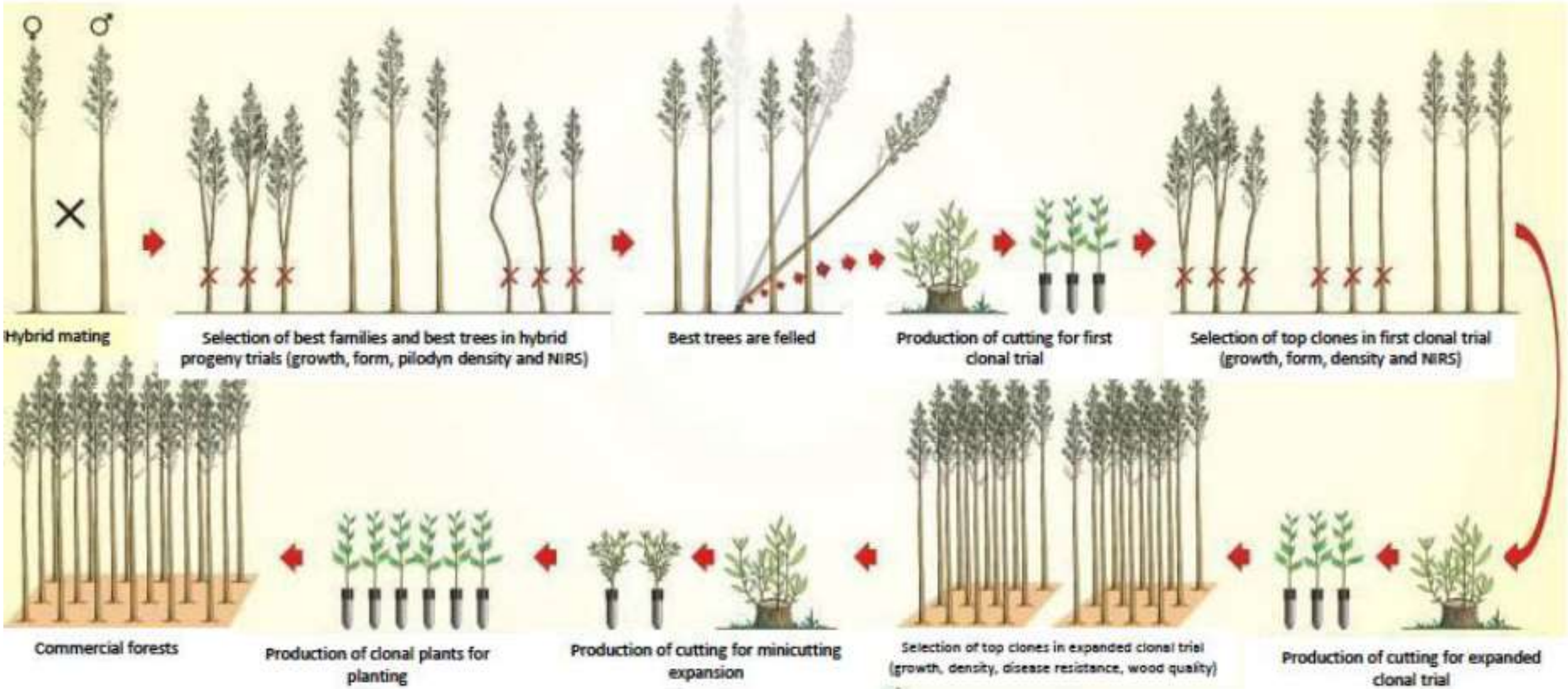
❖ **Stem structure**

✓ Related to the ascent of sap, translocation of carbohydrates, and cambial growth.

❖ **Root structure**

✓ The knowledge of root structure is important for an appreciation of the mechanisms of absorption of water and mineral nutrients.

The selection of trees is a long process…



…that can take up to **18 years to select the most suitable genotypes for a particular use.**

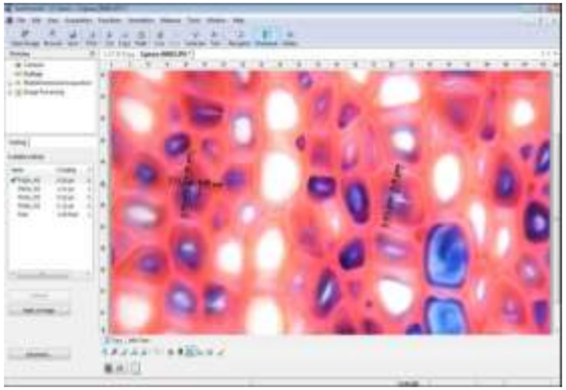
Variation of dasometric characteristics in Eucalyptus *clones*

Property	Average	Std. dev.	Minimum	Maximum	*p*-value*
Total height (m)	20.6	1.0	16.1	22.7	0.031
DBH (cm)	16.1	1.6	12.5	21.1	0.010
Stem volume (m^3)	0.148	0.039	0.064	0.282	0.008
Bark volume (m^3)	0.026	0.006	0.010	0.054	0.237
Bark content (%)	15.2	1.36	9.6	20.8	0.668

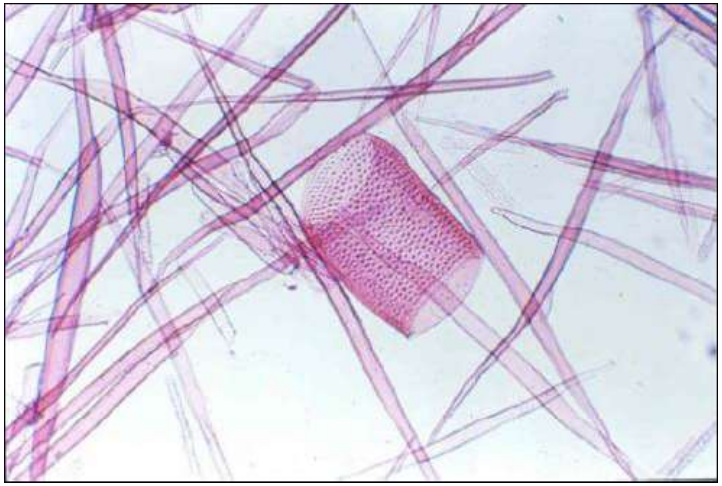
*Variables with p-value < 0.05 differ significantly among clones.

Biomass Components	Mean	Std. dev.	Min-Max
Tree height, m	19.5	3.7	13.5 – 26.1
Diameter at 1.3 m, cm	14.8	4	9.5 – 21.6
Bolewood, kg/tree	81.8	60.1	13.9 – 182.7
Bark, % bolewood	15.2	4.3	9.6 – 23.0
Tops, % bolewood	13.5	7.1	3.9 – 24.2
Branches, % bolewood	7.9	2.2	4.3 – 10.9
Foliage, % bolewood	10.2	3.6	4.9 – 16.0

Wood anatomy and fiber morphology

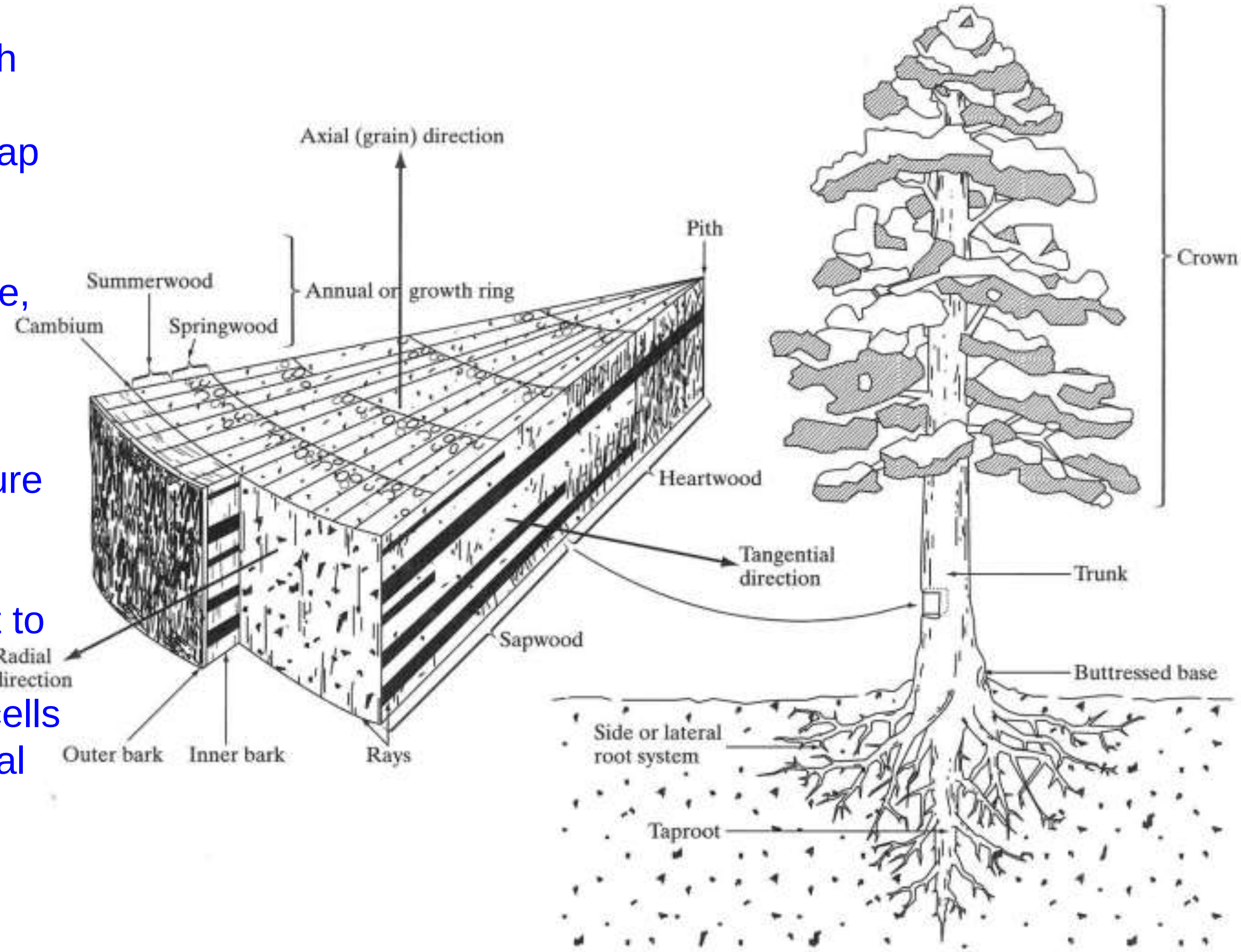


- ✓Cell wall thickness
- ✓Lumen and fiber width
- ✓Fiber length
- ✓Vessels
- ✓Coarseness
- ✓Runkel ratio



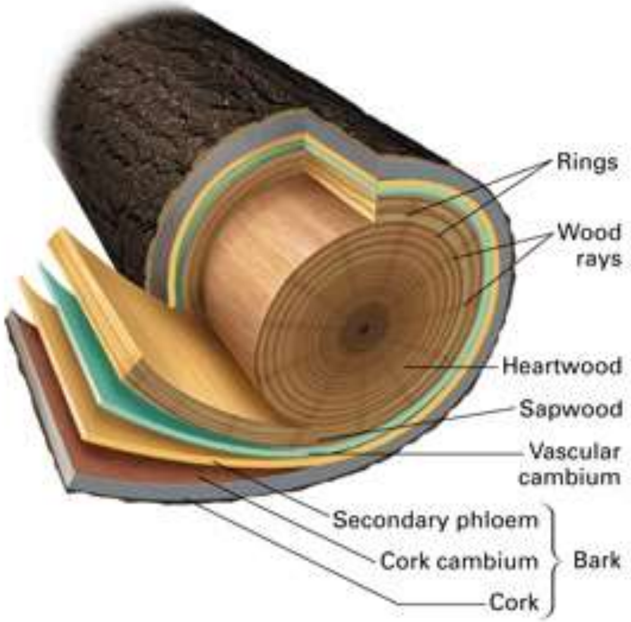
Structure of Wood

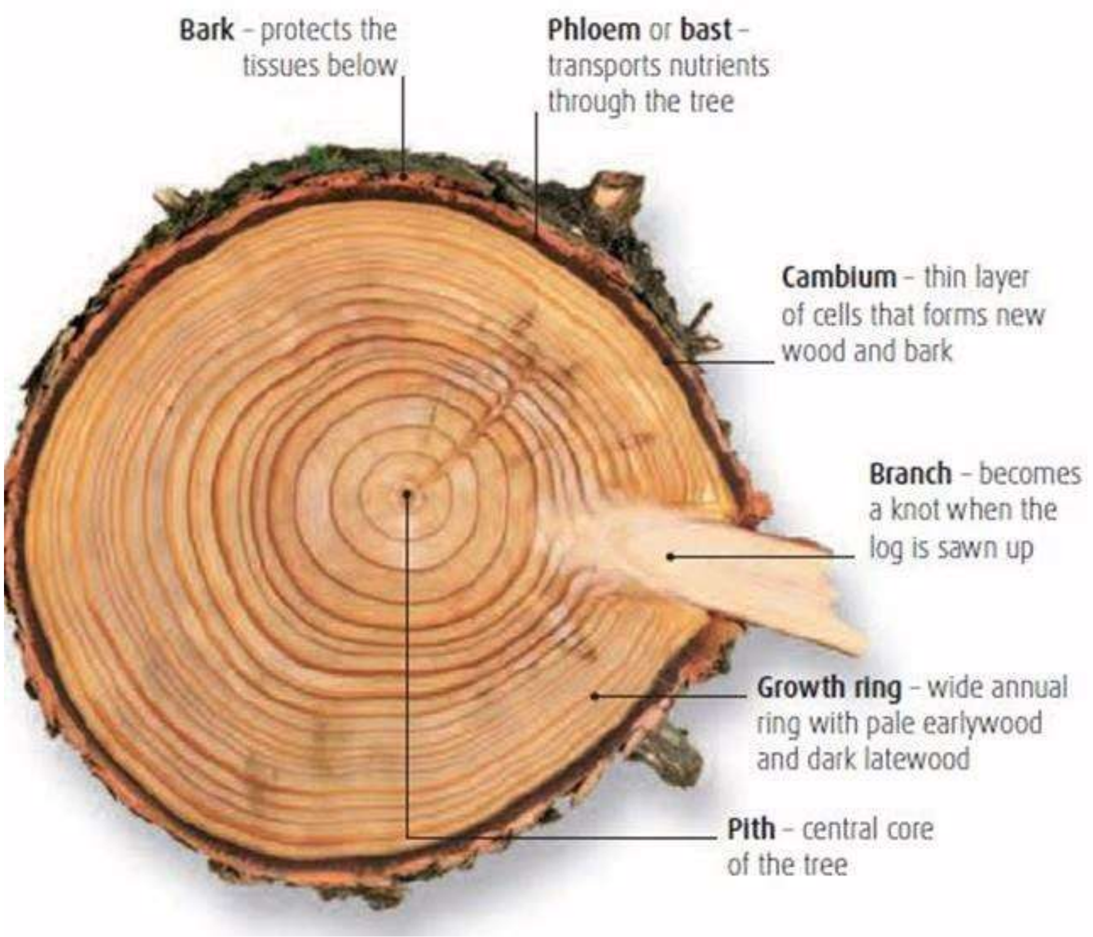
- ✓ **Outer bark:** dense rough layer of protection.
- ✓ **Inner bark:** transports sap from leaves to growing parts of the tree.
- ✓ **Cambium**: layer of tissue, one to ten cells thick, between bark and wood.
- ✓ **Sapwood:** wood on the outside, conducts moisture from roots, stores food.
- ✓ **Heartwood:** inner core, nonliving, more resistant to decay, drier and harder.
- ✓ **Rays:** small amount of cells that grow in the horizontal direction



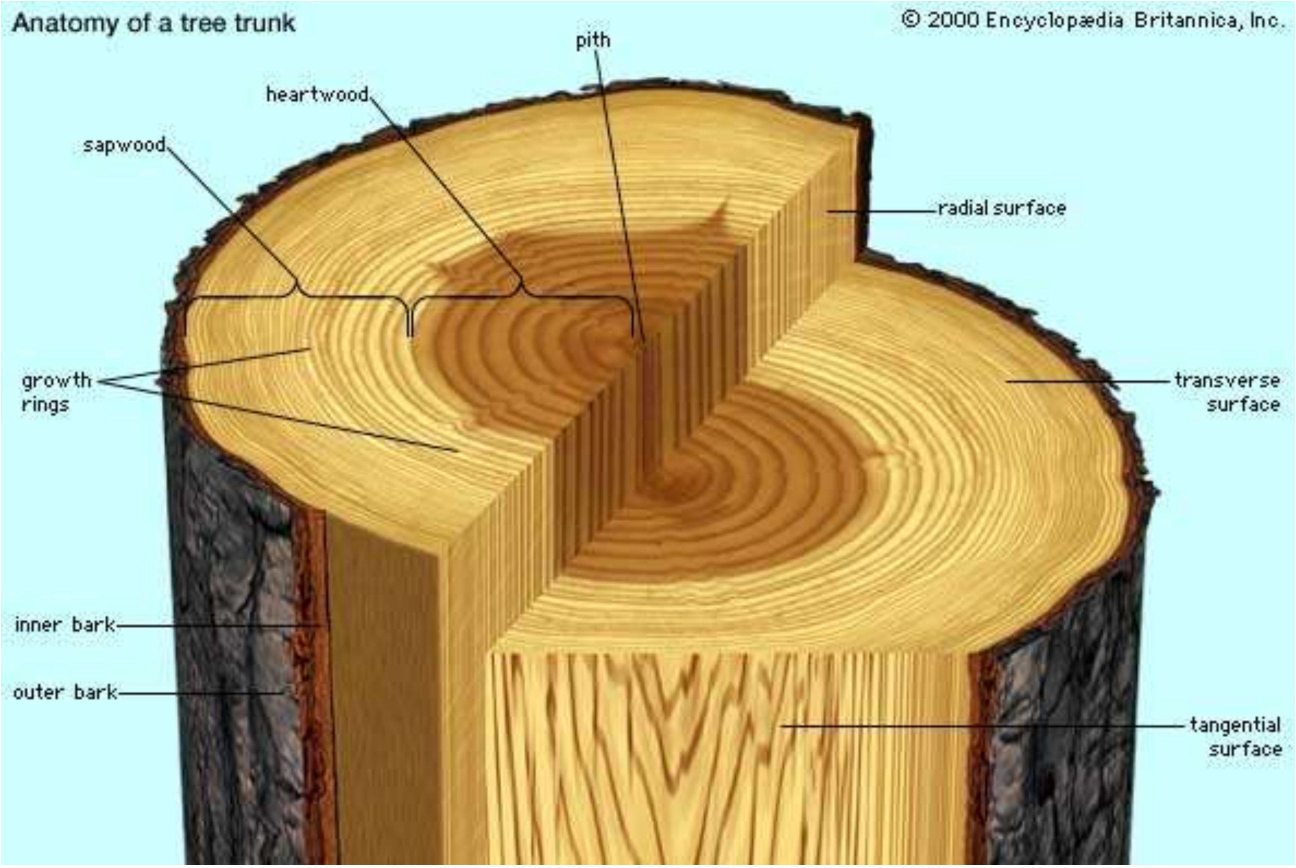
Structure of Wood

Macroscopic level

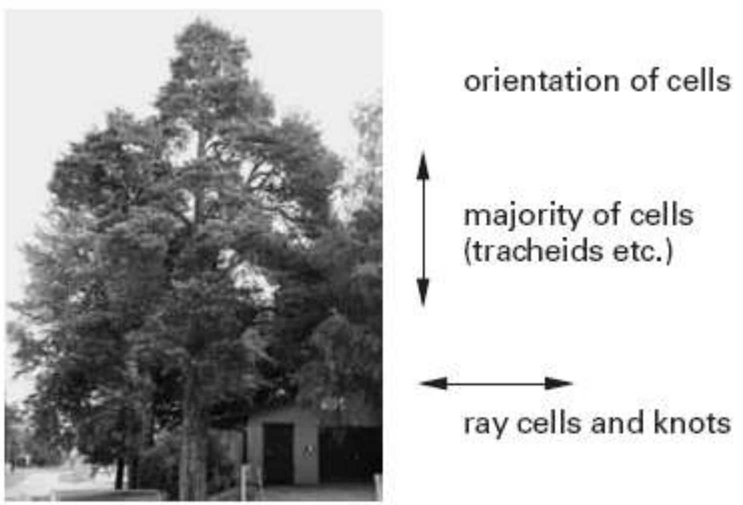




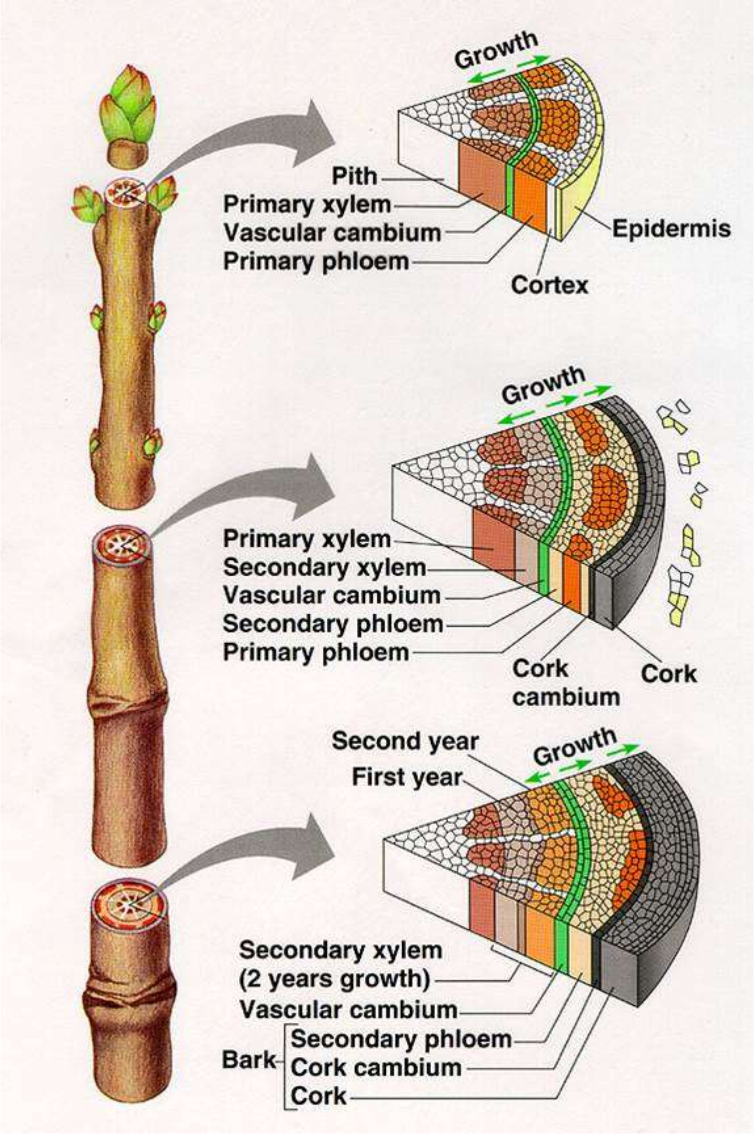
Structure and composition Macrostructure

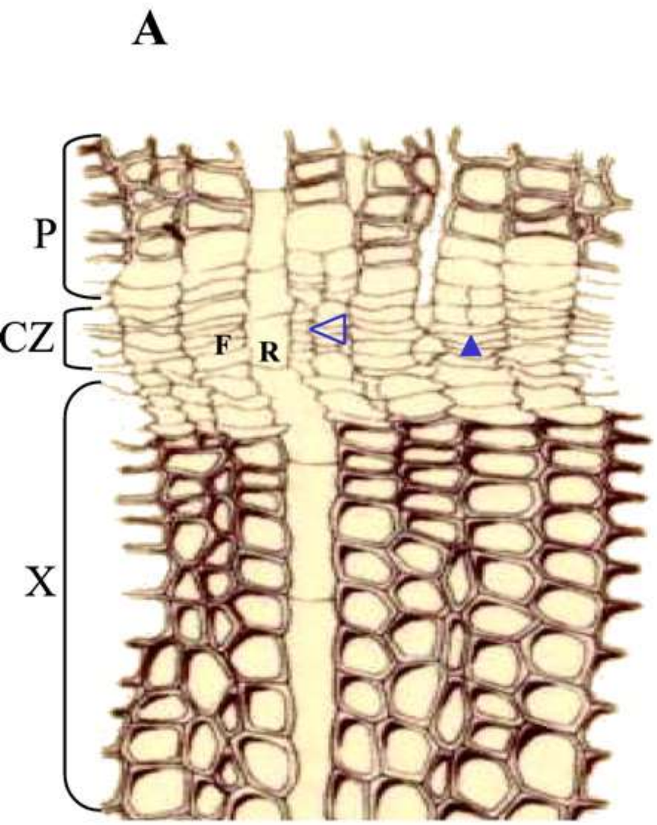


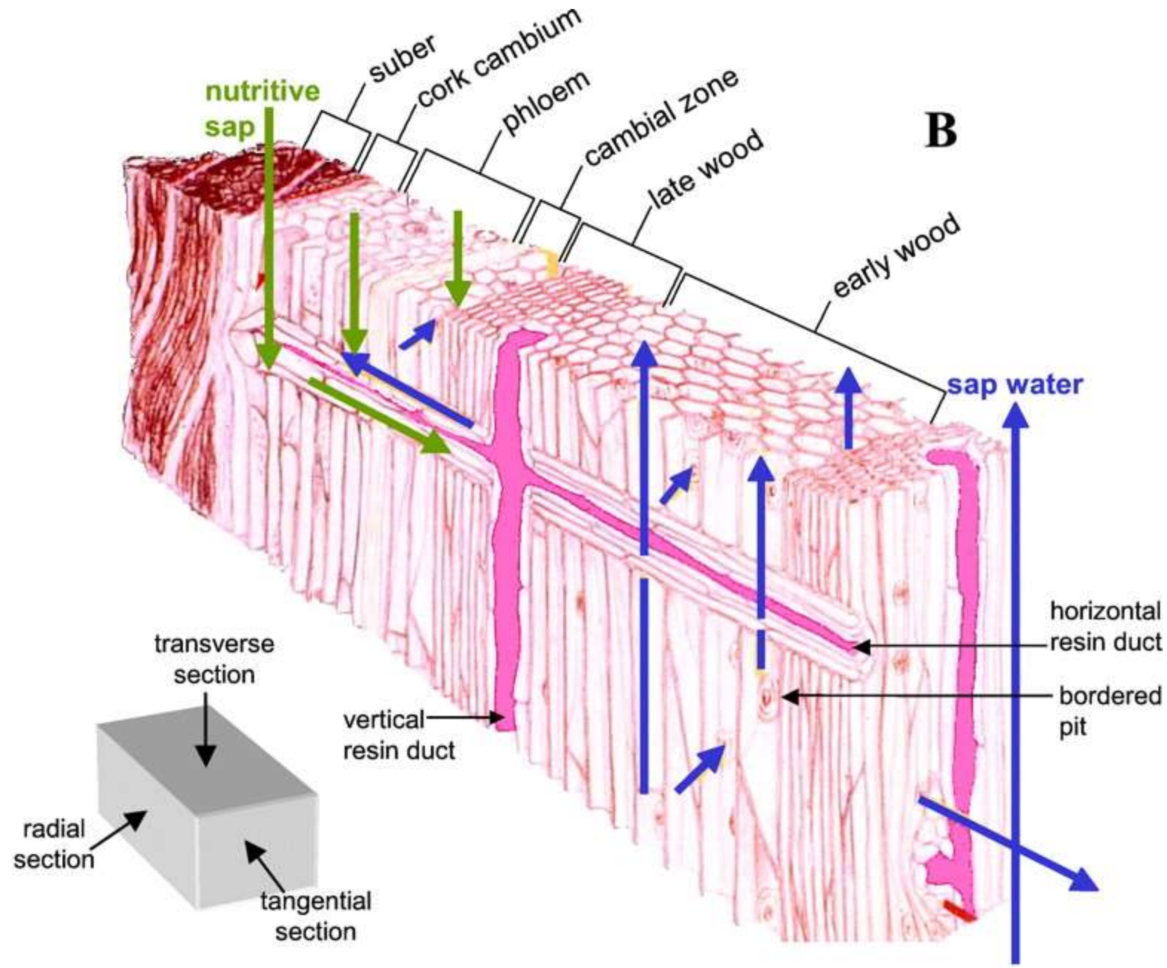
Cells growth in plant



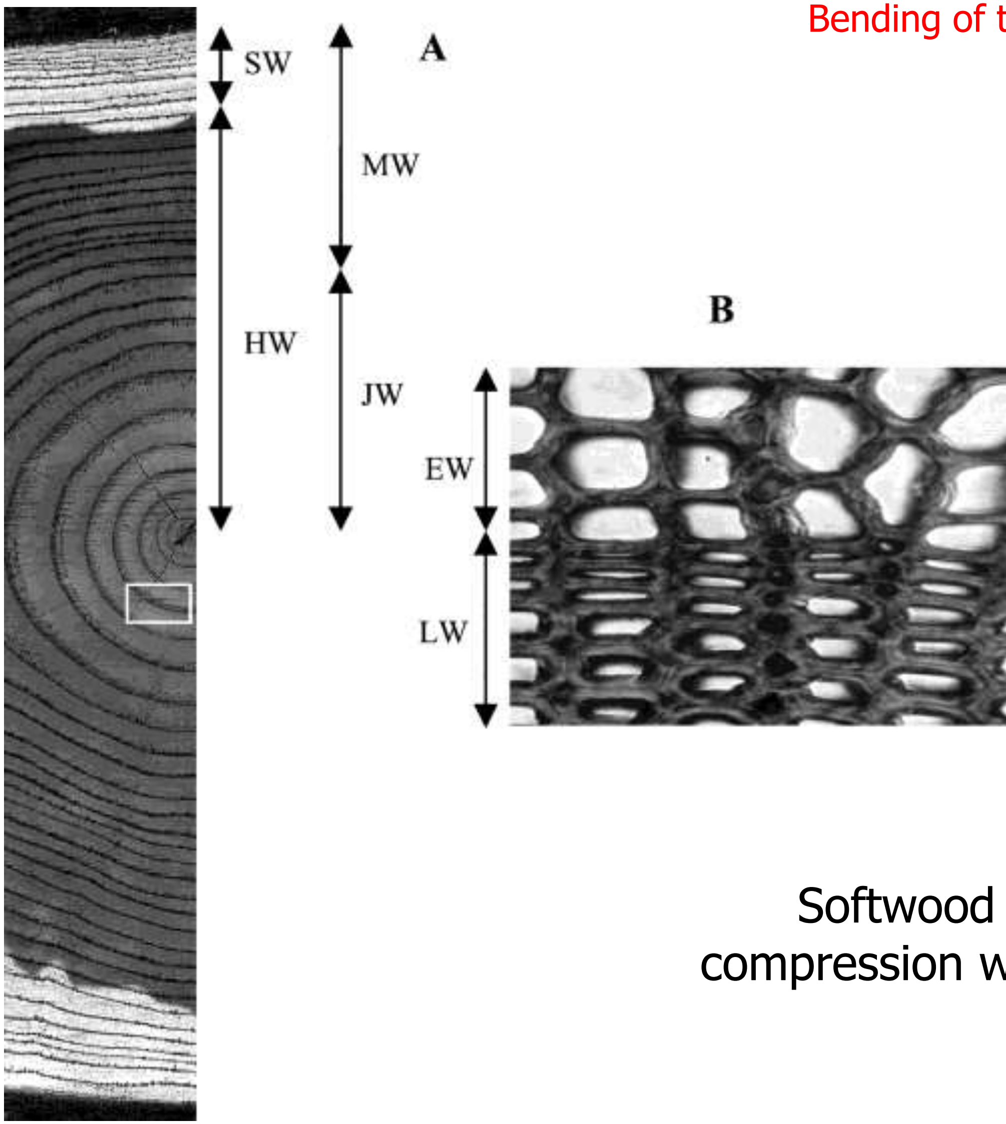
Direction of cells in wood.



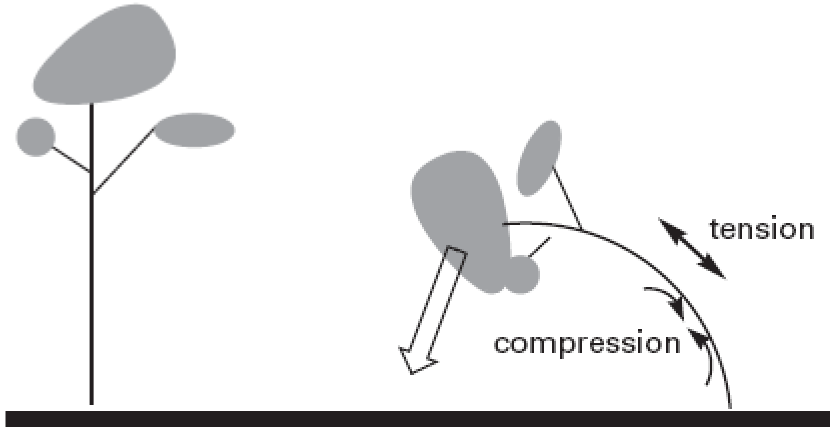

A
P
CZ
F
R
X

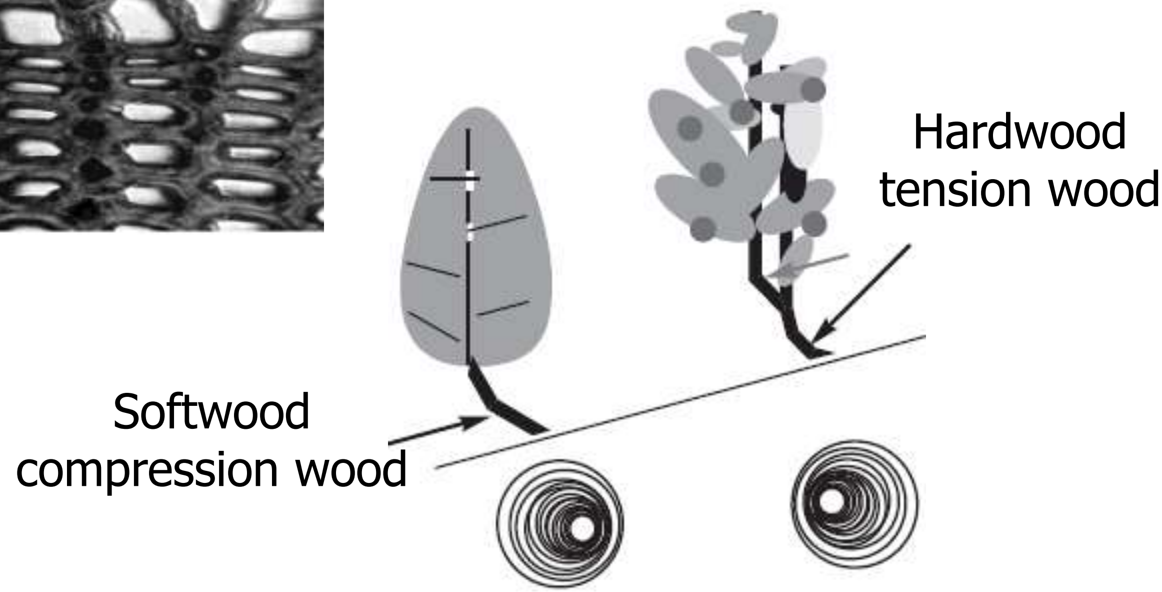

B
nutritive
sap
suber
cork cambium
phloem
cambial zone
late wood
early wood
sap water
horizontal
resin duct
bordered
pit
vertical
resin duct
transverse
section
radial
section
tangential
section

Reaction Wood

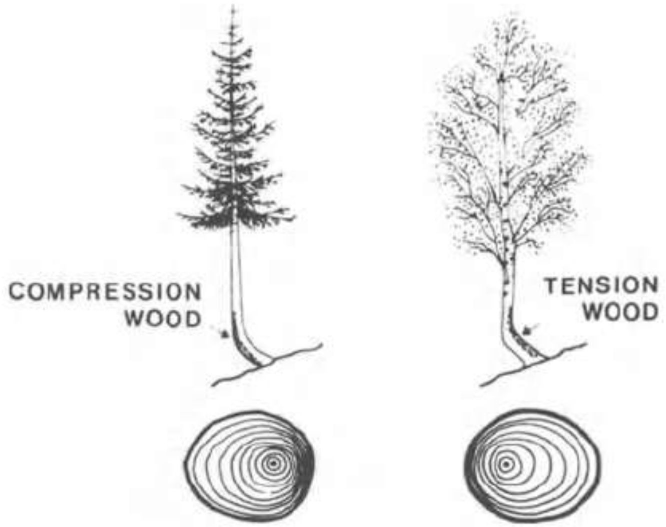


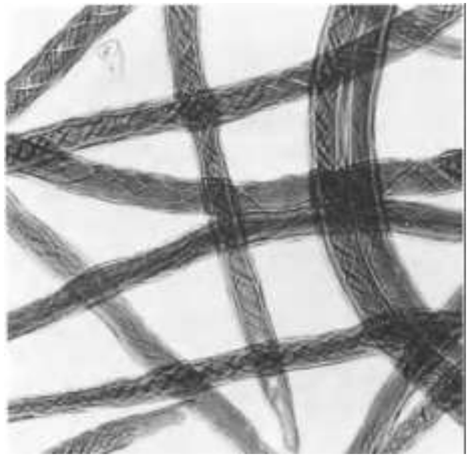
Bending of trees causes different kinds of stress on the two sides



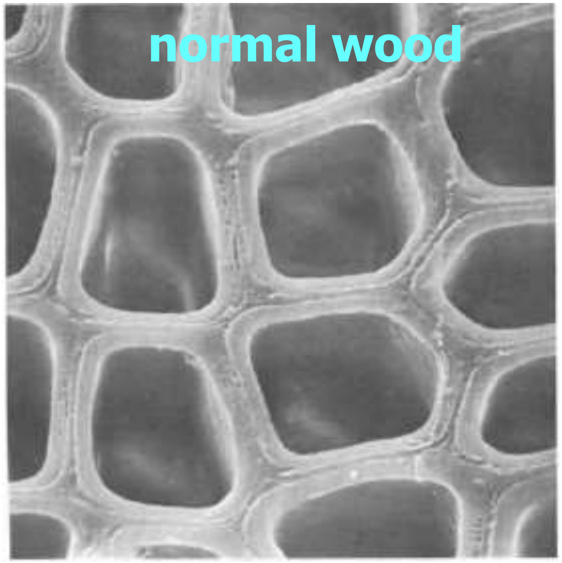


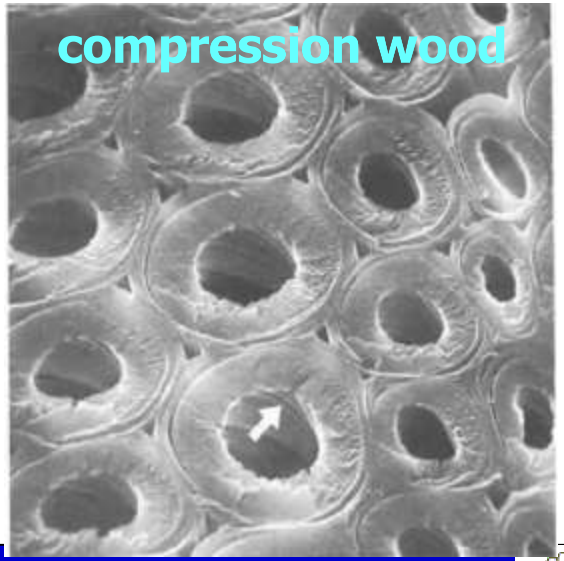
Compression Wood & Tension Wood





Fibers of compression wood showing criss-cross patterns.





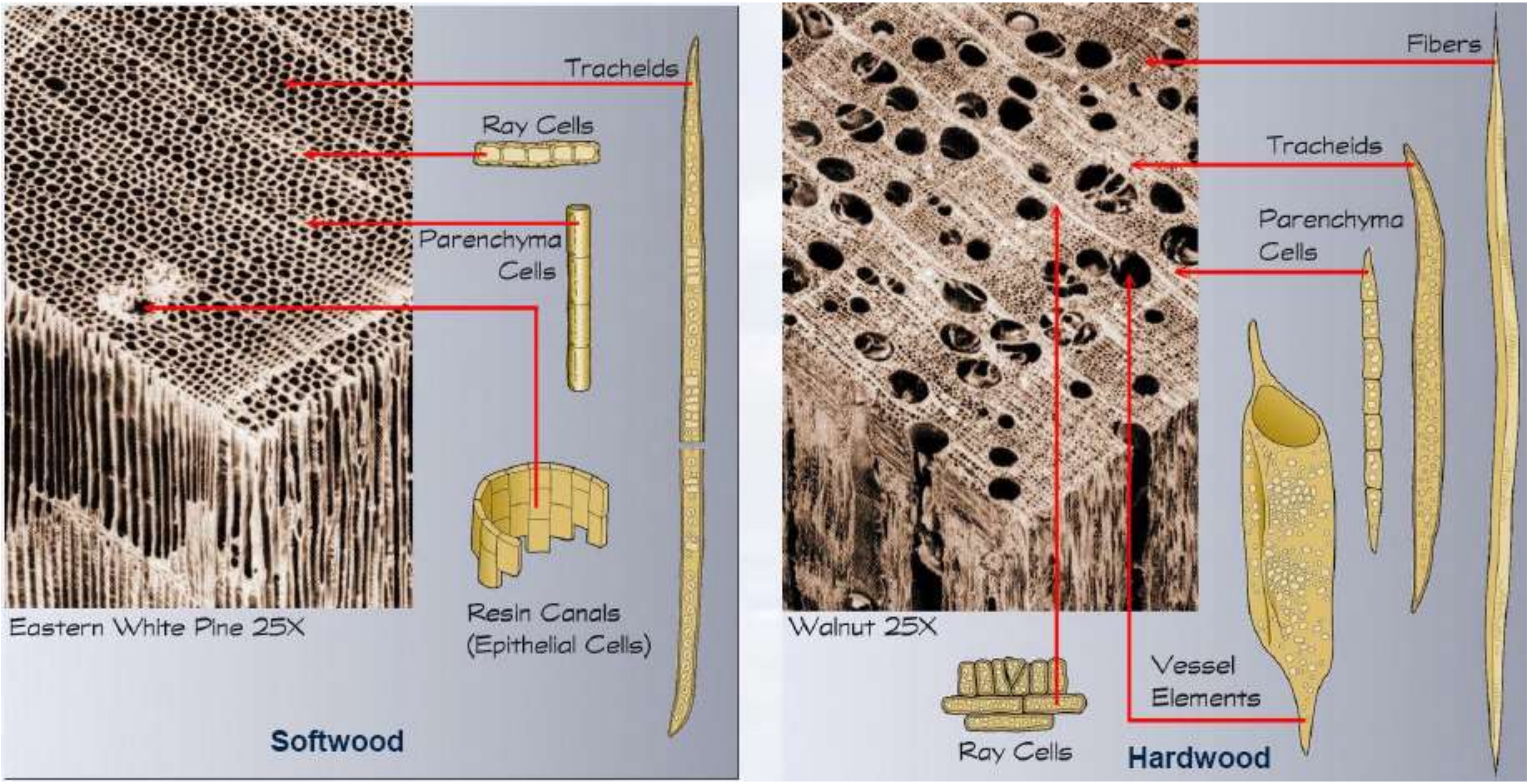
Helical checks (arrow), rounded fibers, and intercellular spaces in the compression wood.

Volumetric composition of hardwood and softwood

	Hardwoods	Softwoods
Fiber (%)	27-76	90-95
Vessels (%)	7-55	-
Ray cells (%)	5-25	5-10

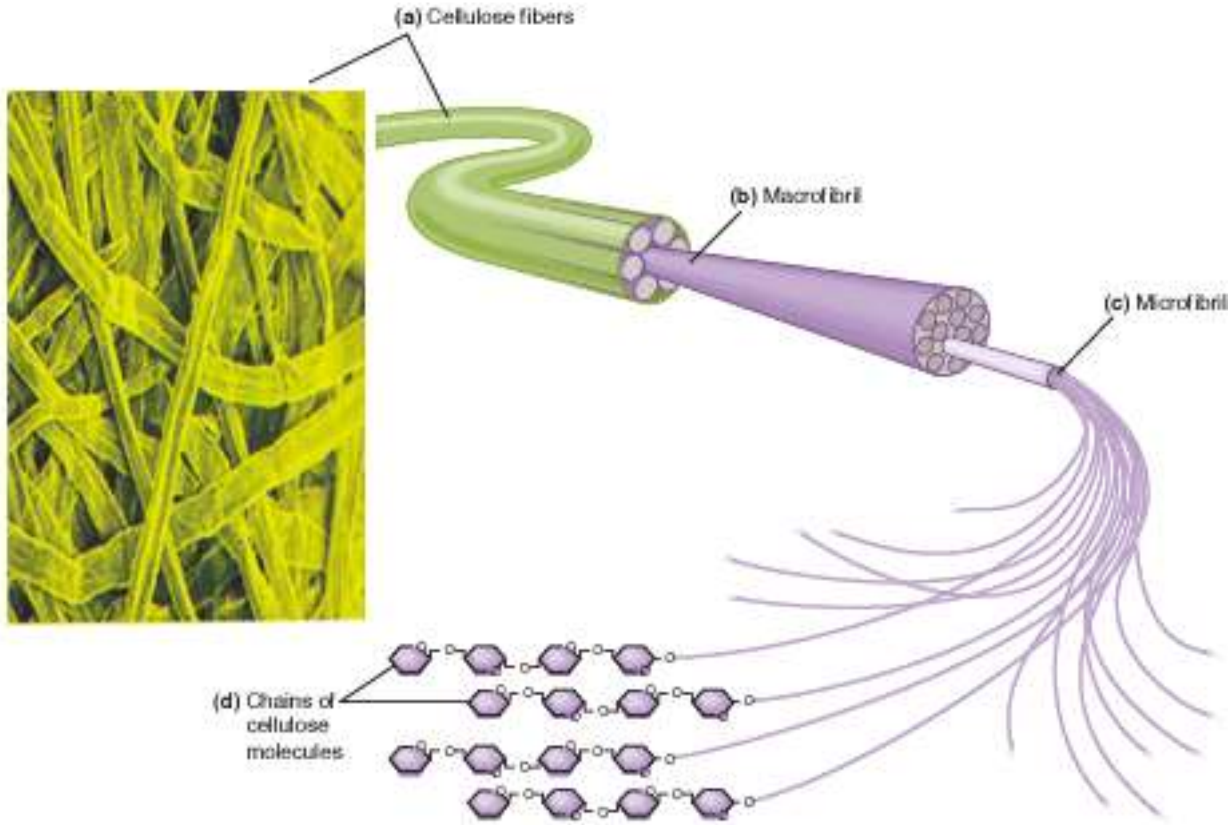
Wood cell types

Fibers/tracheids are best for papermaking. Other cell types cause mainly problems. This is one reason that softwood fibers are best and nonwood fibers worst fibers.

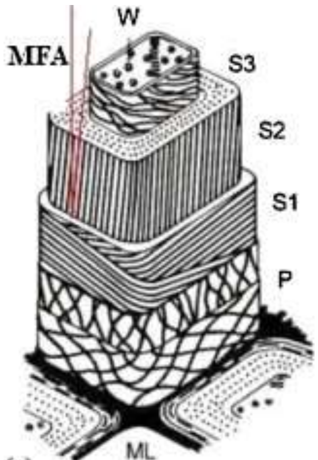


Wood fibers

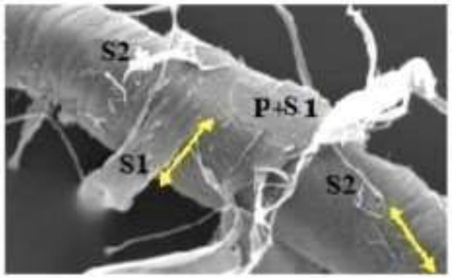
- Wood is a complex natural composite built up of fibers that are glued together by lignin.
- Fibers consist of fibrils that are held together by lignin and hemicellulose.
- Fibrils are built up of bundles of microfibrils.



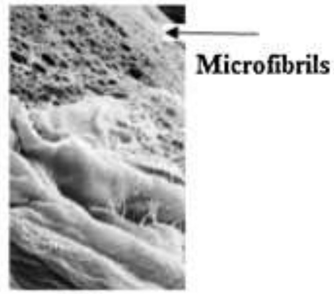
Fibre unit structure



(a)

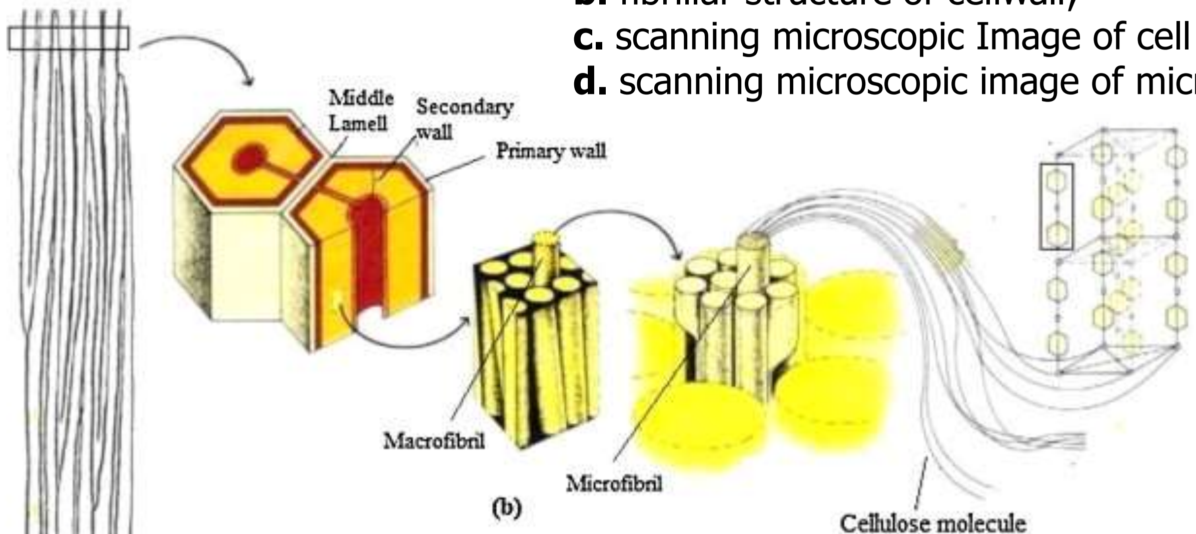


(c)

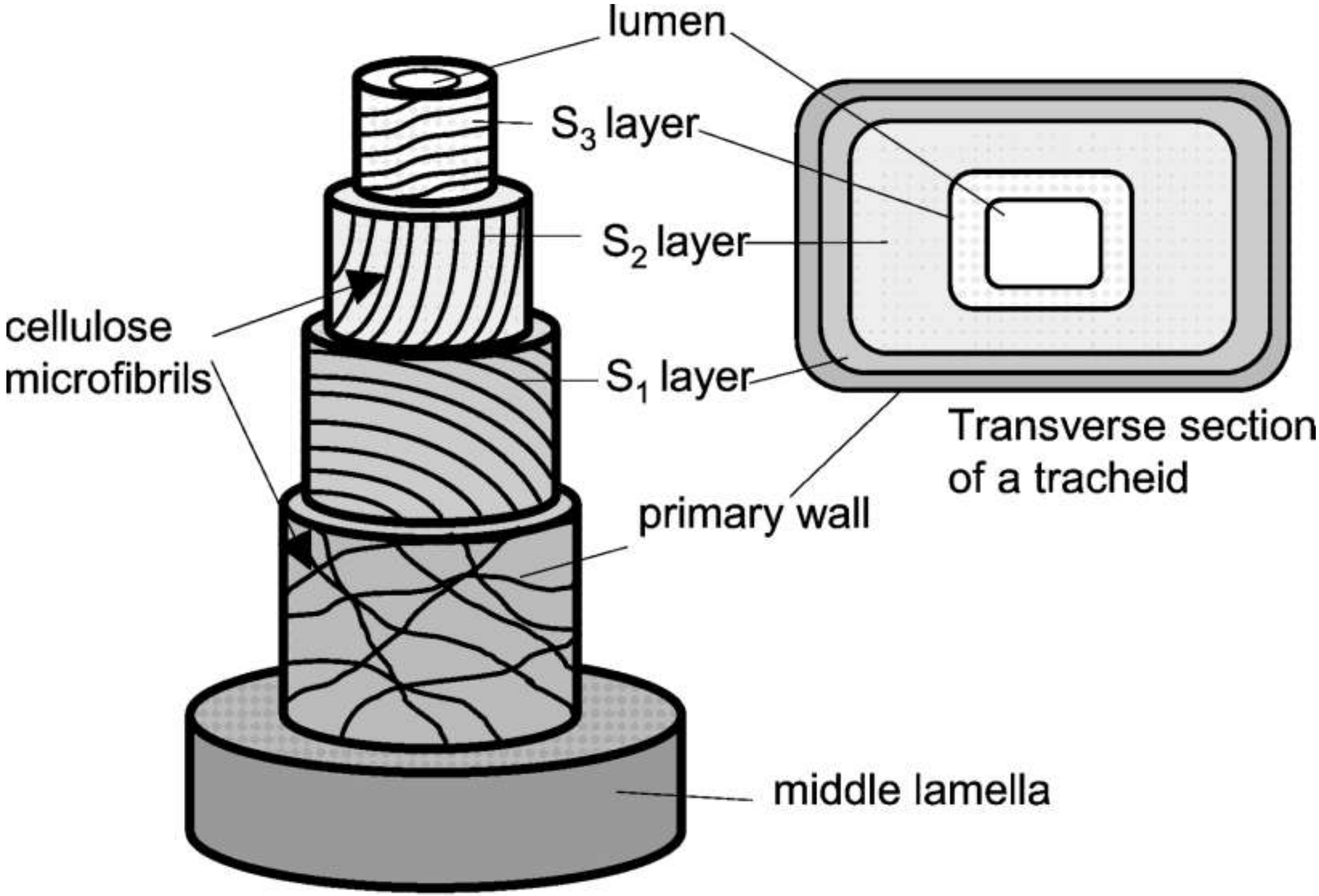


(d)

a. Schematic of cell wall layers (middle lamella (ML),primary wall (P), secondry wall (S1, S2, S3) and lumen (W);
b. fibrillar structure of cellwall;
c. scanning microscopic Image of cell wall layers;
d. scanning microscopic image of microfibrils

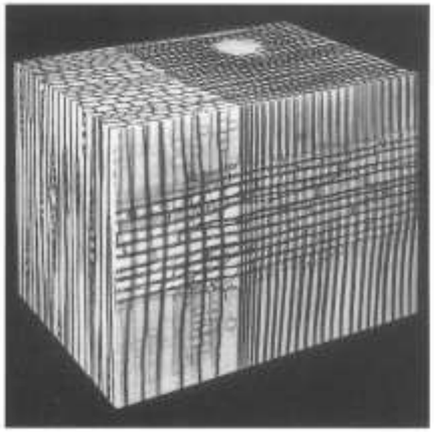


(b)


lumen
S3 layer
S2 layer
cellulose microfibrils
S1 layer
Transverse section of a tracheid
primary wall
middle lamella

Structure of Wood

Microstructure: Cellular Arrangement - Anisotropic



Softwood

- ✓ Larger, longer cells
- ✓ Water transported by cells

Hardwood

- ✓ Contains large-diameter vessels
- ✓ Water transported by these vessels

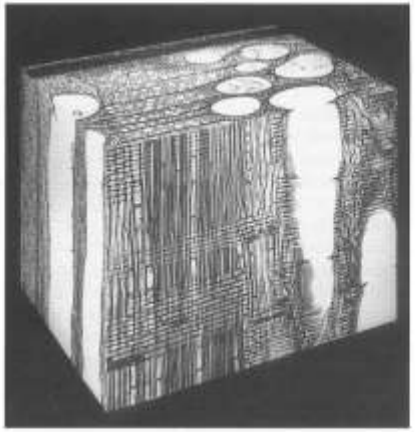
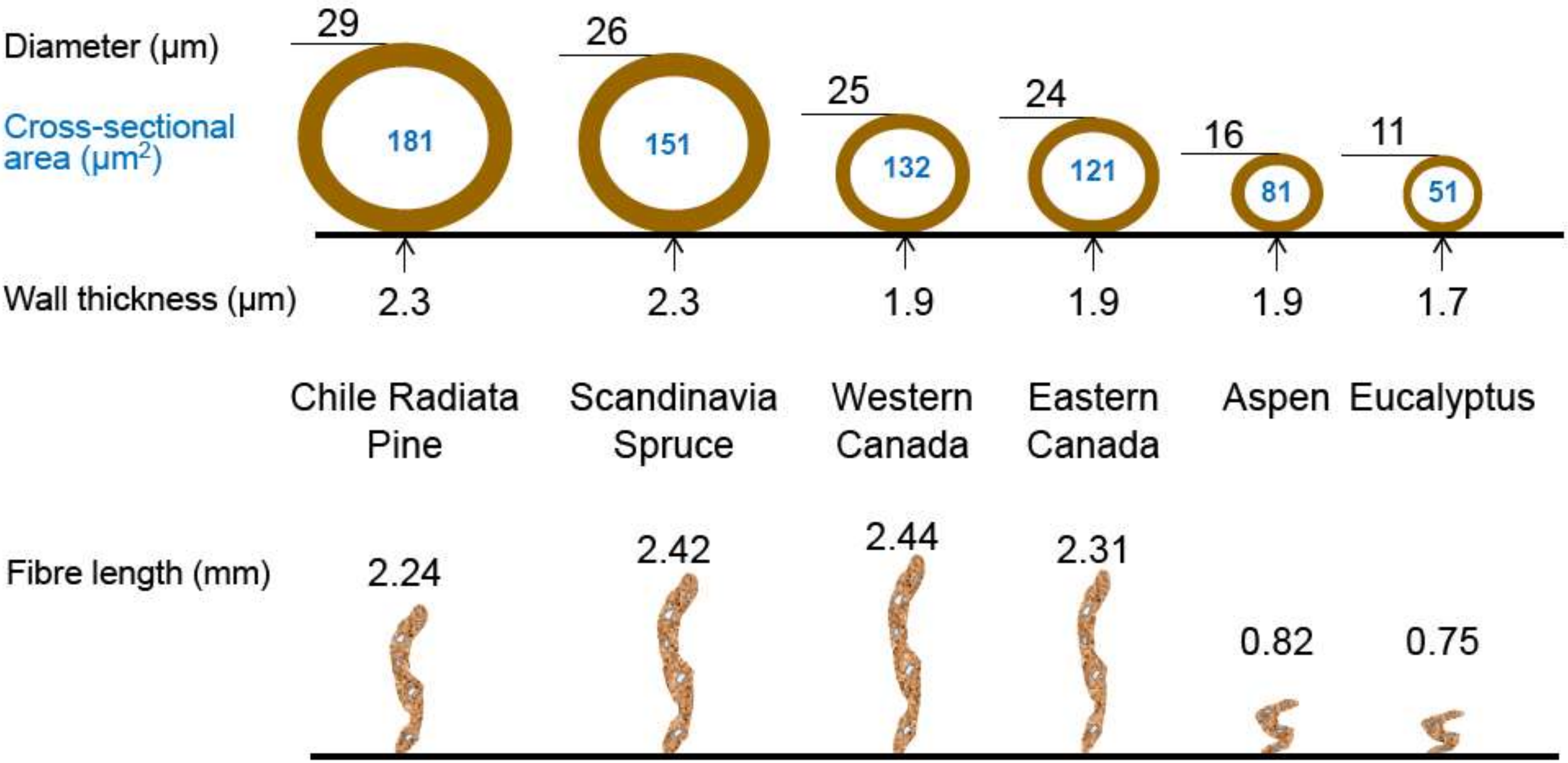


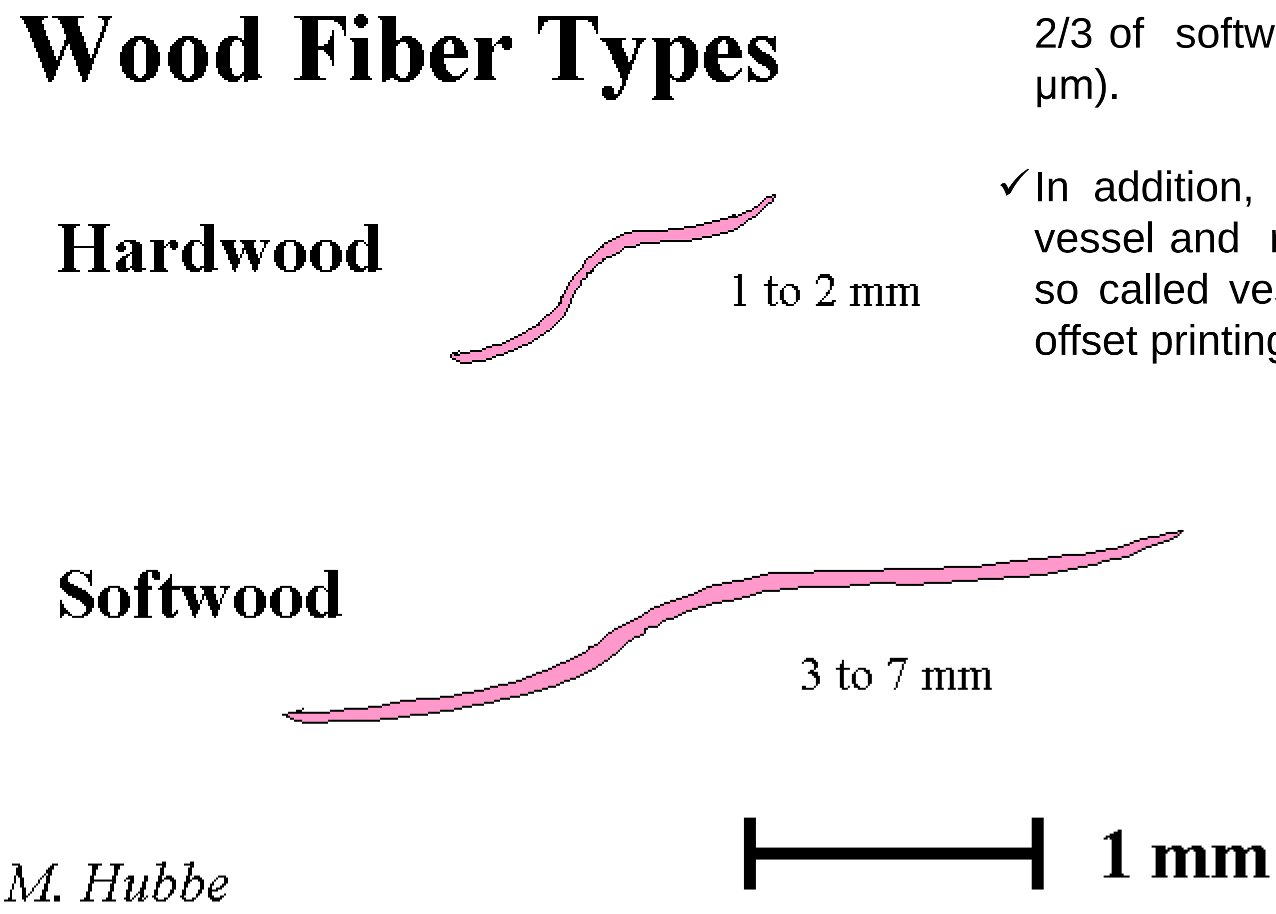
TABLE 14.2 The Functions and Dimensions of the Various Types of Cells Found in Softwoods and Hardwoods

Cells	Softwood	Hardwood	Function	Wall Thickness	Length	Width
Parenchyma	+	+	Storage		200 μm	30 μm
Tracheids	+	+	Support Conduction		2–5 mm	20–50 μm
Fibers		+	Support		0.7–3 mm	10–20 μm
Vessels (pores)		+	Conduction		0.2–1.2 mm	500 μm

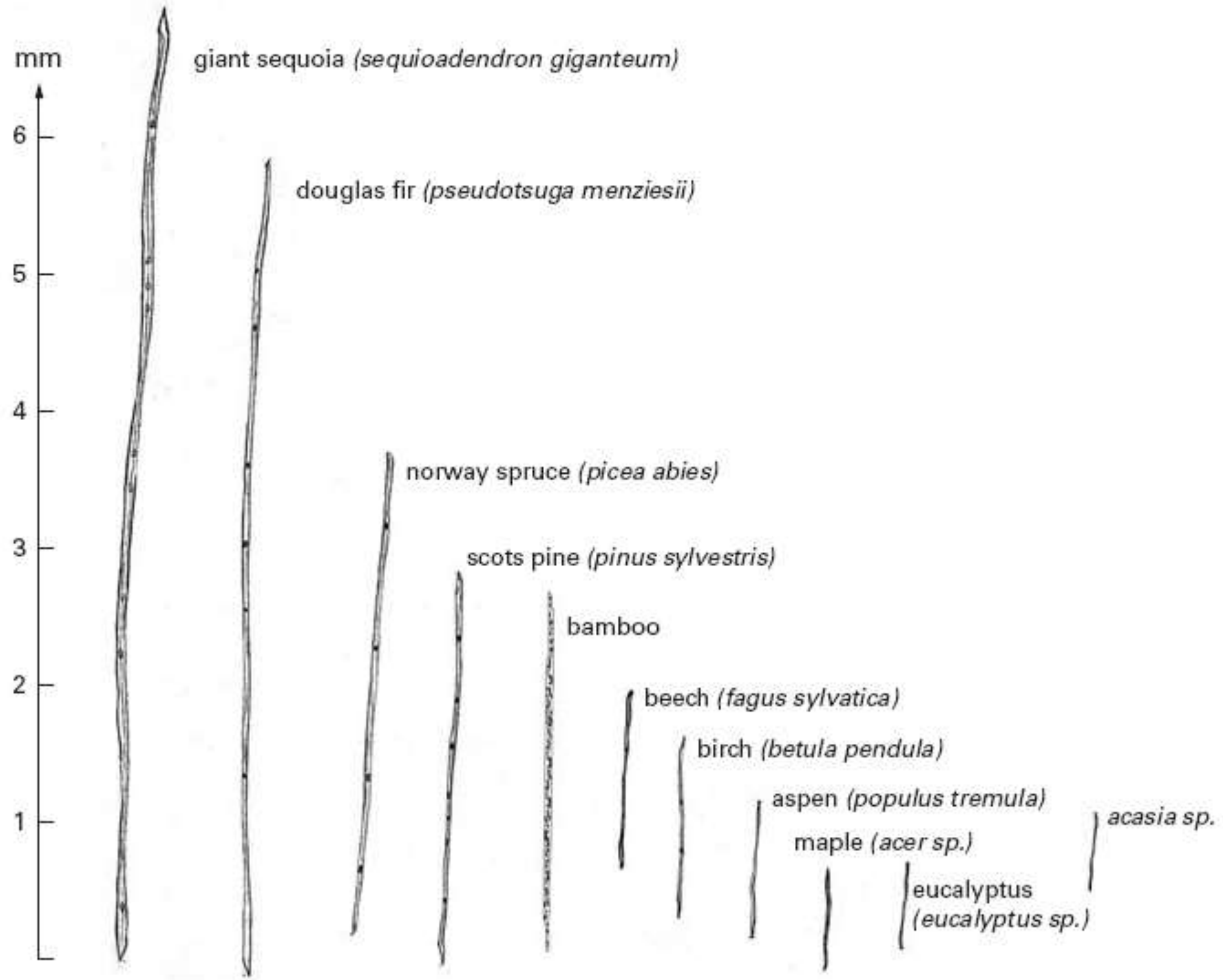
Typical Fiber Morphology



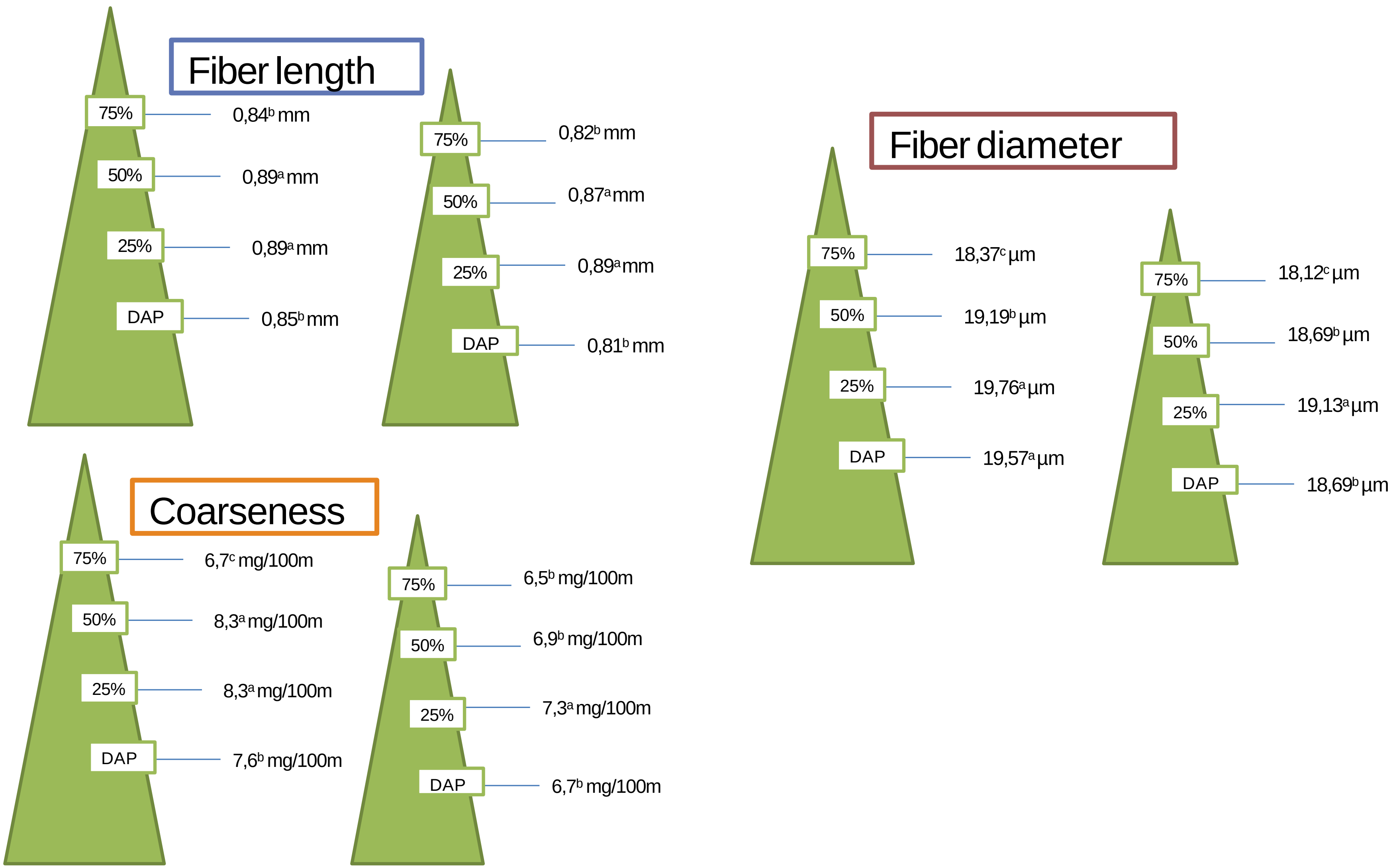
Hardwood vs. softwood cells



- ✓ Hardwood fibers are about 1/3 of the softwood fiber length (1 vs.3 mm) and 2/3 of softwood fiber thickness (20/30 µm).
- ✓ In addition, hardwood includes lot of vessel and ray cells, which can cause so called vessel picking and linting in offset printing.


mm
6
5
4
3
2
1
giant sequoia *(sequoiadendron giganteum)*
douglas fir *(pseudotsuga menziesii)*
norway spruce *(picea abies)*
scots pine *(pinus sylvestris)*
bamboo
beech *(fagus sylvatica)*
birch *(betula pendula)*
aspen *(populus tremula)*
acasia sp.
maple *(acer sp.)*
eucalyptus
(eucalyptus sp.)

Fiber characteristics: Height sampling



Fibre Dimensions, Basic Density, and Chemical Composition of Wood

Fiber and Chemical Characteristics	Wood	Bark	Tops
Density, kg/m^3	602.8	387.6	588.8
Mean fibre length, mm	0.98	1.12	0.91
Fibre width, μm	18.8	18.1	16.2
Wall thickness, μm	4.9	7.0	5.0
Chemical composition,%			
Ash	1.0	2.9	1.0
Non-polar extractives	1.4	1.3	2.0
Polar extractives	1.6	5.3	1.7
Insoluble lignin	17.8	16.9	18.8
Cellulose	56.9	56.0	52.8
Pentosans	21.7	23.7	17.7
1% NaOH solubility	12.2	19.9	14.4

Wood and fiber properties

- The big difference between softwoods and hardwoods is amount of real fibers (tracheids). Only tracheids can form fiber network and help papermaking.
- Biggest problem with nonwood fibers is low share of real fibers (commonly less than 50%).

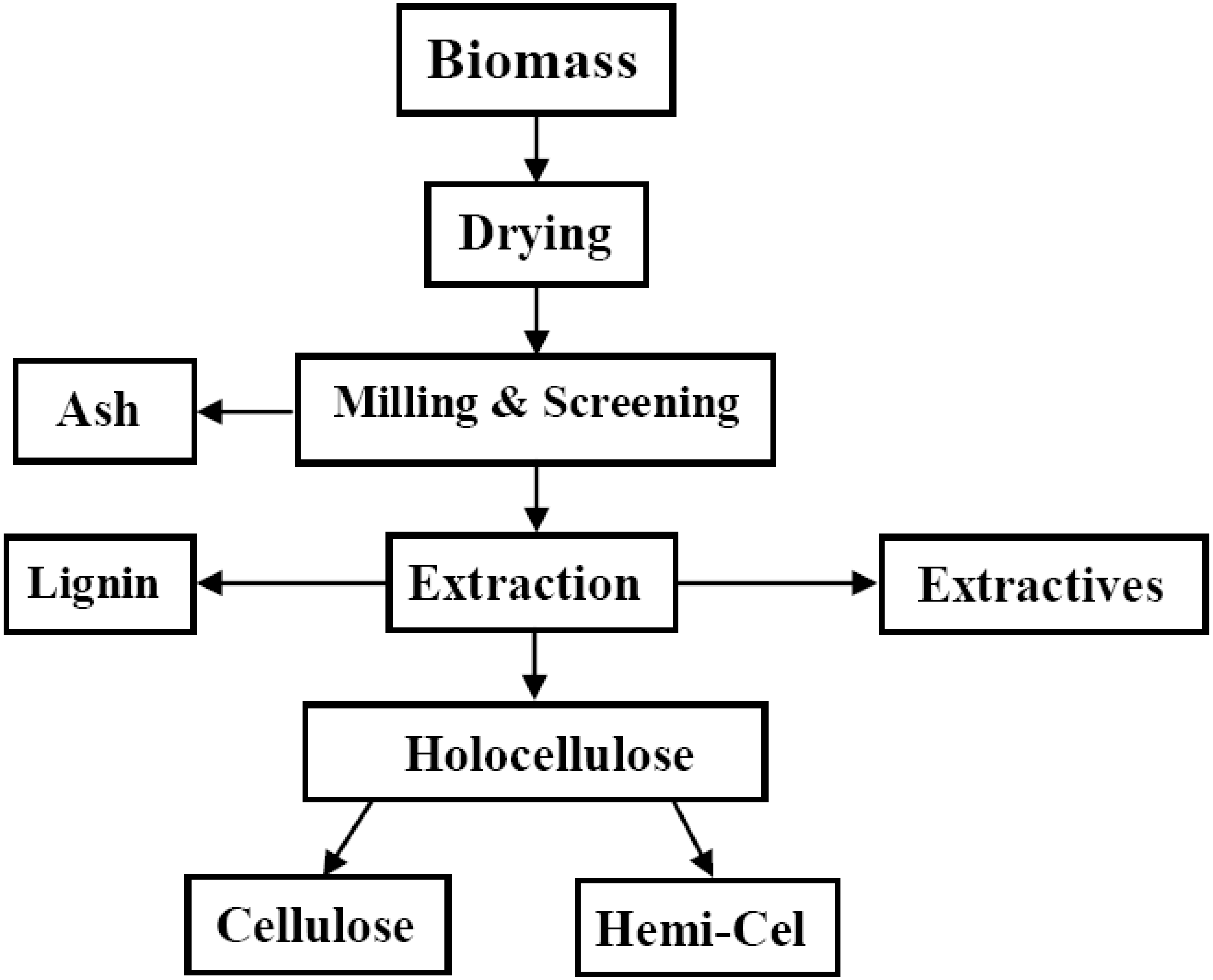
Wood properties	**Unit**	**Picea abies**	**Pinus sylvestris**	**Pinus radiata**	**Populus tremula**	**Betula pendula**	**Eucalyptus globulus**
Amount of wood volume							
Fibers (tracheids)	%	95	93	89	61	65	49
Vessels	%	0	0	0	26	25	21
Ray cells etc.	%	5	7	11	13	10	30
Average fiber dimensions							
Length	mm	3,3	3,1	3,3	1.0	1.1	1.0
Diameter	µm	31	30	40	20	21	16
Cell wall thickness	µm	3,1	3,0	7,0	3,2	3,8	3,8
2 x cell wall/width	%	20	20	35	32	36	48
Wood Density (dried)	kg/m^3	405	550	515	450	640	820

Structure of Wood

Microstructure: Chemical composition

- All wood is composed of cellulose, lignin, hemicelluloses and minor amounts of extraneous materials contained in a cellular structure. Variations in the characteristics and volume of these components and differences in cellular structure make the wood heavy or light, stiff or flexible, hard or soft.
- **Cellulose,** the major component, constitutes approximately 50% of the wood, by weight. It is a high-molecular-weight linear-polymer built from the glucose monomer. During growth the cellulose molecules are arranged into strands called fibrils (bonded by a combination of hydrogen and van der Waals bonding), which make up the cell walls of the word fibres. Most of the cell wall cellulose is crystalline.
- **Lignin** constitutes 23-33% of the softwood and 16-25% of the hardwood. It is the cementing agent that binds the cells together. Lignin is a three-dimensional phenylpropanol polymer.
- **Hemicelluloses** are branched, low-molecular-weight polymers.
- **Extraneous materials** in wood include oils, resins, fats, calcium, potassium and magnesium.

Scheme of chemical analysis of biomass



Significance of chemical analysis of biomass

- ✓ The **α-cellulose** indicates undegraded, higher-molecular-weight cellulose content in biomass.
- ✓ The **β-cellulose** indicates that of a degraded cellulose.
- ✓ The **γ-cellulose** consists mainly of hemi-cellulose.
- ✓ **Holo-cellulose** is mixture of cellulose and hemi-cellulose in wood
- ✓ The **lignin** represents "incrusting material" forming a part of the cell wall and middle lamella in wood. It is an aromatic, amorphous substance containing phenolic methoxyl, hydroxyl, and other constituent groups.
- ✓ The **cold-water** procedure removes a part of extraneous components, such as inorganic compounds, tannins, gums, sugars, and coloring matter present in wood and pulp.
- ✓ The **hot-water** procedure removes, in addition, starches.

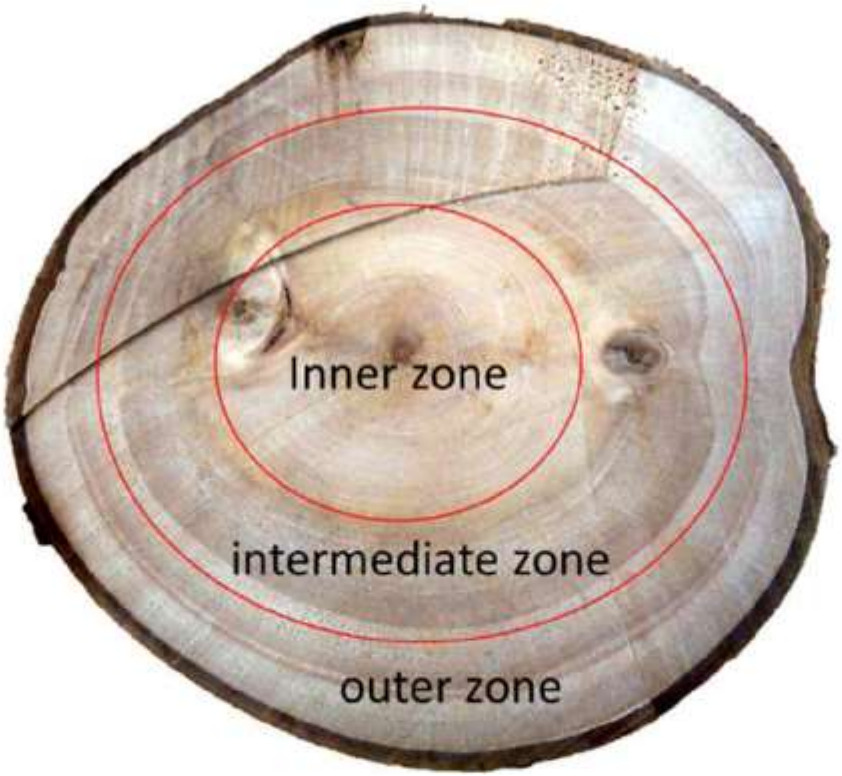
Continue…..

- **Extractives** in wood consist of those components that are soluble in neutral organic solvents. The amount of solvent extractable matter is markedly influenced by staking or drying of the wood.
- The **dichloromethane-extractable** content of wood is a measure of such substances as waxes, fats, resins, sterols and non-volatile hydrocarbons.
- The **ethanol-benzene extractable** content of wood consists of certain other dichloromethane-insoluble components, such as low-molecular-weight carbohydrates, salts, polyphenols and other water-soluble compounds .
- **Hot alkali** solution extracts low-molecular-weight carbohydrates consisting mainly of hemi-cellulose and degraded cellulose in wood and pulp.
- The **solubility of wood** indicate the degree of a fungus decay or of degradation by heat, light, oxidation, etc.

Chemical composition of wood

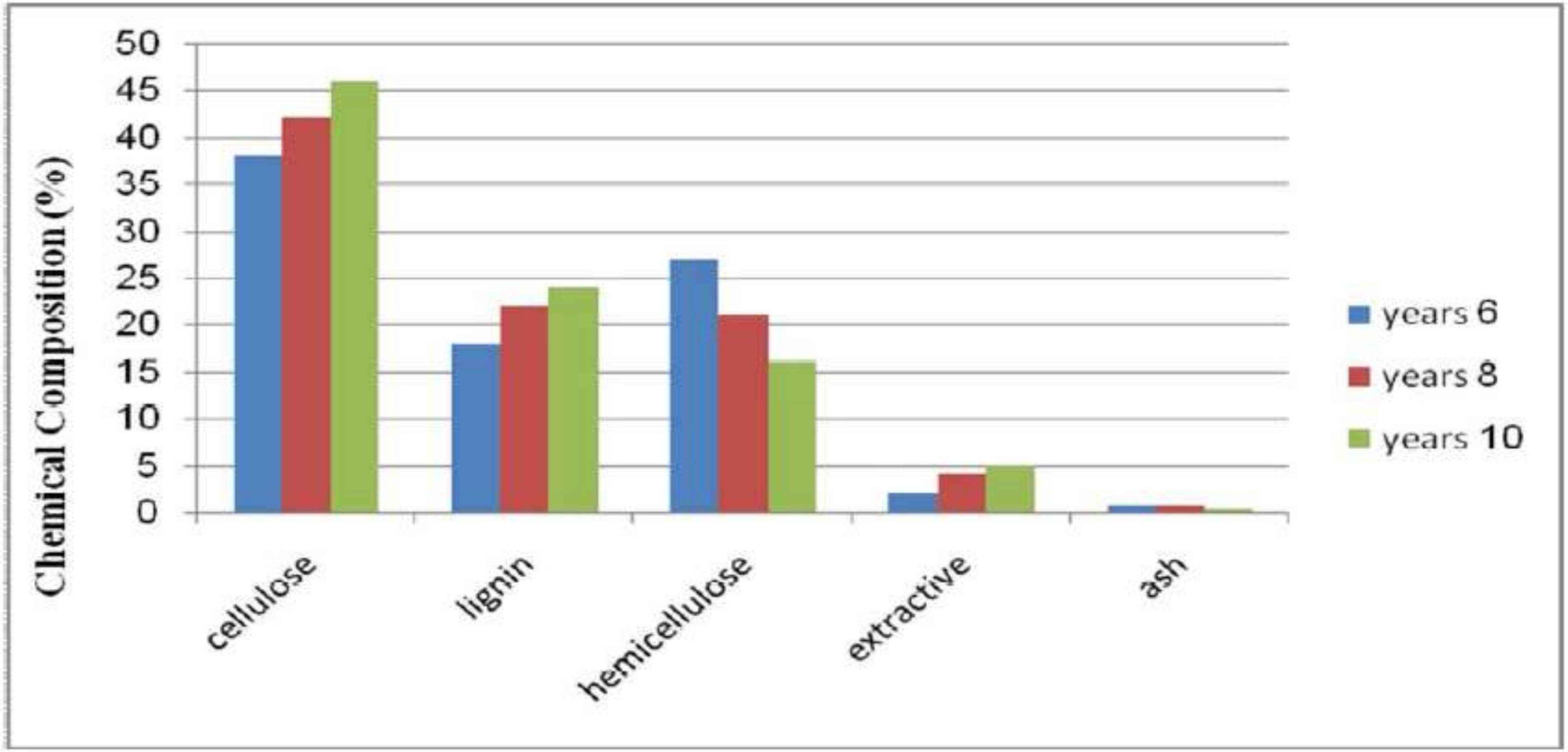
Common Name	Holo Cellulose	Alpha Cellulose	Pentosans	Klason Lignin	Solubility: 1% NaOH	Solubility: Hot Water	Solubility: EtOH/Benzene	Solubility: Ether	Ash
Hardwood									
Red alder	74	44	20	24	16	3	2	0.5	0.3
Yellow birch	73	47	23	21	16	2	2	1.2	0.7
American beech	77	49	20	22	14	2	2	0.8	0.4
White poplar	N/A	52	23	16	20	4	5	0.9	N/A
White oak	67	47	20	27	19	6	3	0.5	0.4
Eucalyptus Kirtoniana	74	50	15	28	14	3	2	0.3	0.1
Eucalyptus Urophylla	N/A	53	19	24	17	2	2	N/A	0.4
Casurina	70.9	N/A	18.5	25.7	14	3.6	1.2	N/A	0.35
Subabul	70.2	N/A	18.3	26.7	10.7	4.4	2.9	N/A	0.5
Acasia confusa	87	54	19	19	21	7	6	1.5	0.4
Softwood									
White fir	66	49	6	28	13	5	2	0.3	0.4
Subalpine fir	67	46	9	29	12	3	3	0.6	0.5
Noble fir	61	43	9	29	10	2	3	0.6	0.4
Lodgepole pine	68	45	10	26	13	4	3	1.6	0.3
Shortleaf pine	69	45	12	28	12	2	4	2.9	0.4
Slash pine	64	46	11	27	13	3	4	3.3	0.2
Western hemlock	67	42	9	29	14	4	4	0.5	0.4
Mountain hemlock	60	43	7	27	12	5	5	0.9	0.5

Eucalyptus cross sectional chemical analysis



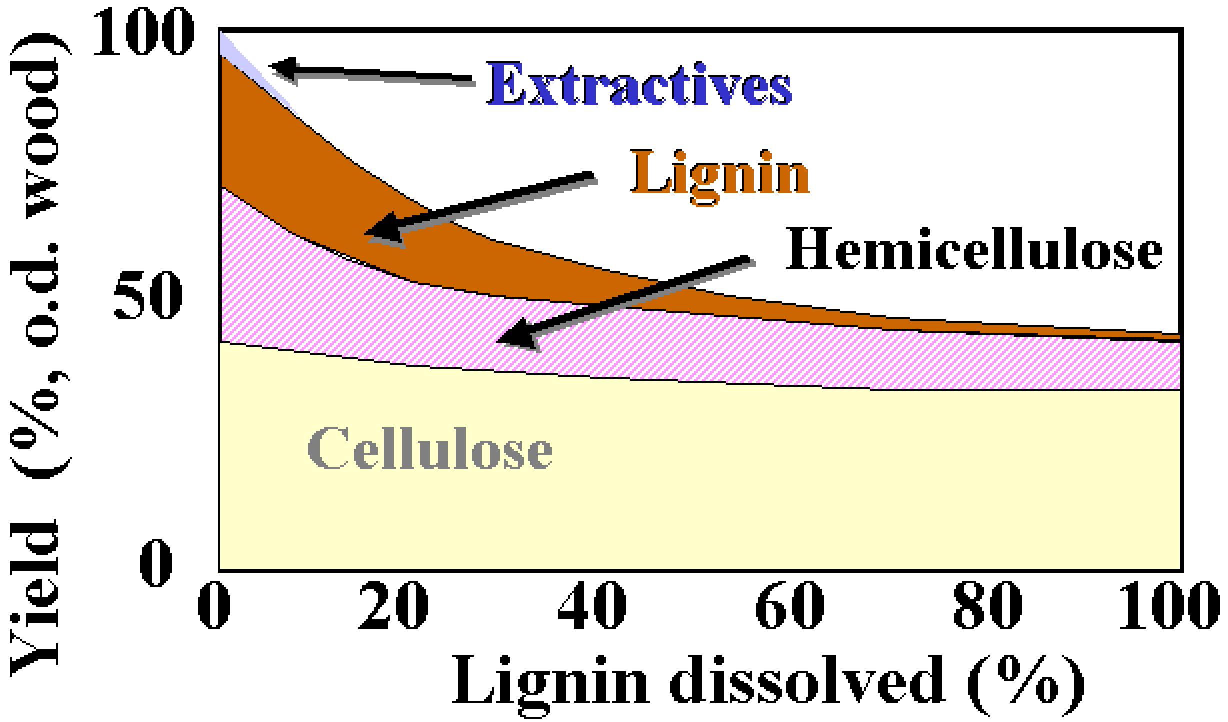
Particulars	Inner zone	Intermediate zone	Outer zone
pH	4.5	5	5.4
Holo cellulose (%)	79.2	78.57	78.86
Lignin(%)	20.98	21.43	21.14
Water soluble(%)	1.73	1.56	4.24
1 % NaOH soluble(%)	14.25	10.52	12.02
Alcohol -benzene Soluble(%)	13.8	12.13	11.72
Ash (%)	0.32	0.52	0.54

Age effect :Chemical composition



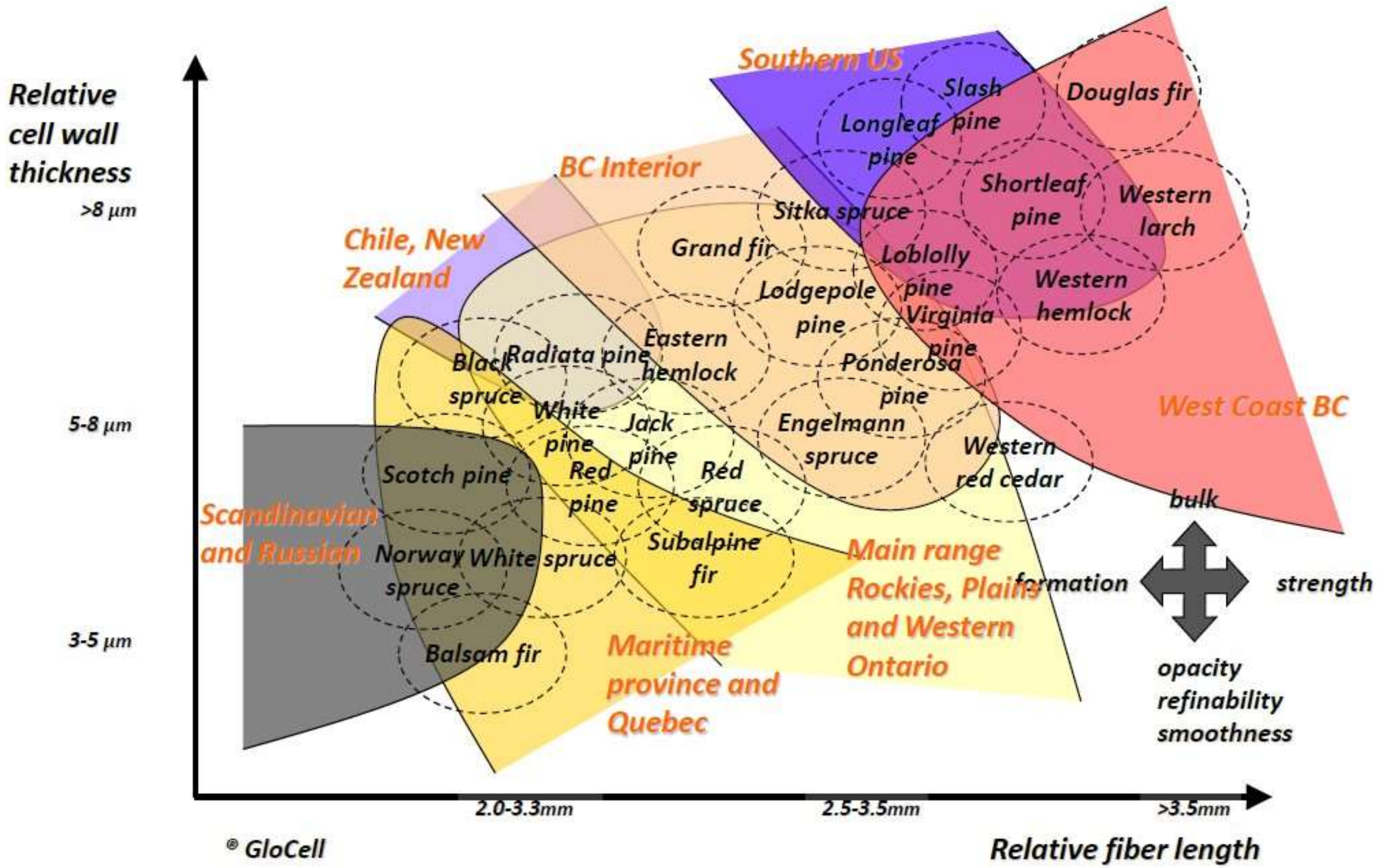
Eucalyptus camledulnnesis

Fiber composition depends on extent of pulping & bleaching.

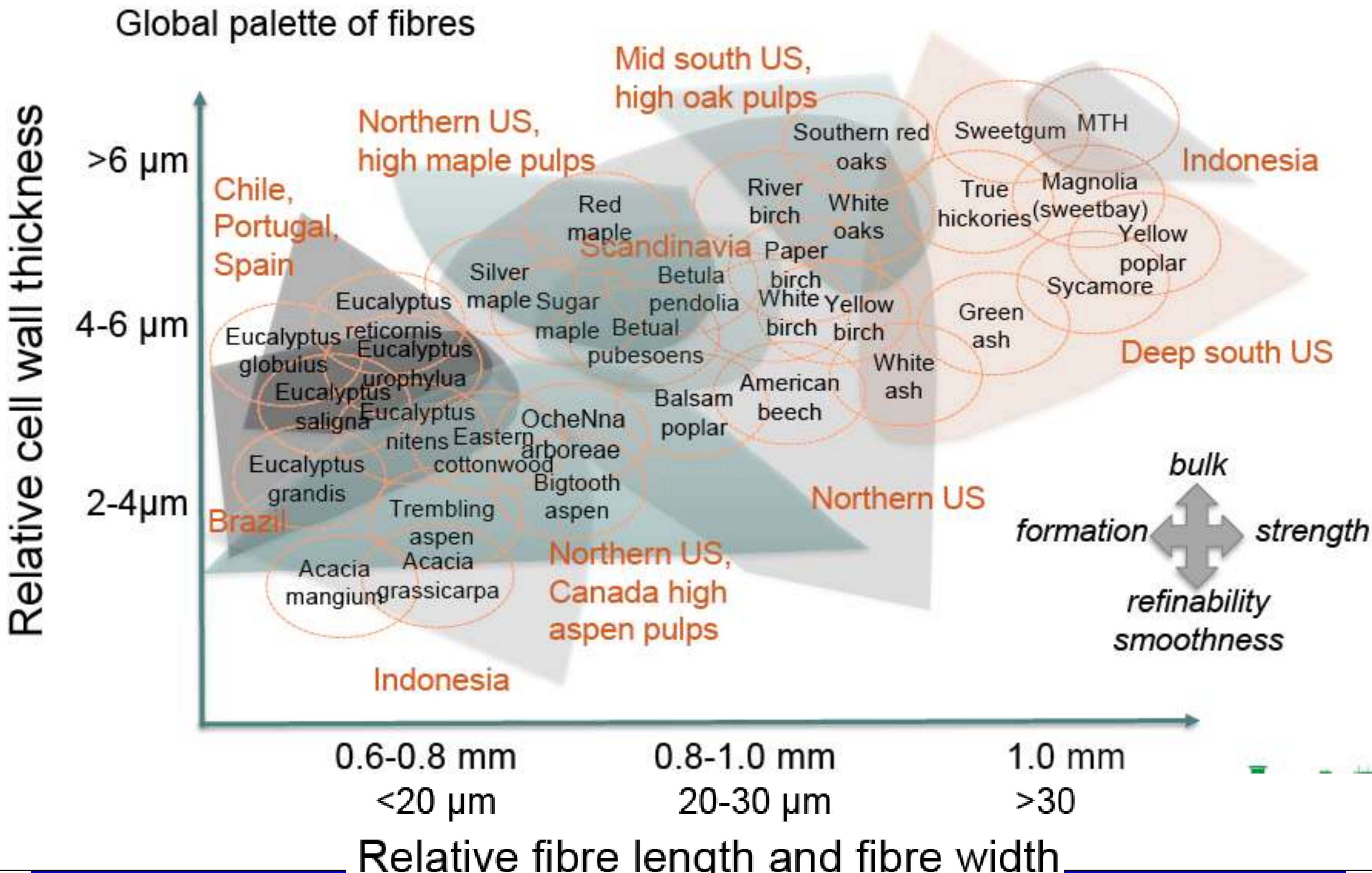


Proc. TAPPI 1997 Kraft Pulping Short Course, 47.

Example of softwood fiber basket



HW Fiber Basket: A Large Selection



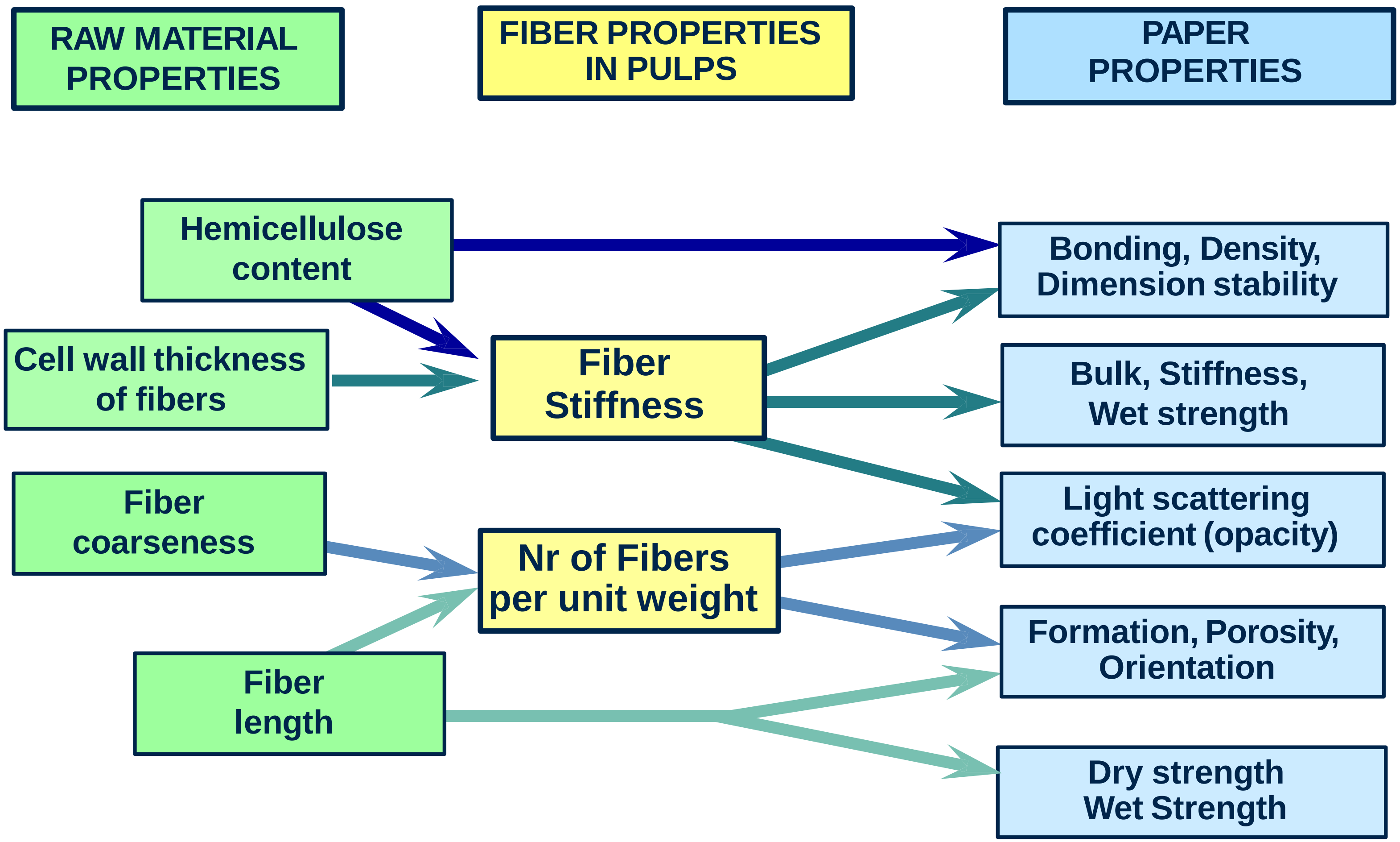
Roles of different papermaking pulps

- **Softwood chemical pulps**
  - Wet and dry runnability for papermaking, finishing and converting
  - Ensuring strength and stiffness for packaging materials
- **Hardwood chemical pulps**
  - Good end use properties of woodfree printing papers and tissues
  - Good formation, brightness, opacity and printability
  - Decrease the costs of the fiber furnish
- **Mechanical pulps**
  - Good runnability and end use properties of mechanical grades
  - Formation, printability
  - Better yield and lower costs of the fiber furnish
  - Bulk and stiffness, especially for filler ply of multilayer products
- **Recycled and nonwood pulps**
  - Decrease fiber furnish costs, can be more environmentally friendly
  - Enlarge the raw material base for papermaking

Roles of different raw materials

- **Fillers and coating pigments**
  - Improve the end use printability properties of paper
  - Decrease costs, carbonate widely available
  - Save forests
- **Additives**
  - Improve the papermaking process (performance chemicals)
  - Improve the end use properties of the paper (functional chemicals)
- **The desired paper properties can be obtained by**
  - Selecting the proper furnish components
  - Adjusting the fiber furnish composition
  - Adjusting the properties of the different fiber furnish components used
  - Properly controlling the total papermaking and finishing processes

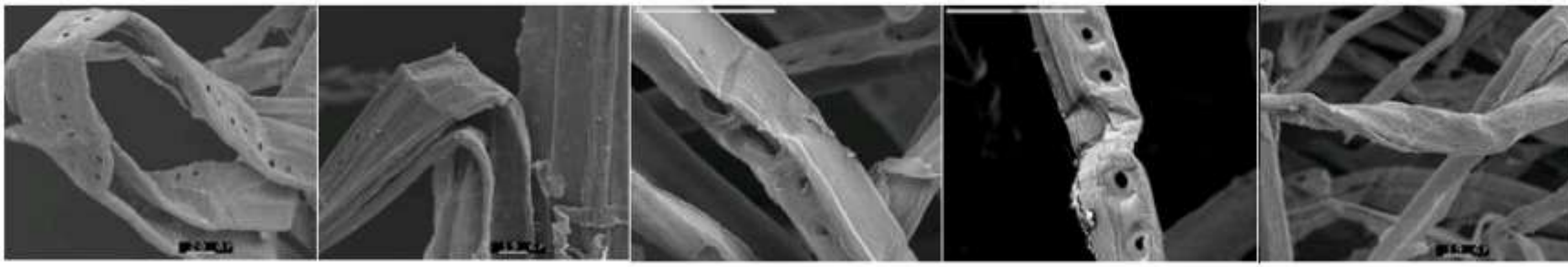
Wood, fiber and paper properties



Pulping and fiber wall strength

- ✓Fiber wall is like a brick wall. In the wood the strong cellulose groups are surrounded with lignin and hemi-cellulose.
- ✓During cooking the wall looses most of lignin and hemicelluloses.
- ✓There will be lot of porosity in the structure and it is vulnerable to mechanical forces in the following processes.
- ✓At the end of cooking more than 50 % of the wall volume is dissolved.
- ✓Fiber length can be original, but coarseness is only half and strength of individual fiber is much less than in the beginning

Defects and failure zones in fibers



Curl Kink Dislocation Microcompression Twist

- ✓Examples of non-homogeneous zones in fibers include curl, kink, dislocation, micro-compression and twist.
- ✓In mill operation, fiber damages can be induced accidentally or intentionally, by shearing at high consistency. Some pulps are highly susceptible to damages, others are more resistant.
- ✓The most important damage might be curl which is not necessarily stable. It is readily removed from some pulps but not from others. Curl can be stabilized by certain treatments, notably by heat treatment at high consistency.
- ✓Curl and other damages are often disregarded because they cannot be easily measured. Yet in practice their effects often dominate the properties of pulp suspensions, wet webs and dry sheets. Ignoring these effects has led to costly surprises, both in research and mill operation.

Pulps and paper grades

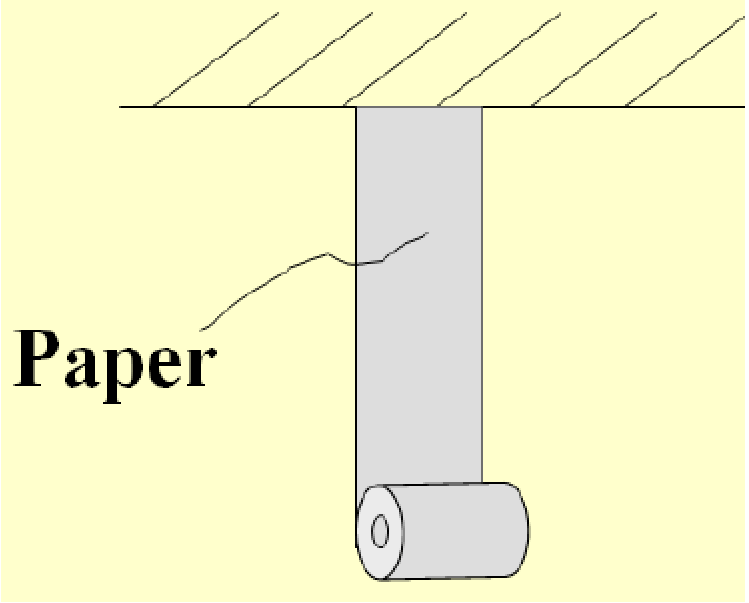
- Actual fiber furnishes may vary largely and can be quite different especially in small unintegrated paper mills
- Very often ***the price of fiber seems to be more important than the performance of fiber*** in the product; within each end-product the quality and the price of end-products may vary largely
- It is important to understand how each furnish component contributes the quality of the product and the performance in the paper machine, finishing, and converting

Paper Grades	Short fibers for printability	Long fibers for runnability
Mechanical grades	GW, PGW, TMP, BCTMP, DIP	Long fiber softwood (BSKP)
Woodfree grades	BHKP, DIP	
Non-wood grades	Several non-woods (bagasse, wheat straw etc.)	Bamboo, kenaf etc.

Breaking lengths of some materials

Breaking length is a very good measure of material strength because it takes the density of the material into account. The following list of breaking lengths is interesting:

✓Graphite	37 km
✓Eastern white pine wood	23
✓Paper from bleached softwood	8-10
✓Steel	4.5
✓Aluminum	3.4
✓Newsprint	2-5

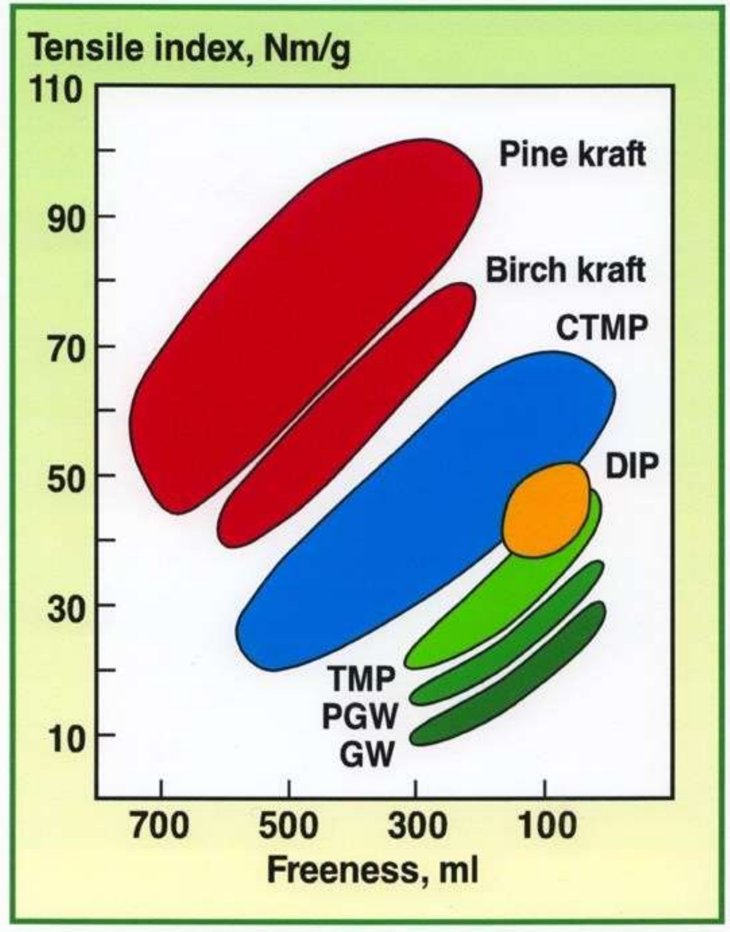


❖We can notice that wood strength is more than double compared to softwood paper strength which is about double to steel strength.

❖There is good potential to improve paper strength closer to wood strength.

Tensile strength of different pulps

- DIP has normally better tensile strength than TMP even if it contains filler.
- Standard newsprint contains 50-100 % DIP.
- TMP fibers of Pinus radiata are coarse and tend to form bulky, low tensile and porous sheet.
- Tensile index of all pulps improve when pulp is made to lower freeness.



Why Refine?

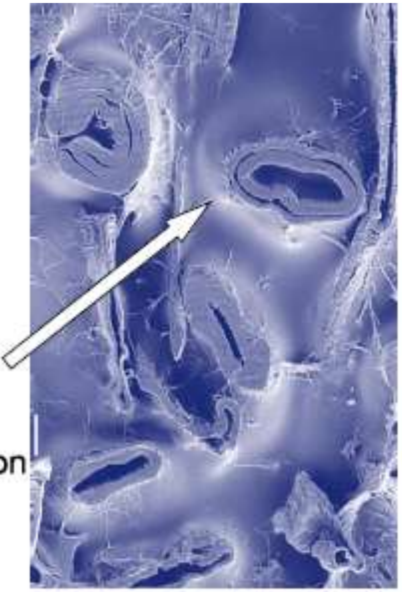
- ✓ Refining is the only piece of equipment that mechanically modifies the structure of fibers
- ✓ Changing the fiber structure yields changes in sheet structure & properties

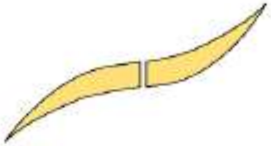
Strength	Formation	Drainage	Runnability
Tensile	Opacity	Couch Vacuum	Machine Speed
Tear	Formation	Freeness	Breaks
Burst	Smoothness	Press Solids	Dry-ability
STFI	Porosity	Etc.	Etc.
Plybond	Density		
Ring Crush	Etc.		
Concora			
Etc			

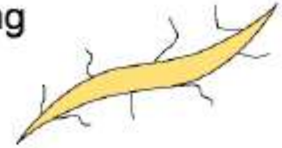
Why refining?

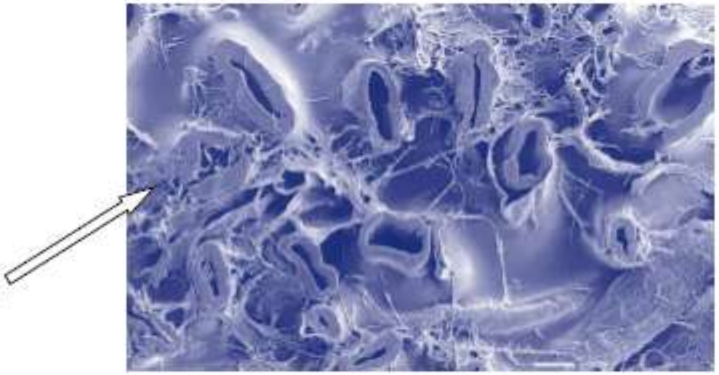
- Refining
  - Process engineering → milling process
  - Pulp and paper industry → forming process

- Through refining, fibres are…
  - internally fibrillated → higher flexibility
  - externally fibrillated → fines production, higher bonding area
  - long fibres are shortened
  - ideally, short fibres are not affected
  - better fibre-fibre bonding



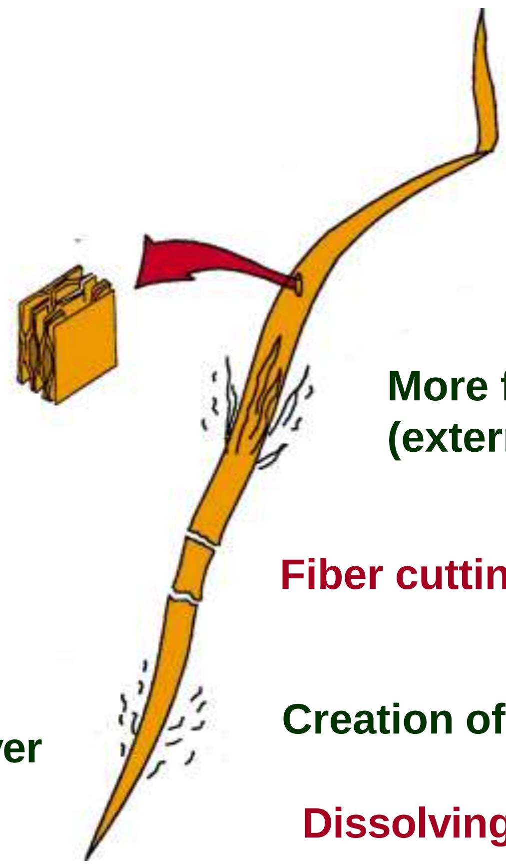






Effects of refining on fibers

- Internal and external fibrillations as well as creation of fines are the main positive effects of refining.



Delamination and swelling of fibers (internal fibrillation)

More fiber hairiness (external fibrillation)

Straightening of fibers

Fiber cutting and shortening

Removal of primary fiber wall and S1 layer

Creation of fines

Dissolving of material

Effects of the refining

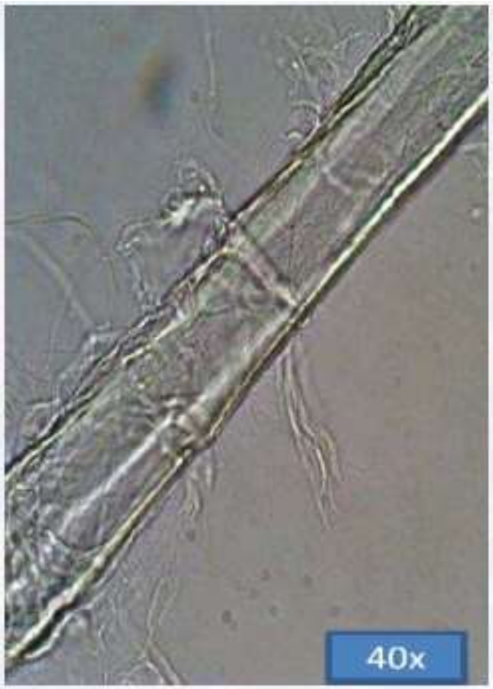
- Cutting or shortening of fibres.
- Production of fines and complex removal of parts of the fibre wall, creating fragments in the suspension.
- External fibrillation. Partial removal of the fibre wall. The parts are still attached to the fibre.
- Internal changes in the wall structure. This is described by delamination, internal fibrillation or swelling.
- Curling/Straightening of fibres.
- Inducing/Removal of kinks, nodes, slip planes and micro compressions in the fibre-wall.
- Dissolving or leaching out colloidal material into the external liquor.
- Redistribution of hemicelluloses from the interior of the fibre to the exterior parts.
- Scrub the surface at the molecular level to produce surface with a gel consistency of the surface.

Fiber Bonding

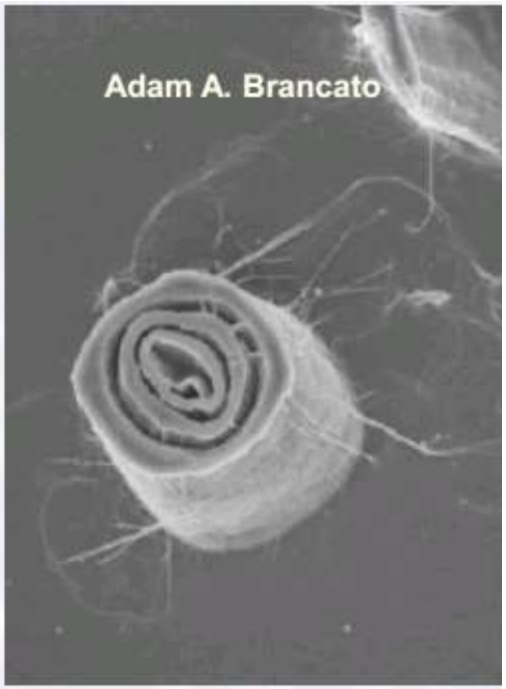
Fibrillation effects on fibers

Target of a good refining is to get external fibrillation (hairy surface and fibril fines) and internal fibrillation (delamination of fiber layers).

Unrefined softwood



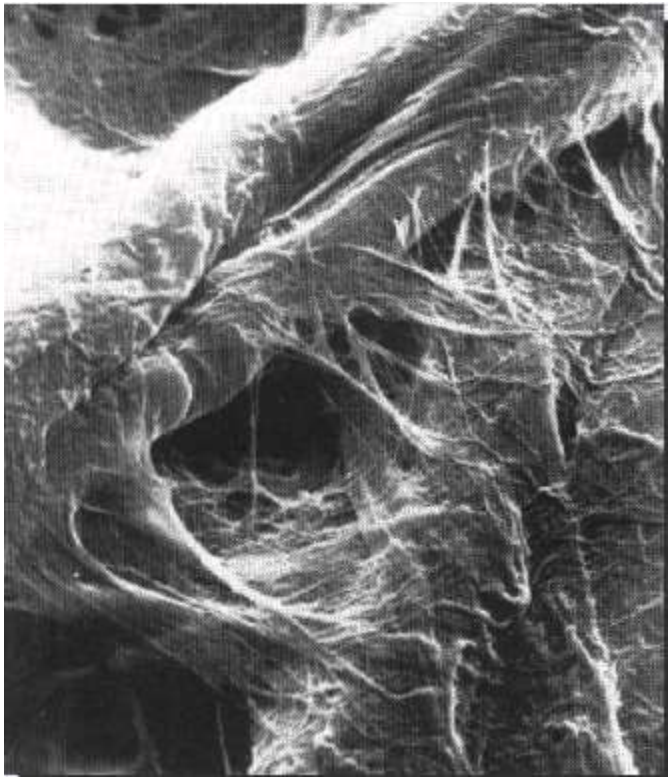
Refined hairy softwood



Delaminated hairy fiber

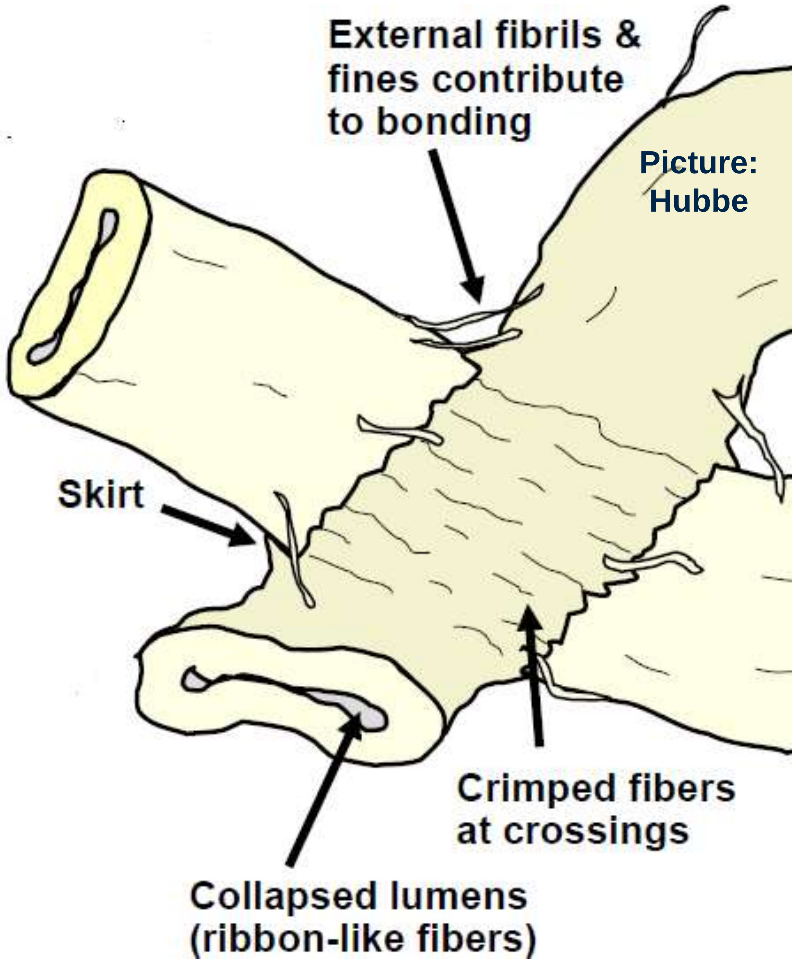
Bonding of refined fibres

- ✓ External fibrillation can make very long bonds compared to fiber thickness.
- ✓ There are more bonds in fiber crossings.
- ✓ Good bonding requires fiber flexibility and lumen collapse to get more intimate contact.
- ✓ Fiber fines and higher surface tension enhance bonding especially at fiber crossings.
- ✓ Curled fibers decrease relative bonded area by geometrically preventing bonding. Low consistency refining straightens fibers.
- ✓ Electrostatic environment in refining can have a large effect on internal fibrillation and refining result.



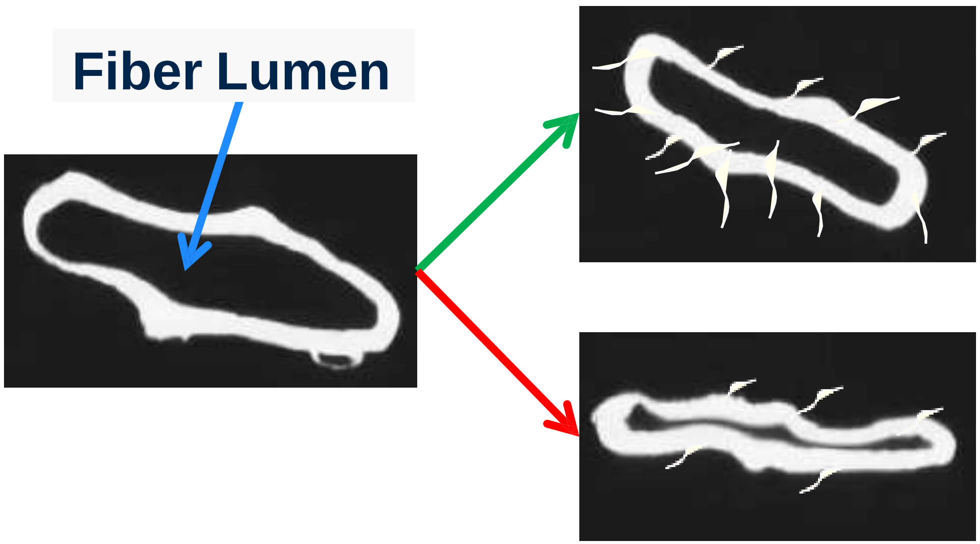
Final bonding in paper

- Picture on the right describes bonded fibers after refining and drying.
- External fibrils and fines from refining are an important part of bonding.
- Secondary fines (fibrillar) has the most positive effects.
- Collapsed lumen in the ribbon-like fibers increase bonded area.
- Crimped section at fiber crossings have effect on the rheological behavior of paper.



Paper density and strength

- How to get bonding without density increase? Dry strength chemicals, surface sizing and micro-fibrilled cellulose are some possibilities.
- Gentle refining or low Specific Edge Load (SEL) gives good bulk and bonding at the same time. Low SEL for never dried hardwood is < 0.5 J/m.



More external fibrillation, not collapsed – good bulk and bonding

More internal fibrillation, collapsed – good bonding but low bulk

Fiber collapse and paper properties

- Differences in relative cell wall thickness have effect on paper properties.
- An example here is Pinus radiata compared to Norway spruce. TMP fibers of Pinus radiata are coarse and tend to form bulky, low tensile and porous sheet with reduced coating and ink holdout.
- Spruce fibers have lot of thin-walled early wood fibers, which form more dense, smooth and strong paper.
- Dense paper, however, can have lower light scattering and stiffness.
- From hardwoods eucalyptus is more thick-walled while birch and acacia are more thin-walled.

Pinus radiata

Norway spruce

Fiber collapse and flexibility

- It is important to increase flexibility and collapsibility of thick-walled fibers.
- The main means to improve collapsibility is refining.
- When using stratified headbox it is possible to fractionate fibers and put coarse fraction to the middle layer.

Good fiber for printing paper

Suitable fiber for tissue, copy paper and cartonboard middle ply

Effect of chemical pulp refining on paper

Positive effects

- Wet web strength □
- Fiber bonding and strength □
- Better formation
- Coating coverage □
- Porosity and ink demand □
- Smoothness and gloss □

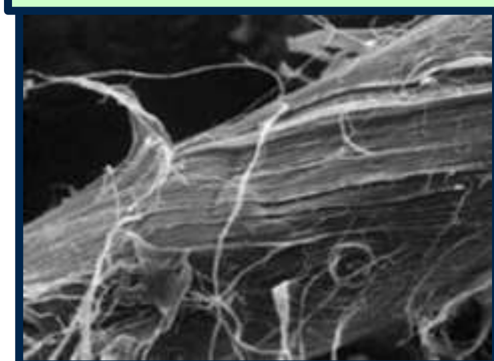
Negative effects

- Water removal and solids content □
- Bulk and stiffness □
- Paper compressibility □
- Opacity and brightness □
- Drying shrinkage □ dimension stability □
- Tear strength □□
- Energy consumption □
- CAPEX and maintenance costs □

Internal fibrillation

+

External fibrillation



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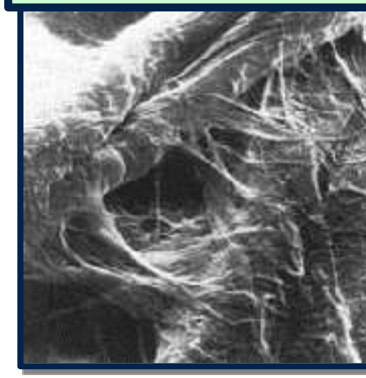
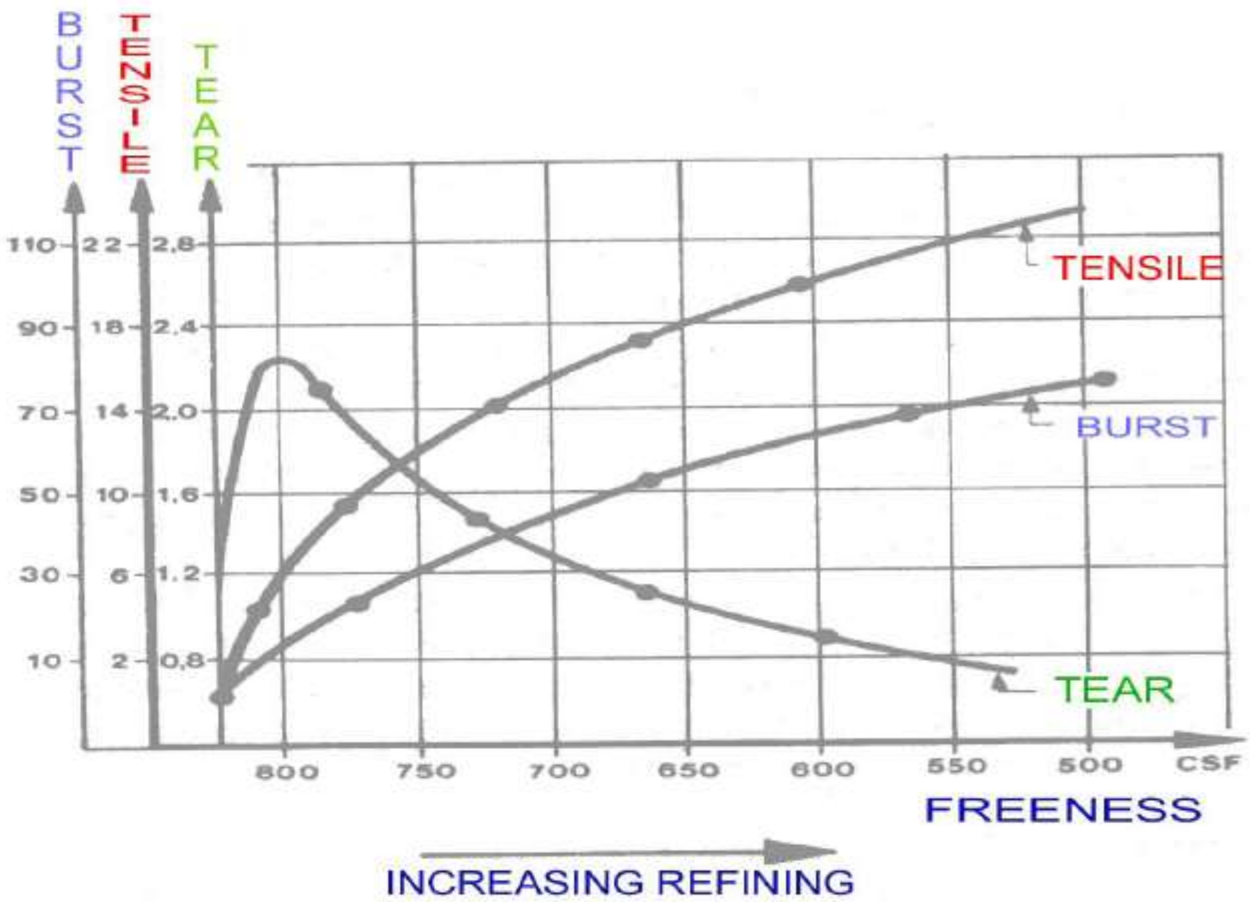
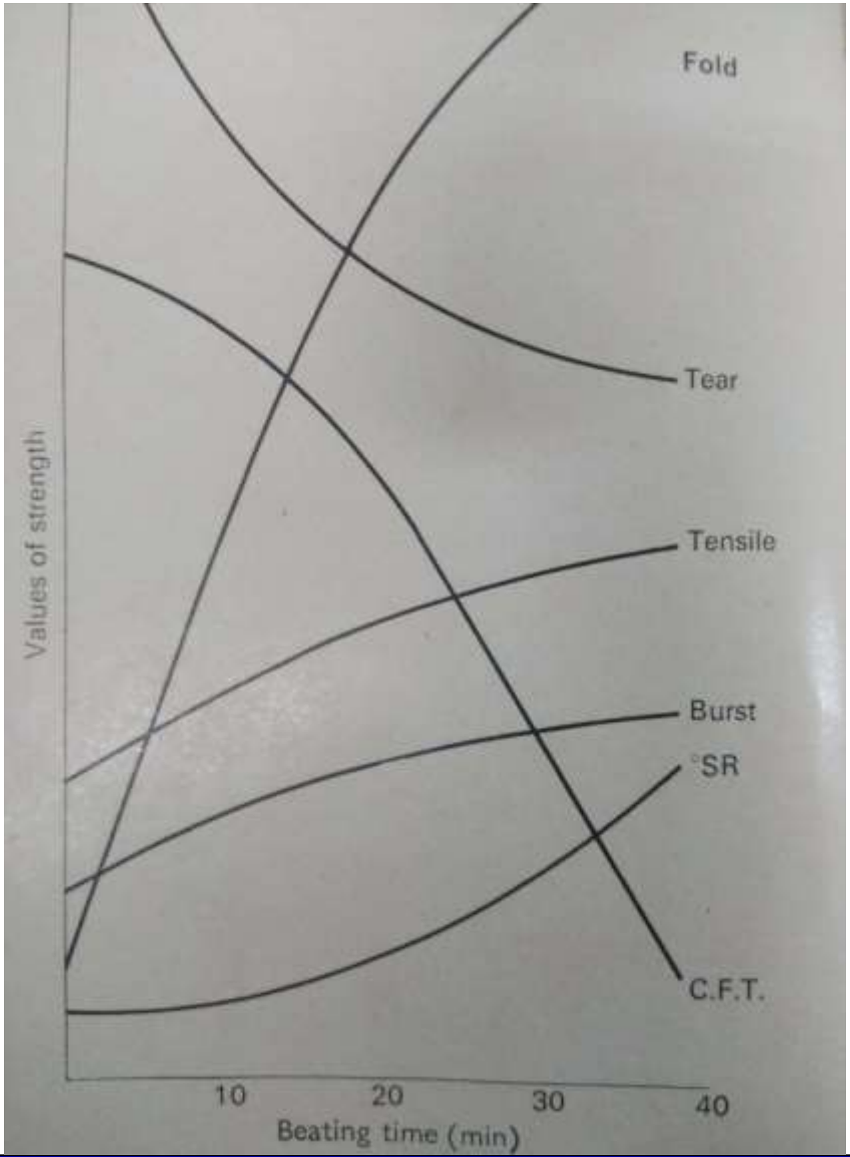
Fiber bonding



Typical strength development during refining

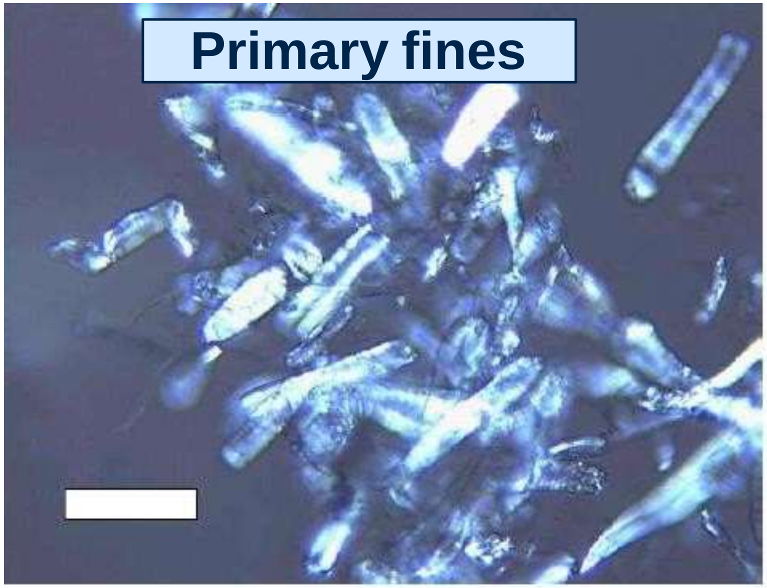


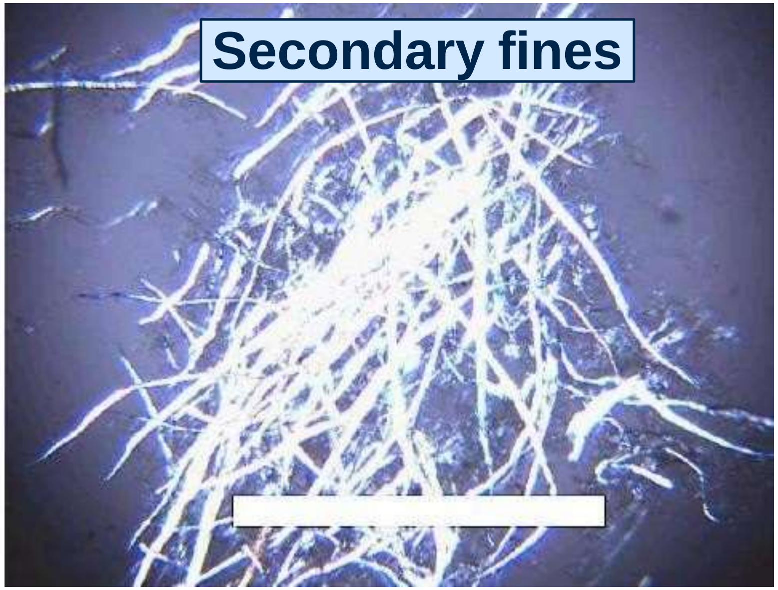
Effect of refining on various paper properties



Primary and secondary fines of hardwood

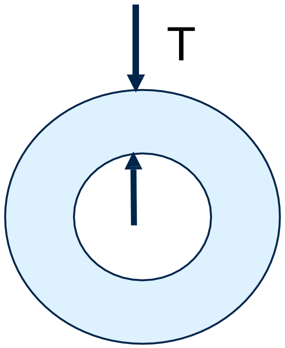
- Primary fines of hardwood pulp (ray and vessel cells) cause picking, linting and reduce bonding.
- Secondary fines formed in refining is mostly thin fibrils and enhance bonding.

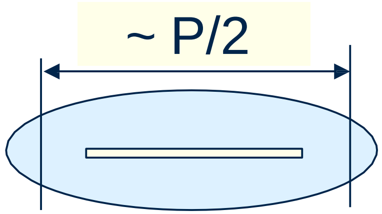




Importance of fiber wall thickness

- It is important to have several fiber layers in a thin paper to get good formation, smoothness, opacity and gloss. This correlates with thin fiber wall.
- Fiber wall of Norway spruce is about 2 µm while Radiata pine has 4-6 µm. In a 40 gsm paper there can be only 3-4 fibers of Pinus radiata in the total paper thickness.





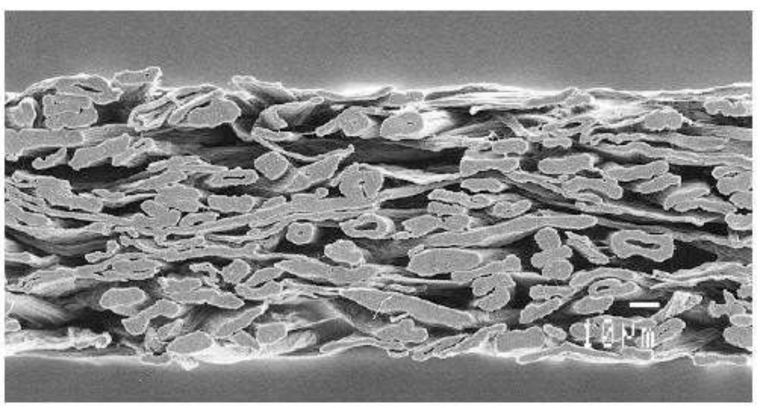
Wall density ~ 1500 kg/m^3

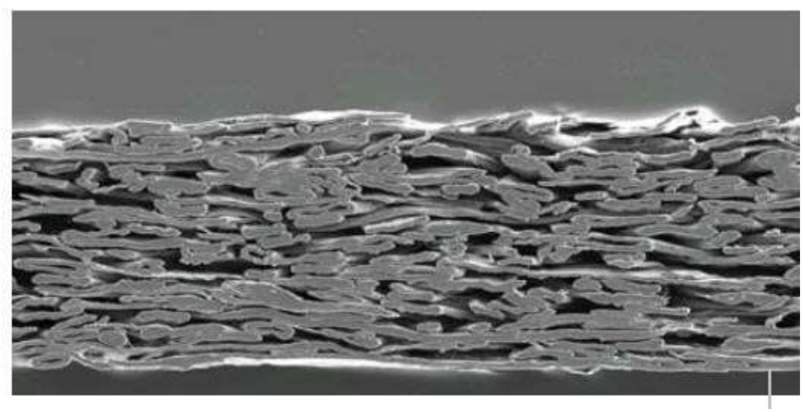
Fiber Wall µm	Fiber Grammage g/m^2
1	3
2	6
3	9
4	12
5	15
6	18

Area = Perimeter x Wall Thickness, A=P*T
Fiber volume = Area x Length, V=A*L=P*T*L
Coarseness = Fiber weight/Length, C=W/L
C = Volume*Density/Length, C=V*ρ/L=P*T*L* ρ/L= P*T*ρ
Fiber Grammage (g/m^2) = Coarseness/fiber Width = P*T*ρ/P*2 = 2*T*ρ = 3*T (µm)

Hardwood chemical pulp

- For woodfree paper grades mainly hardwood kraft is used. Thick walled eucalyptus can be better than thin-walled or birch.
- On the left side paper is bulky and thicker giving better stiffness, which is important e.g. for copy paper.
- Thick-walled fibers are better in cartonboard middle ply because smoothness is not as important there as bulk and stiffness.

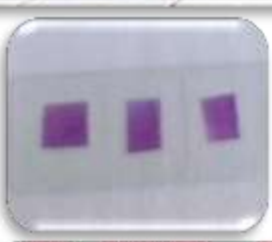


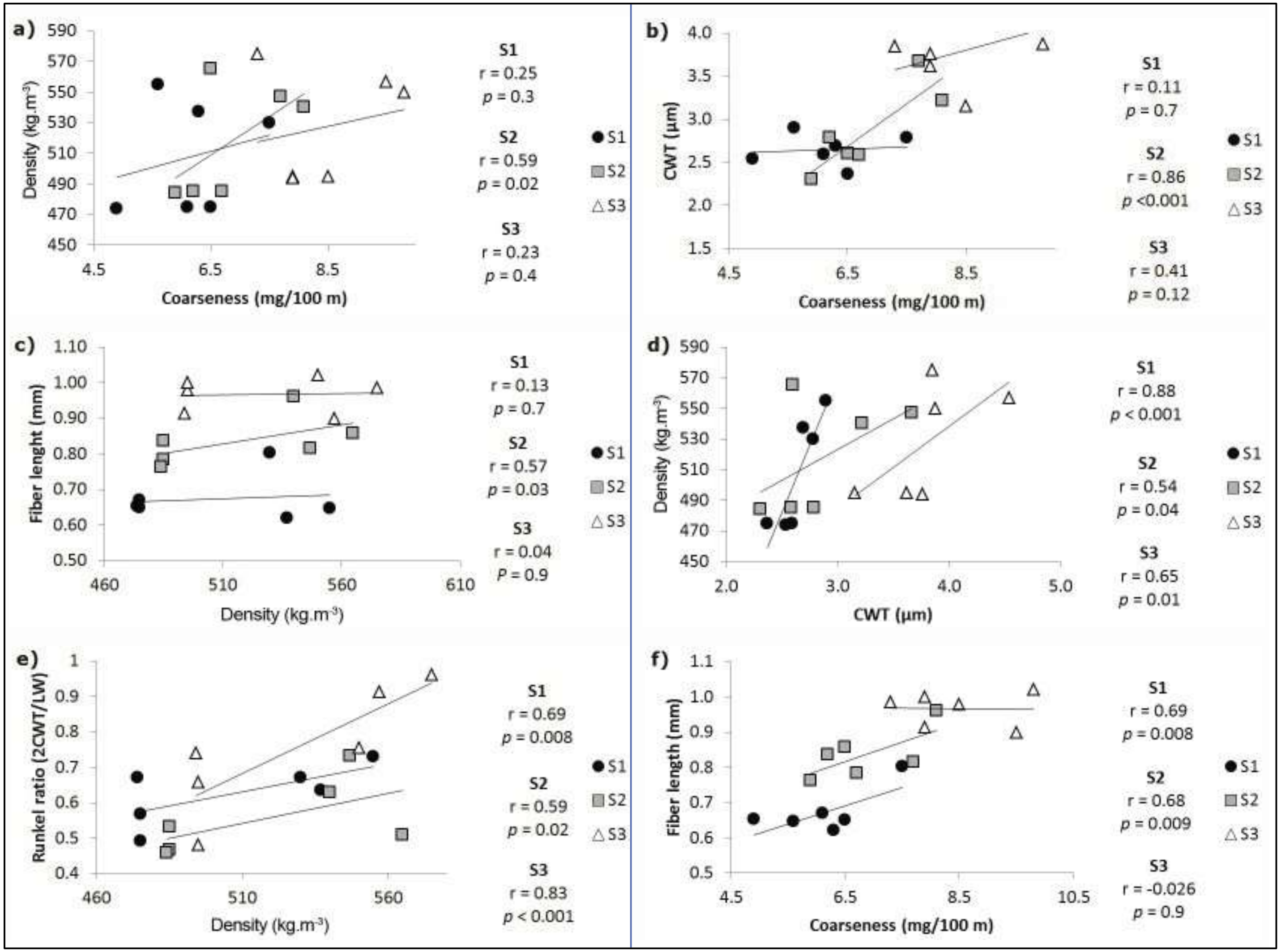


Paper properties affected by the thickness of the fibre-wall

Property	Latewood	Earlywood
Tear strength	+	
Porosity	+	
Dewatering	+	
Bending stiffness	+	
Tensile strength		+
Compression strength		+
Burst strength		+
Tensile stiffness		+
Stretch		+
Density		+

Correlations between different anatomical and fiber properties





Final thoughts…..

- ✓ We have a lot of information about anatomy of wood.
- ✓ Chemical and anatomical are associated with pulp yield and paper properties.
- ✓ In (near) the future this information can be used to increase the pulp and paper production.
- ✓ As well to generate tools to reduce losses at early stages.

THANK YOU