Transforming trees

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SIRT
Strategic Integrated Research in Timber

Forest Products Research Institute

A random walk through the forest

or how we guess the strength of wood

Dan Ridley-Ellis

Edinburgh Napier UNIVERSITY

The advantages of wood

- Environmental
- A vast range of species and properties
- Versatile
- Good strength to weight ratio
- Easily worked and easily repaired
- A good insulator
- Good shock absorption
- Attractive
- Can last a very long time

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The Stadthaus, Murray Grove, London

ARCHITECT: WAUGH THISTLETON ARCHITECTS **BUILDER/MAIN CONTRACTOR:** TELFORD HOMES PLC
STRUCTURAL ENGINEERS: TECHNIKER LTD **JOINERY:** KLH

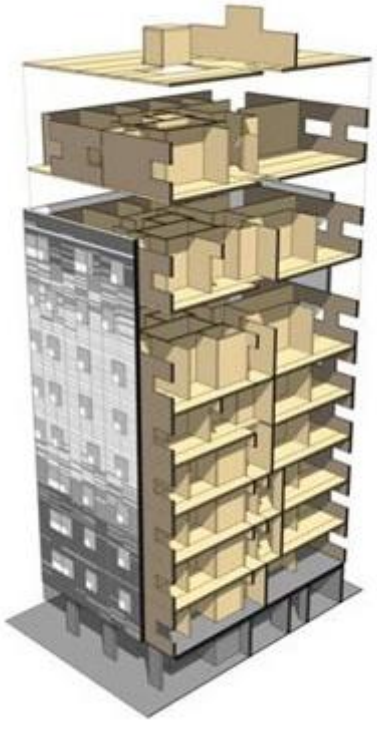

Image : wood for good

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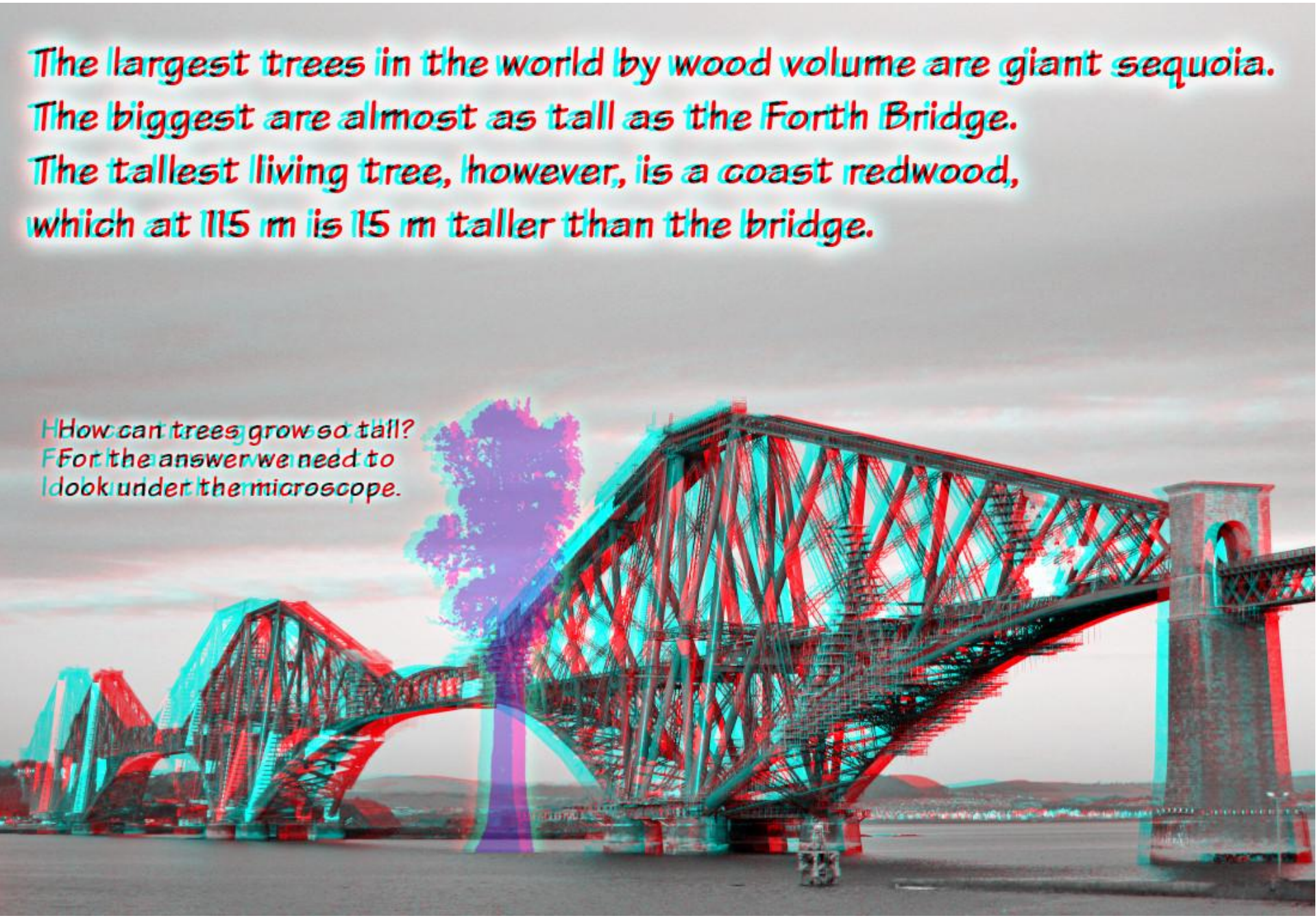
3D

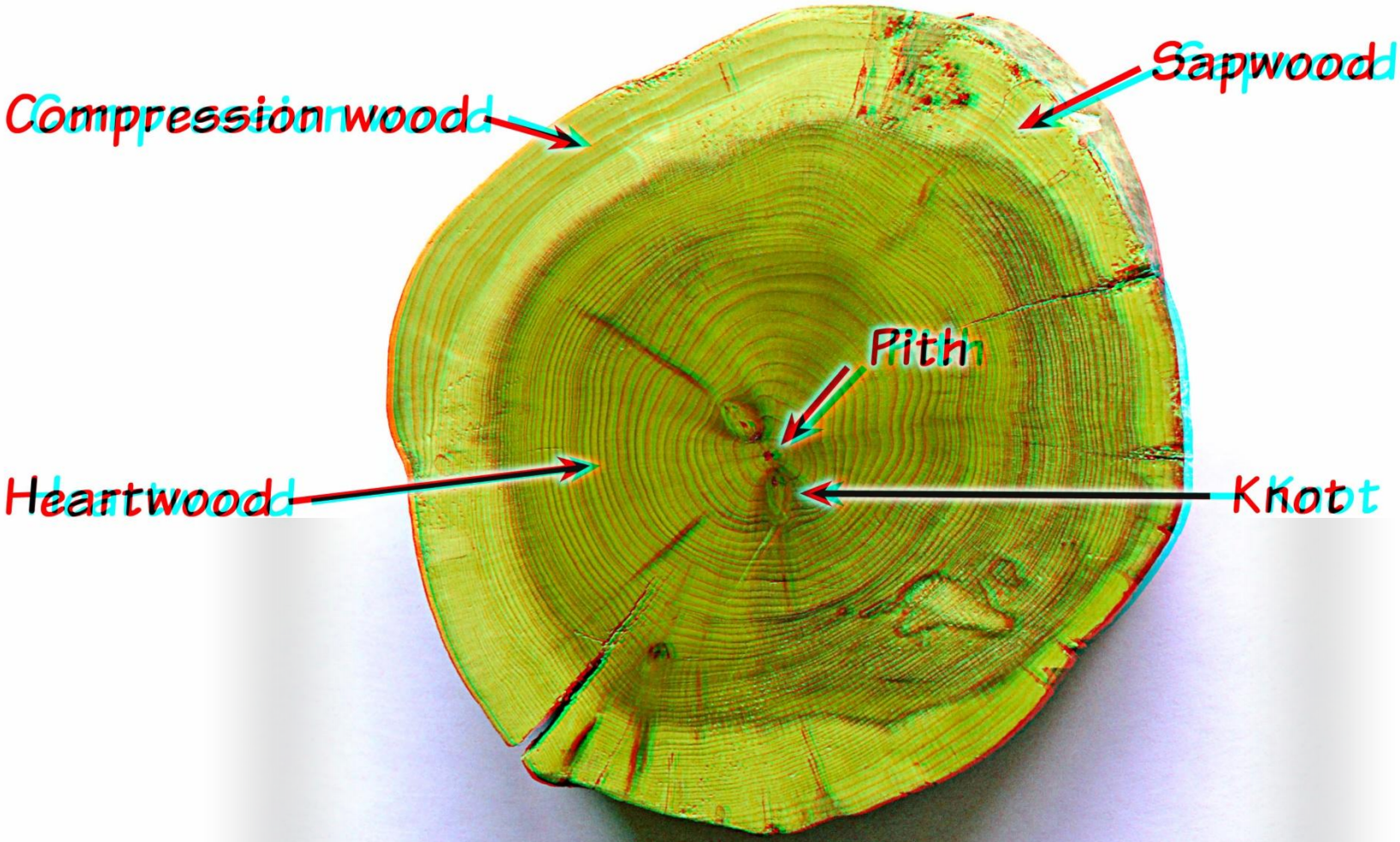
The largest trees in the world by wood volume are giant sequoia.
The biggest are almost as tall as the Forth Bridge.
The tallest living tree, however, is a coast redwood,
which at 115 m is 15 m taller than the bridge.

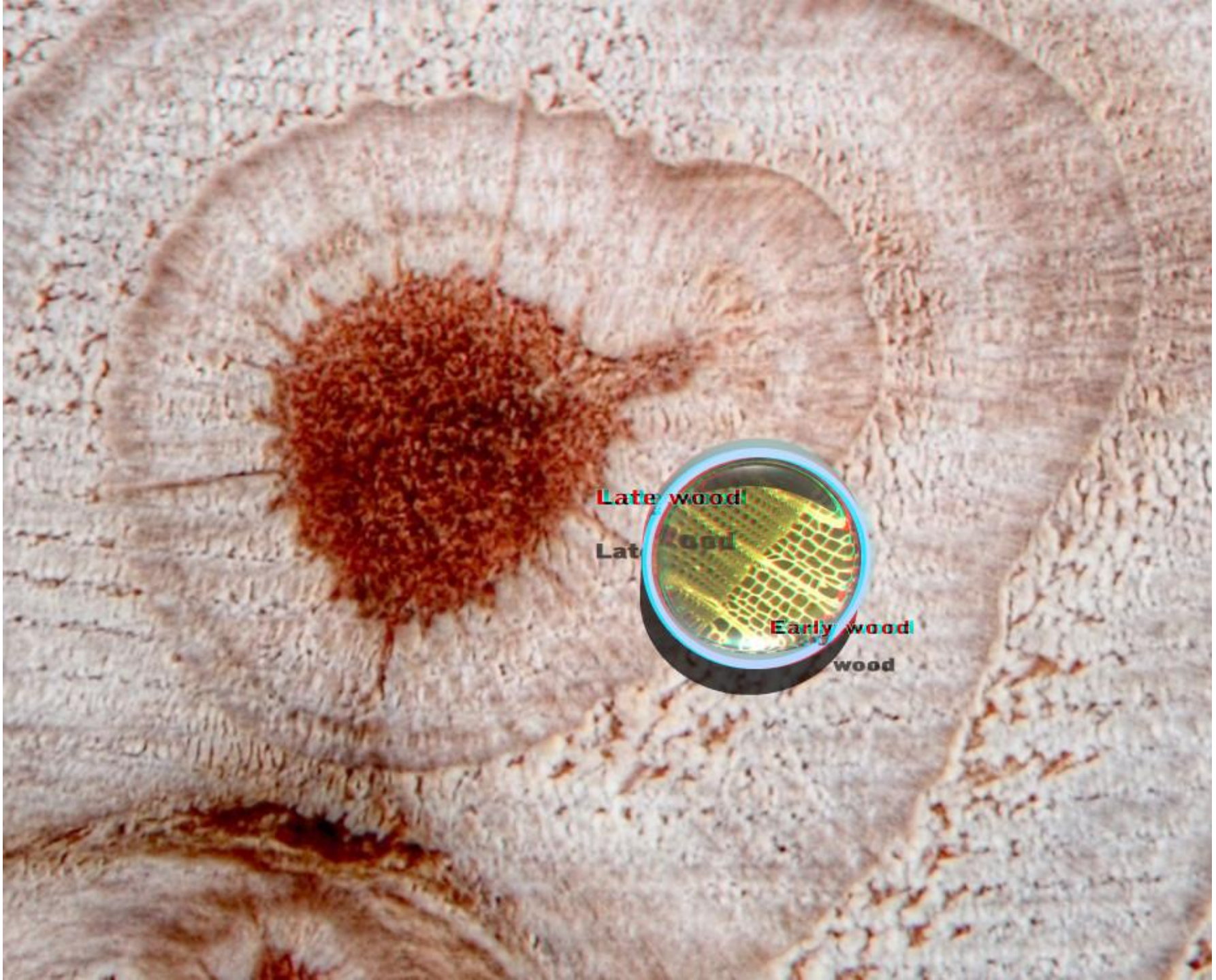


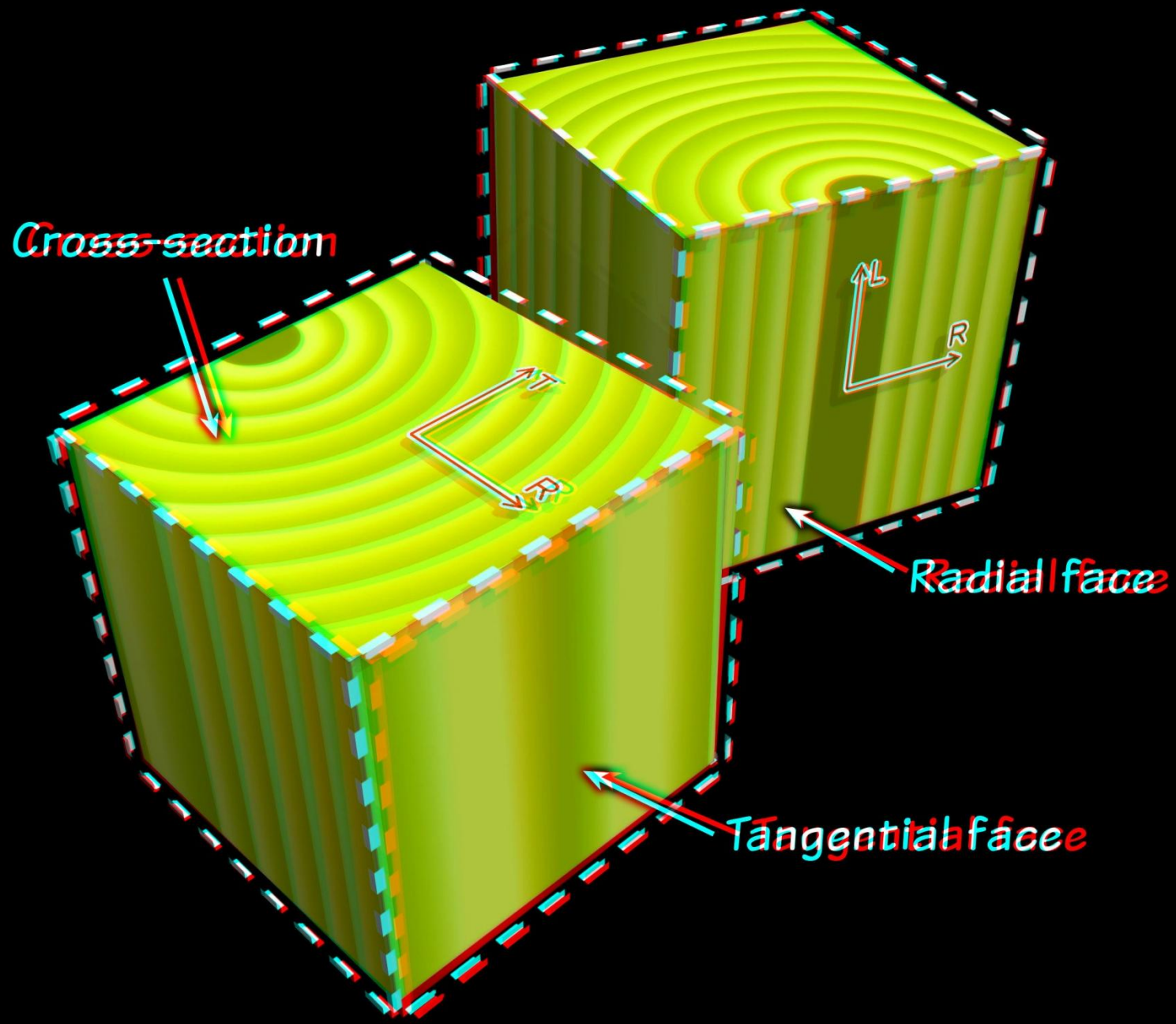
How can trees grow so tall?
For the answer we need to
look under the microscope.

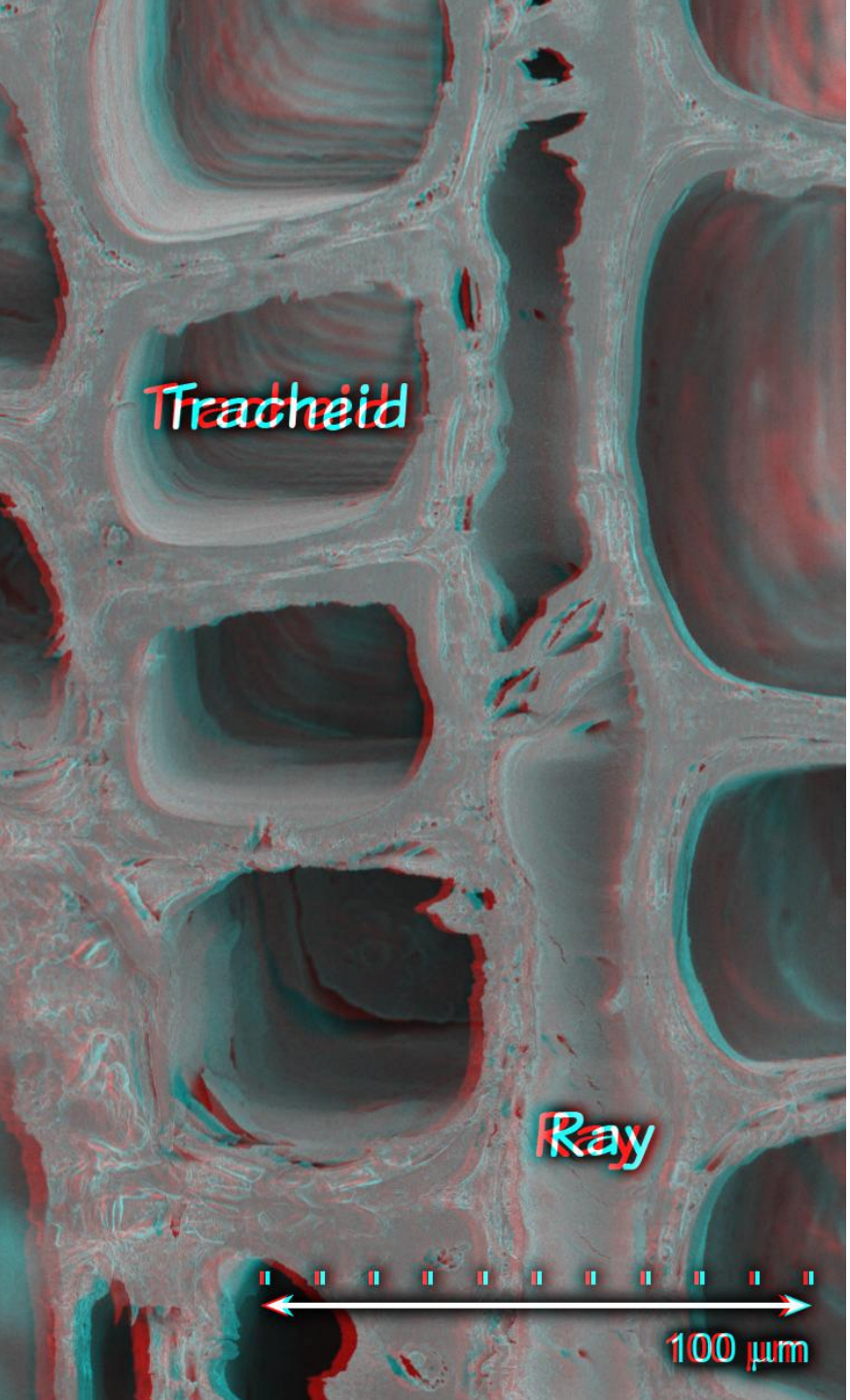

Softwood trees

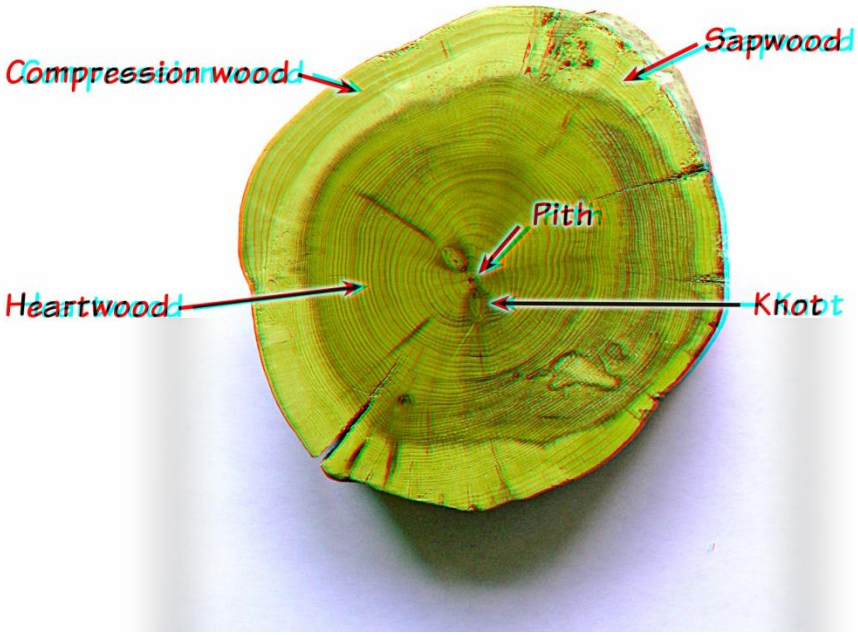

Hardwood tree

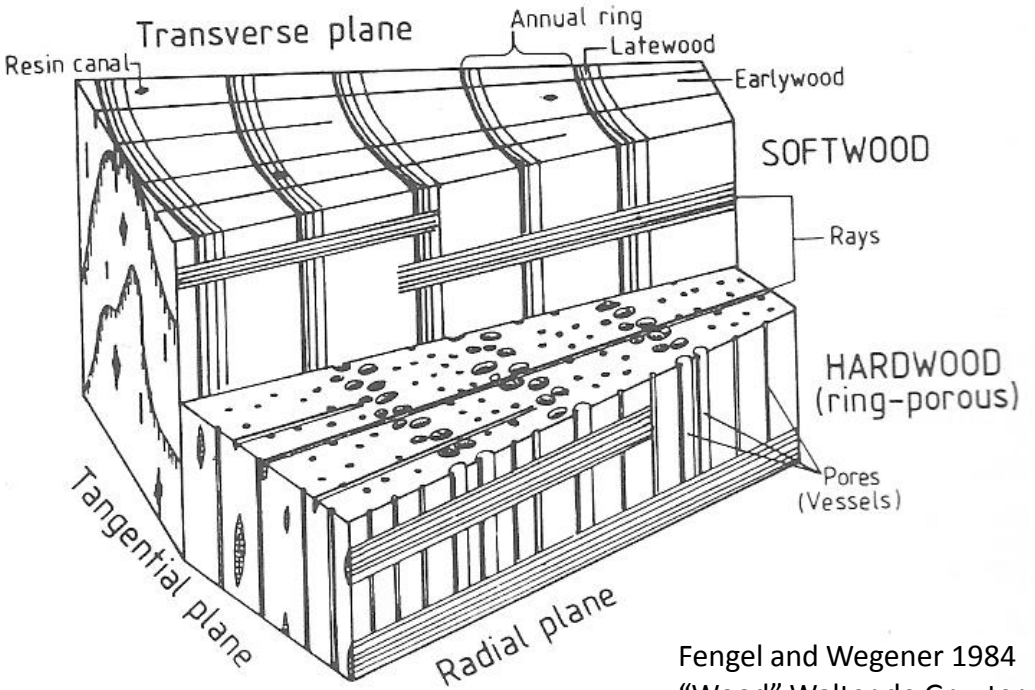

Compressionwood
Sapwood
Pith
Heartwood
Knot


Late wood
Early wood
wood

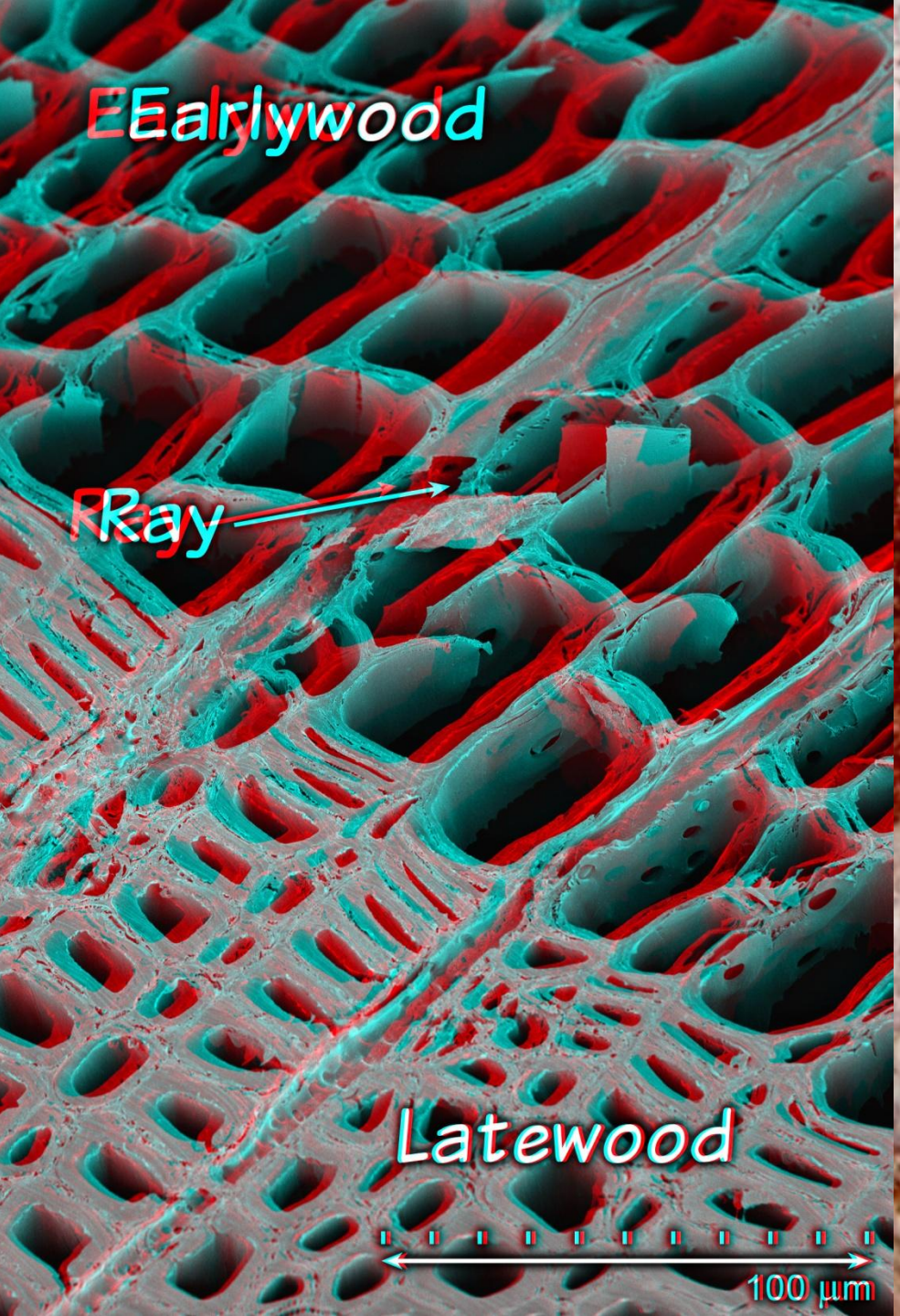

Cross-section
L
R
T
R
Radial face
Tangential face

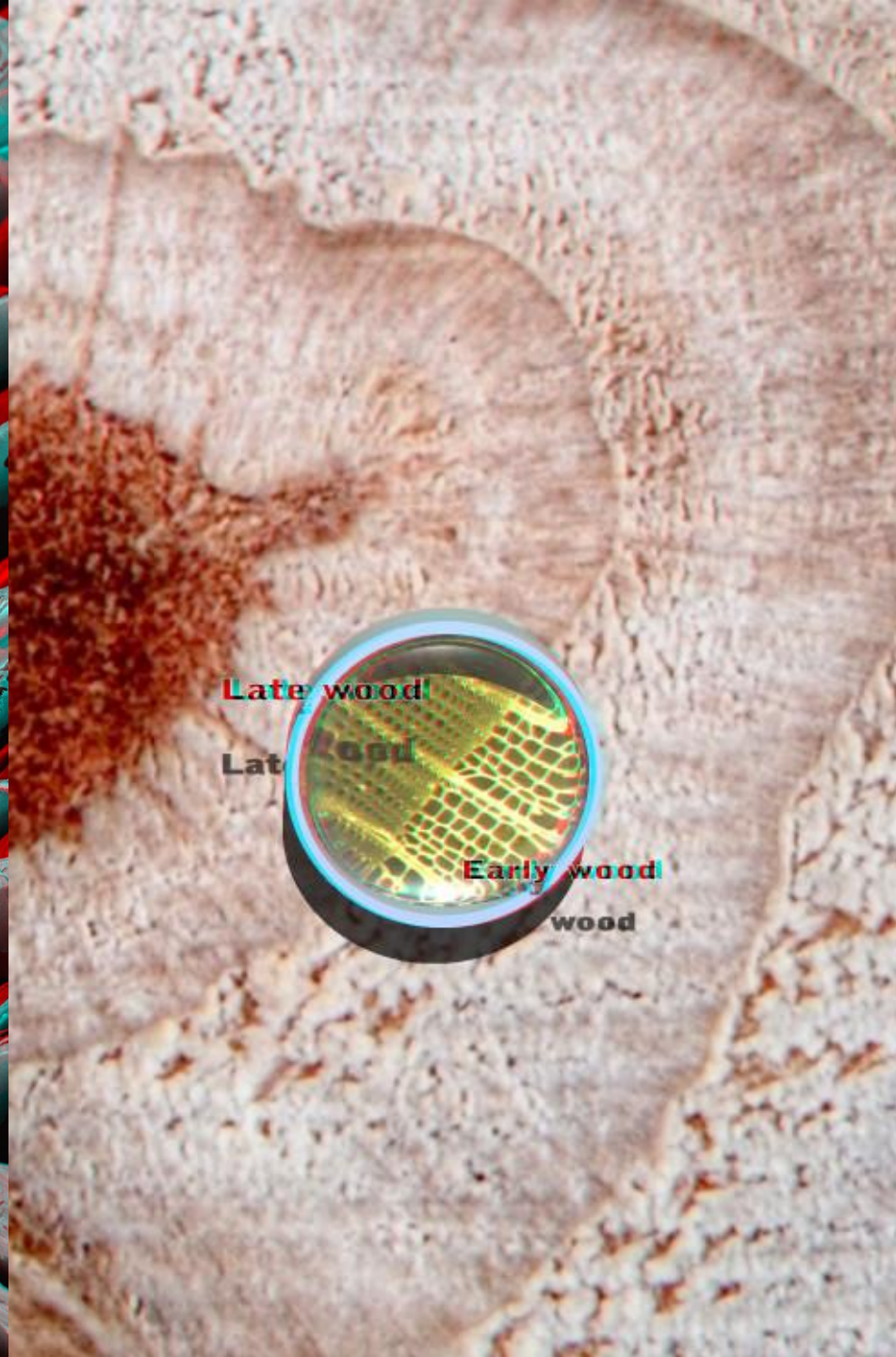




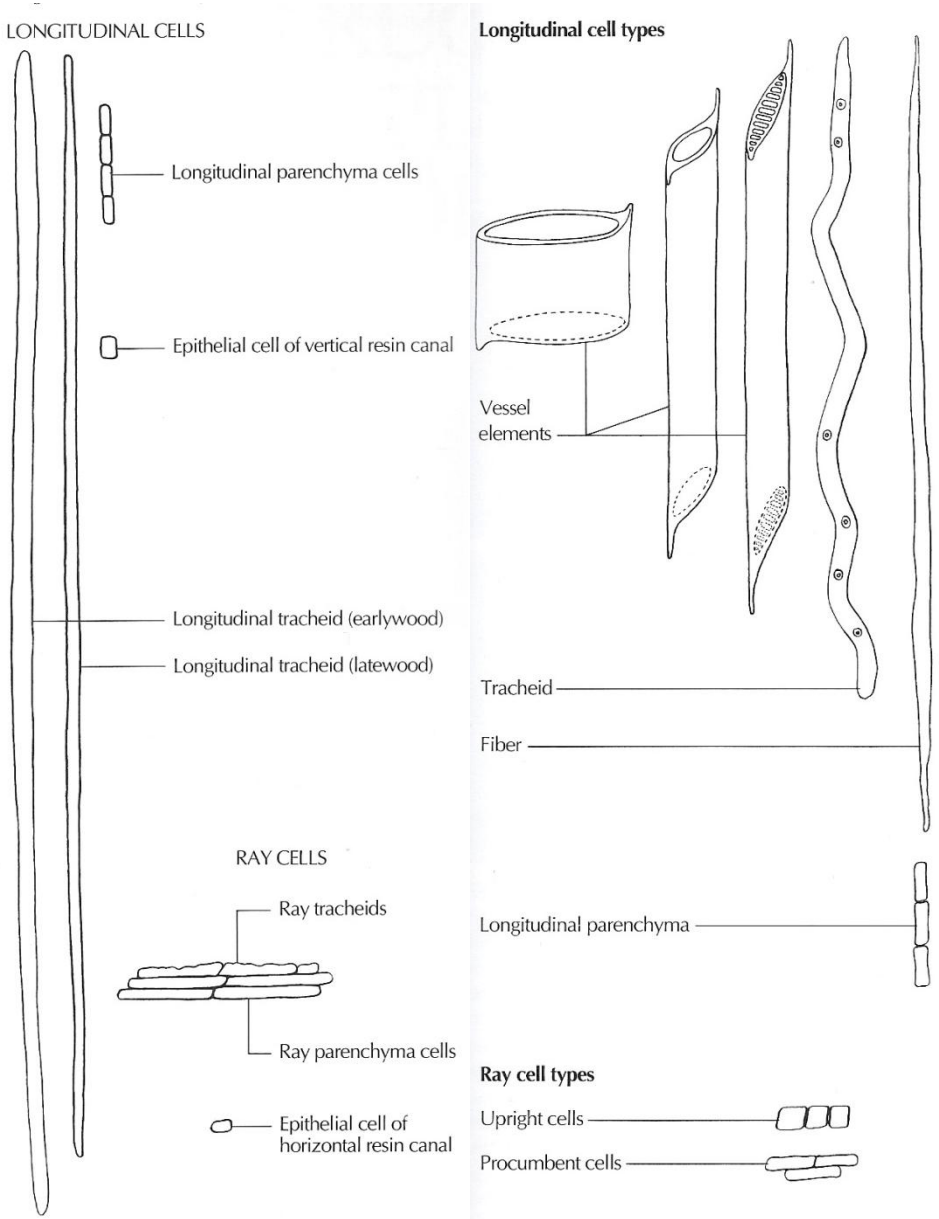


Fengel and Wegener 1984
"Wood" Walter de Gruyter

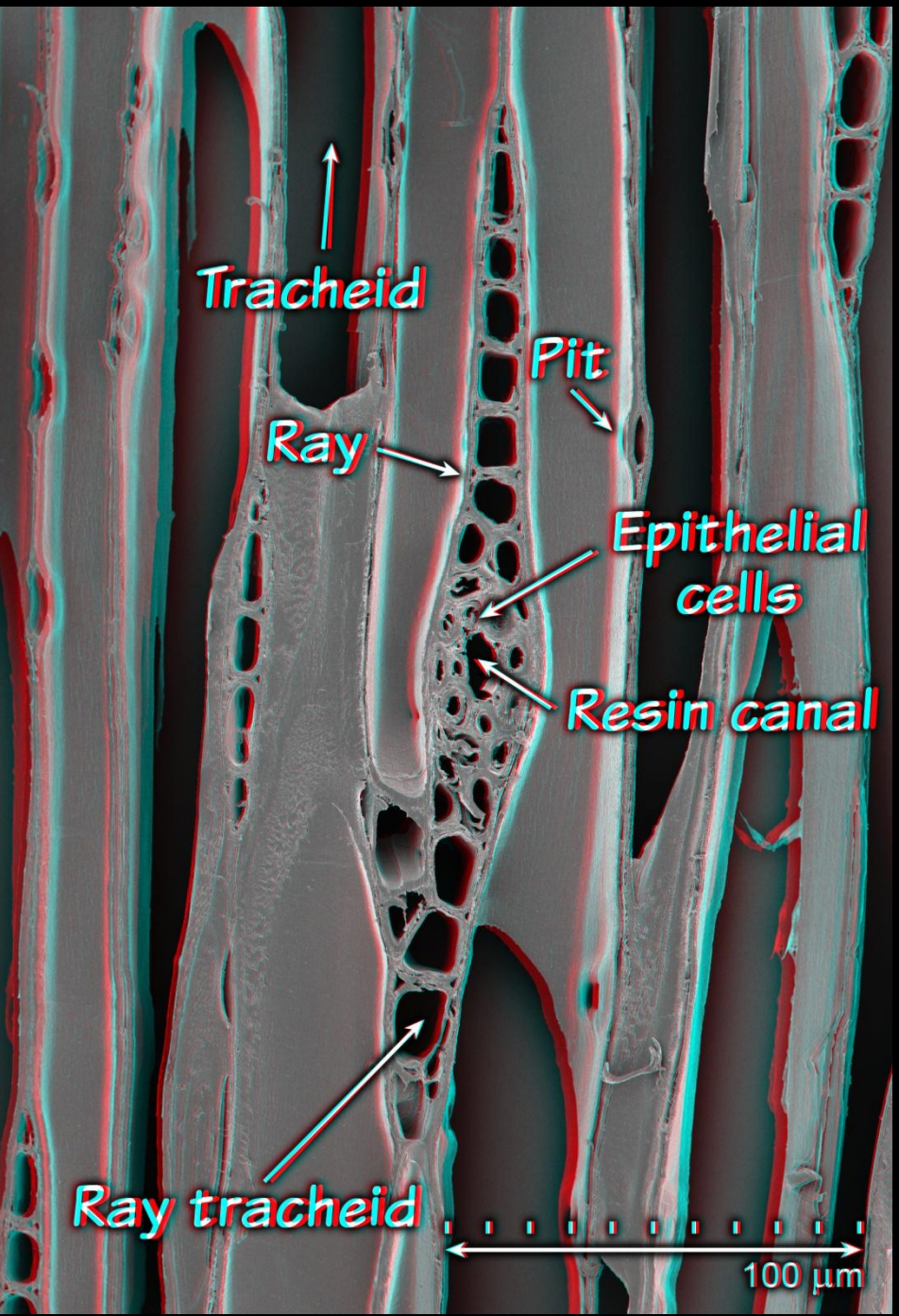

Earlywood
Ray
Latewood
100 µm

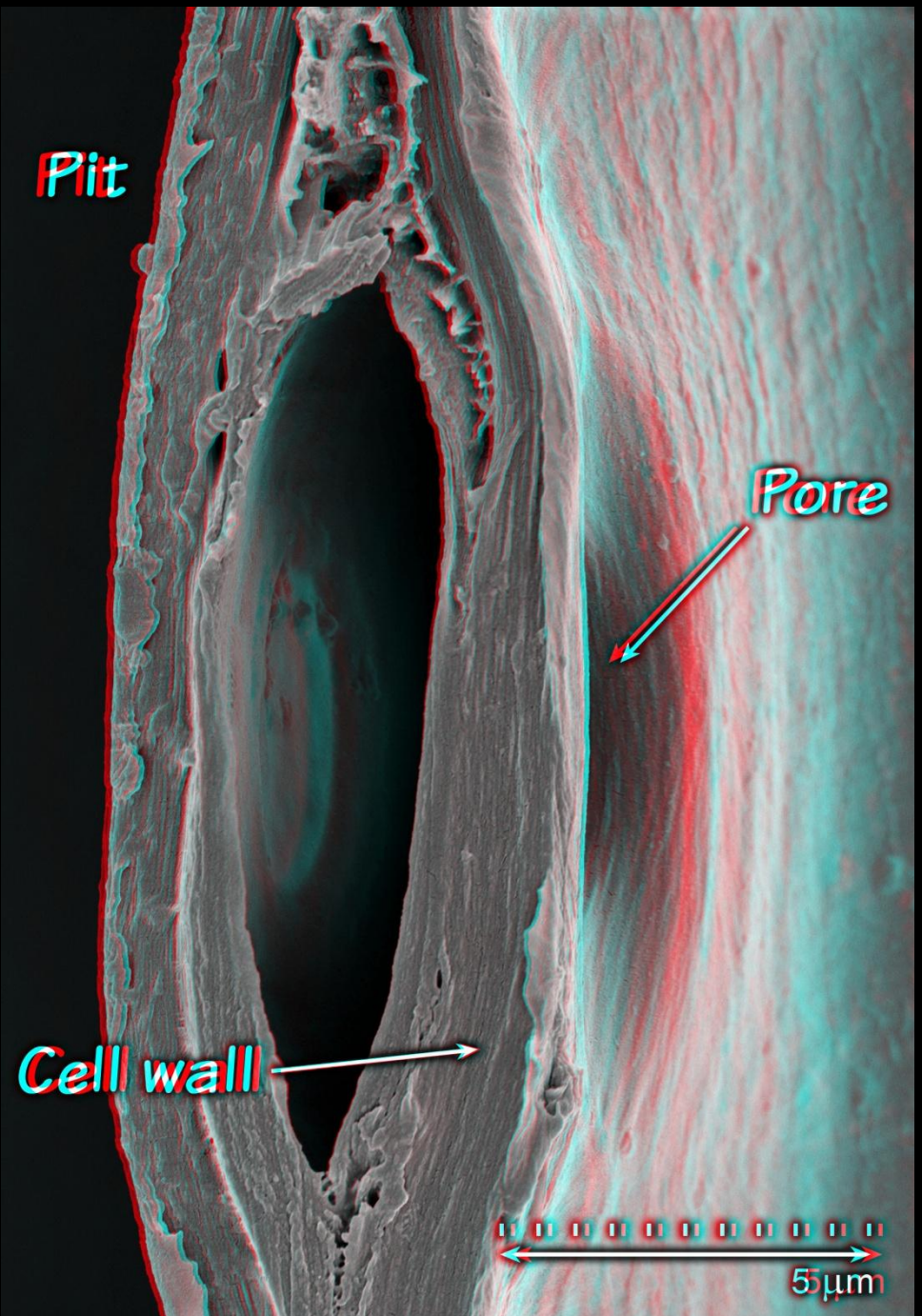

Late wood
Early wood
wood

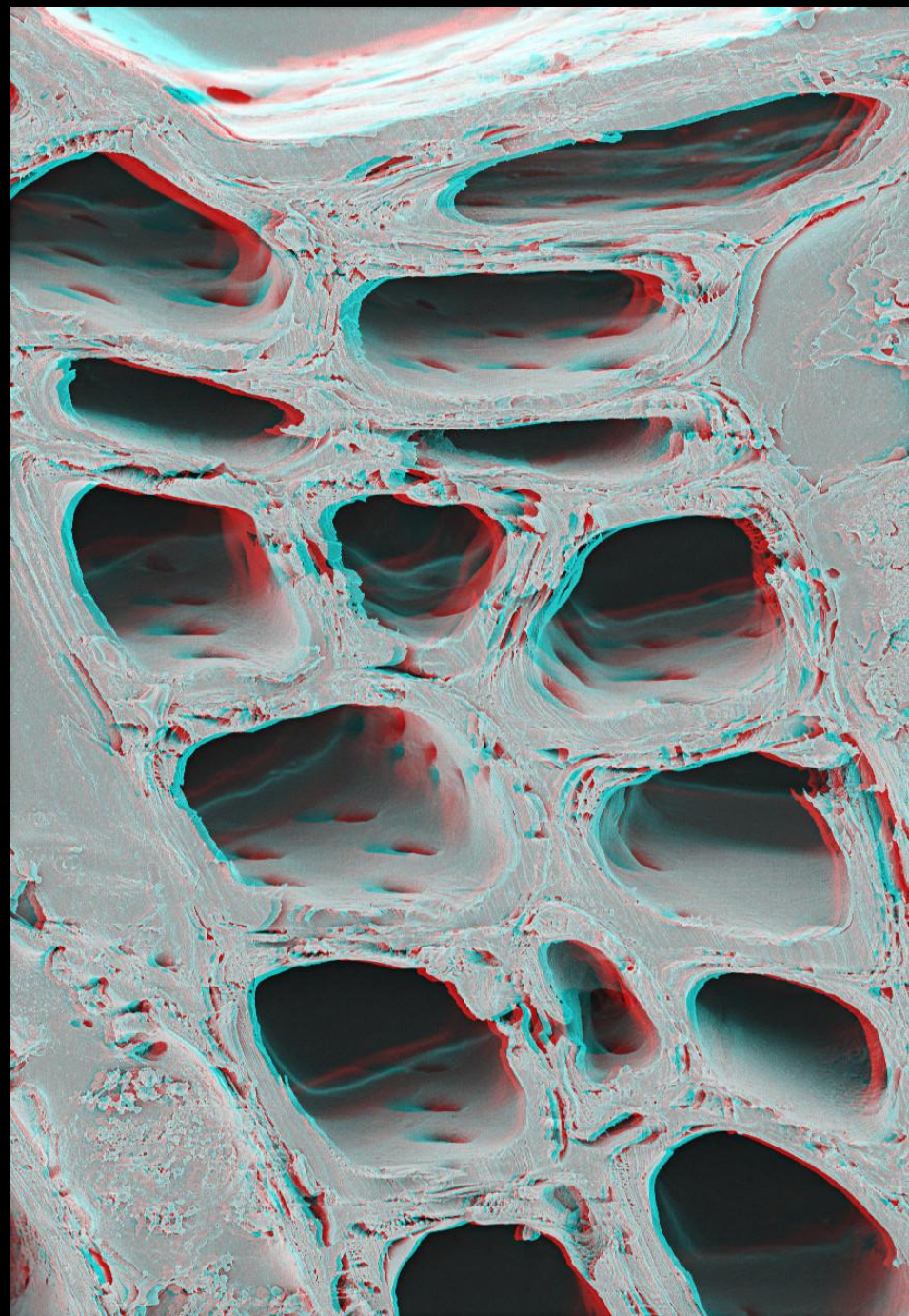
softwood **hardwood**

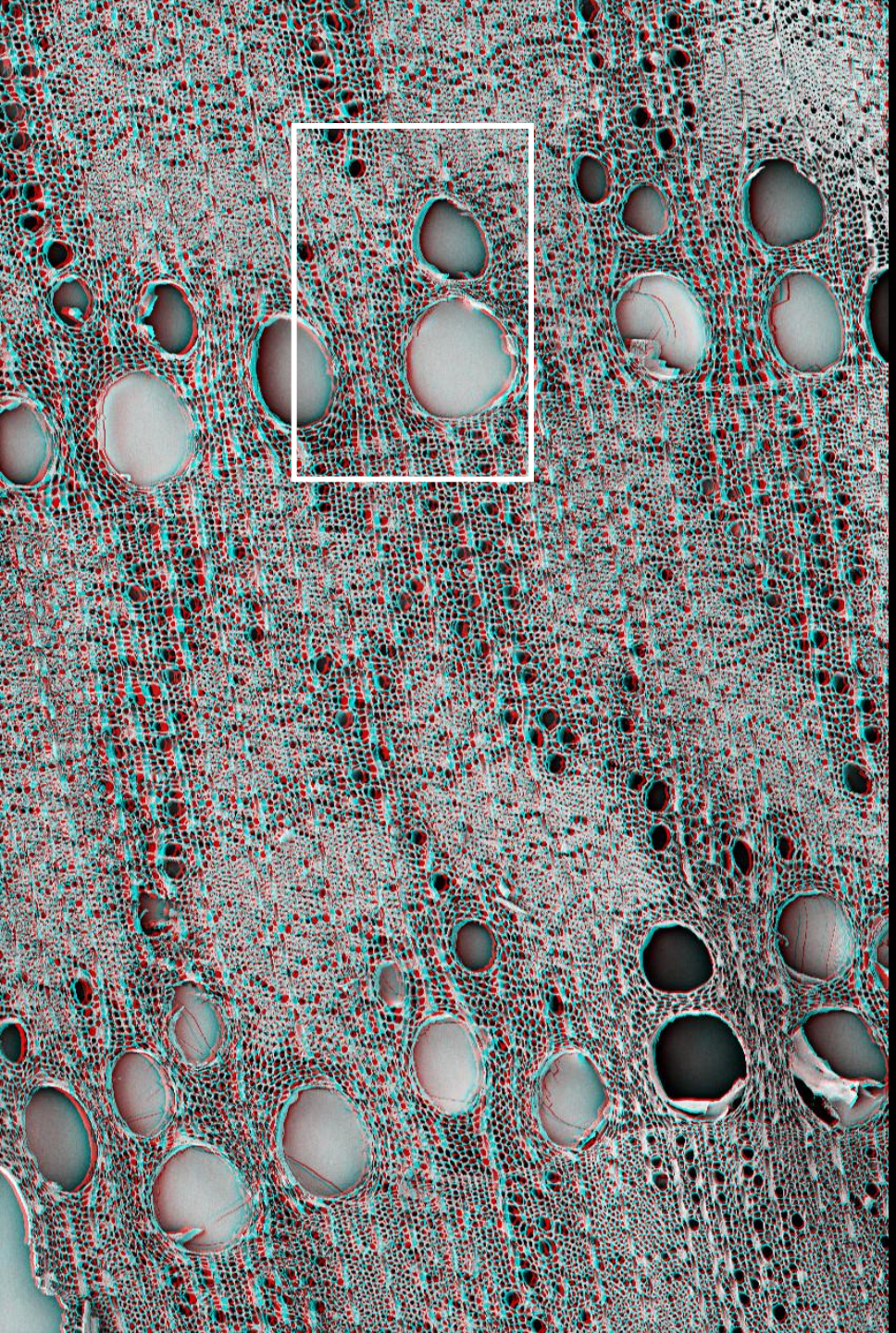


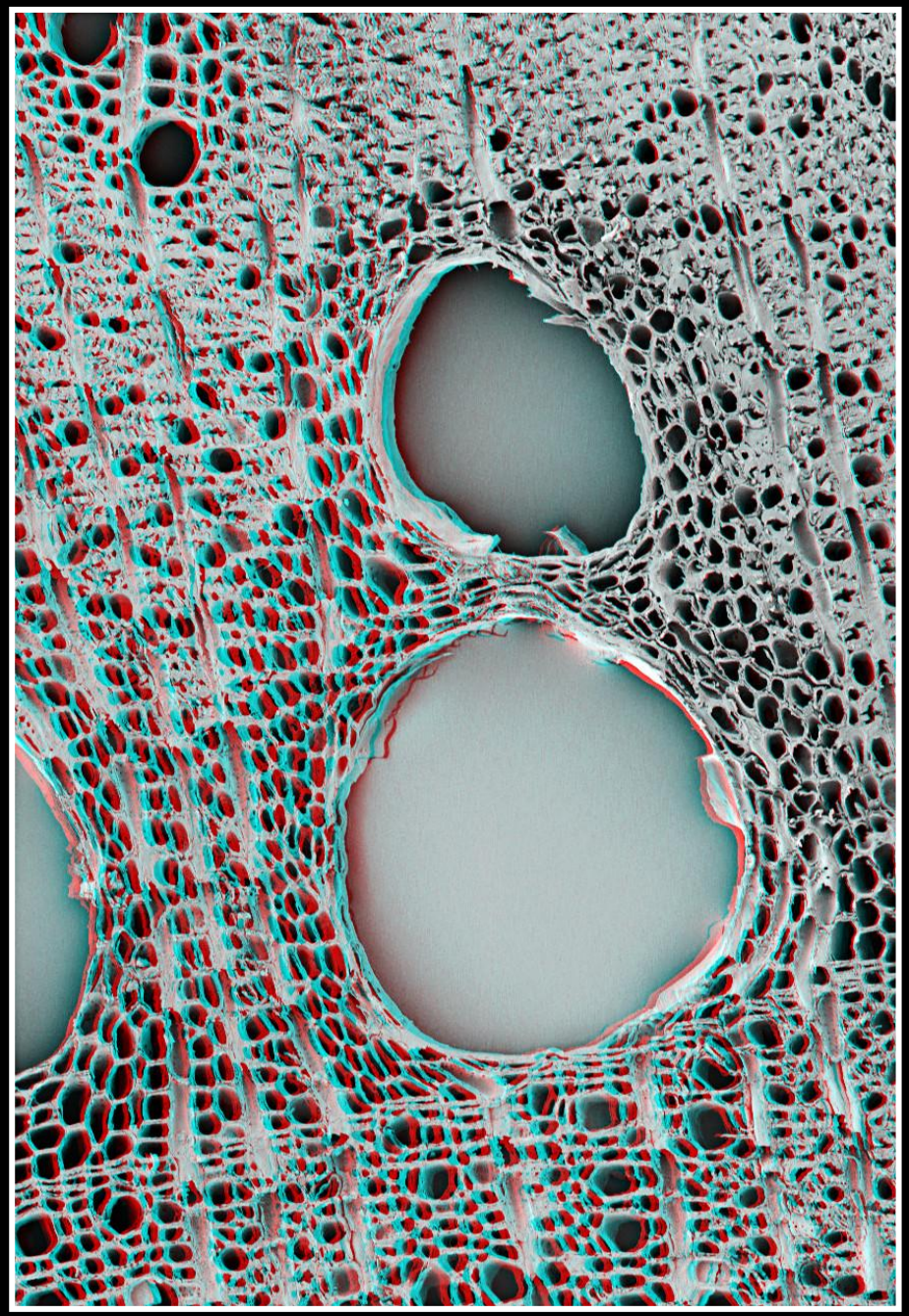
"Identifying Wood" R Bruce Hoadley, Taunton, 1990

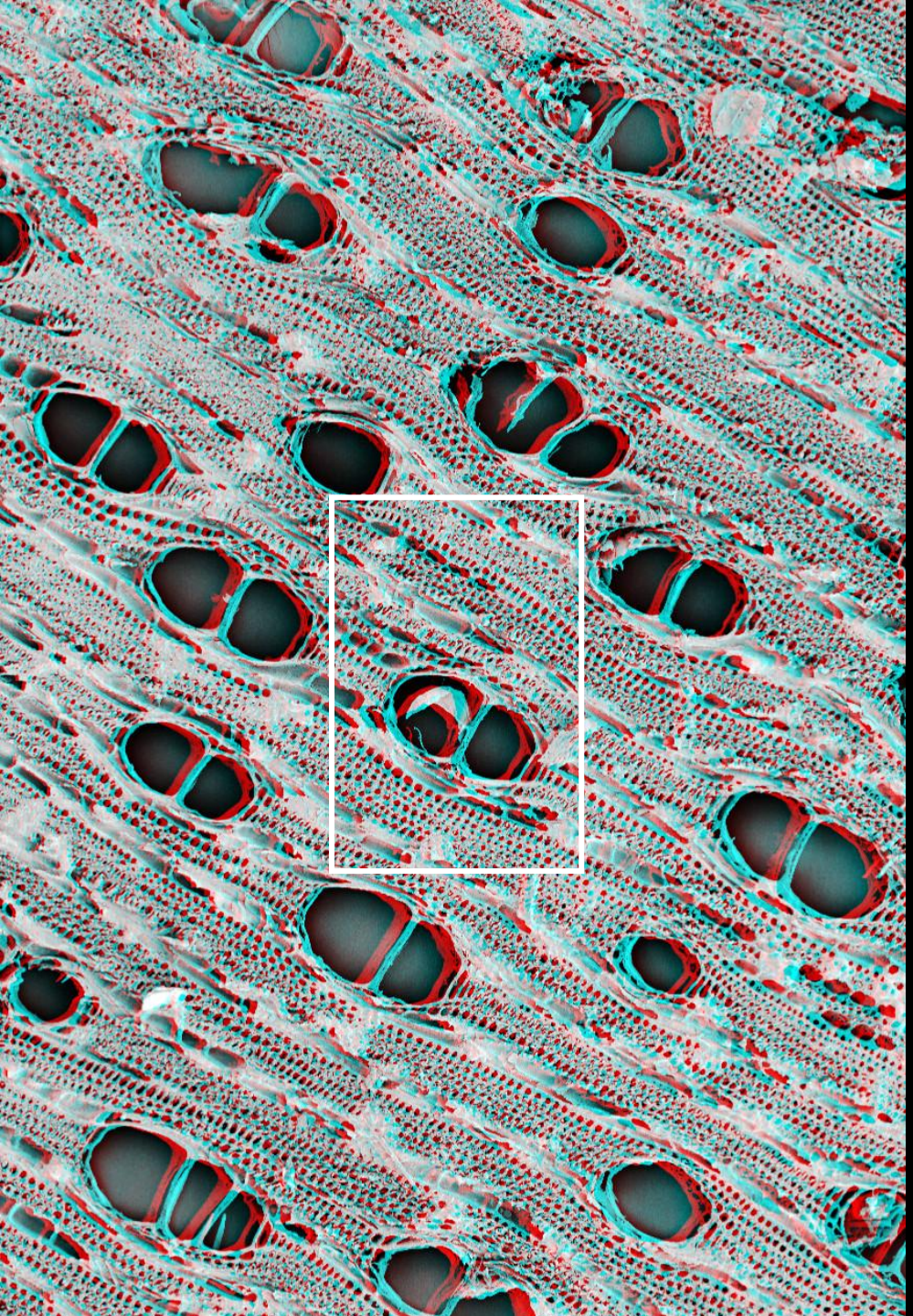

Tracheid
Pit
Ray
Epithelial cells
Resin canal
Ray tracheid
100 µm

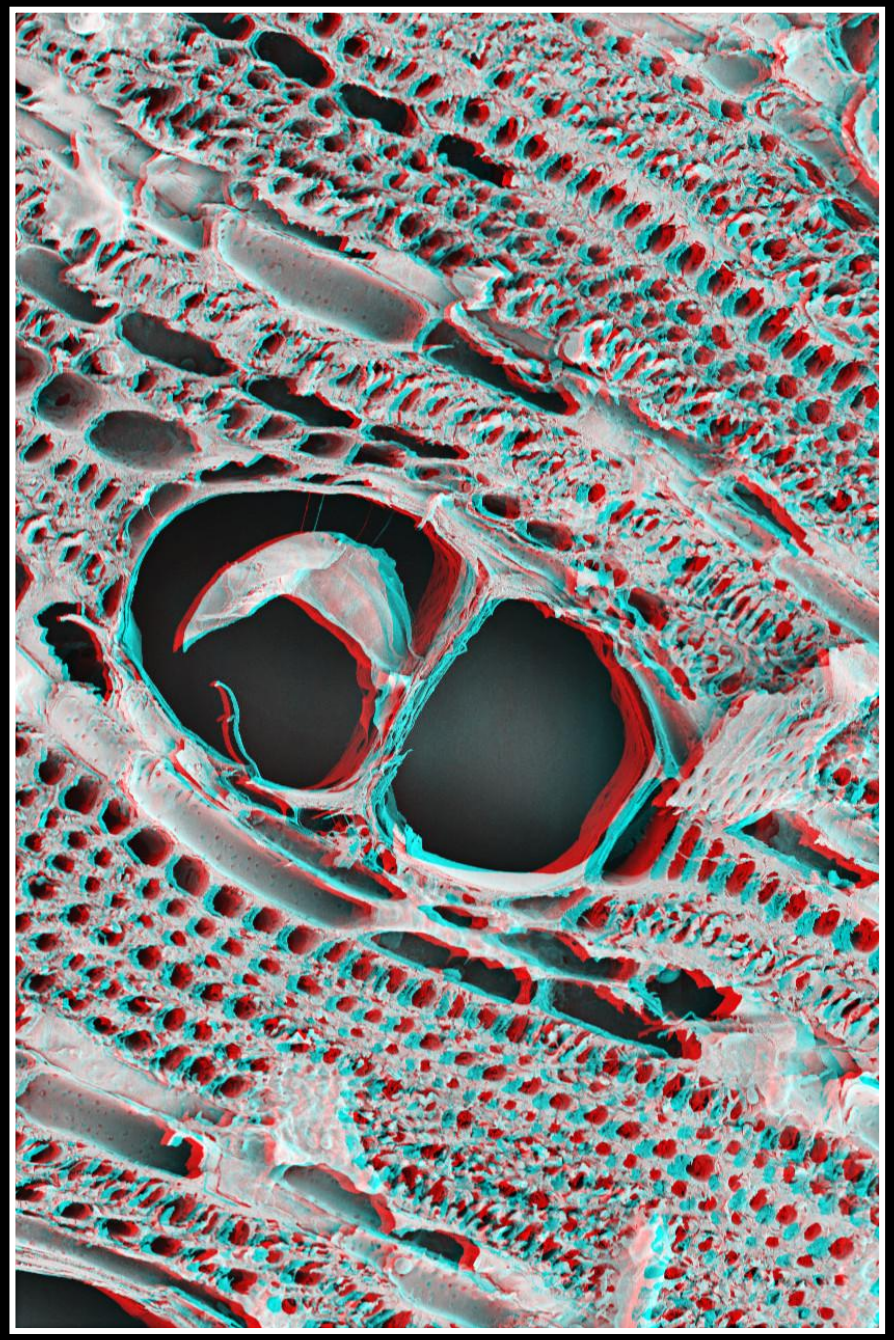

Pit
Pore
Cell wall
5µm

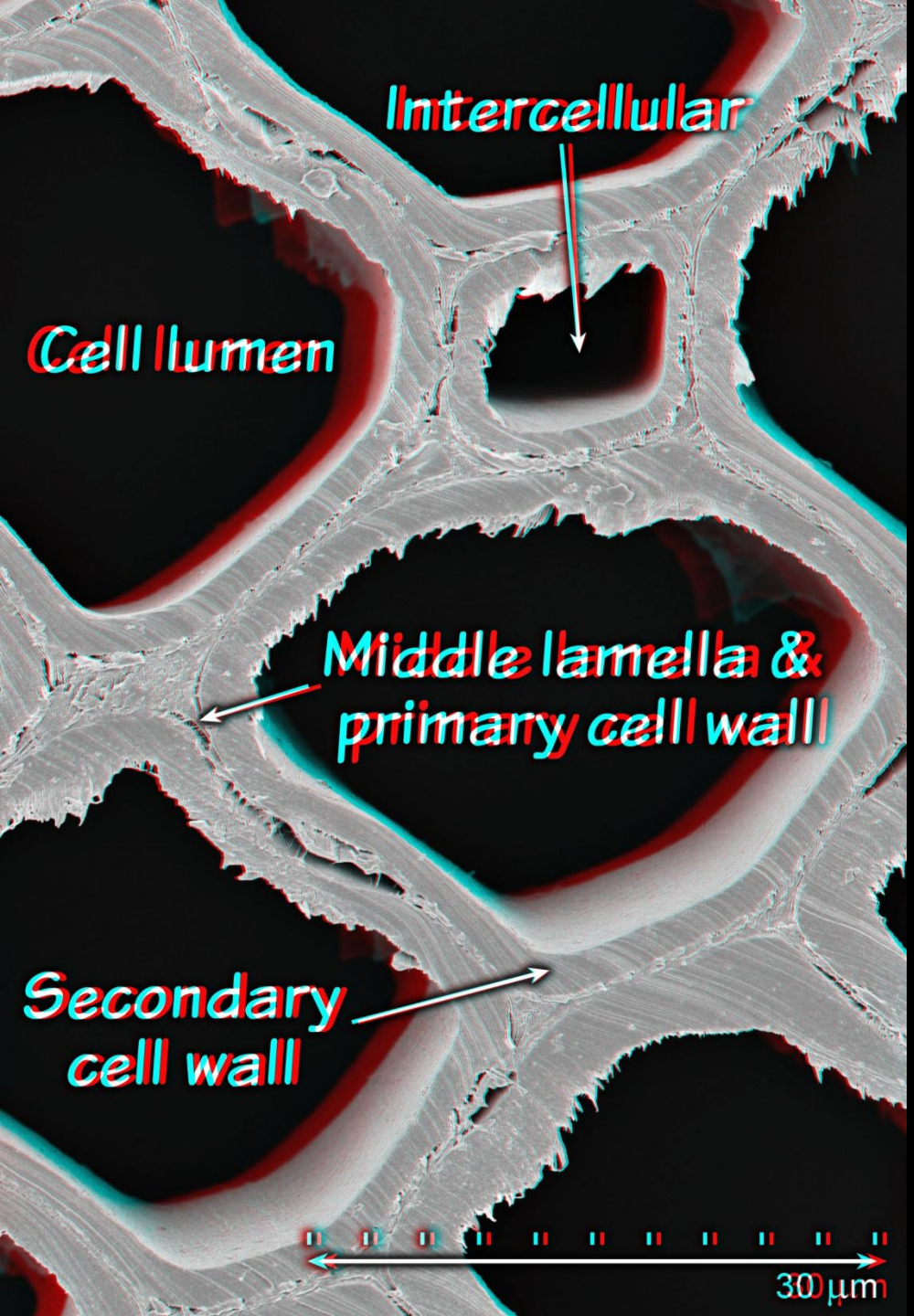




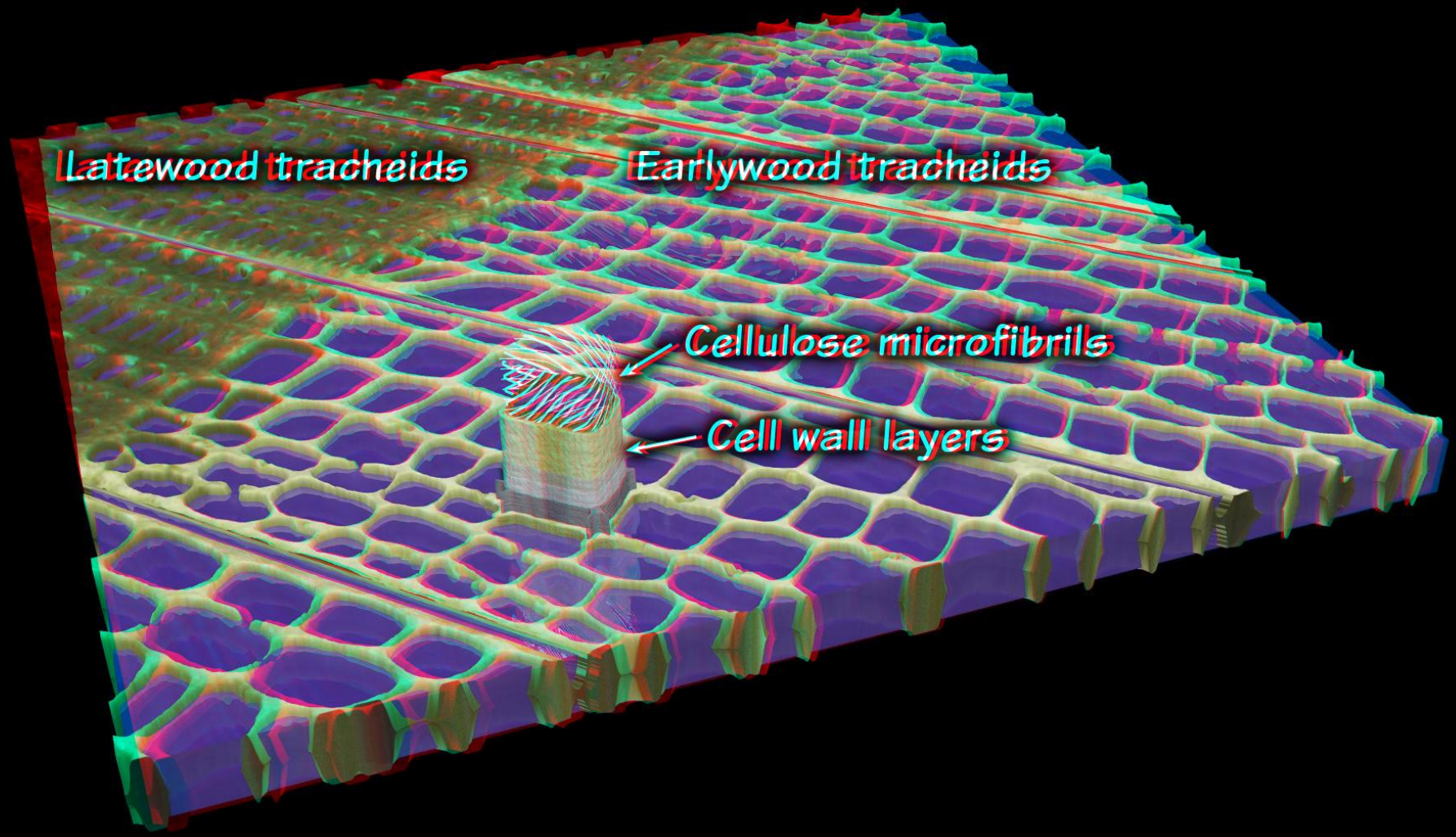


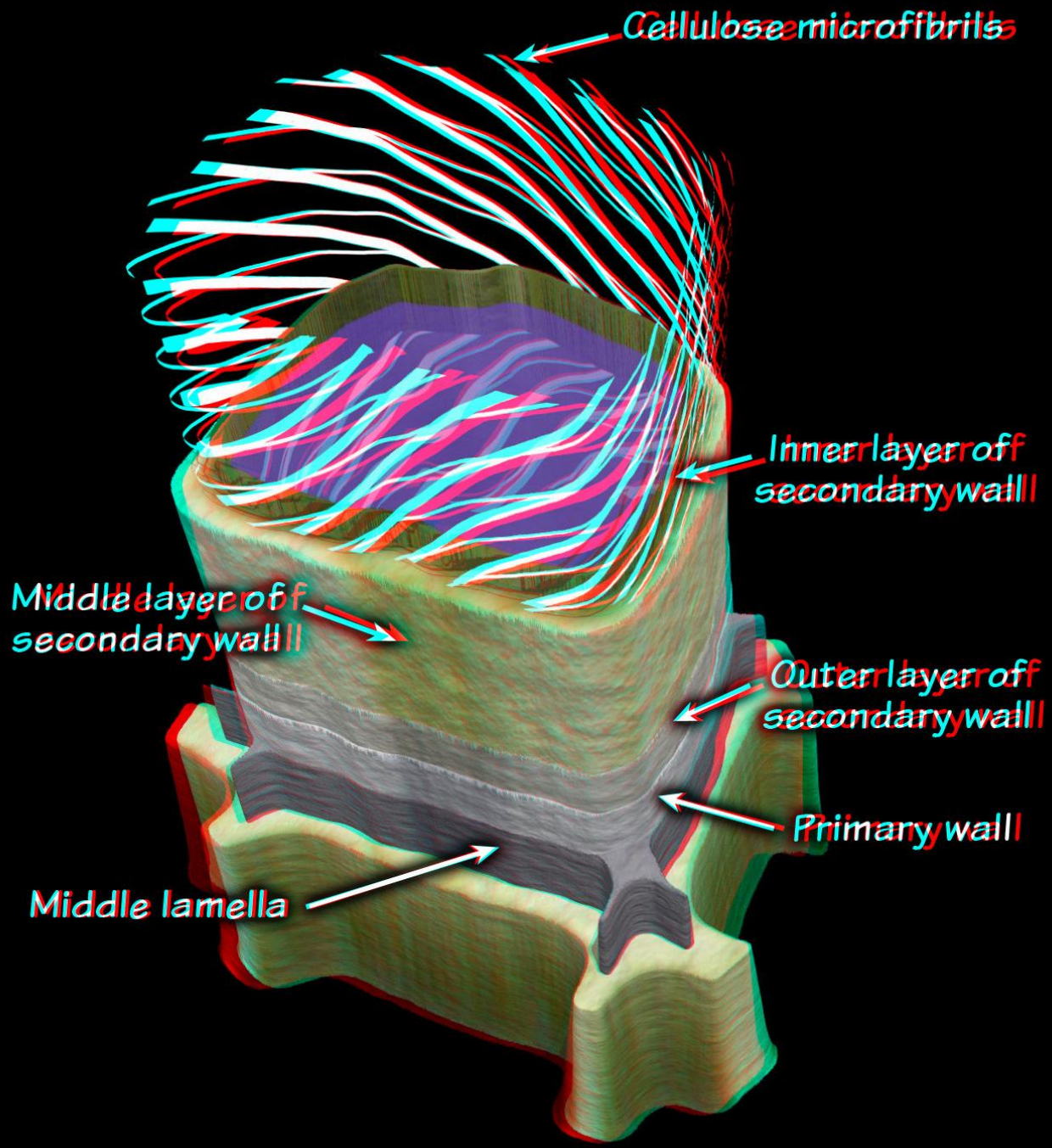


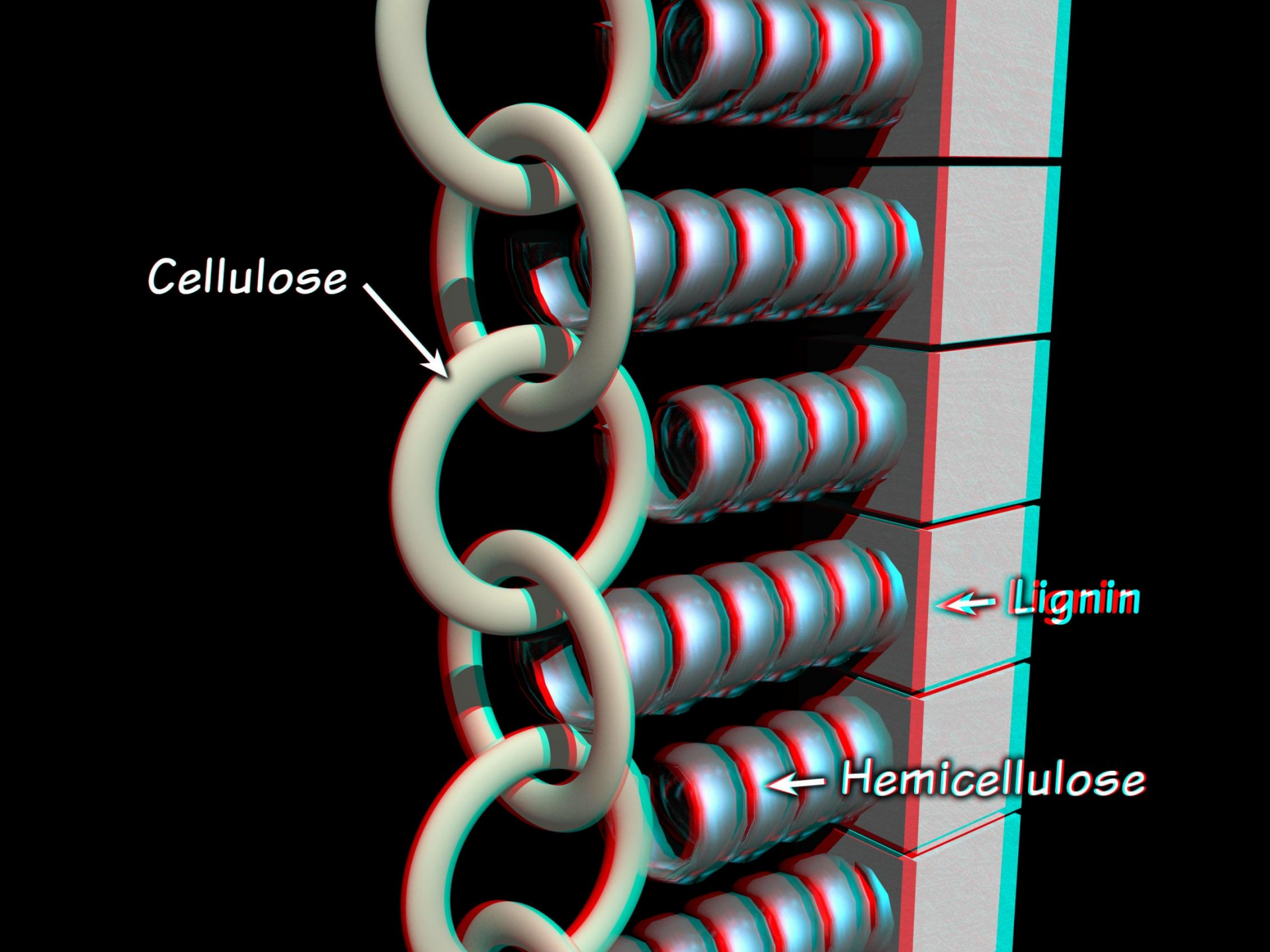


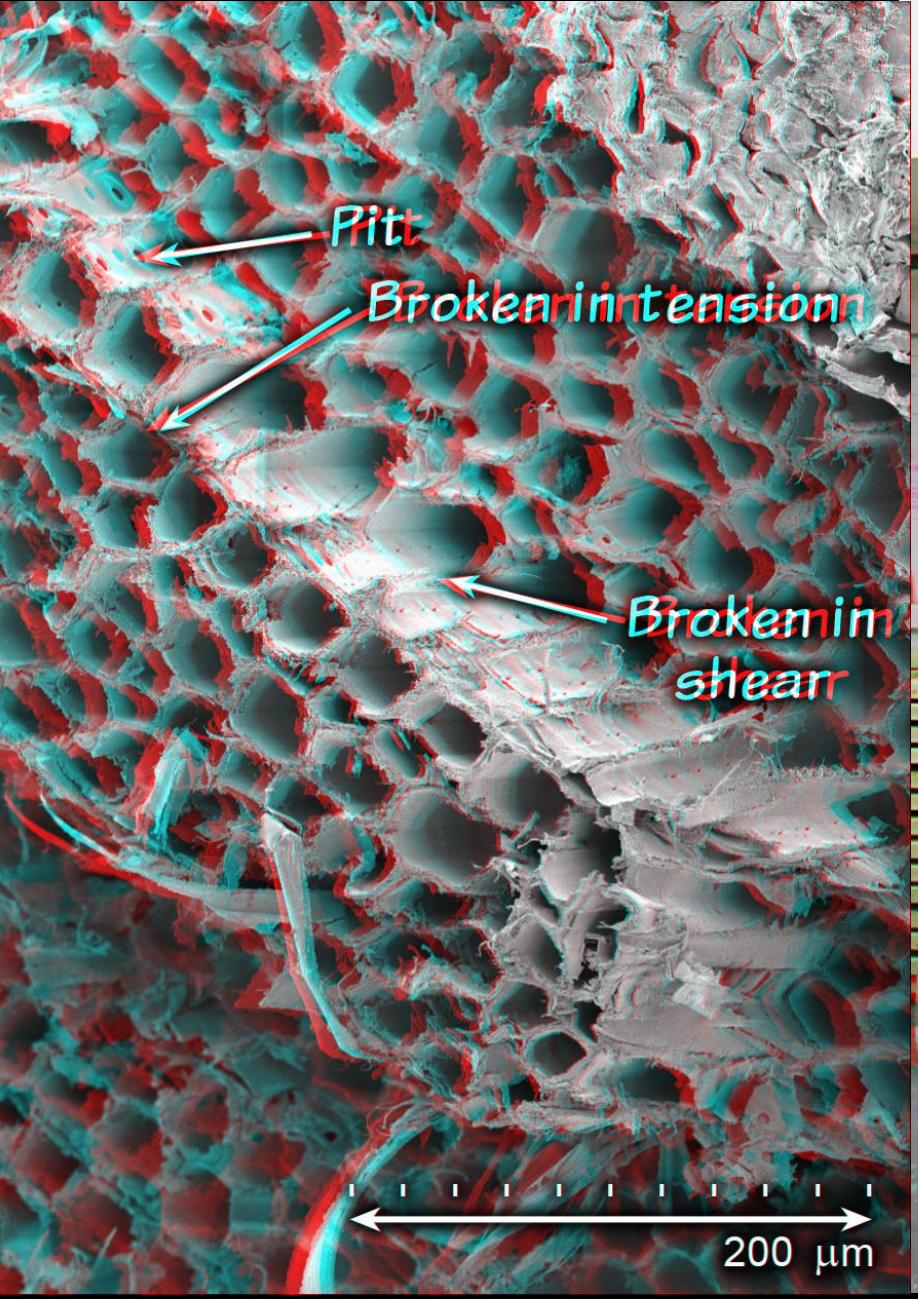


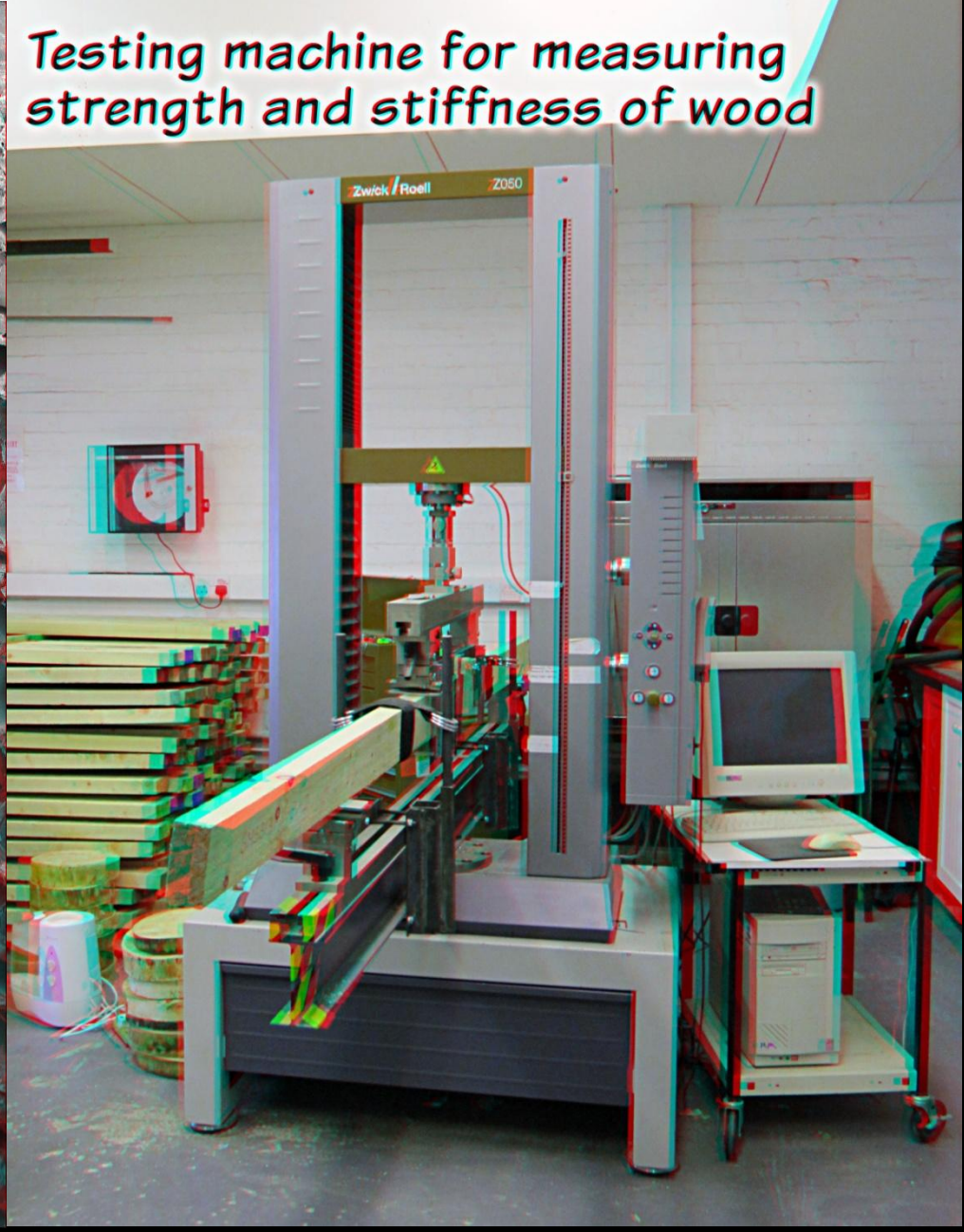
- Cellulose
  - A long polysaccharide molecule $(C_6H_{10}O_5)_n$
  - Analogous to reinforcing strand (main role tension)
- Lignin
  - A number of complex 3D biopolymers
  - Analogous to cement (main role compression)
- Hemicelluloses
  - Mixture of different sugar monomers
  - Links the cellulose and the lignin (giving flexibility)
- Extractives
- Water


Latewood tracheids
Earlywood tracheids
Cellulose microfibrils
Cell wall layers


Cellulose microfibrils
Inner layer of secondary wall
Middle layer of secondary wall
Outer layer of secondary wall
Primary wall
Middle lamella


Cellulose
Lignin
Hemicellulose


Pit
Broken in tension
Broken in shear
200 µm


Testing machine for measuring strength and stiffness of wood
Zwick / Roell
Z050

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What are material grades?

- Material properties are uncertain
- They vary from piece to piece
- …and within pieces
- This is true of all materials
- …although the degree of certainty differs
- Material is assigned to “classes”
- …which are described by characteristic material properties

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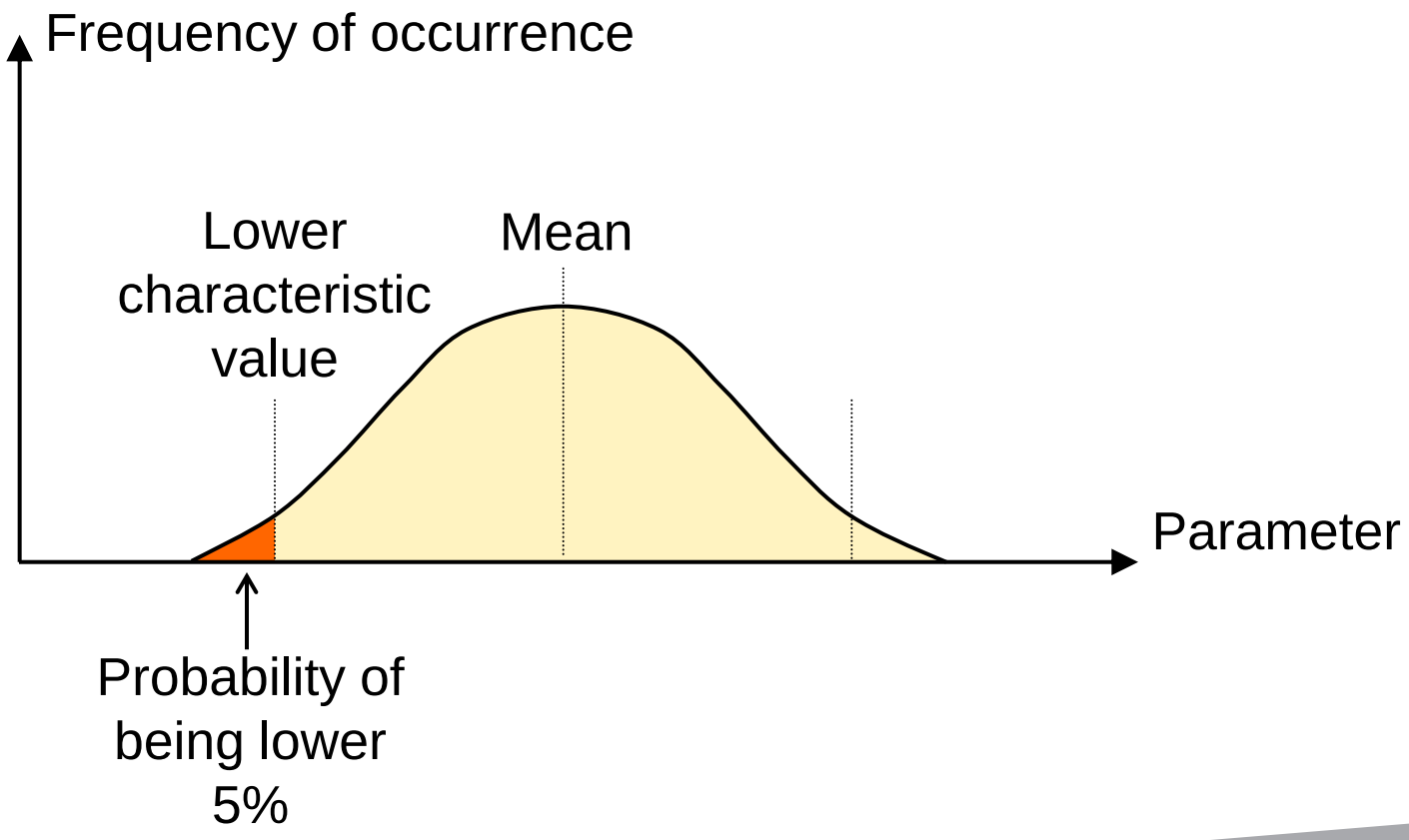
Characteristic values



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Timber

- We don’t manufacture it – trees do
- They have their own priorities
- Variable
  - Between species
  - Between origins
  - Between trees
  - Within a tree
- So how can we assign timber to classes?

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Grade-determining properties?

- Strength
  - Usually bending strength
- Stiffness
  - Usually bending stiffness
- Density
  - Also an indirect measure of strength in some elements of timber design
- All other properties are derived from these 3 properties

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Critical property?

- Strength classes are defined by
  - Strength (lower 5th percentile)
  - Stiffness (mean)
  - Density (lower 5th percentile)
- The limits are general across species
  - Softwoods (C grades)
  - Hardwoods (D grades)
  - (other grade systems exist)

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Critical property?

- To comply with the grade, characteristic values must be met (at least)
- For a species and grade combination usually one property is limiting
  - Strength
  - Stiffness
  - Density
- So strength grading isn't *always* about predicting strength

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How do we predict strength?

- Can only be measured destructively
- But strength is correlated with:
  - Stiffness
  - Density
  - Knots
  - Grain e.g. ring width
    - Rate of tree growth & radial position
  - Species
  - Origin

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How do we predict stiffness?

- Stiffness can be measured non-destructively
  - Mechanical bending (within elastic range)
  - Dynamic stiffness (vibration or time of flight)
- It is also correlated with
  - Density
  - Knots
  - Grain e.g. ring width
    - Rate of tree growth & radial position
  - Species
  - Origin

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How do we predict density?

- Density can be measured non-destructively
  - By weighing and measuring dimensions
  - Using x-rays (and similar methods)
  - Pin indent
  - But is confounded by moisture content
- It is also correlated with
  - Stiffness
  - Grain e.g. ring width
    - Rate of tree growth & radial position
  - Species
  - Origin

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Grading methods for timber

- Visual grading
  - Manual inspection (can be machine assisted)
  - Based only on what we can see (and infer)
  - Of limited accuracy…
  - …due to the parameters being measured
  - …and the human element
  - …so assignment to grades is conservative
  - A slow process using trained people

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Grading methods for timber

- Machine grading
  - Relates an ‘indicating parameter’ to the critical grade-determining parameter(s)
  - Better accuracy than visual grading…
  - …due to the parameters being measured
  - …and the automation
  - …so assignment to grade is less conservative
  - Fast but expensive equipment

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Assignment to grades

- Machine grading does not operate on a piece by piece basis
- Pieces are individually assigned to classes
- …but it is the population of timber in that class that matters
- Packages of timber should meet the characteristic values …on average

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Does this make timber bad?

- No
- In fact this applies for all materials
- There is always some uncertainty
- It's why we have material partial safety factors in design

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How do we machine grade?

- Now many types of grading machines
  - Bending stiffness
    - Bending about the minor axis
  - Dynamic (acoustic/vibration)
    - Essentially a measure of stiffness
    - May or may not include density
  - X-rays
    - A combination of knots and density
    - Perhaps with optical camera
  - Mixtures of the above

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The indicating property (IP)

- Ideally want a good predictor of the critical grade-determining property
- Generally, additional measures improve IP
- But... It's a compromise with cost

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Approved grading machines

- Many devices can predict grade-determining properties
- …but that does not make them grading machines
- Machines must be approved by CEN TC124 TG1 according to EN14081
- To ensure operation is reliable
- …including the human element

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Bending graders

- Measure mechanical stiffness
  - Through application of defined load
  - or defined deflection
  - Minor axis
  - Accounting for pre-existing bow
- Relatively slow (with dynamic errors)
- Limited by cross-section
- Cannot measure the whole piece

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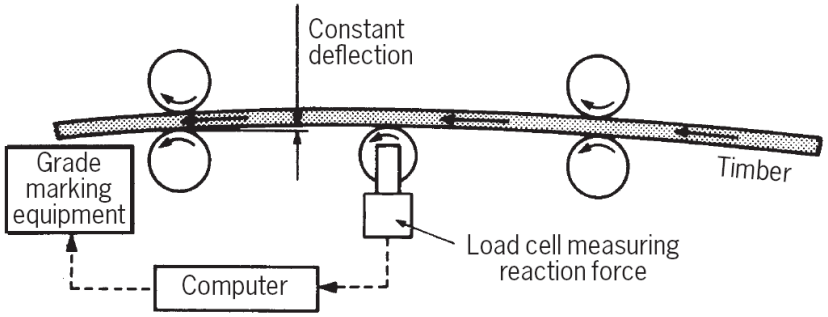
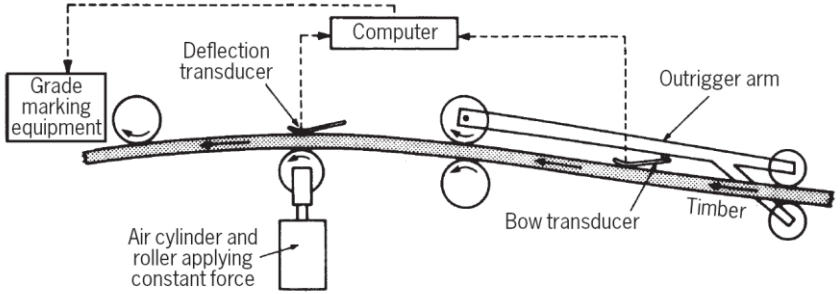
Bending graders

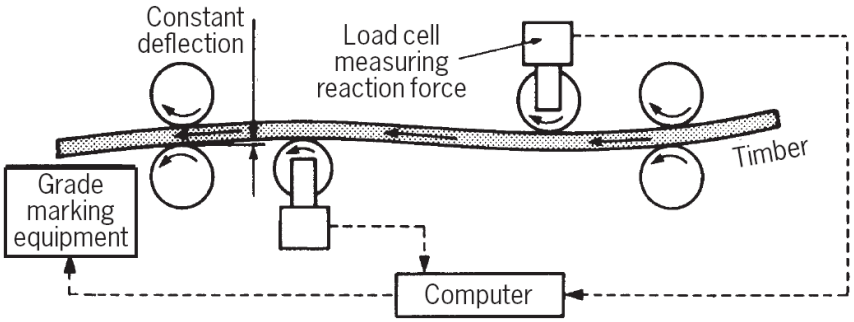
Cook-Bolinder



Computermatic



Timgrader



Figures from BRE Digest 476 “Guide to machine strength grading of timber”

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Acoustic graders

- Measure acoustic velocity
  - Through axial or transverse vibration
  - Or time of flight (including ultrasonic)
  - May or may not include density ($MoE_{dyn} = \rho v^2$)
- Fast
- Can be hand-held
- Measure the whole piece
- …but all at once

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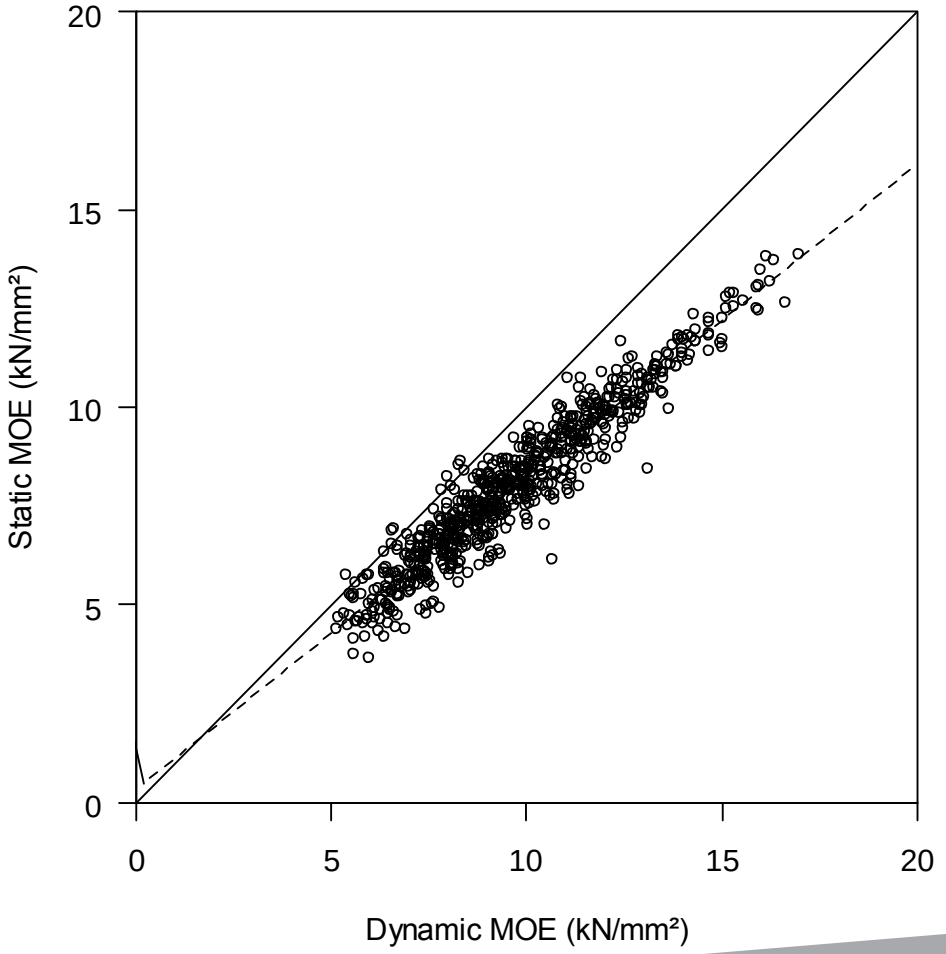
Acoustic graders



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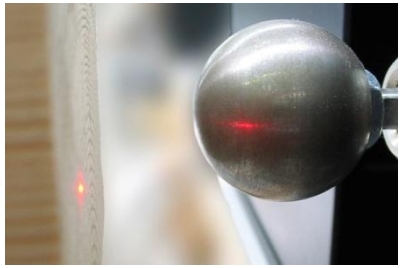
Acoustic graders

ViSCAN (MiCROTEC)



MTG (Brookhuis)

Precigrader (Dynalyse AB)

Triomatic (CBS-CBT)

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X-ray graders

- Measure
  - Clear wood and average density
  - Knot size and location
- Very fast (and permit board splitting)
- …but big and expensive
- Measure the whole piece
- …and all parts of it individually
- But not great at predicting stiffness

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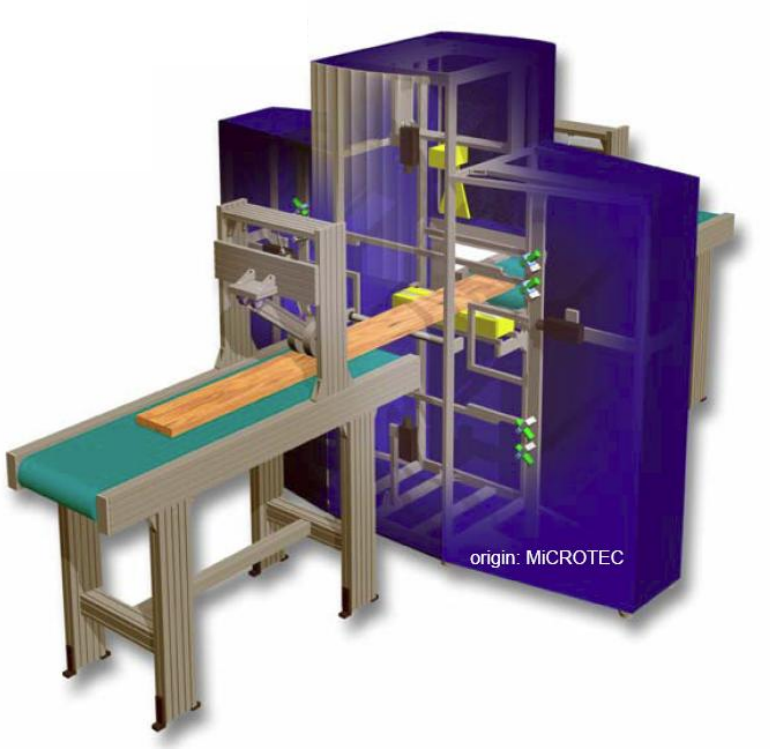
X-ray graders

GOLDENEYE 702 (MiCROTEC)



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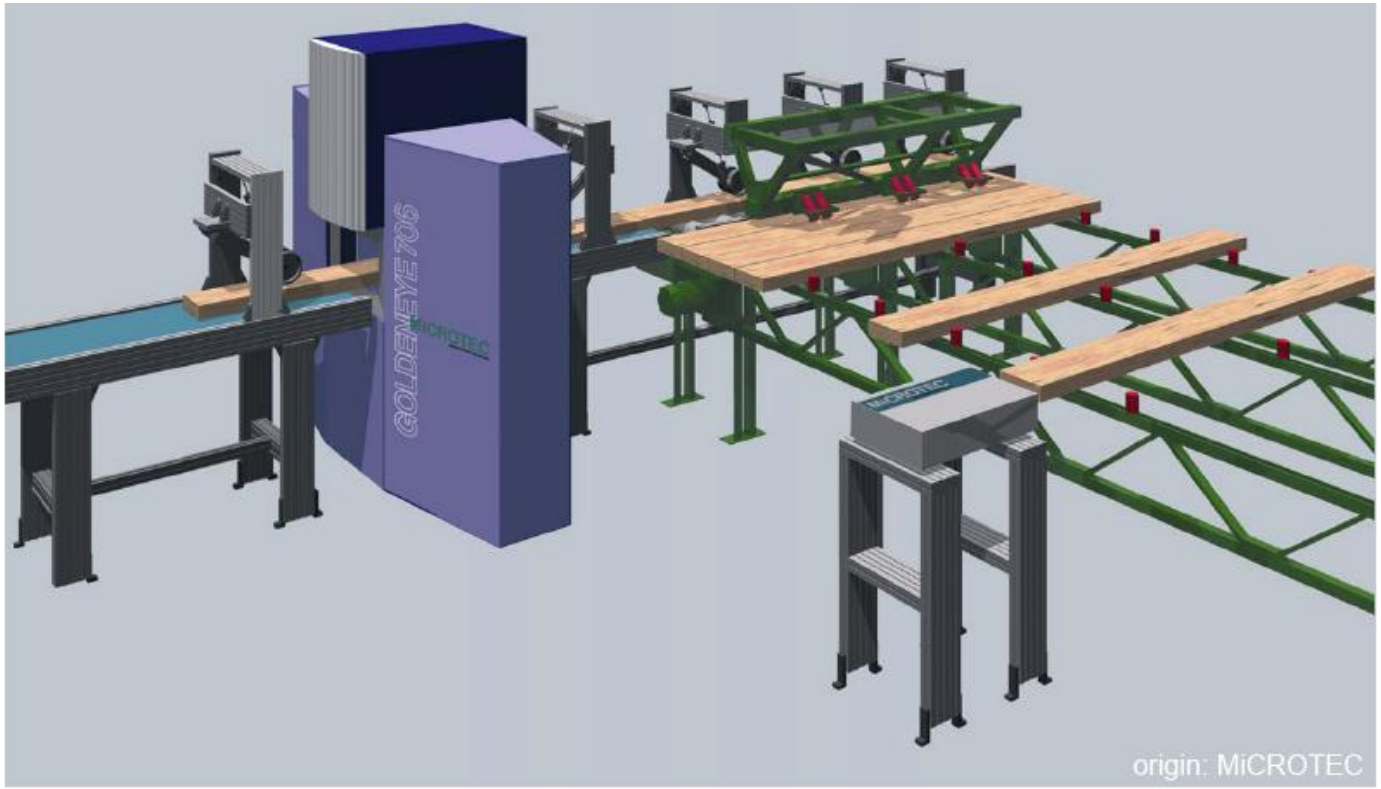
Combination graders

GOLDENEYE 706 (MiCROTEC)



But that's not everything yet

- "Visual" override
  - Distortion (might be by machine)
  - Fissures (cannot be detected by machine)
  - Wane
  - Soft rot and insect damage
  - Knots and slope of grain on any portion that cannot be machine graded (i.e. the ends of the timber for bending type machines)
  - Anything else that causes concern

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Two types of machine grading

- Output control
  - Periodic destructive testing of output from grader
  - Testing element is costly
  - But adapts the machine settings to optimise yield
  - Appropriate for large sawmills with few species
- **Machine control**
  - Sawmills don't normally test the output
  - Relies on strict assessment and control of machines
  - No regular fine adjustment of machine settings
  - Appropriate for UK sawmills (& most European ones)

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How are settings developed?

- The relationship between IP and the three grade determining properties varies
  - from species to species
  - from region to region
- Grading machines measure IP differently
- And so…

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How are settings developed?

- Machine output control settings are required for each combination of:
  - Species (or group of similar species)
  - Growth area
  - Strength grading machine
  - Strength grade combination

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The procedure

1. Obtain a sample of timber that represents the population to be graded
   - Species or species group throughout the growth region
   - Production practice (cutting patterns and dimensions)
   - Condition in which timber is to be graded (moisture content, finish etc)
   - Quality of timber to be graded (i.e. not selected lower or higher quality)
2. Remove pieces that would be rejected under visual override rules
3. Pass the timber through the grading machine for which settings are required
4. Condition the timber to the in-service moisture content (usually 12%)
5. Test to EN408 to obtain strength, stiffness and density at the worst defect
6. Relate the IP to the strength, stiffness and density (as EN384 and EN14081)
7. Present the derived settings and calculations in a report to CEN TC124 TG1
8. Settings are approved, rejected or required to be revised and resubmitted

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The grading dataset

- Minimum of 450 pieces
- From four subsample areas
- With no less than 100 pieces in each
- More pieces means less uncertainty
  - Better yields
  - More grade combinations possible
- Typically ~1000 pieces

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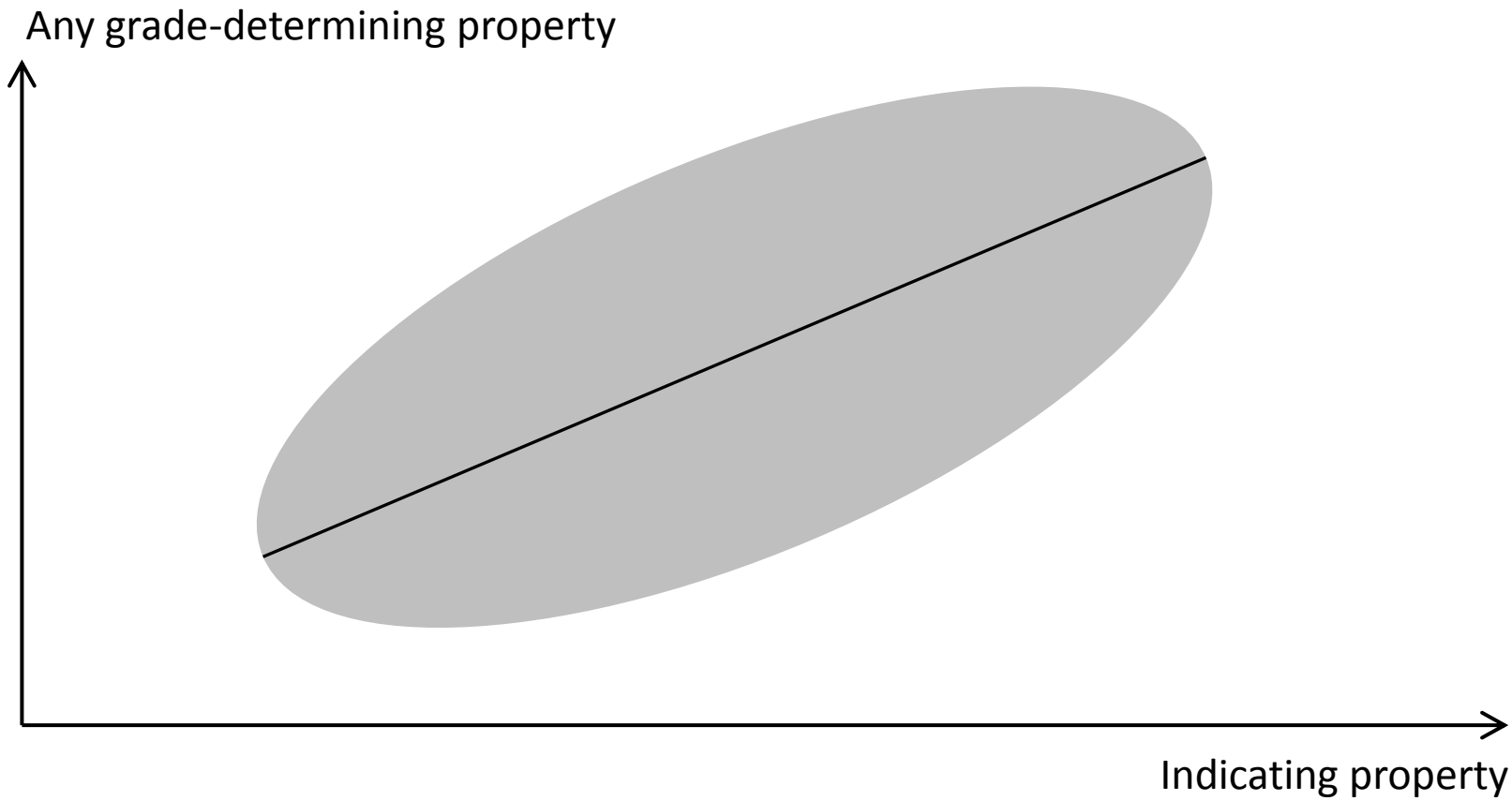
The results…



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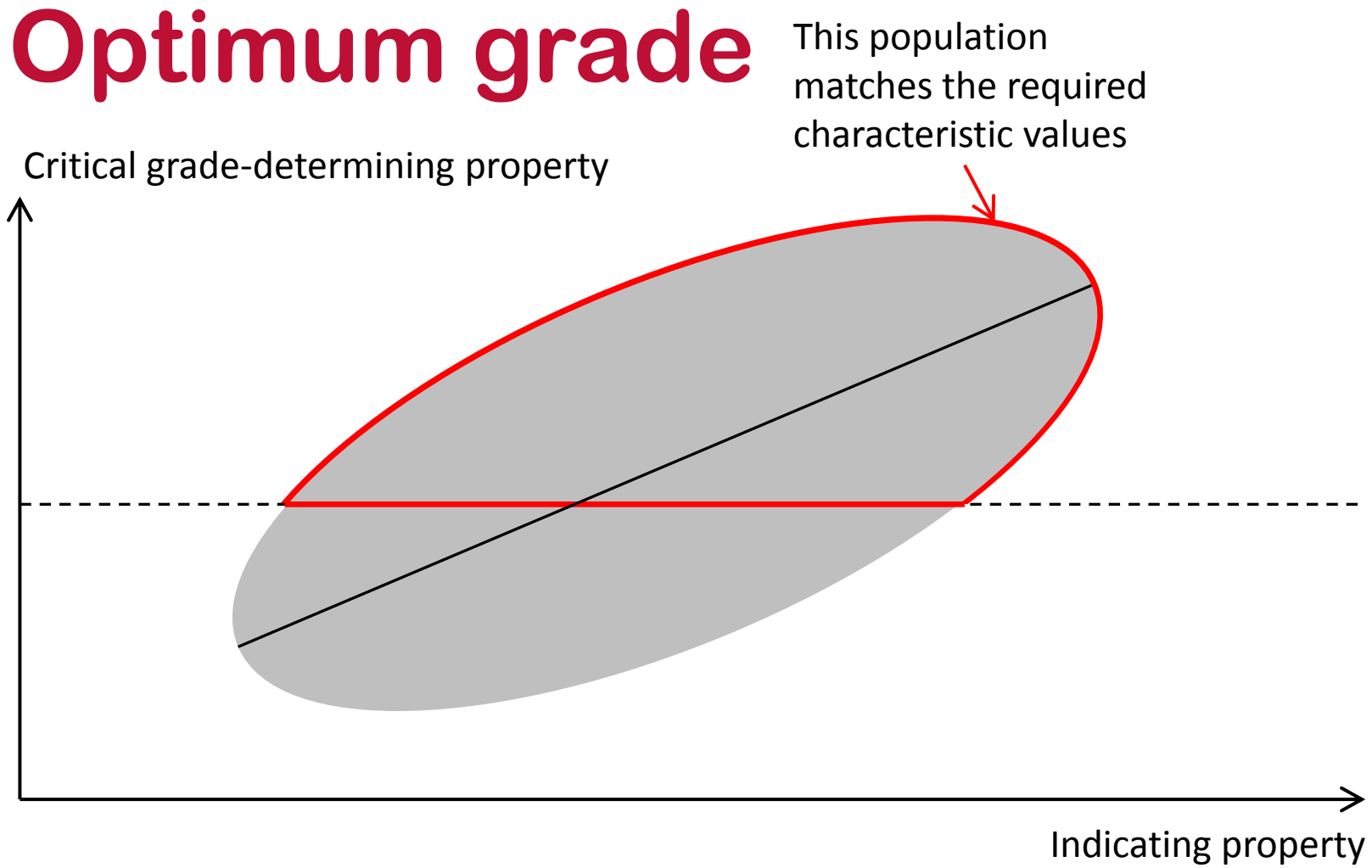
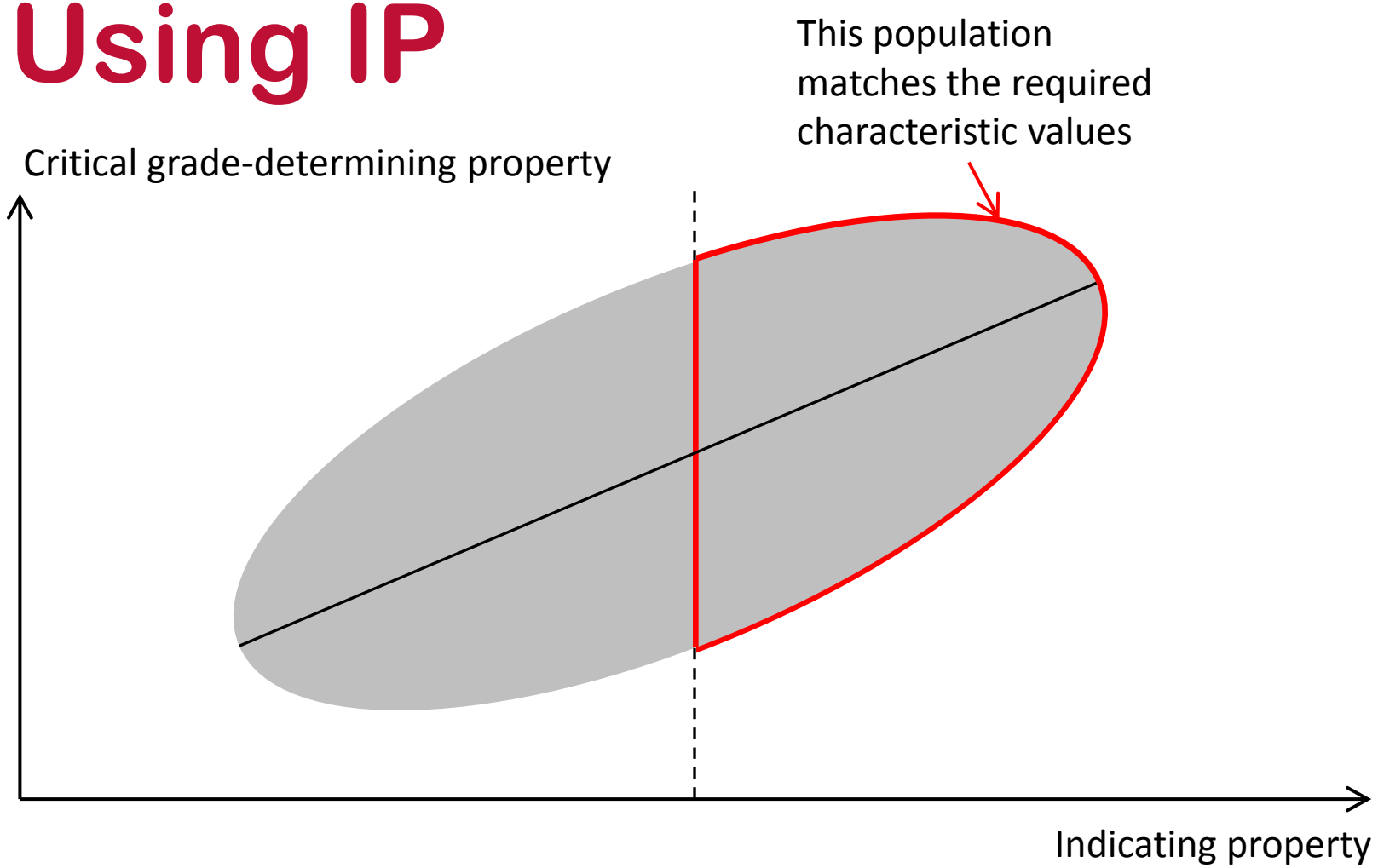
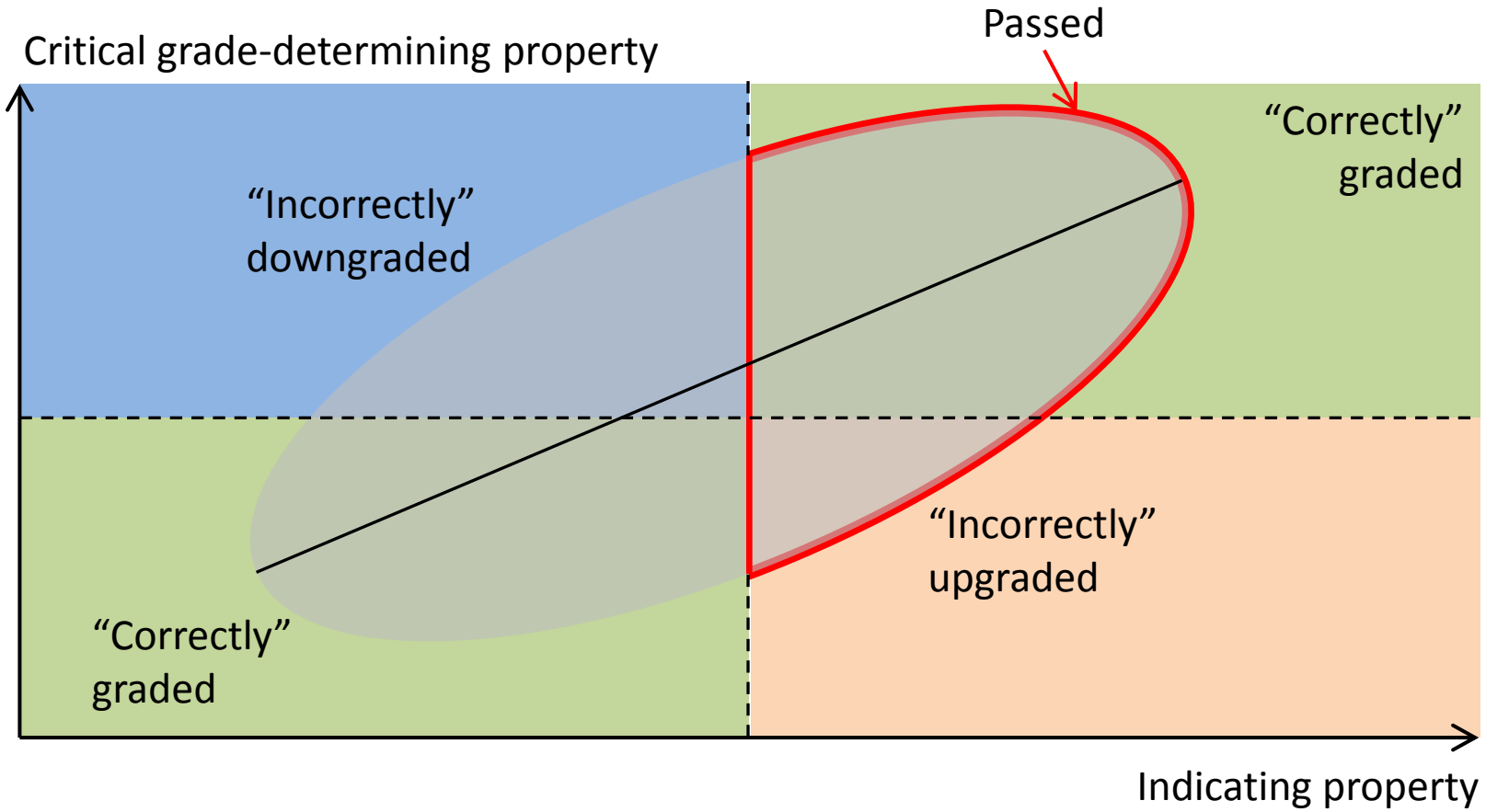
Optimum grade



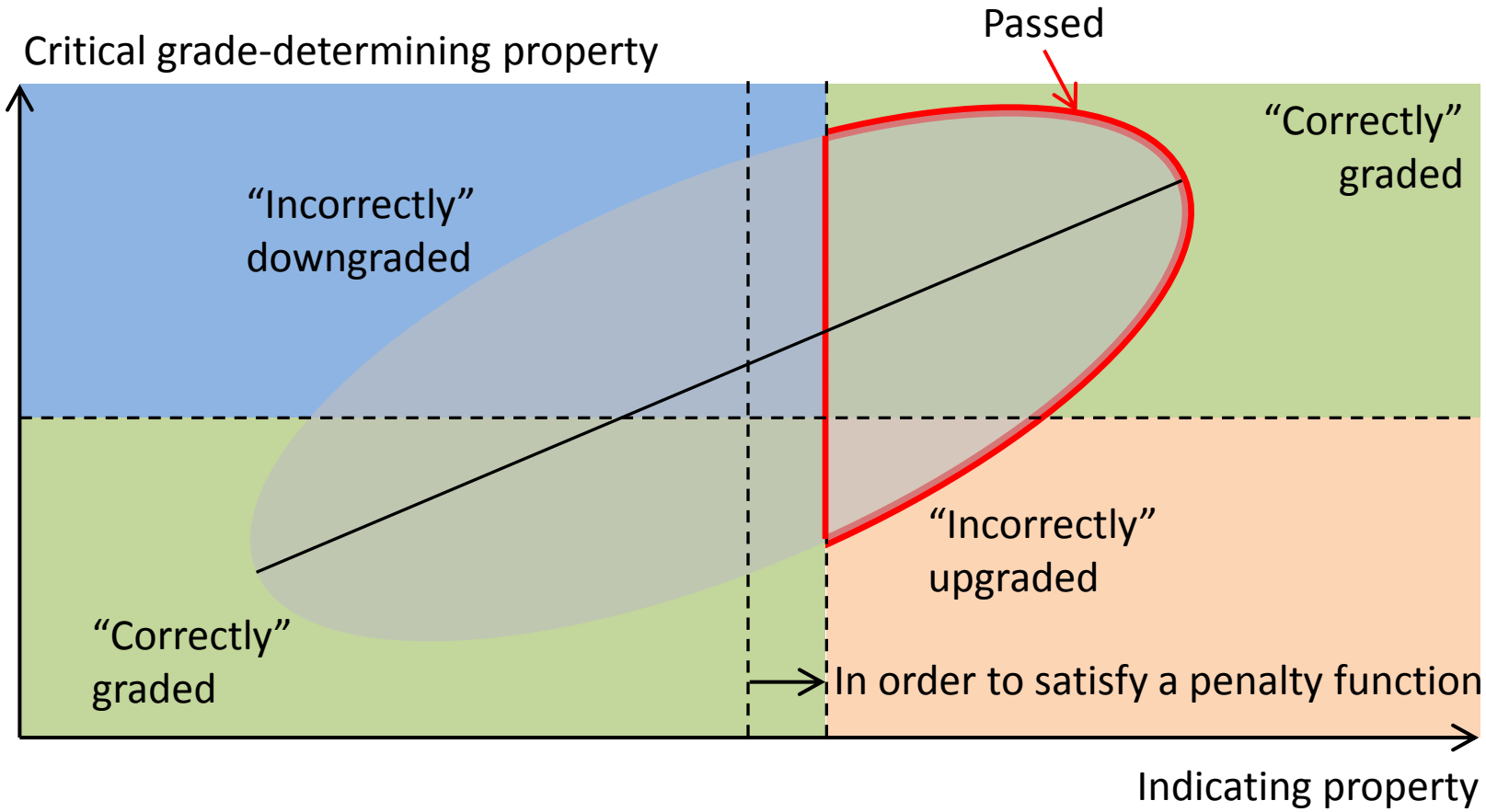
Using IP


This population matches the required characteristic values
Critical grade-determining property
Indicating property

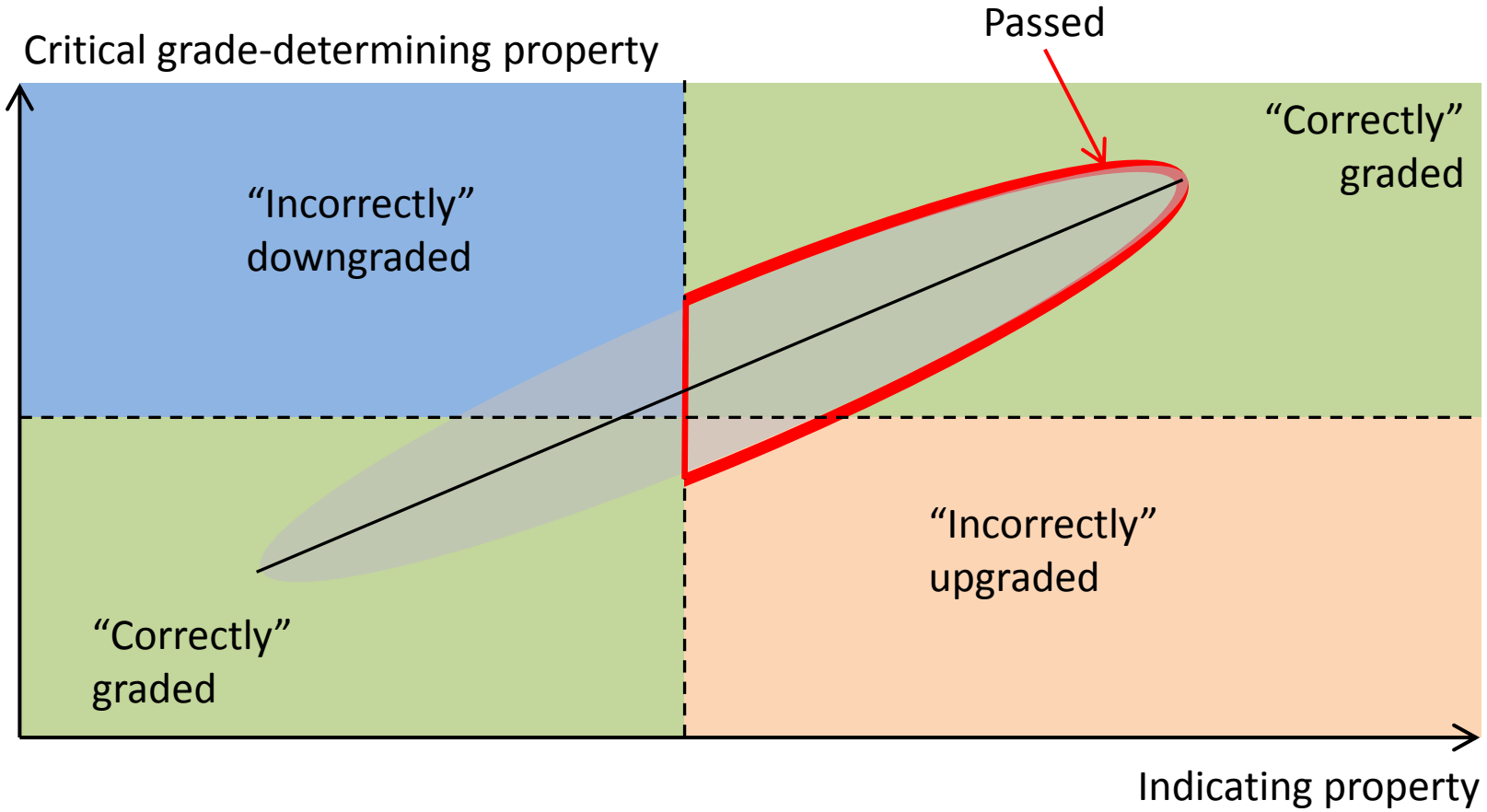
Cost matrix


Critical grade-determining property
Passed
"Incorrectly" downgraded
"Correctly" graded
"Incorrectly" upgraded
"Correctly" graded
Indicating property

Cost matrix


Critical grade-determining property
Passed
"Incorrectly" downgraded
"Correctly" graded
"Incorrectly" upgraded
"Correctly" graded
In order to satisfy a penalty function
Indicating property

Why a powerful IP is better



Some things to bear in mind

- There are 3 properties to satisfy
- Everything is correlated with everything
- But often very weakly
- And these correlations vary
- Industrial production is not like the lab

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Some questions

- What if the population changes?
- What if the correlation with IP changes?
- What do we do about growth regions?
- How can we compare measurements?
- Should we monitor production?
- Can we reduce wastage?
  - Better processing
  - Through silviculture

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British Timber

- UK is one of the biggest importers of timber
- Perception “UK plantation timber grows too quickly”

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	Region
km	Forest
	Stand
	Tree
m	Log
	Sawn timber
cm	Clear wood
mm	Growth layer
	Wood anatomy
	Cell
µm	Cell wall
	Cell wall layers
	Microfibril clusters
nm	Molecular

Forest Research
Forestry Commission

Forest Products Research Institute
Edinburgh Napier University

Department of Chemistry
The University of Glasgow

Harrington, J. J. (2002). Hierarchical Modelling of Softwood Hygro-Elastic Properties. PhD thesis, University of Canterbury.

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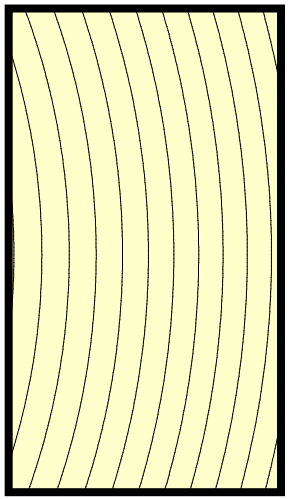
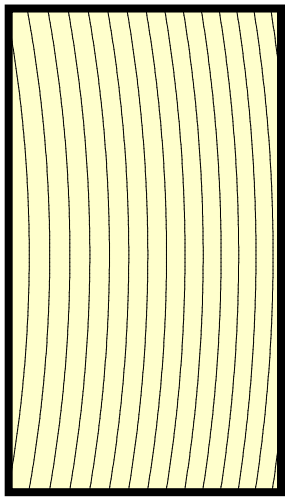
Rate of growth

Grew in ~11 years



Grew in ~15 years



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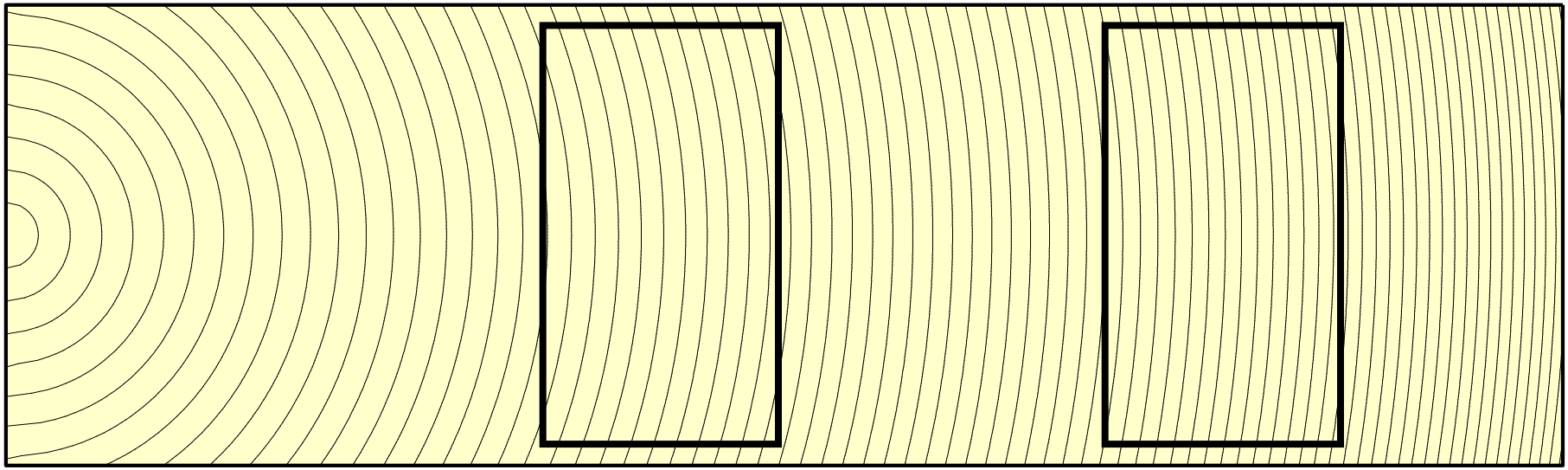
Rate of growth



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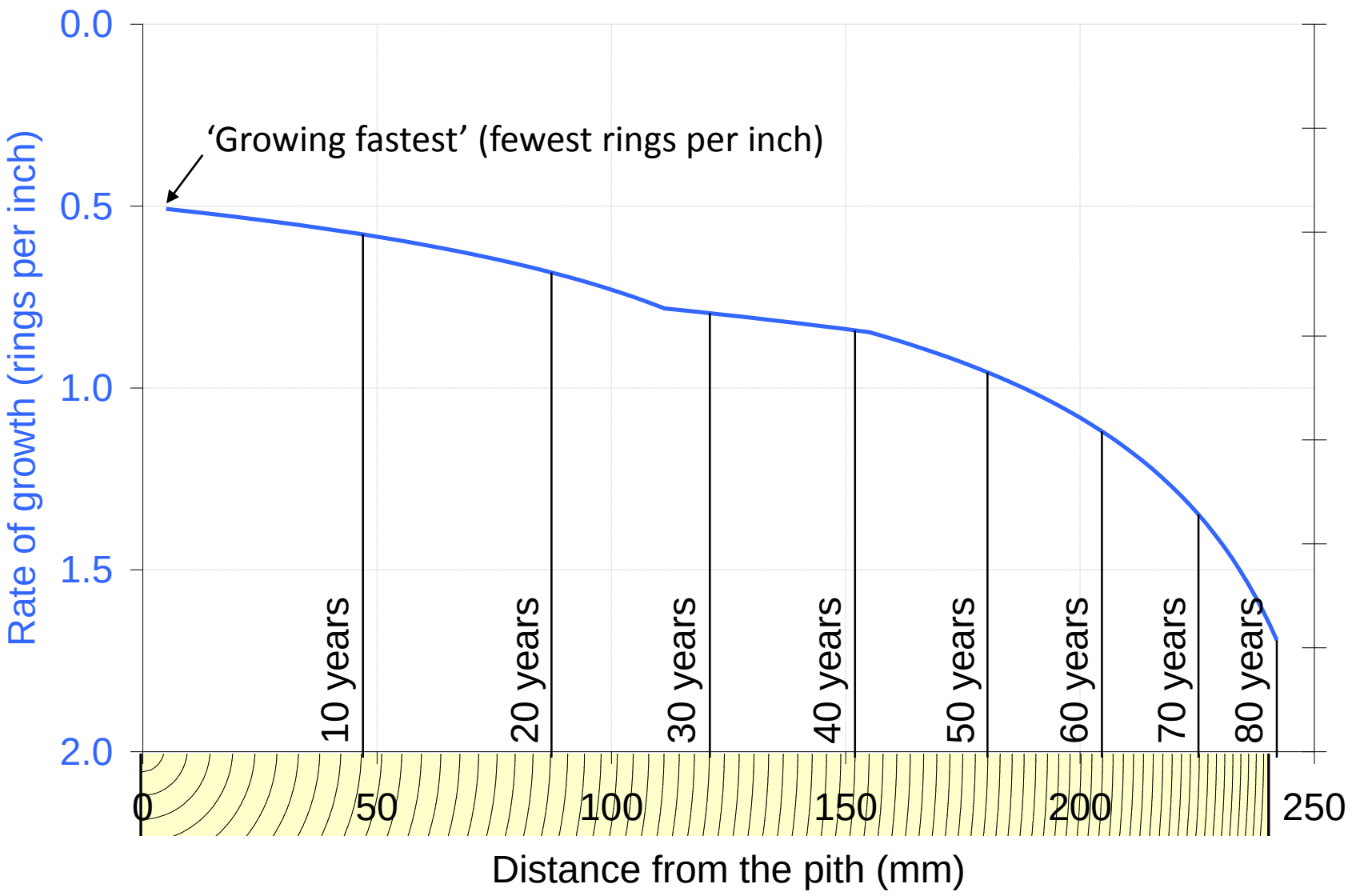
0.0
0.5
1.0
1.5
2.0
Rate of growth (rings per inch)
'Growing fastest' (fewest rings per inch)
10 years
20 years
30 years
40 years
50 years
60 years
70 years
80 years
0
50
100
150
200
250
Distance from the pith (mm)

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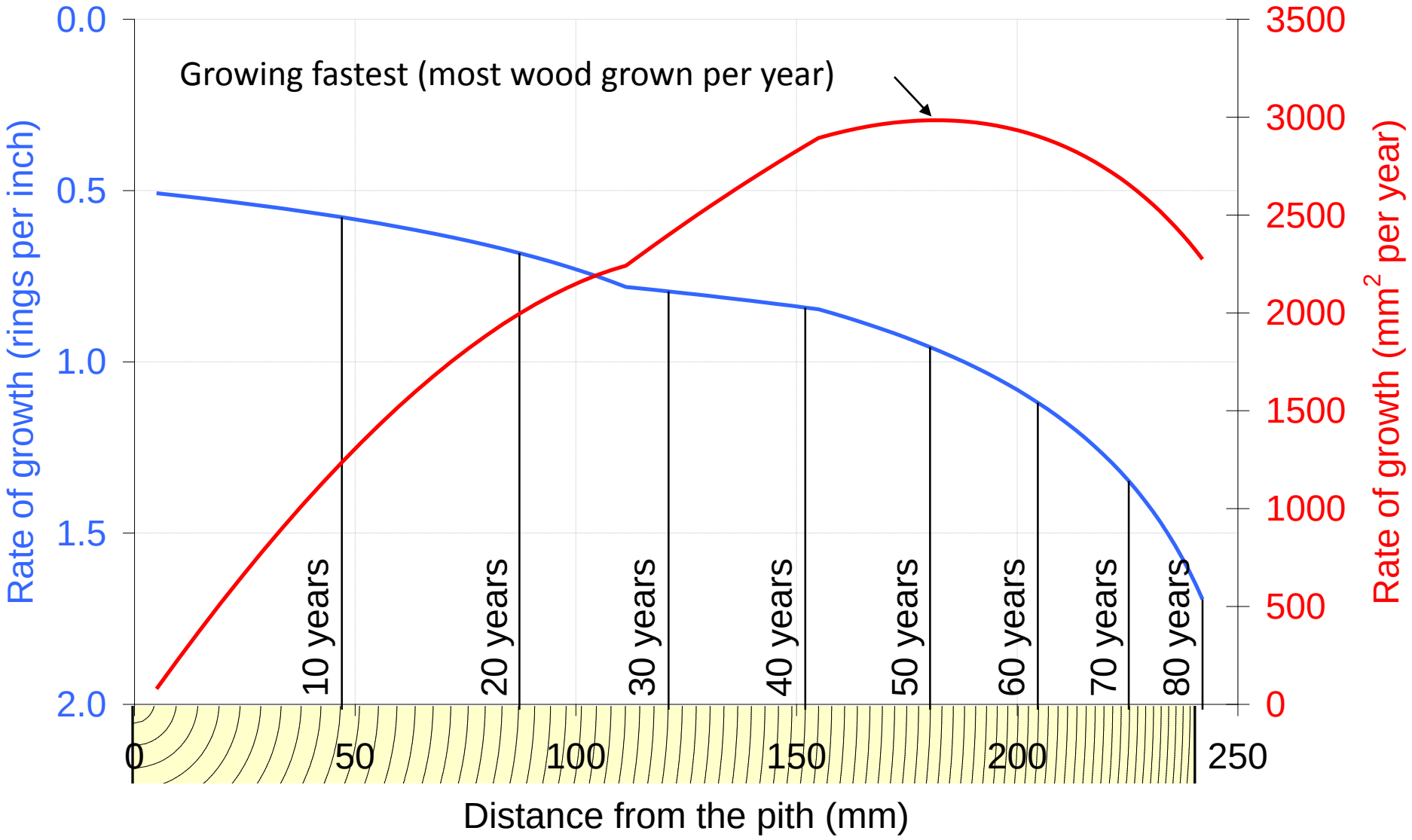
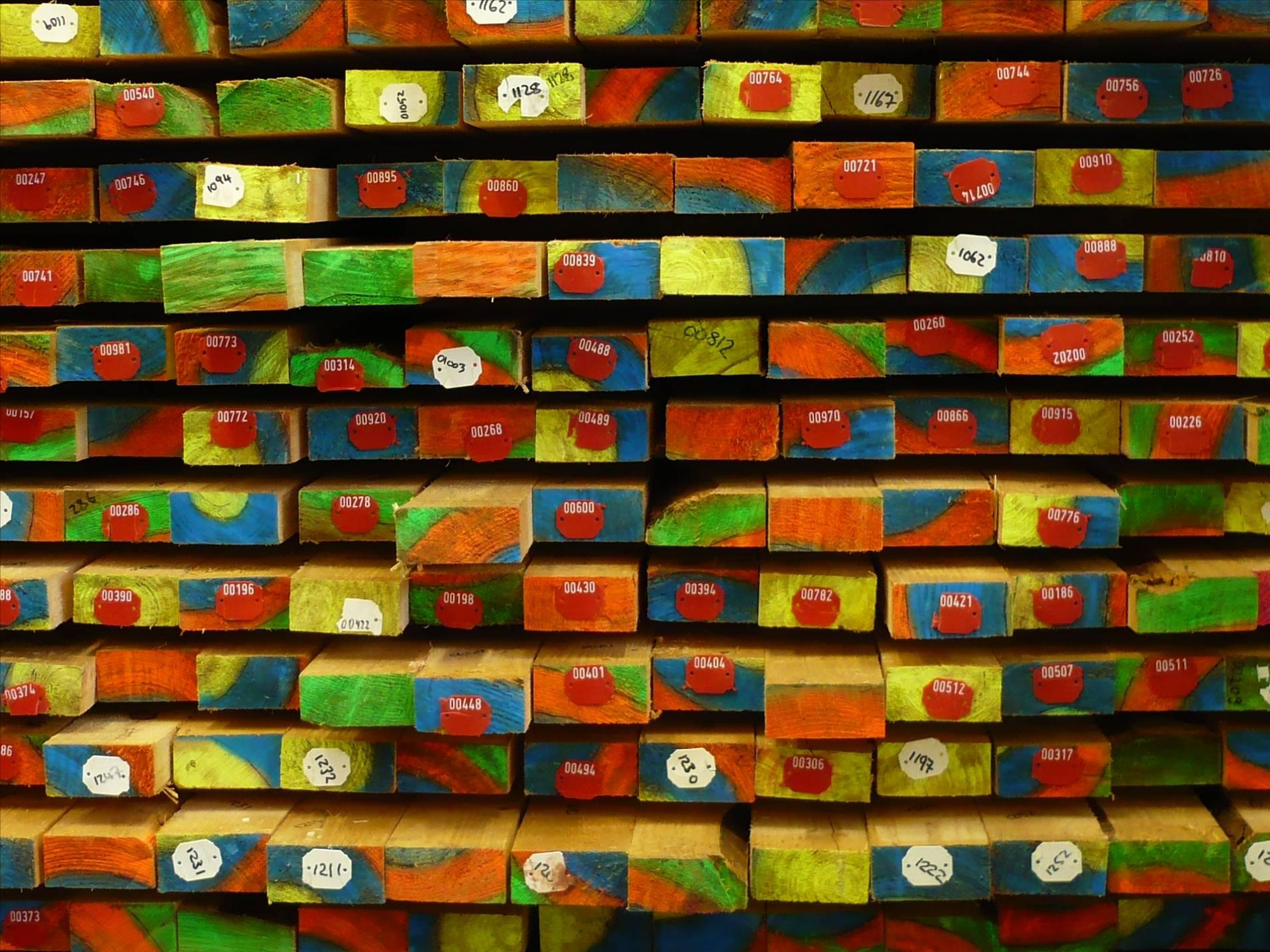


Birkley Wood Study

(83-year old Sitka spruce trees)


00540
00764
00744
00756
00726
00247
00746
00895
00860
00721
00910
00741
00839
00888
00981
00773
00314
00488
00260
00252
00772
00920
00268
00489
00970
00866
00915
00226
00286
00278
00600
00776
00390
00196
00198
00430
00394
00782
00421
00186
00374
00401
00404
00507
00511
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00306
00317
00373

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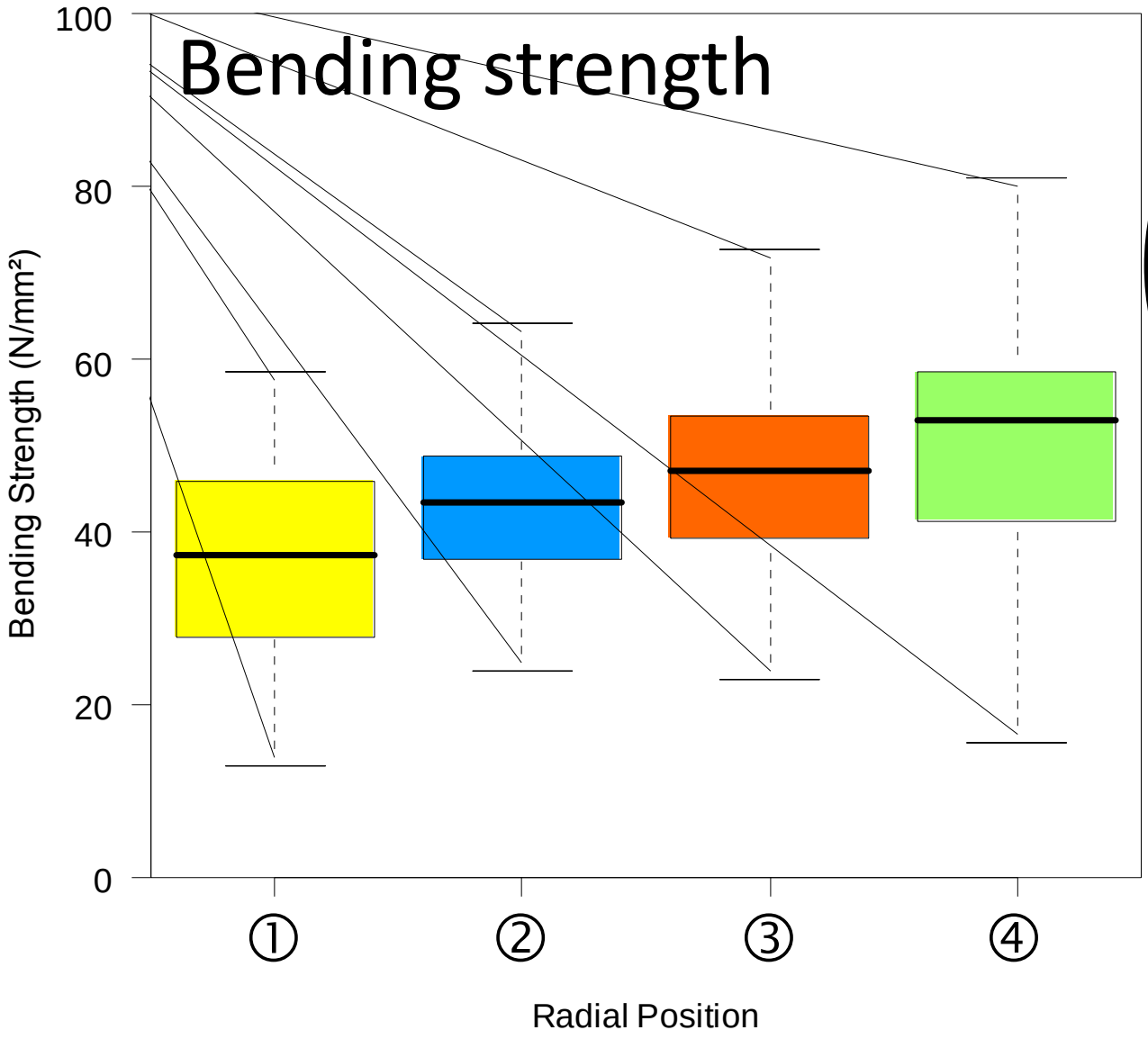
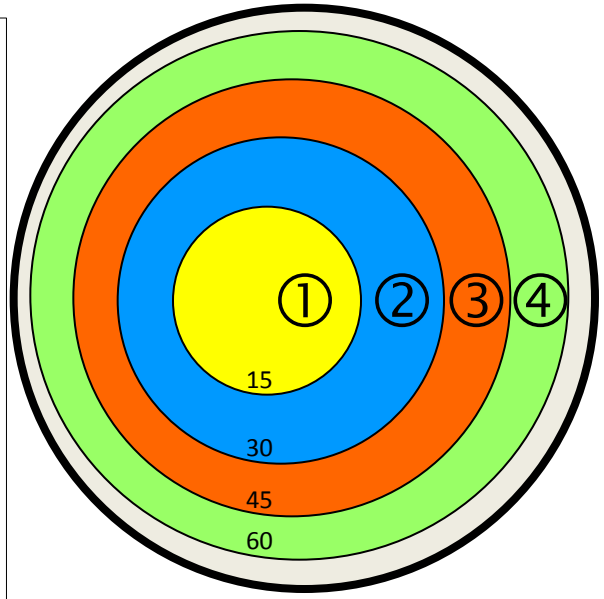
Bending strength





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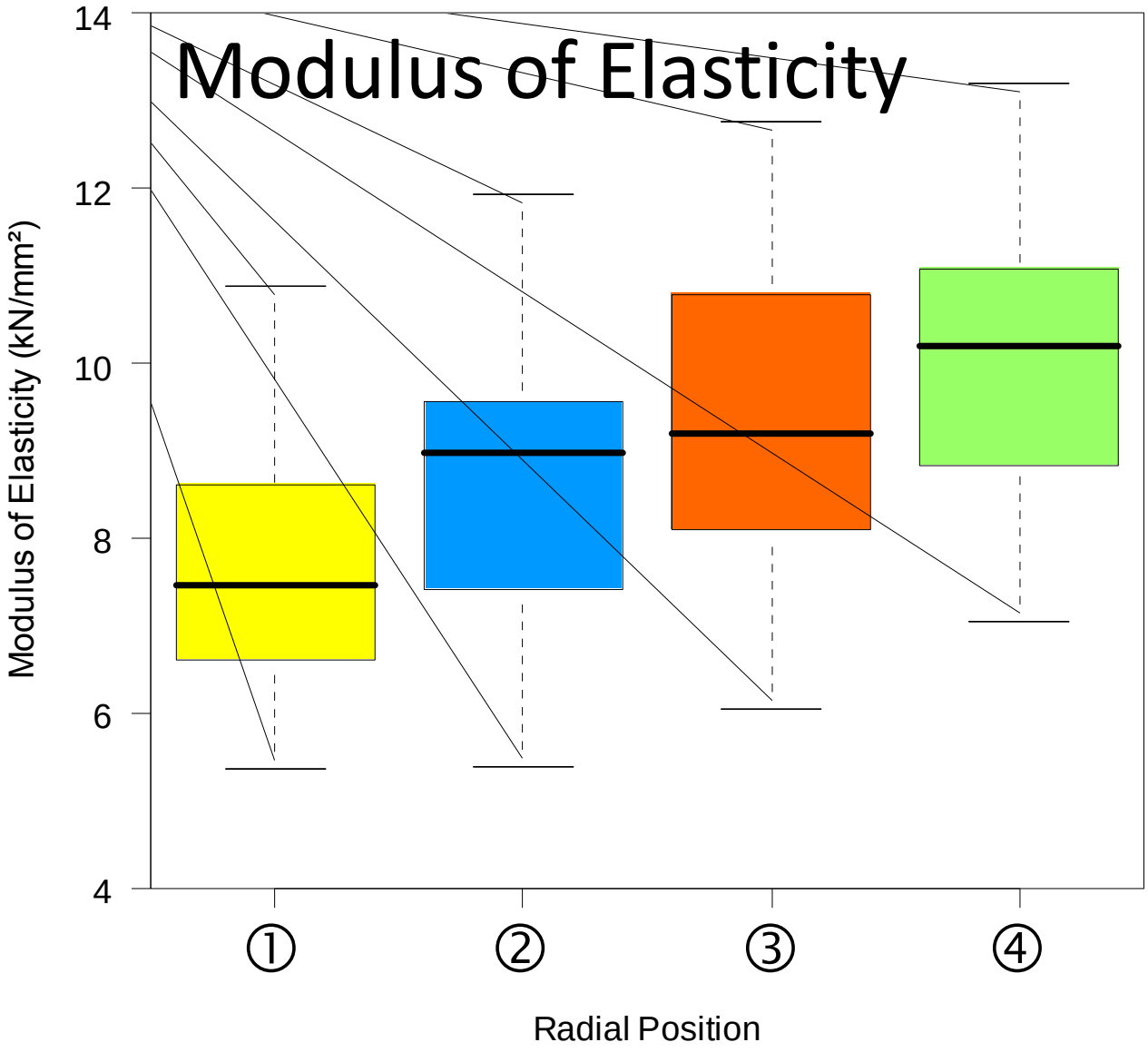
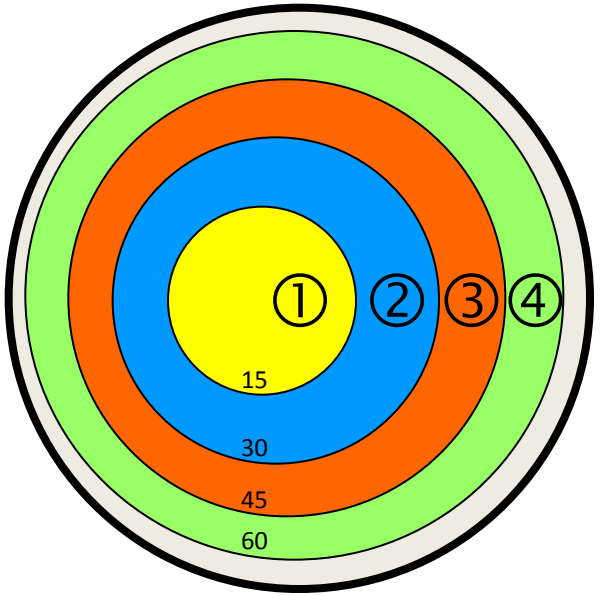
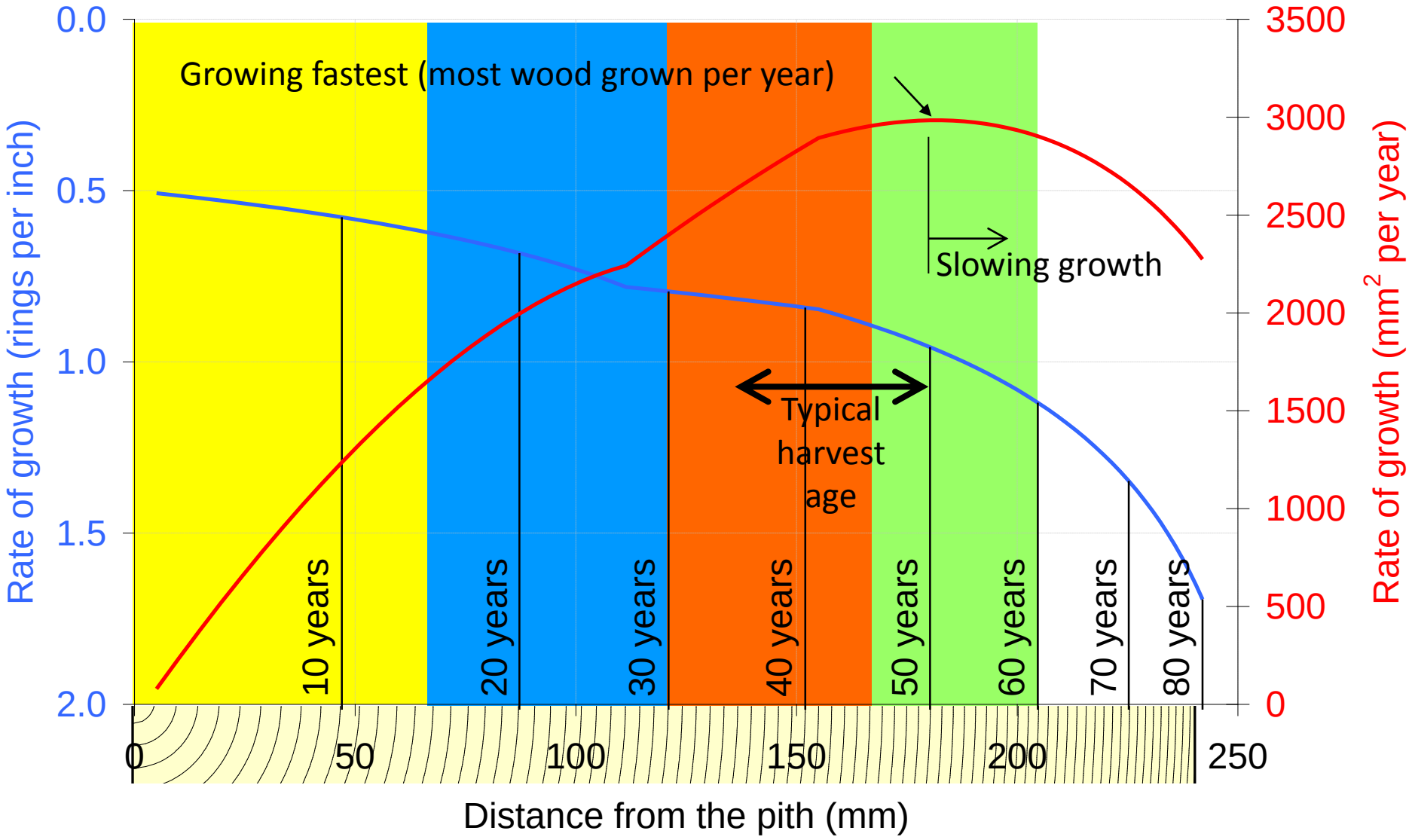
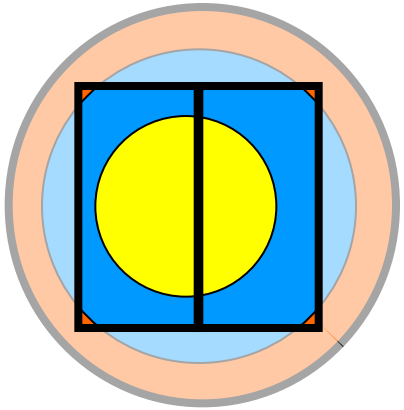
Modulus of Elasticity






Growing fastest (most wood grown per year)
Slowing growth
Typical harvest age
10 years
20 years
30 years
40 years
50 years
60 years
70 years
80 years
0.0
0.5
1.0
1.5
2.0
Rate of growth (rings per inch)
3500
3000
2500
2000
1500
1000
500
0
Rate of growth (mm2 per year)
0
50
100
150
200
250
Distance from the pith (mm)

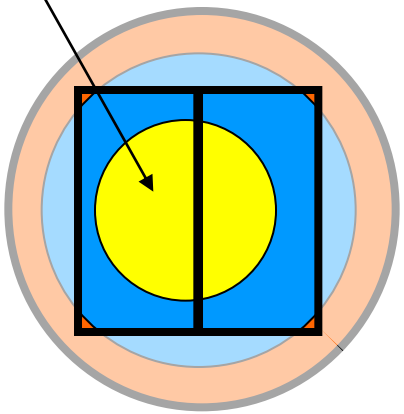
Economics of rotation length



2 pieces sold
after 40 years

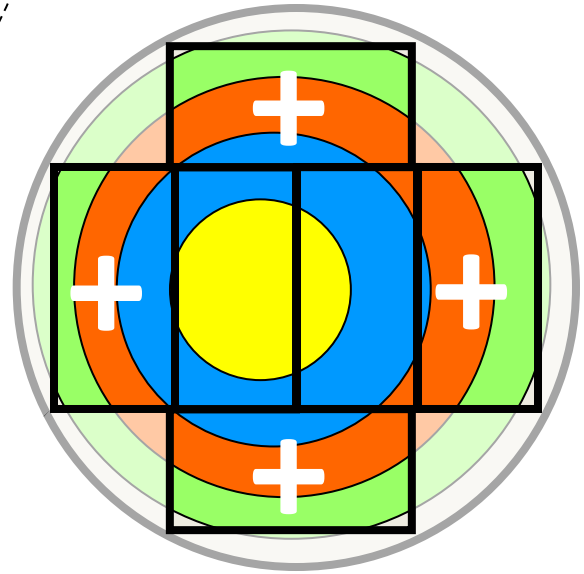
40 years
of interest

‘juvenile core’



2 more sold
after 80 years

Risk of losing
crop



6 pieces sold
after 80 years

What is quality?

- Mechanical properties
  - Strength and stiffness …or hardness…
- Physical properties
  - Density
- Knottiness
- Other defects
- Dimensional stability and distortion
- Durability

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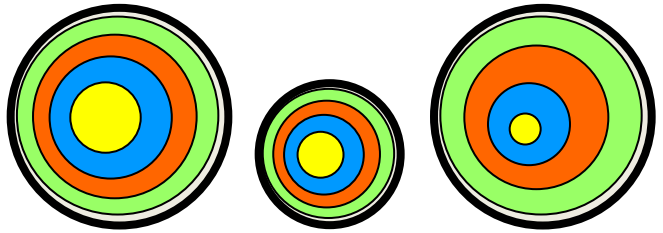
Factors affecting softwood quality

- Position within the tree
  - Radially & vertically



- Silviculture
  - Spacing, thinning, rotation length etc
- Site
  - Exposure, temperature, rainfall, soil type etc
- Genetics
  - Species, variety and individual

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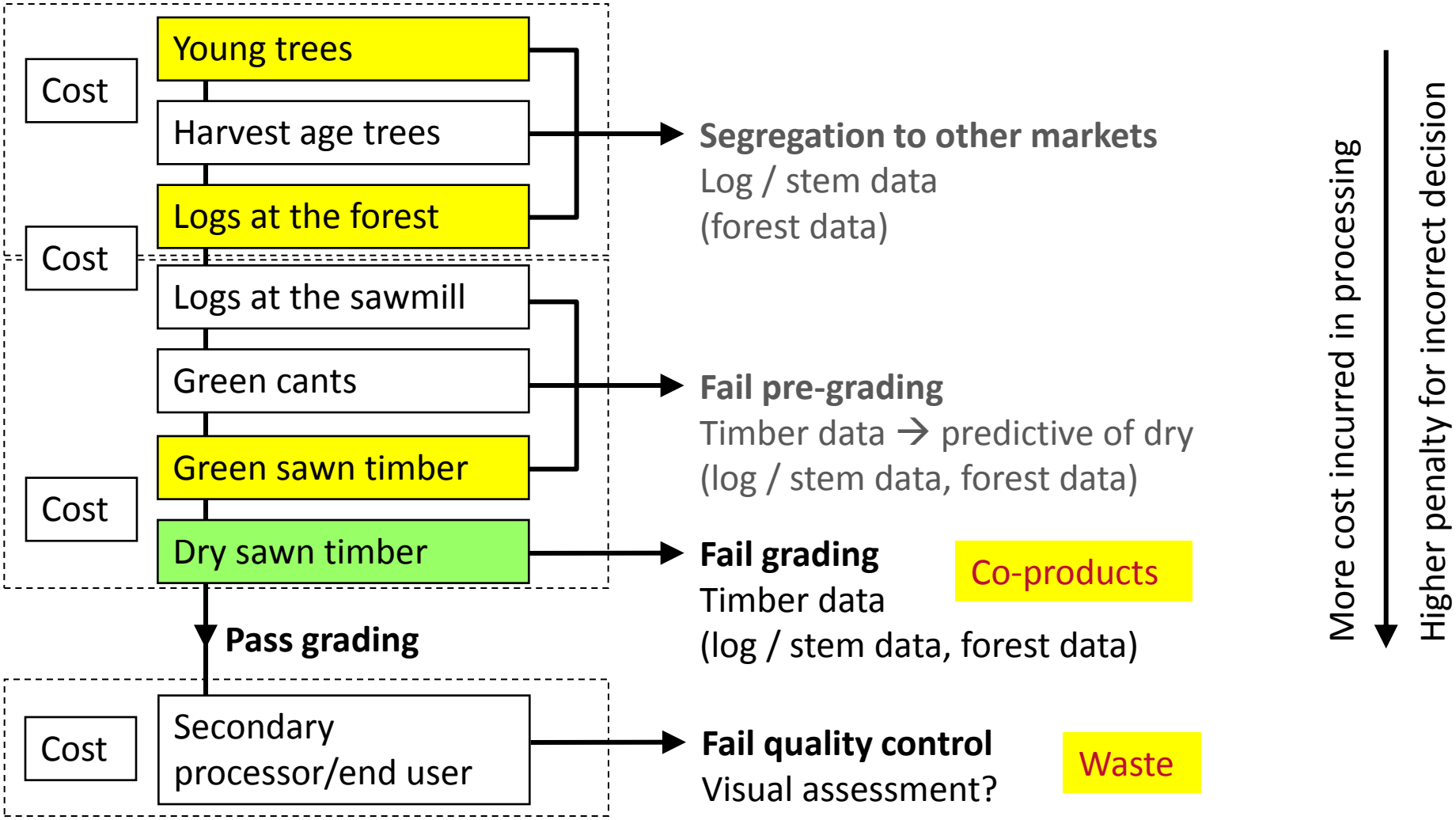
Reducing wastage



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INTERNATIONAL YEAR OF FORESTS • 2011

To celebrate people's action to sustainably manage the world's forests …to raise awareness of sustainable management, conservation and sustainable development.

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People and forests

- Home to 300 million people
- Livelihoods to many more
  - UN: 1.6 billion
  - 60 million people employed by forest industries
- Resources for almost all of us
  - Wood, fibre, fuel and food
- Amenities
  - Recreation and tourism

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People and forests

- Local weather moderation
  - Temperature and rainfall
- Watersheds
  - Rivers
  - Water quality
- Defence against flooding
- Land stabilisation and soil protection
- Buffer against pollution

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People and forests

- Wild pollinators and pest control
- Moderate the spread of insect and animal-borne diseases
- Cultural enrichment
- Physical and mental wellbeing
- Medicines

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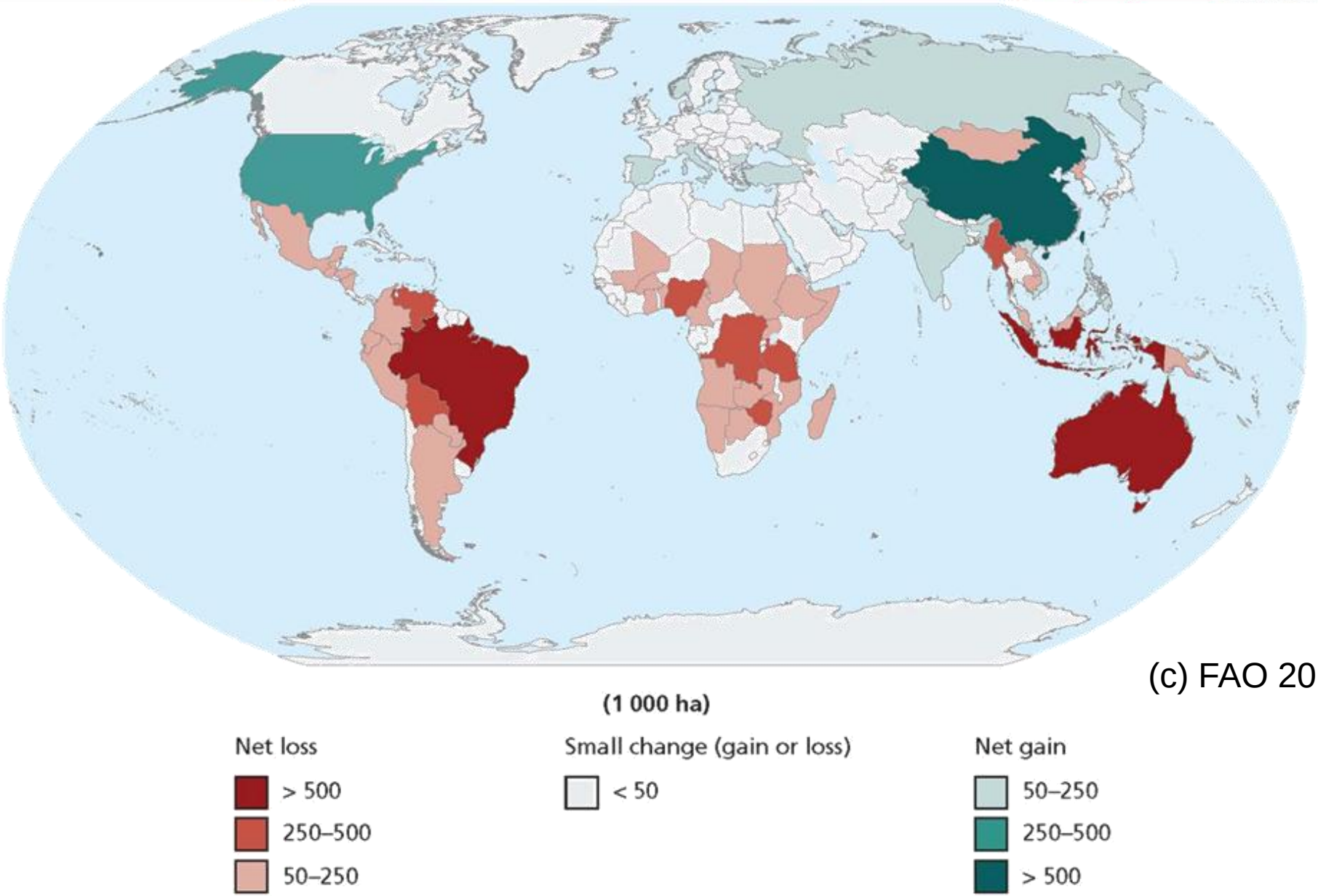

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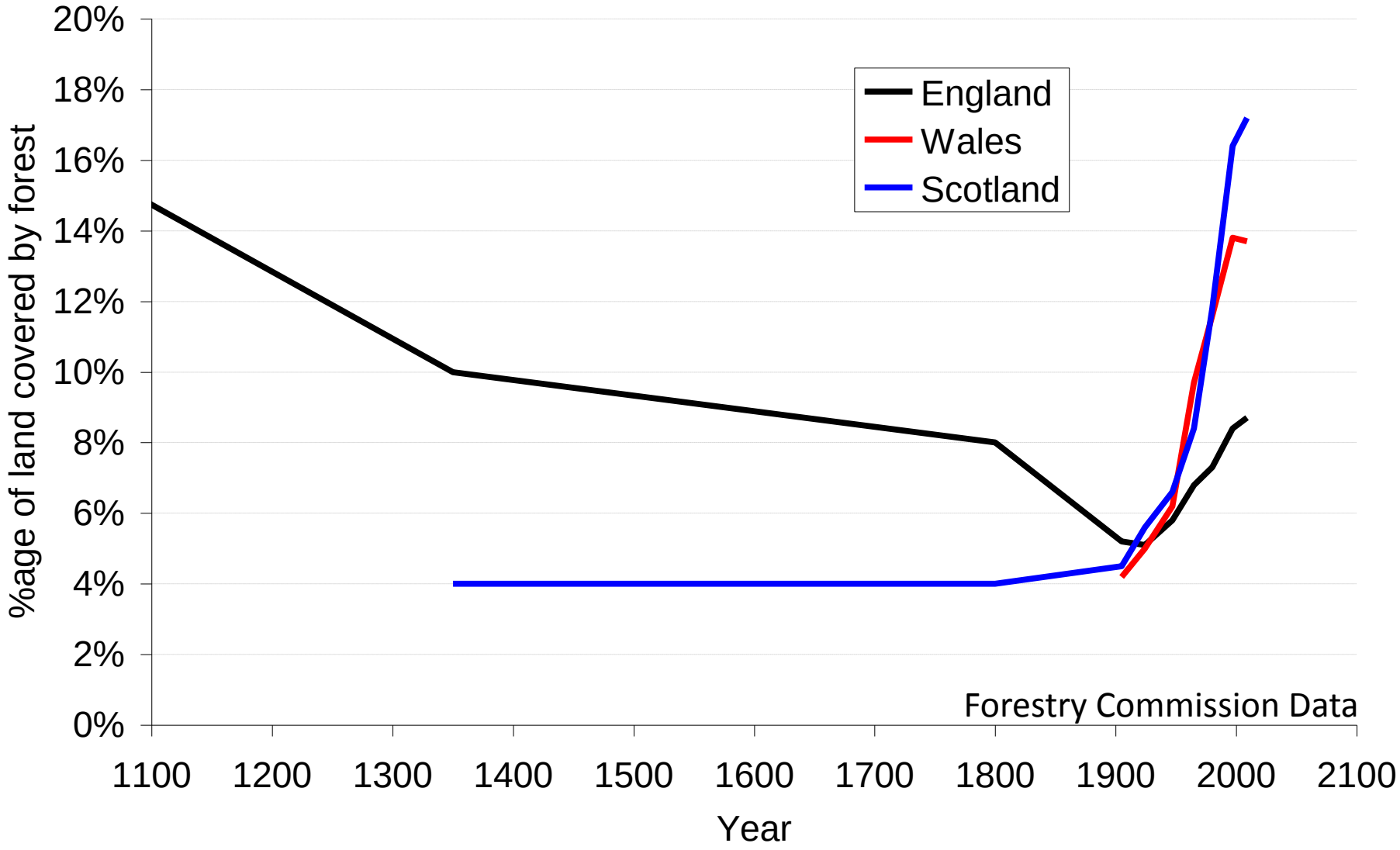
Forest cover in Great Britain



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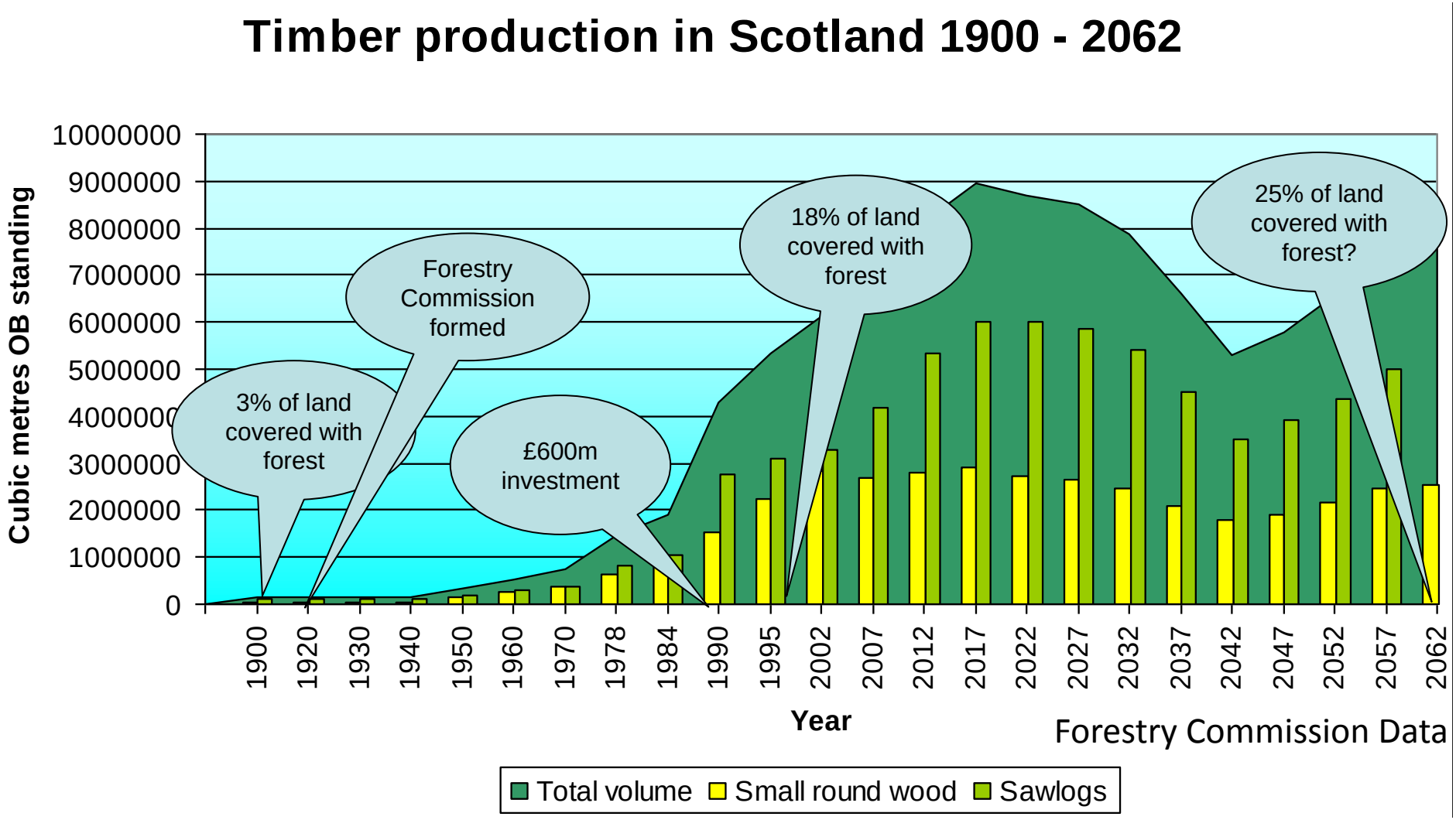
Forest cover in Great Britain



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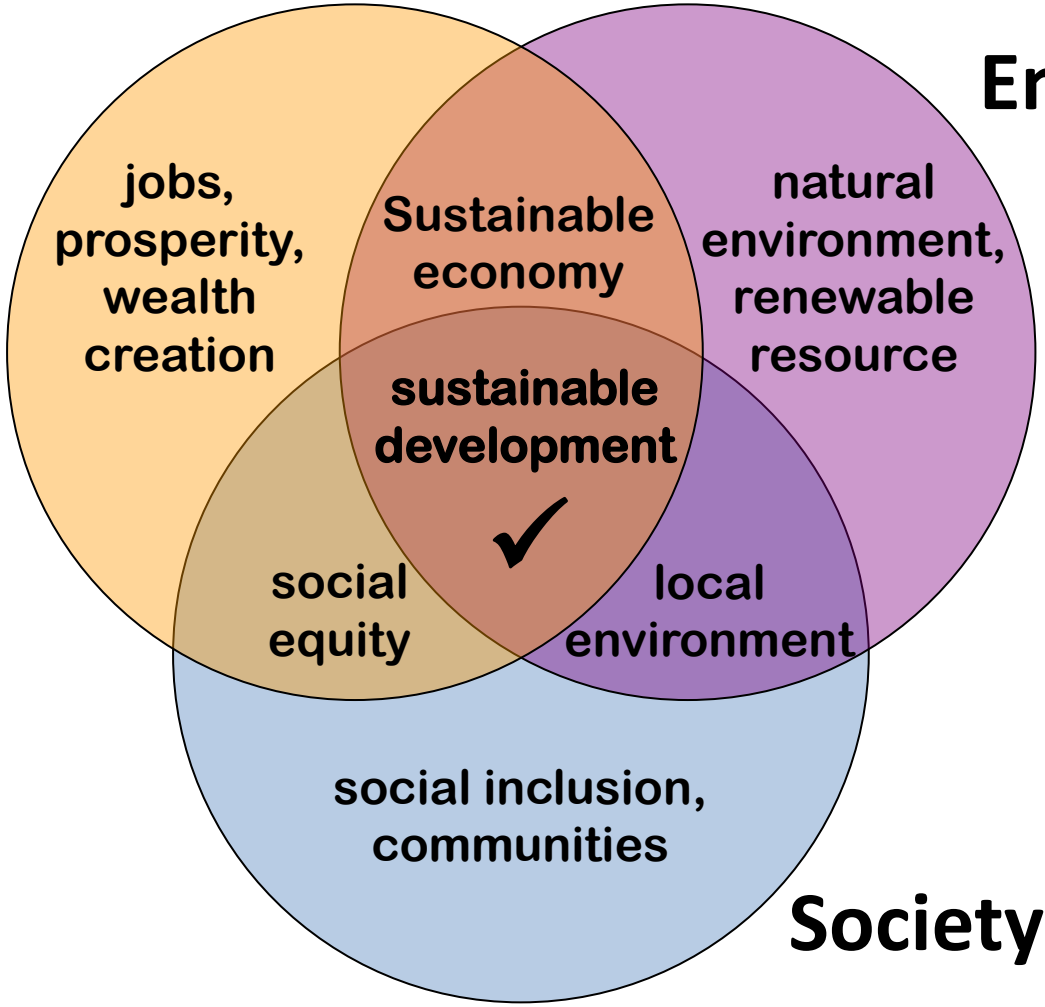
Sustainable forestry

Forestry Commission



FSC

PEFC