Transforming trees

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Strategic Integrated Research in Timber

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Acoustic assessment of timber from 16th Century painted timber ceilings in Scotland

Dan Ridley-Ellis
Carmen-Mihaela Popescu

Edinburgh Napier UNIVERSITY

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Scottish painted ceilings

Image: Kim Traynor (via Wikimedia Commons)

Image: Historic Scotland(?)

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Scottish painted ceilings

Image: Historic Scotland(?)

Properties of interest

- Strength
- Stiffness
- Density
- Thermal movement
- Moisture movement
- Distortion
- Creep

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Non-destructive methods

- Visual
- Acoustic
- Mechanical
- X-ray
- Cores
- Spectroscopy?

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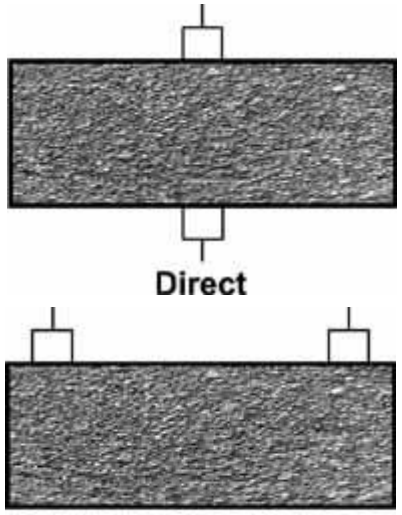
Ultrasonic

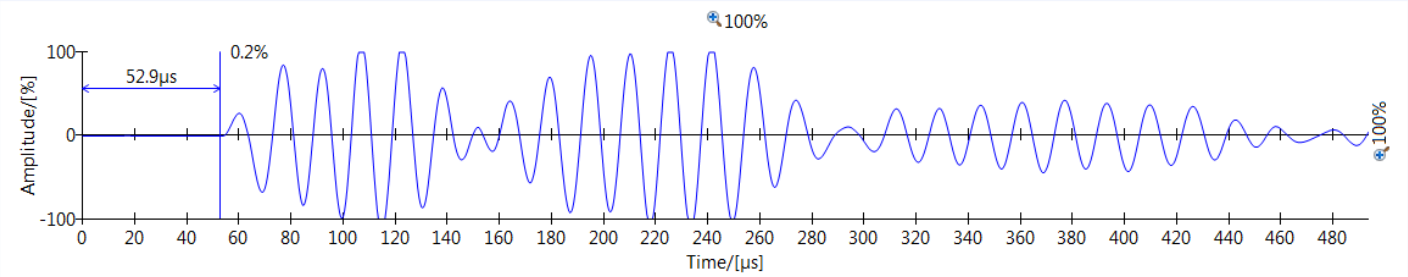
$$E = \rho v^2$$

Image: Proceq



Id	Name	Date & Time	Measurement Type	Velocity	Time 1	Time 2	Distance	Crack Depth	Correction Factor	Temperature	Compressive Strength
65970		04/18/2012 12...	Direct (default)	5652 m/s	52.9 µs	0.0 µs	0.299 m	0.000 m	1.00	22.7 °C	--

Signal curve



Settings

Pulse length:	9.3 µs
Probe frequency:	54 kHz
Pulse amplitude:	350V
Rx probe gain:	5x
Calib. time offset:	-6.1 µs
Device name:	Pundit Lab+
Serial number:	PL02-001-0038
Software version:	2.0.5
Hardware index:	B0

Comment

[Add]

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Impulse excitation

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Impulse excitation

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Mechanical loading

But it's not that simple

- Static properties vary
  - With direction and within a piece
  - With moisture content
- The relationships between dynamic and static properties varies
  - By origin
  - Because of degradation
    - Biological, environmental, mechanical

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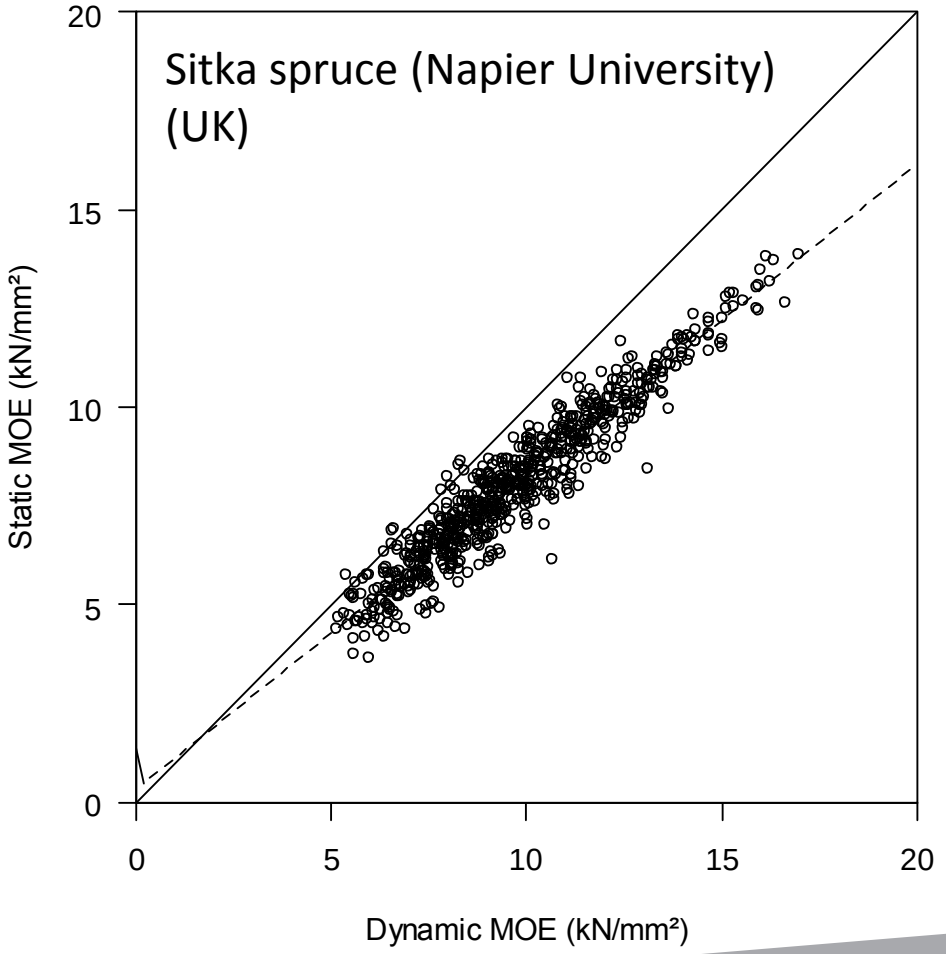
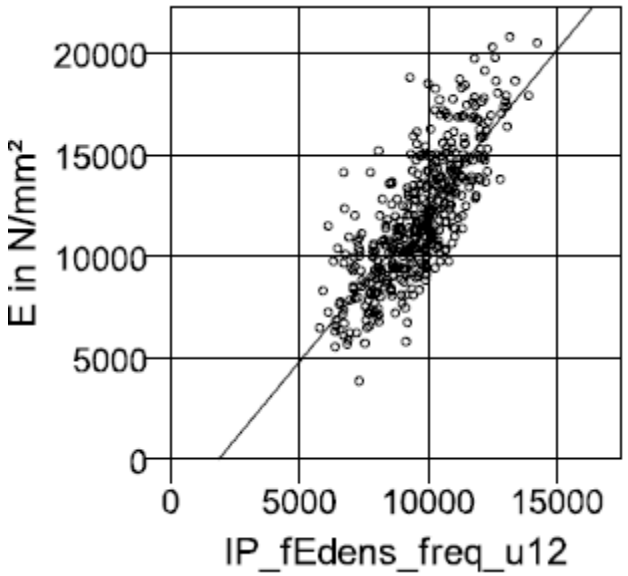
How to interpret results?

- Growth region
- The way it was processed
- What happened to it since
  - Time
  - Light
  - Moisture
  - Biological

Dynamic stiffness



Scots pine (Gradewood data, bending) (Sweden, Poland, Germany, Finland, Russia)



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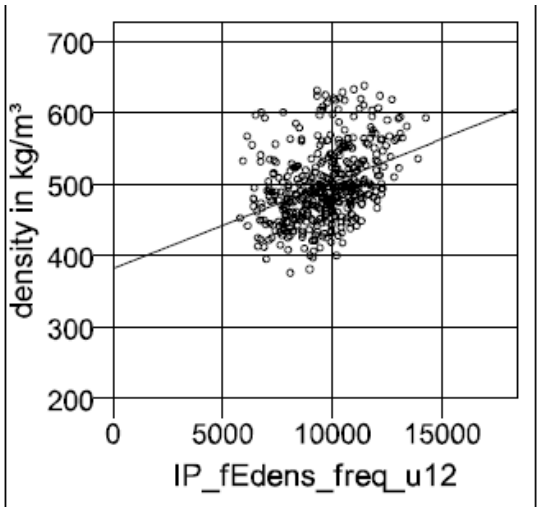

Scots pine (Gradewood data, bending)
(Sweden, Poland, Germany, Finland, Russia)

Sitka spruce (Napier University)
(Scotland)

$R^2 = 0.2277$
at 12% moisture content

Global modulus of elasticity (kN/mm²)

0
2
4
6
8
10
12

250
300
350
400
450
500

Density (kg/m³)

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The Prestongrange ceiling

Image: Crown (via Canmore)

Image: MOW (via Canmore)

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The Prestongrange ceiling


1581

Image: RCAHMS

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Ultrasonic

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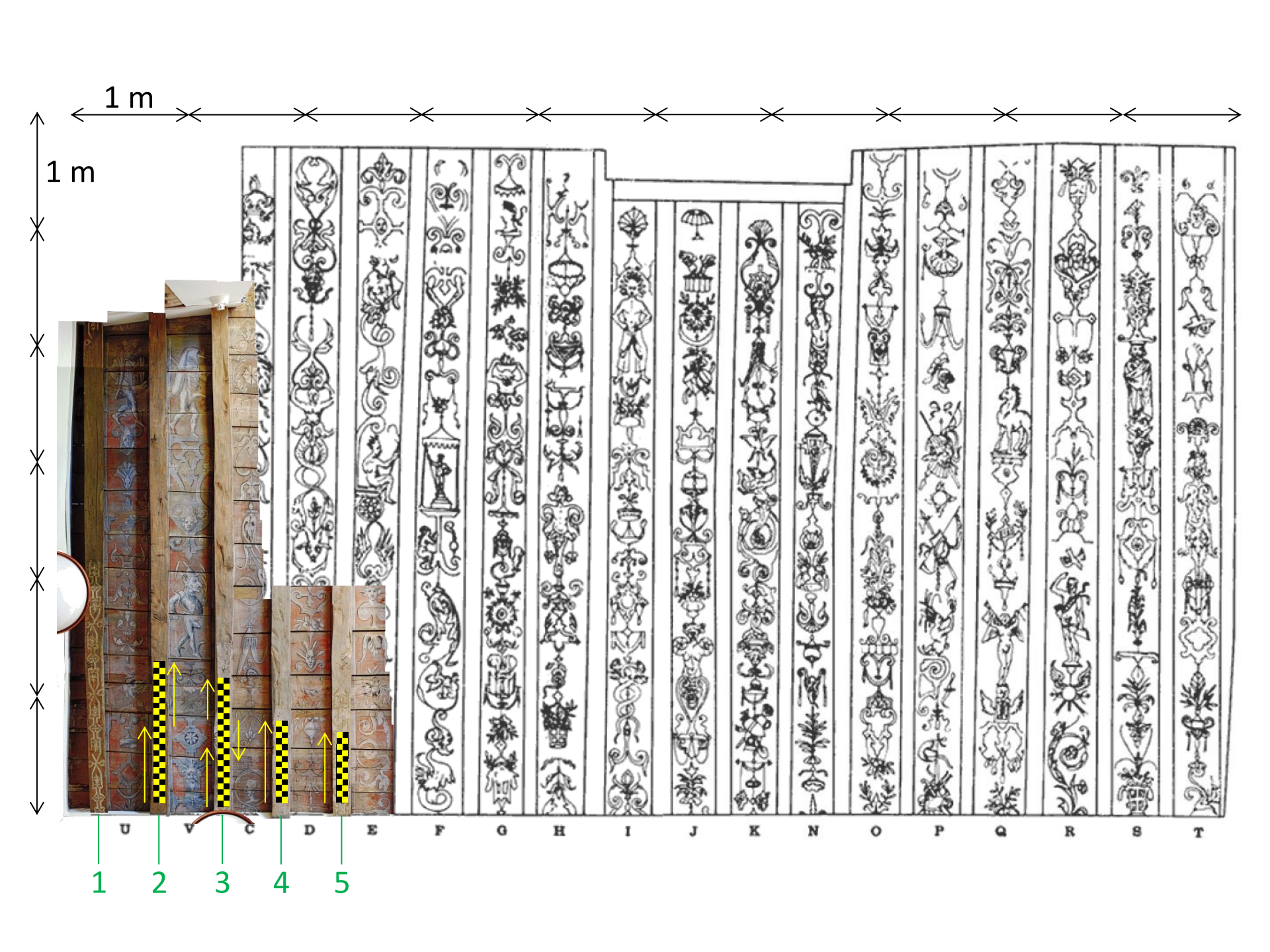
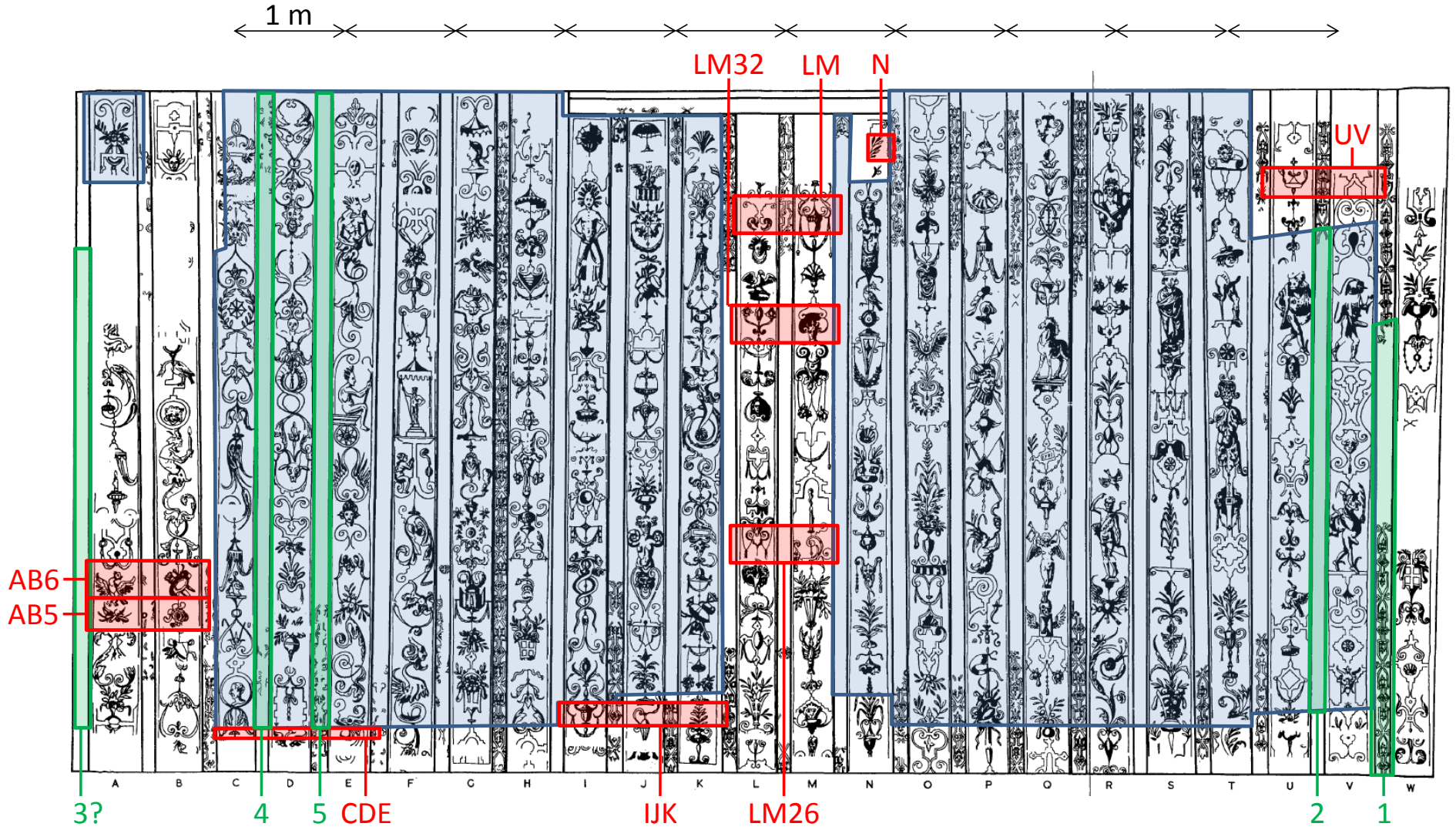
Ultrasonic and impulse


1 m
1 m
U
V
C
D
E
F
G
H
I
J
K
N
O
P
Q
R
S
T
1
2
3
4
5

Original location



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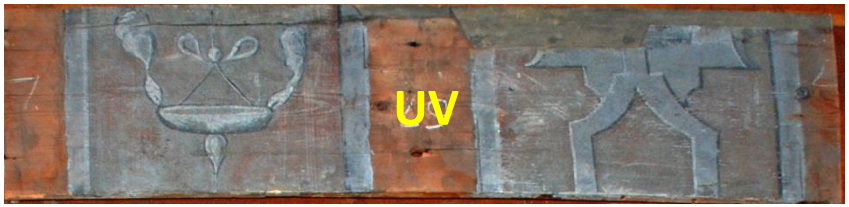
Offcuts

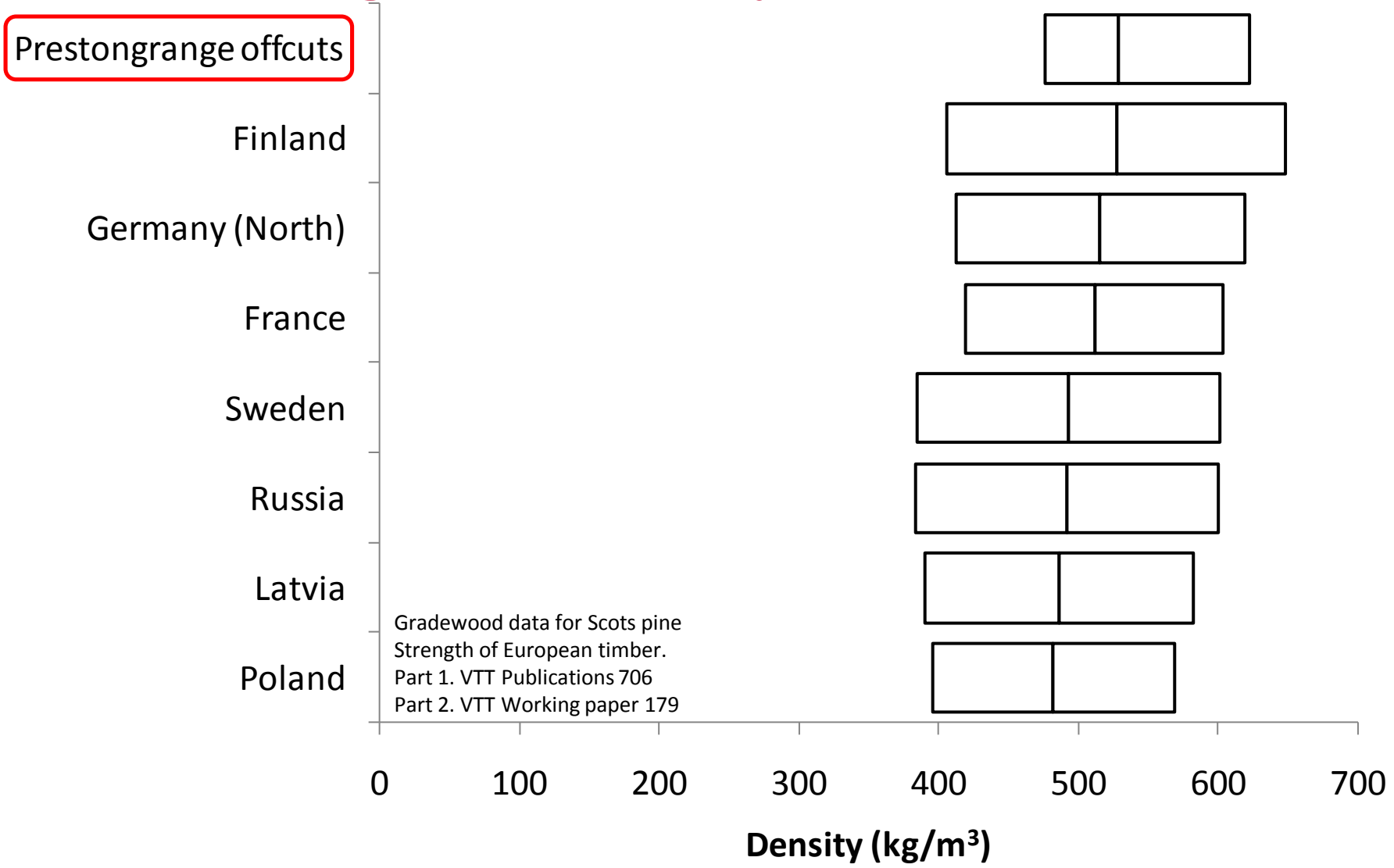


xxx (long)

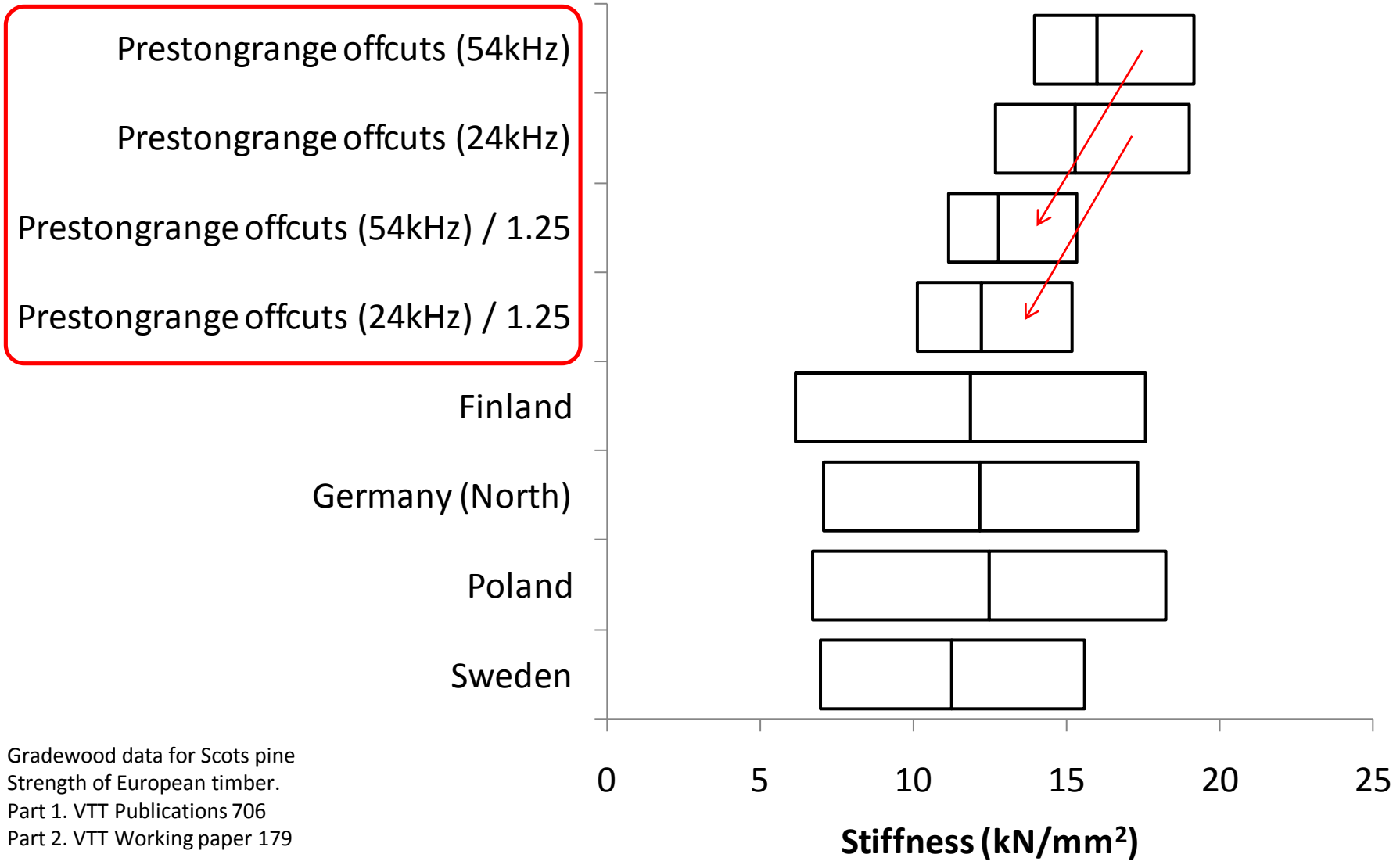
B14

N

Density of the pine offcuts

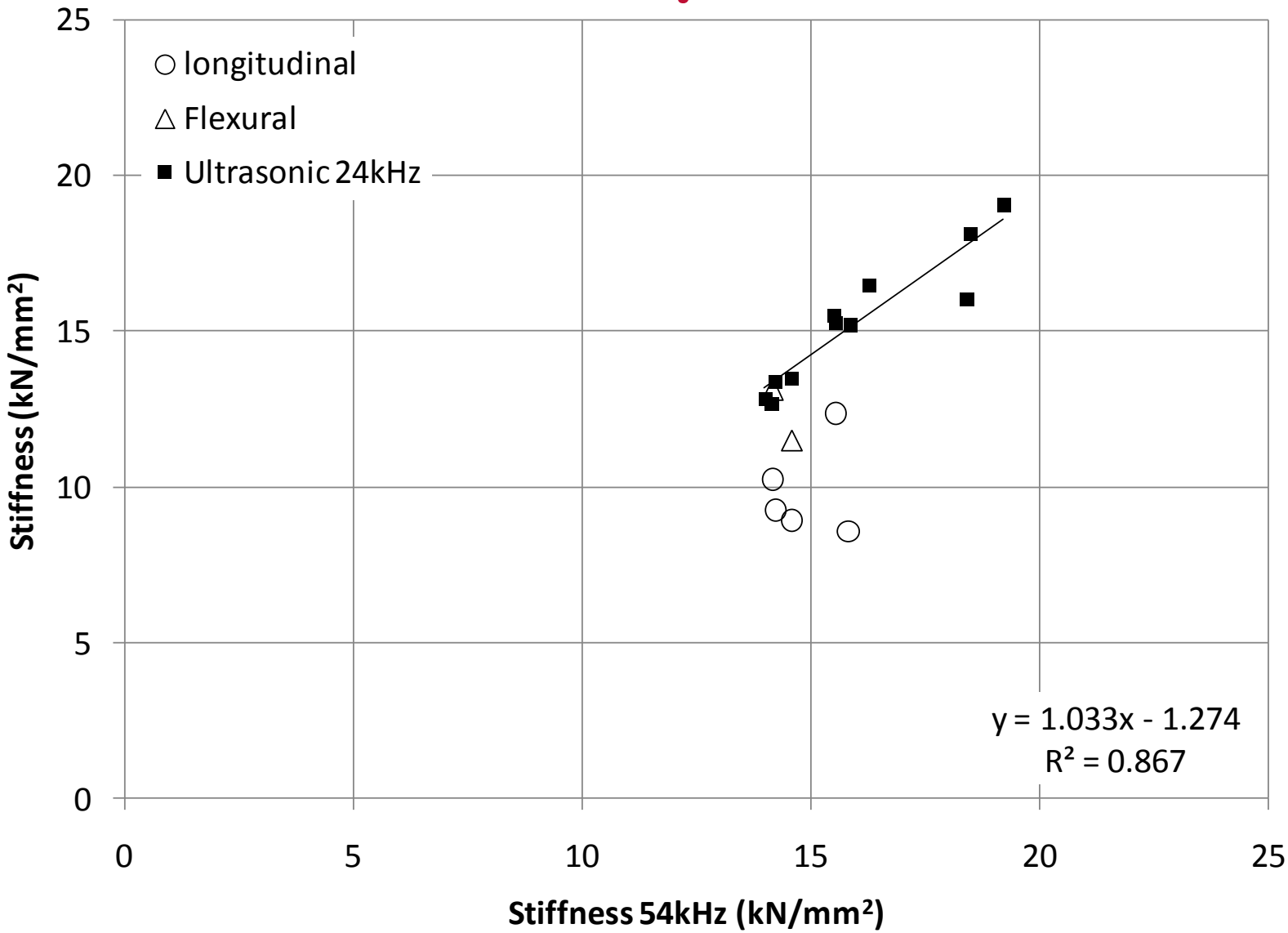


Stiffness of the pine offcuts

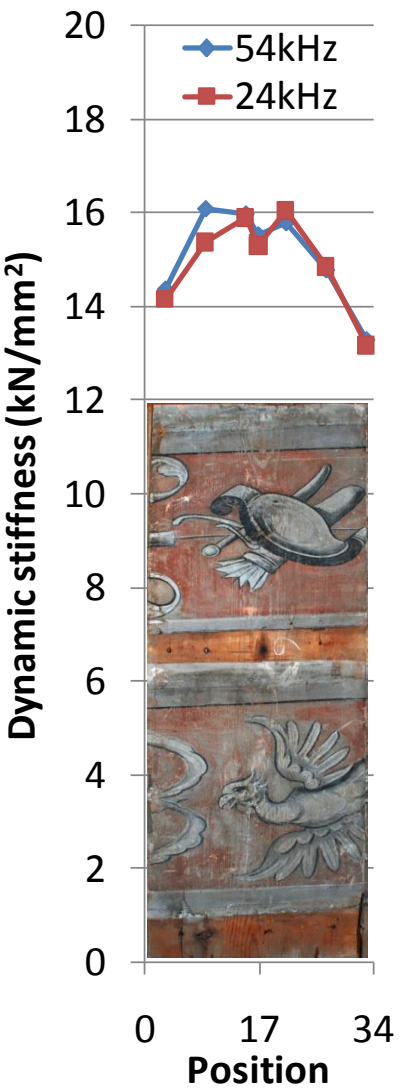


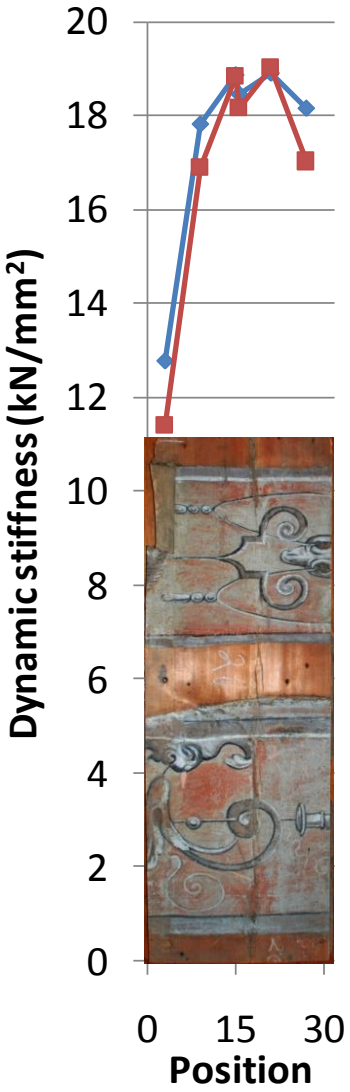
Gradewood data for Scots pine
Strength of European timber.
Part 1. VTT Publications 706
Part 2. VTT Working paper 179

Stiffness of the pine off-cuts



Stiffness of the pine off-cuts





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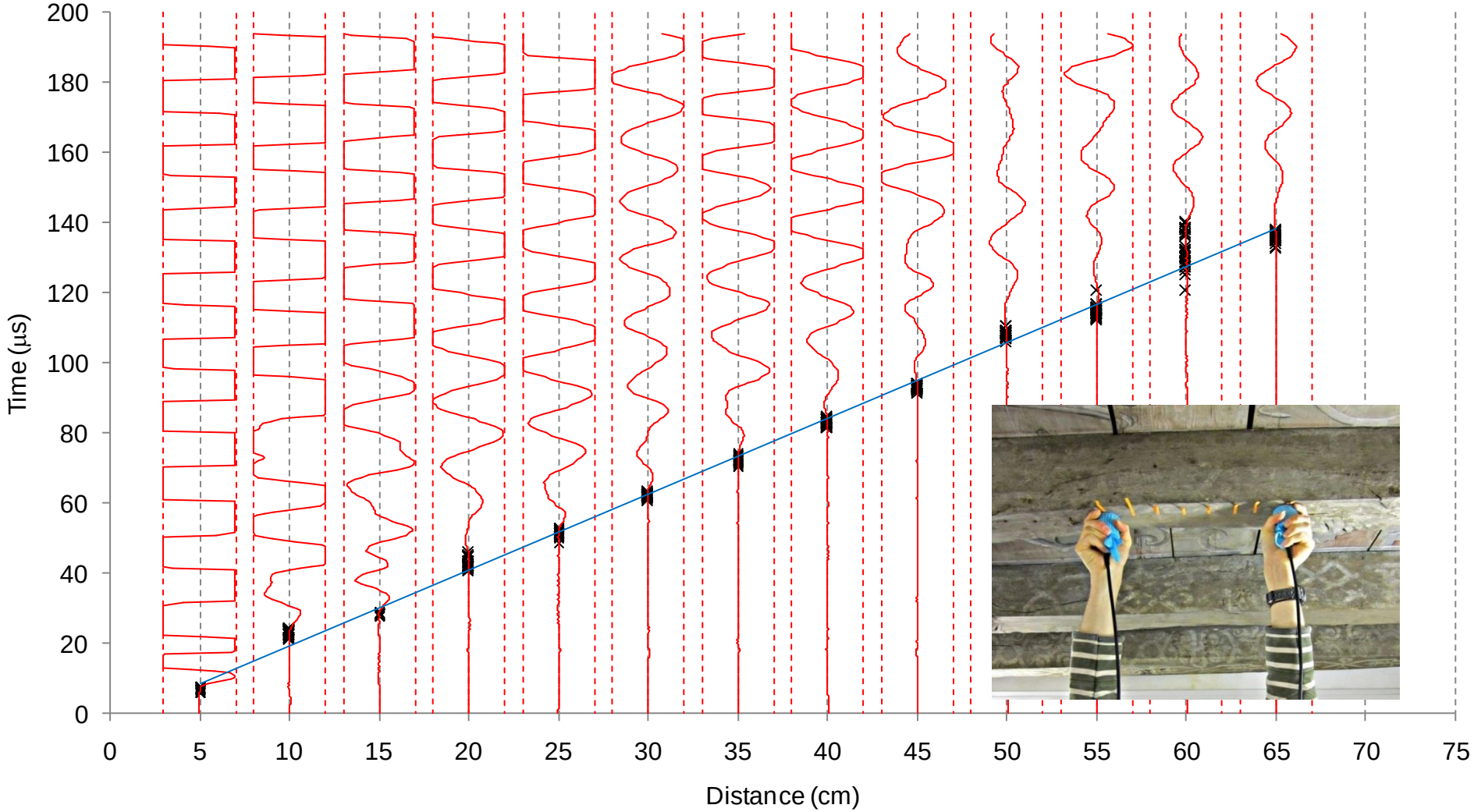
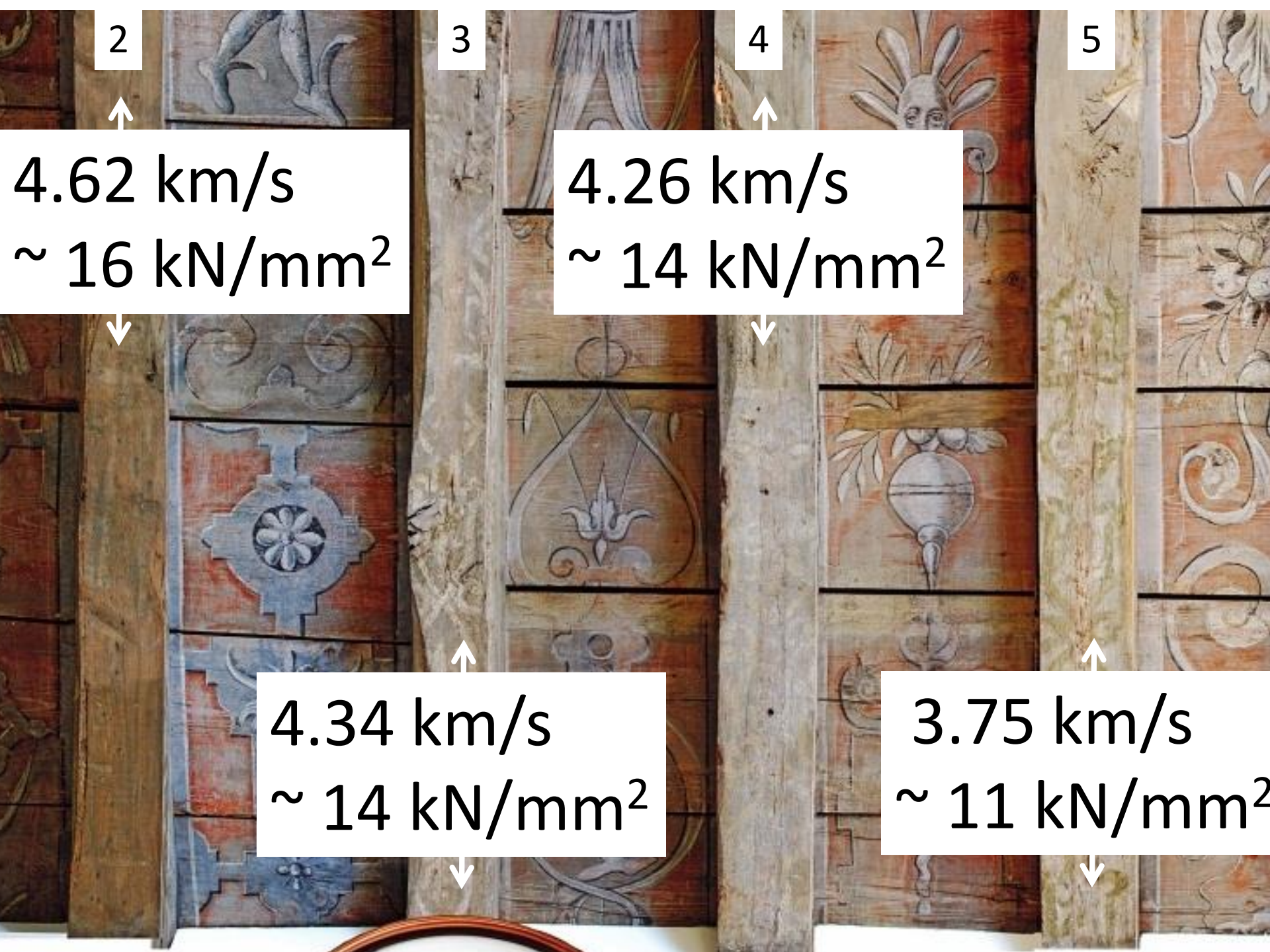
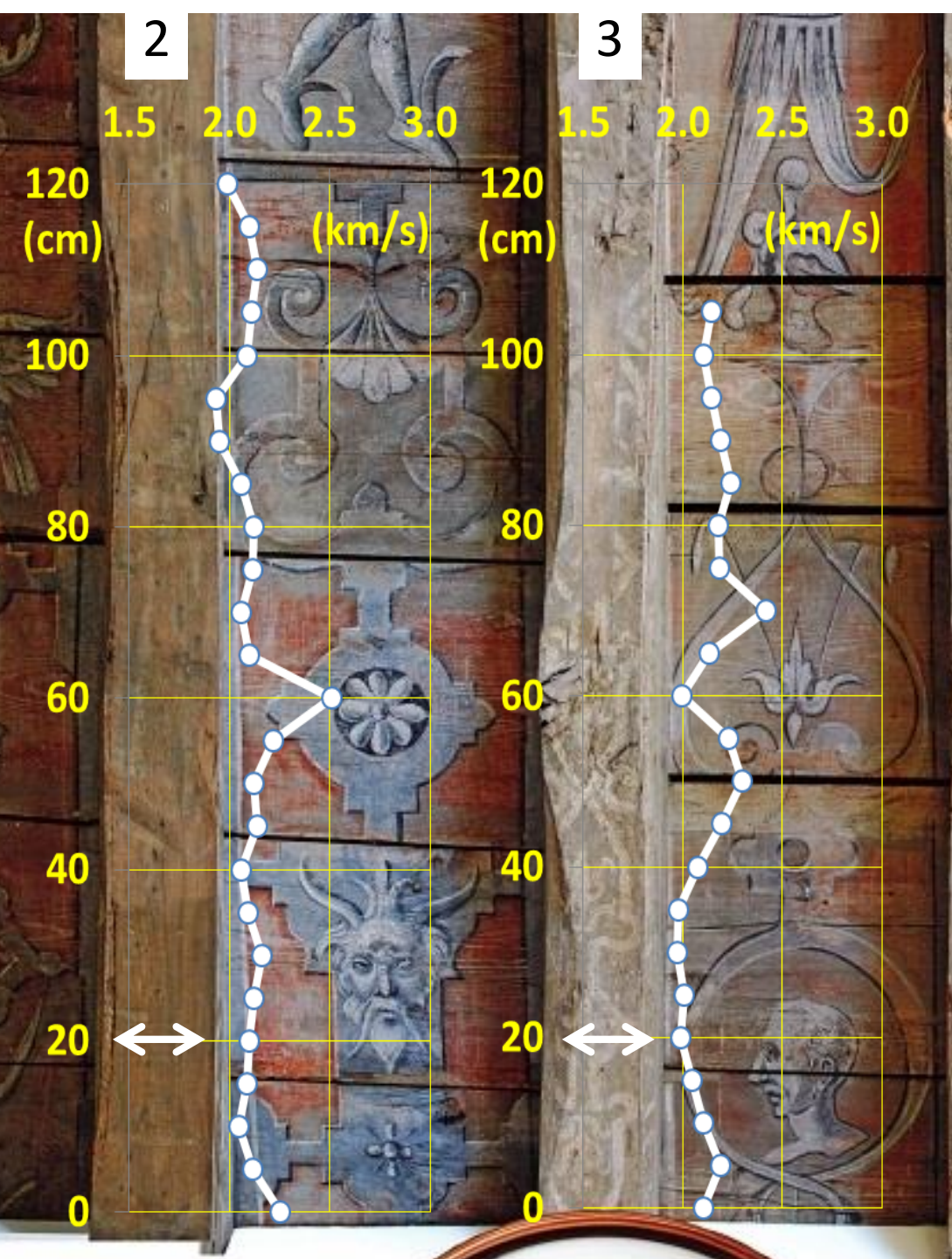
Stiffness of the oak beams




2
3
4
5
4.62 km/s
~ 16 kN/mm²
4.26 km/s
~ 14 kN/mm²
4.34 km/s
~ 14 kN/mm²
3.75 km/s
~ 11 kN/mm²



Beam 2
Etrans/Elo ng
= 0.21

Beam 3
Etrans/Elo ng
= 0.24

Oak
Etan/Elong ≈ 0.08
Erad/Elong ≈ 0.16

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Concluding remarks

- 54 kHz transducers most easiest to use
- Waveforms need inspection for correct time
- Are local measurements
- Cannot really work with assumed density
- Need to know how dynamic and static properties are correlated
- …depends on the origin of the timber
- Need to understand wave propagation better

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We would like to thank Historic Scotland and Forestry Commission Scotland for their research funding.

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Image: RCAHMS (via Canmore)


TR3
CR

Reason for research

- Inspection and repair
- Understand wood aging
- Knowledge of historic timber trade
- Painted ceilings in particular
  - Cannot see wood features
  - Elements in storage

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Image: wood for good

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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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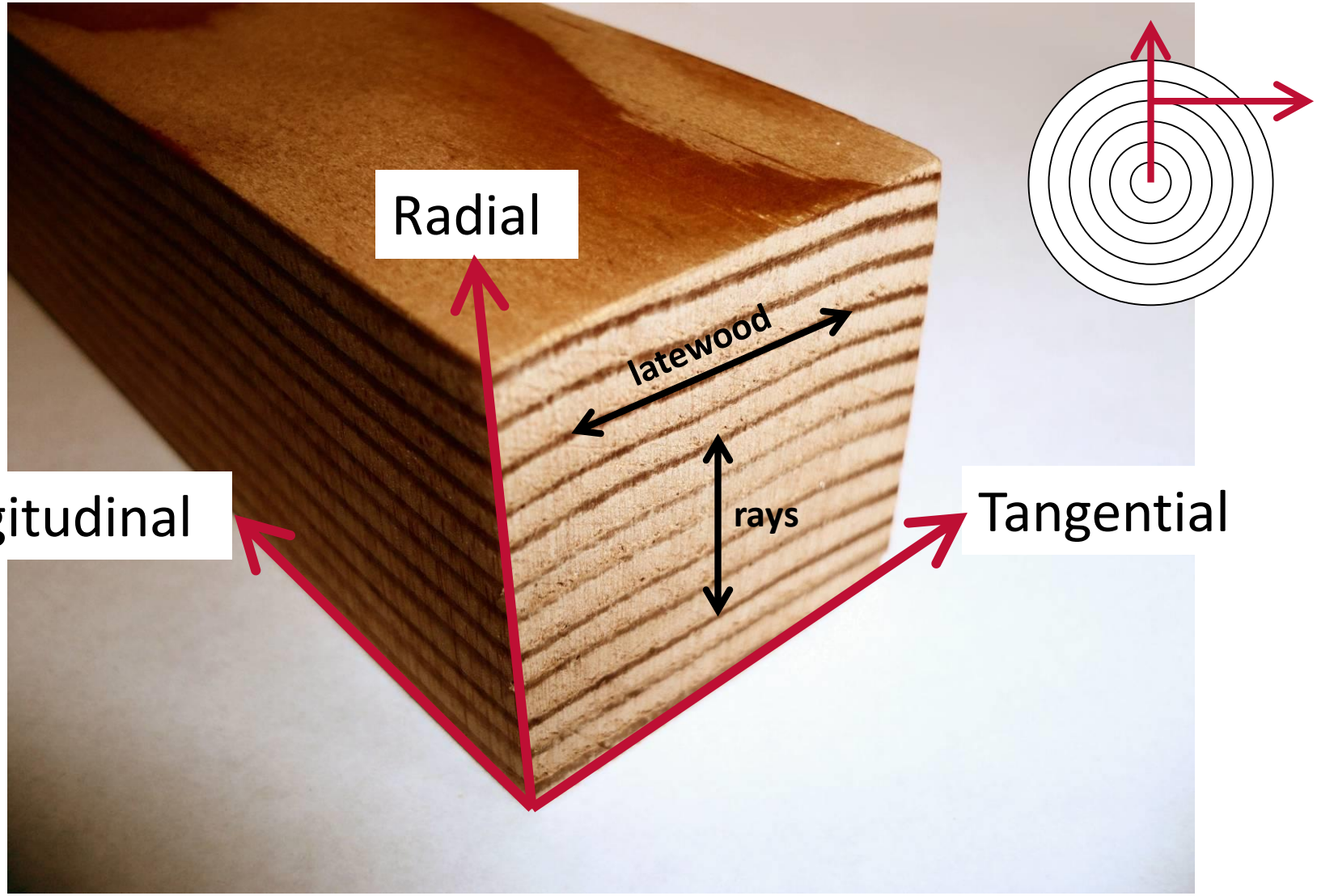
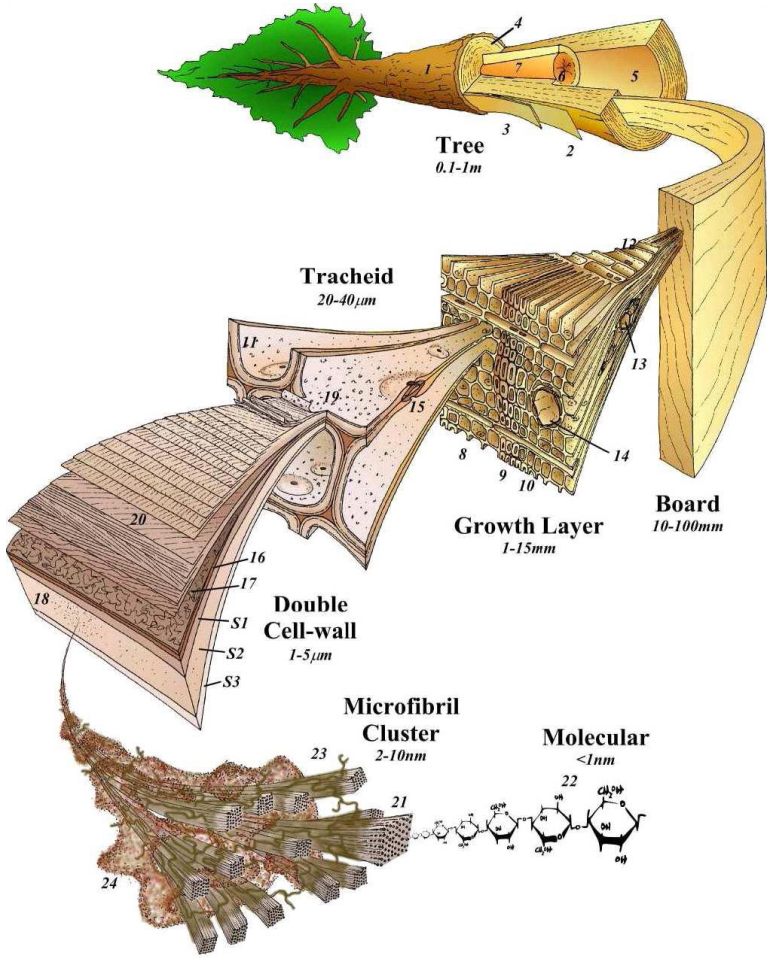
Wood structure

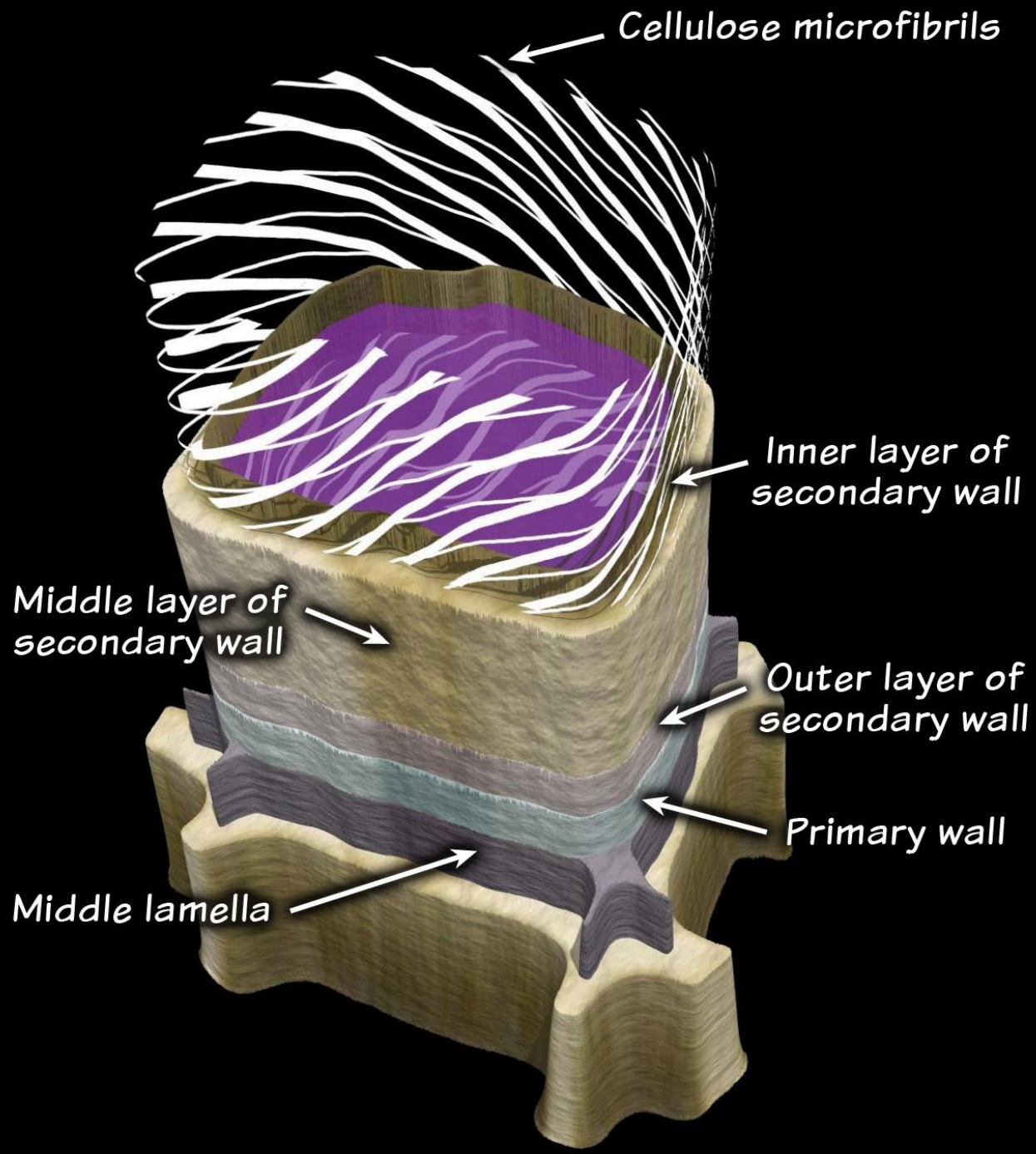


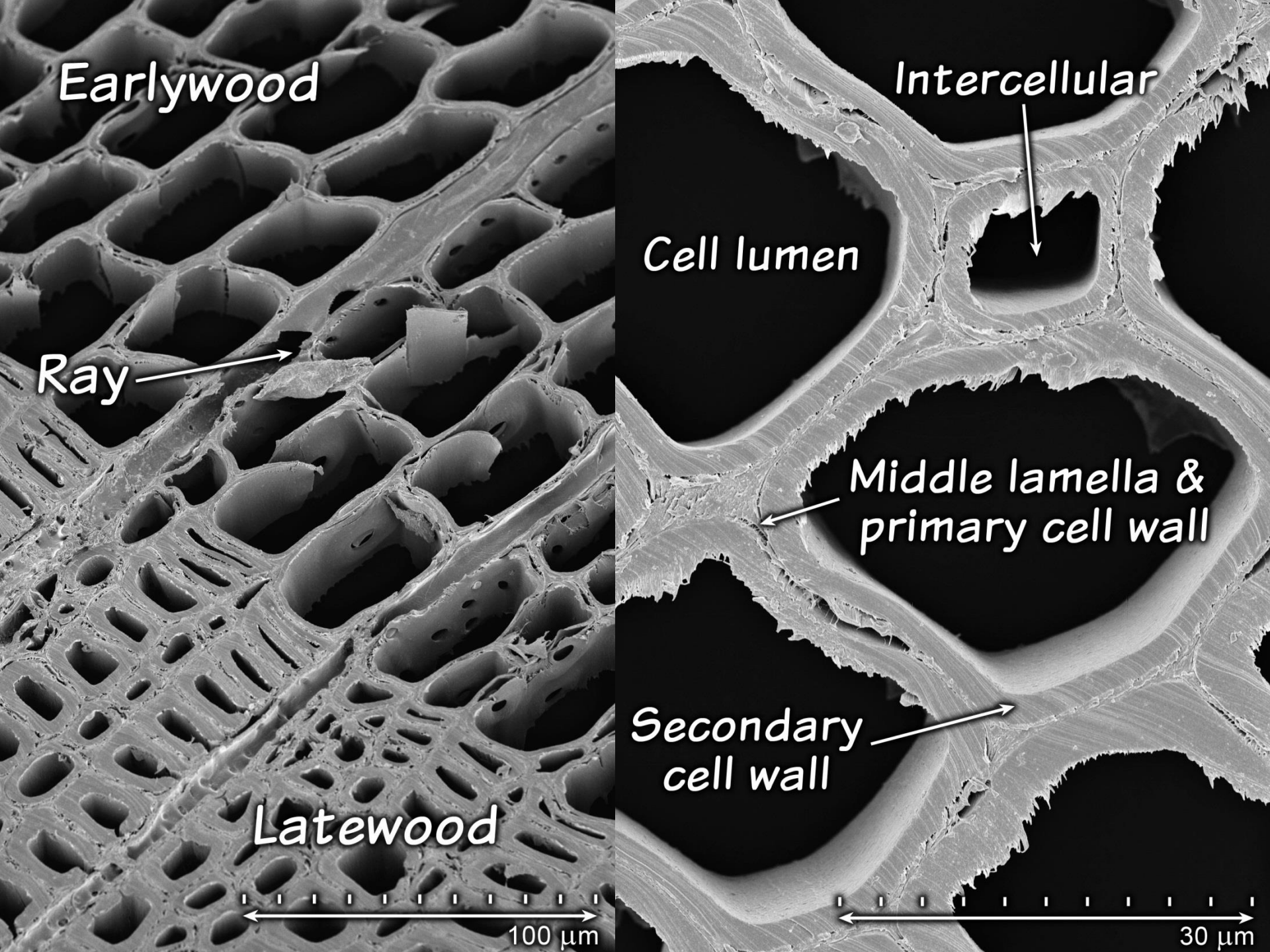
Wood structure

	Tree	Building
m	Log	Assembly
	Sawn timber	
cm	Clear wood	
mm	Growth layer	
	Wood anatomy	
	Cell	
μm	Cell wall	
	Cell wall layers	
	Microfibril clusters	
nm	Molecular	



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


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


Earlywood
Ray
Latewood
100 µm
Intercellular
Cell lumen
Middle lamella &
primary cell wall
Secondary
cell wall
30 µm

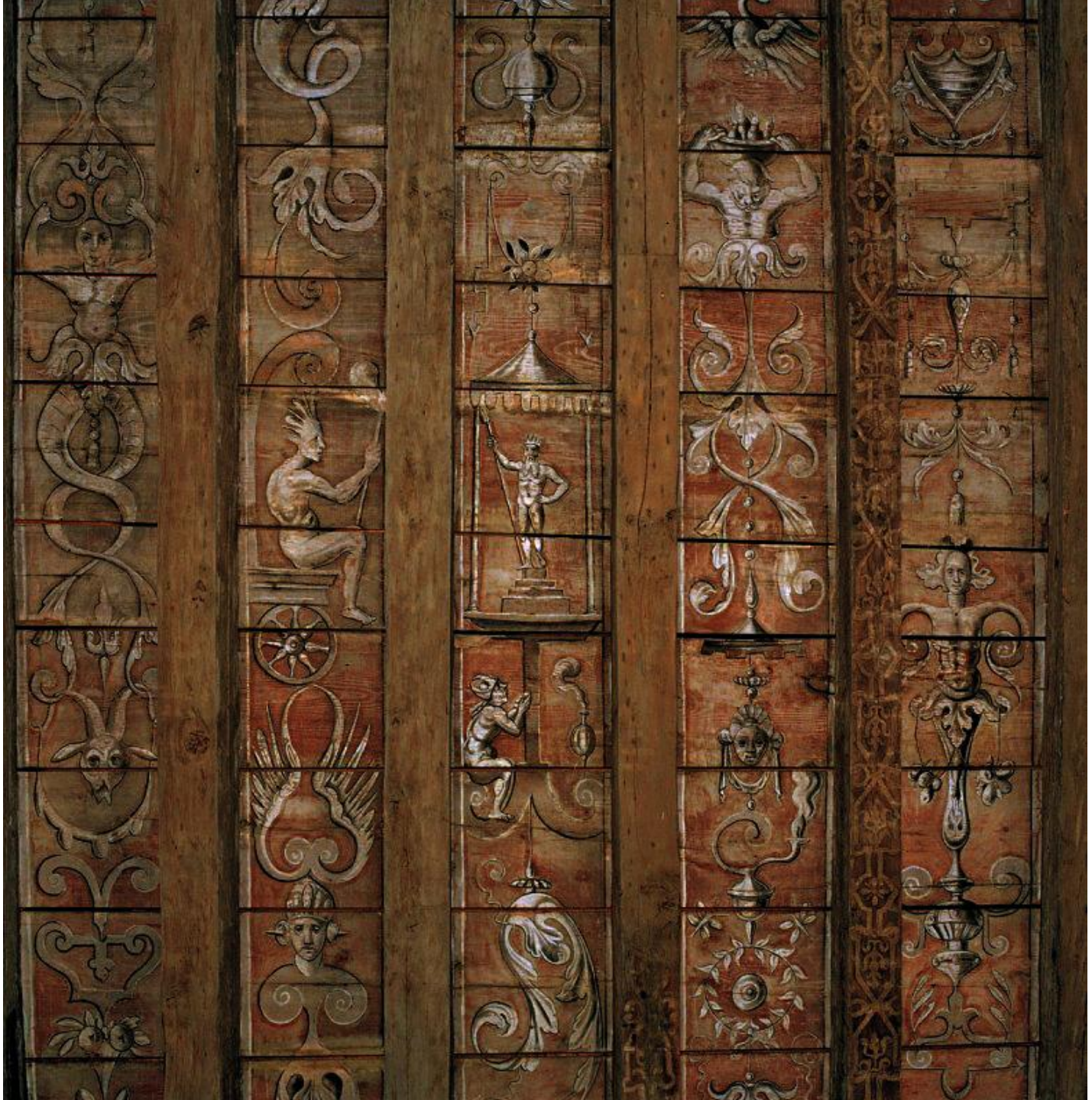


Image: RCAHMS