Technical tree-safety-inspection

Frank Rinn, Heidelberg/Germany

Some basics to be understood BEFORE applying diagnostic technology

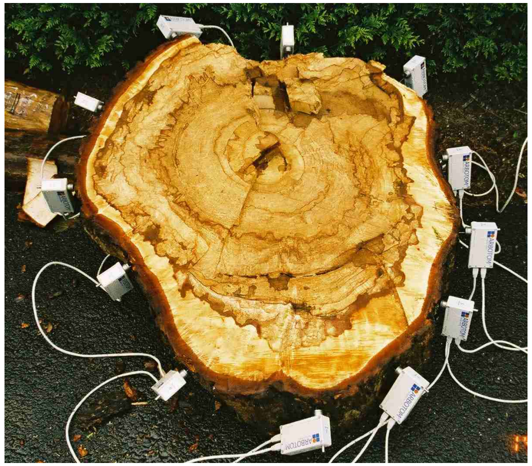
- Trees have species and age specific ways of compensating for changes in mechanical load
  - by building up more/less new wood
  - by changing wood material properties
- Changing cross-sectional dimensions is more efficient for increasing mechanical stability than higher wood material rigidity
- In terms of cross-sectional stability, location of decay is more important than size of decay

> Most common technical diagnostic methods help arborists assessing tree safety:
resistance drilling
sonic tomography
pulling tests

Stress wave ('sonic') tomography

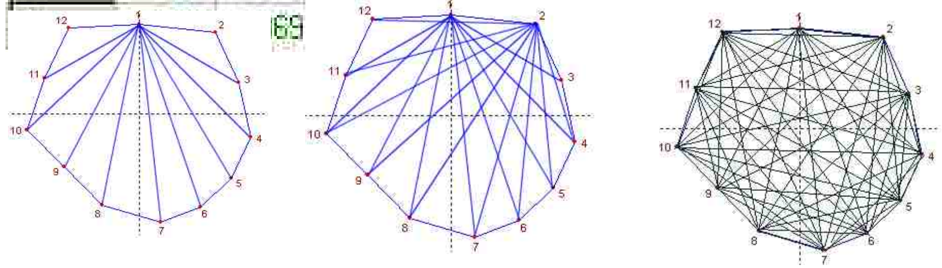
This method, as described in a patent from 1999, was invented because of frustration about the heavy mis-use of the resistance drilling method, applying drilling machines that systematically delivered wrong profiles leading to systematically wrong evaluations of trees.

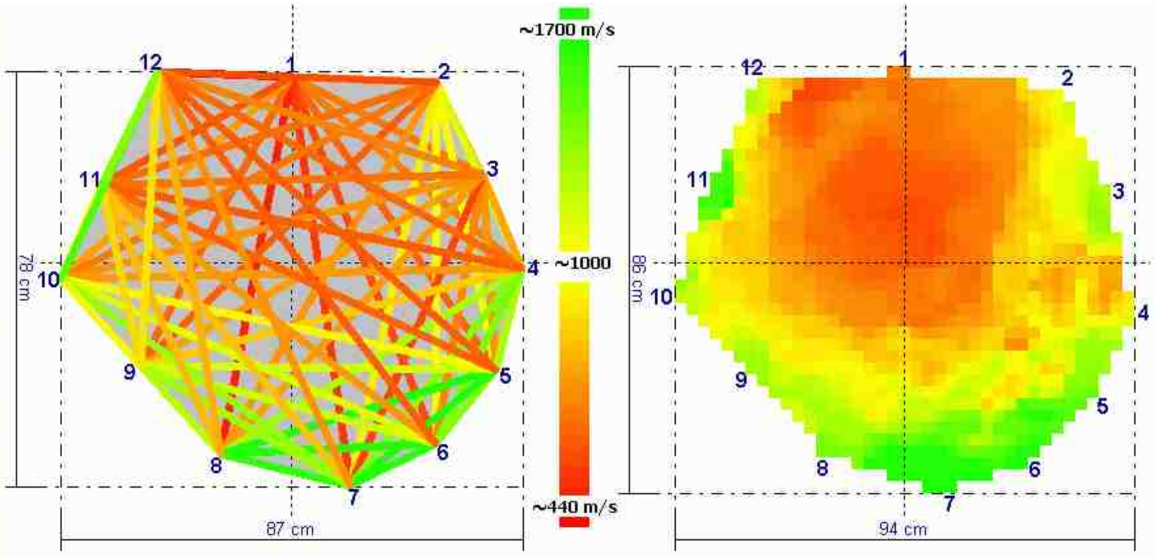
The stress wave sensors just measures time of flight!



Sensor	5	6	7	8
1	1415	1375	1553	1496
1	1409	1394	1555	1512
1	1387	1373	1539	1497

69





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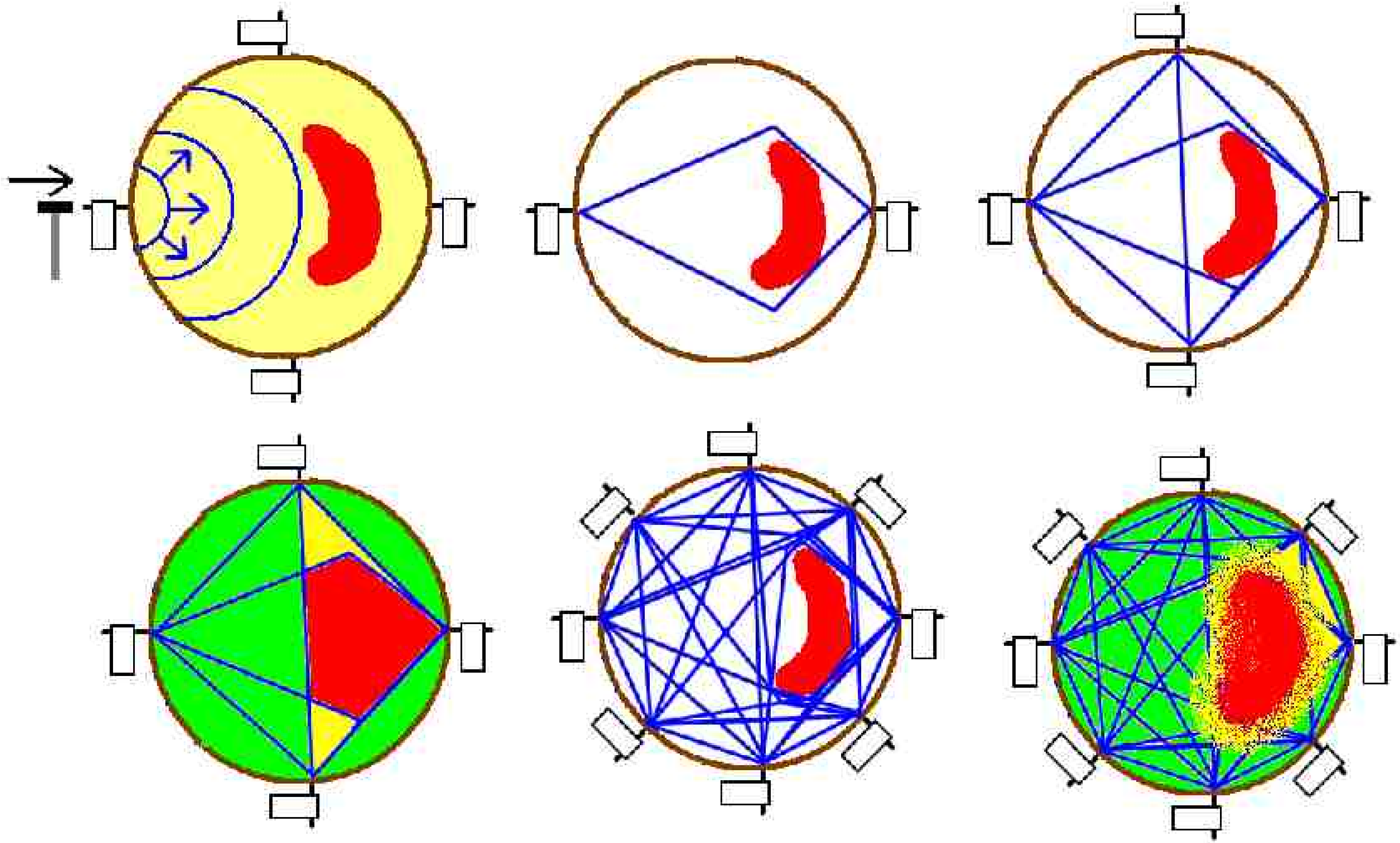
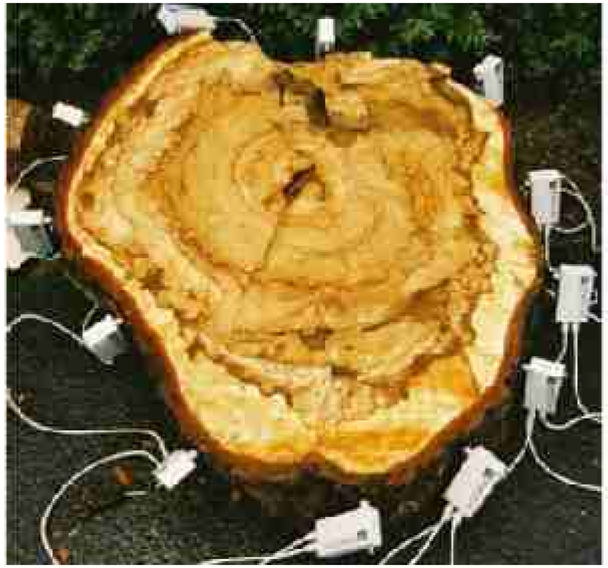
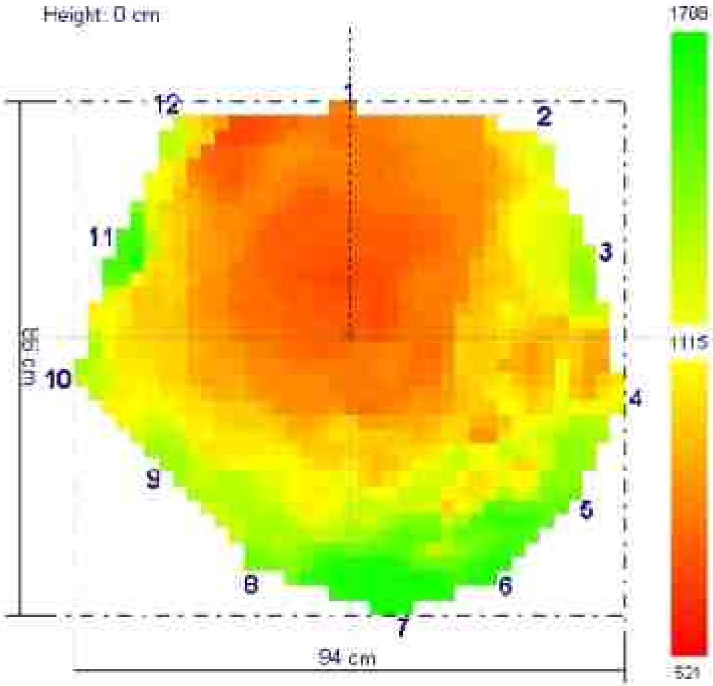
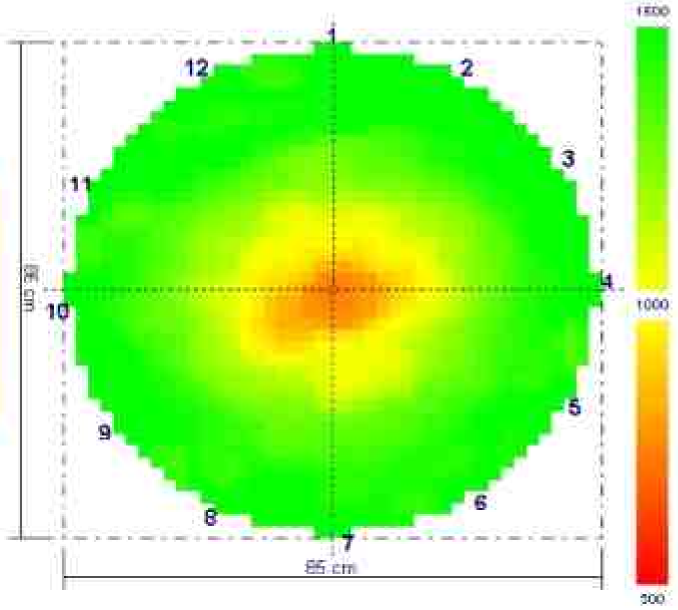
Typical travel paths in wood with defects => reconstruction

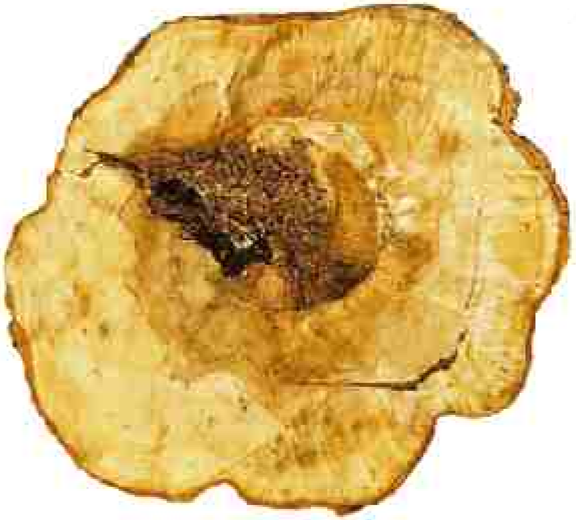


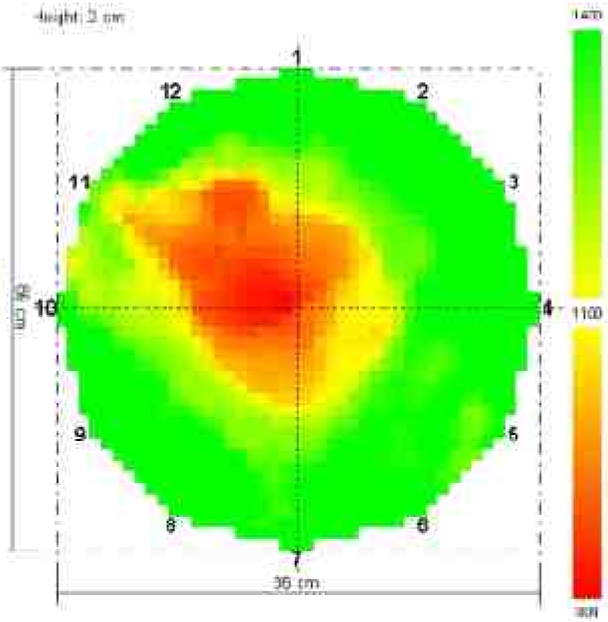
Example tomograms






1
2
3
4
5
6
7
8
9
10
11
12
1000
500





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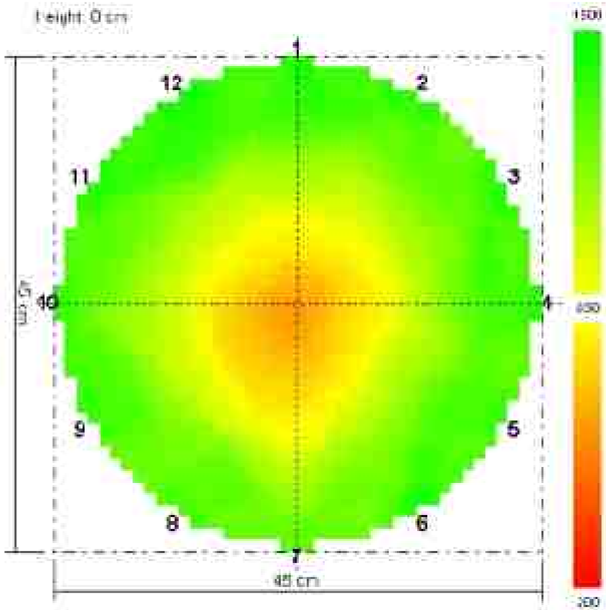
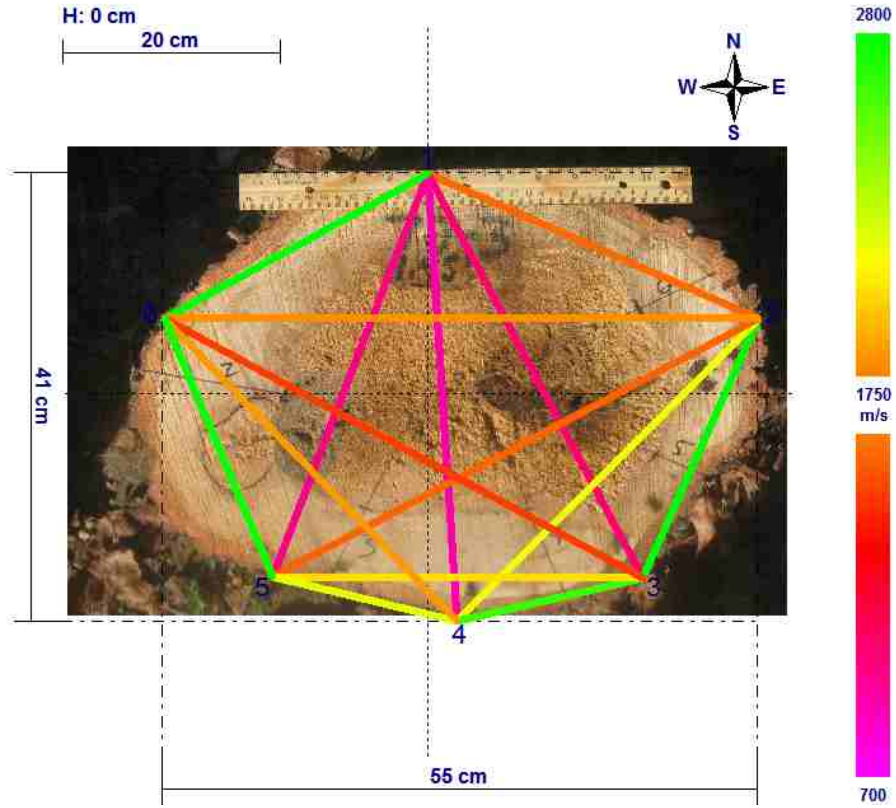
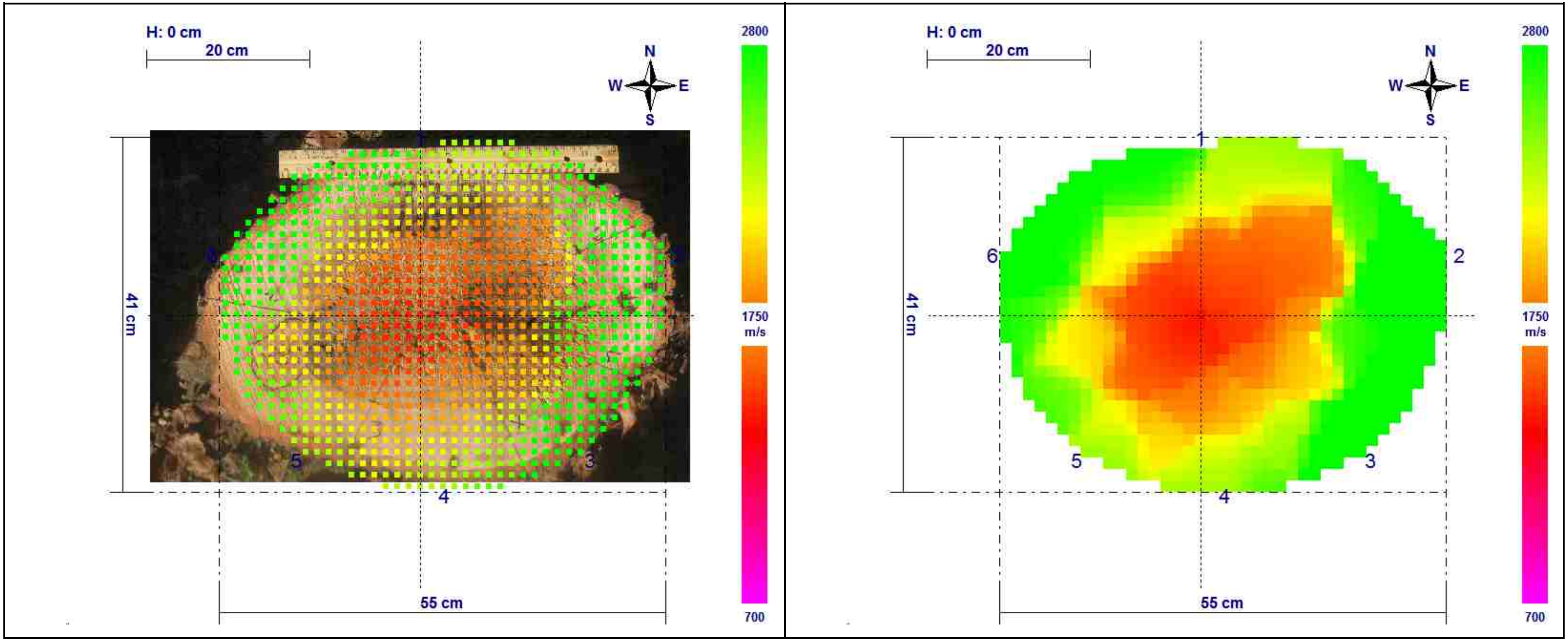
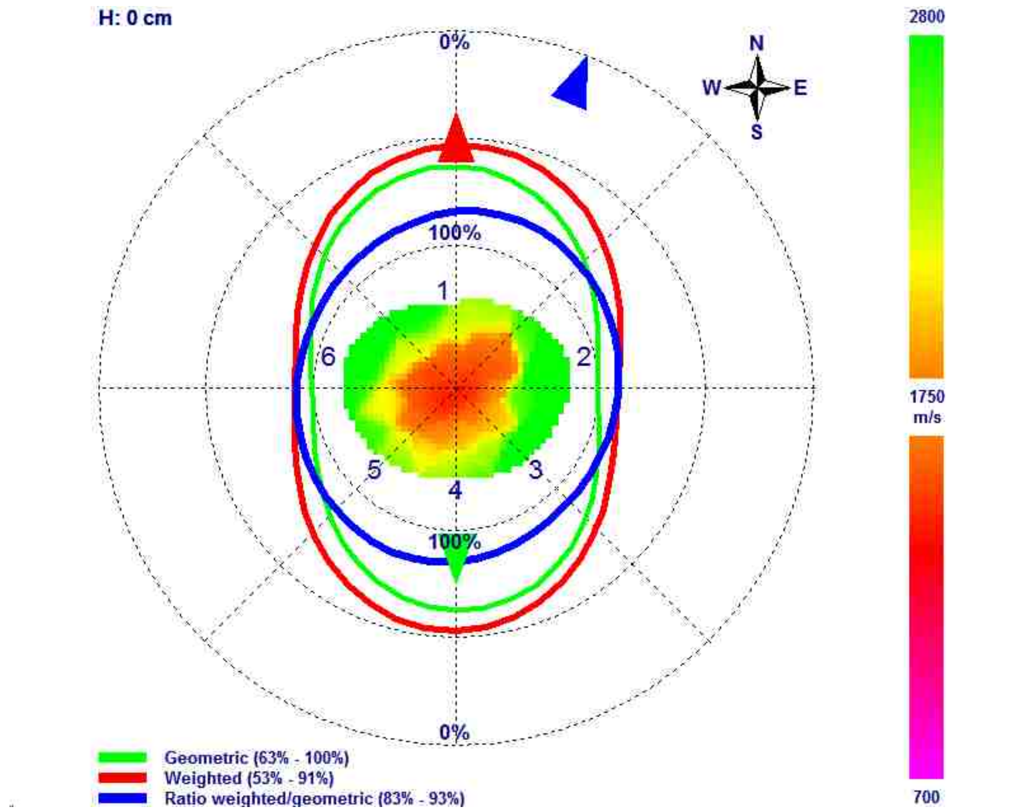
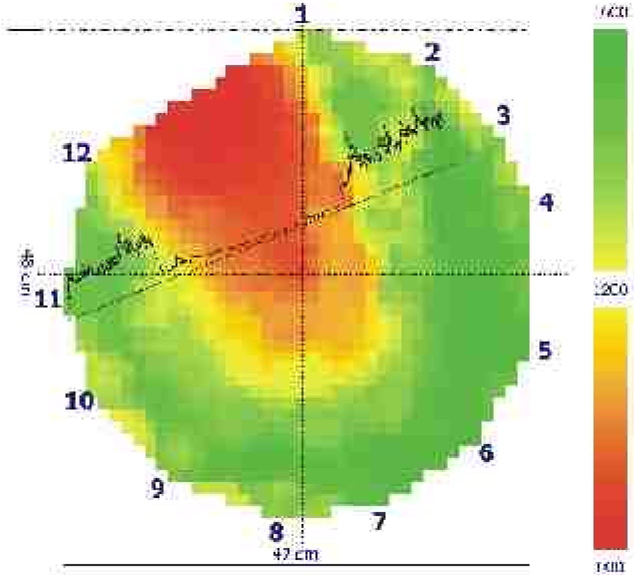
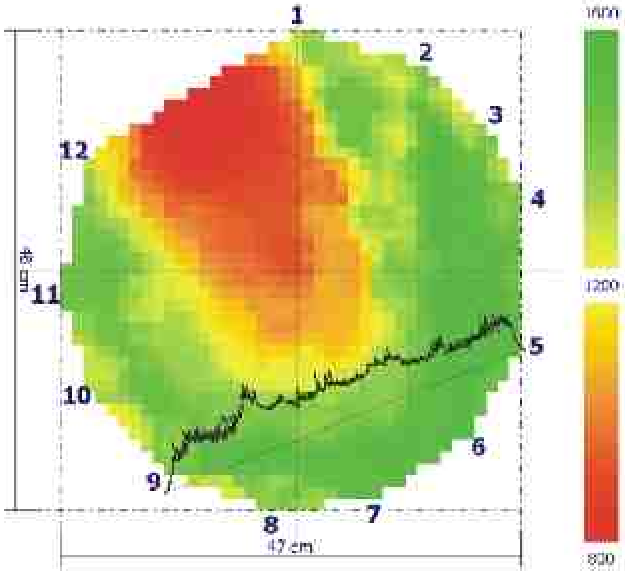

Height: 0 cm
1500
1
2
3
4
5
6
7
8
9
10
11
12
45 cm
200

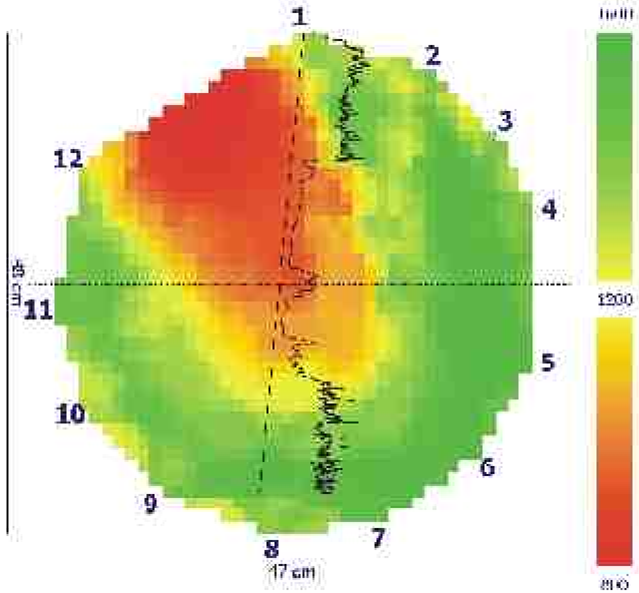

H: 0 cm
20 cm
N
W
E
S
2800
1750
m/s
700
41 cm
55 cm
1
2
3
4
5
6


H: 0 cm
20 cm
N
W
E
S
2800
1750
m/s
700
41 cm
55 cm
1
2
3
4
5
6

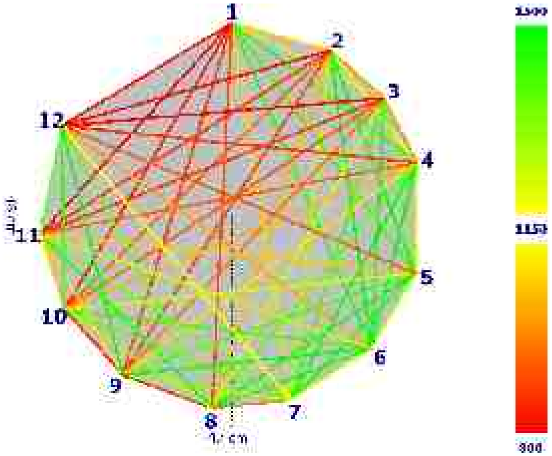

H: 0 cm
0%
100%
1
2
3
4
5
6
100%
0%
N
W
E
S
2800
1750
m/s
700
Geometric (63% - 100%)
Weighted (53% - 91%)
Ratio weighted/geometric (83% - 93%)

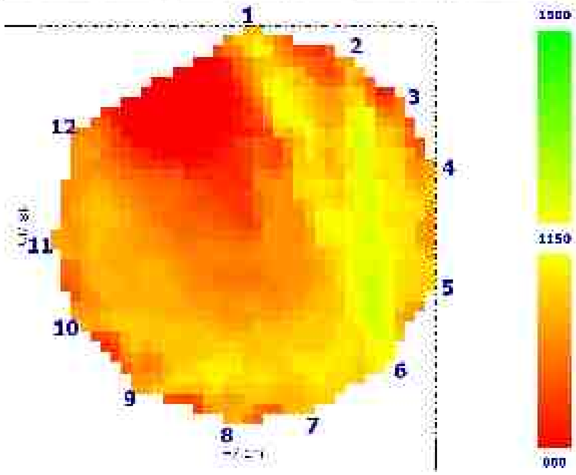

1
2
3
4
5
6
7
8
9
10
11
12
47 cm
1200

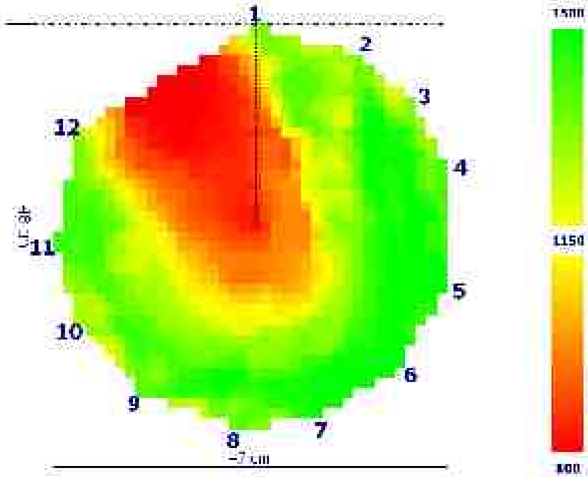

1
2
3
4
5
6
7
8
9
10
11
12
47 cm
1200
800


1
2
3
4
5
6
7
8
9
10
11
12
47 cm
1200

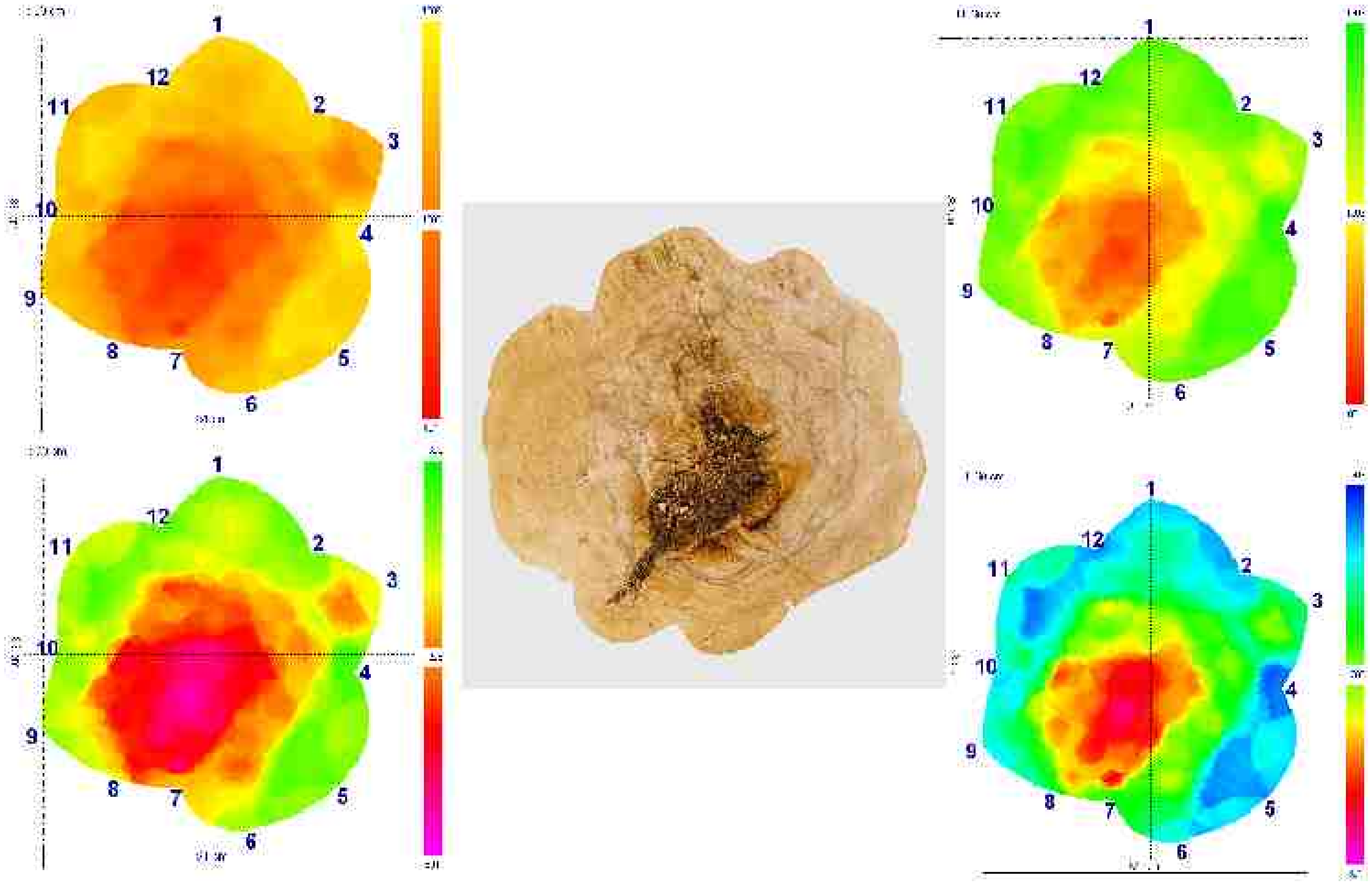
Reconstruction depends on typical species properties



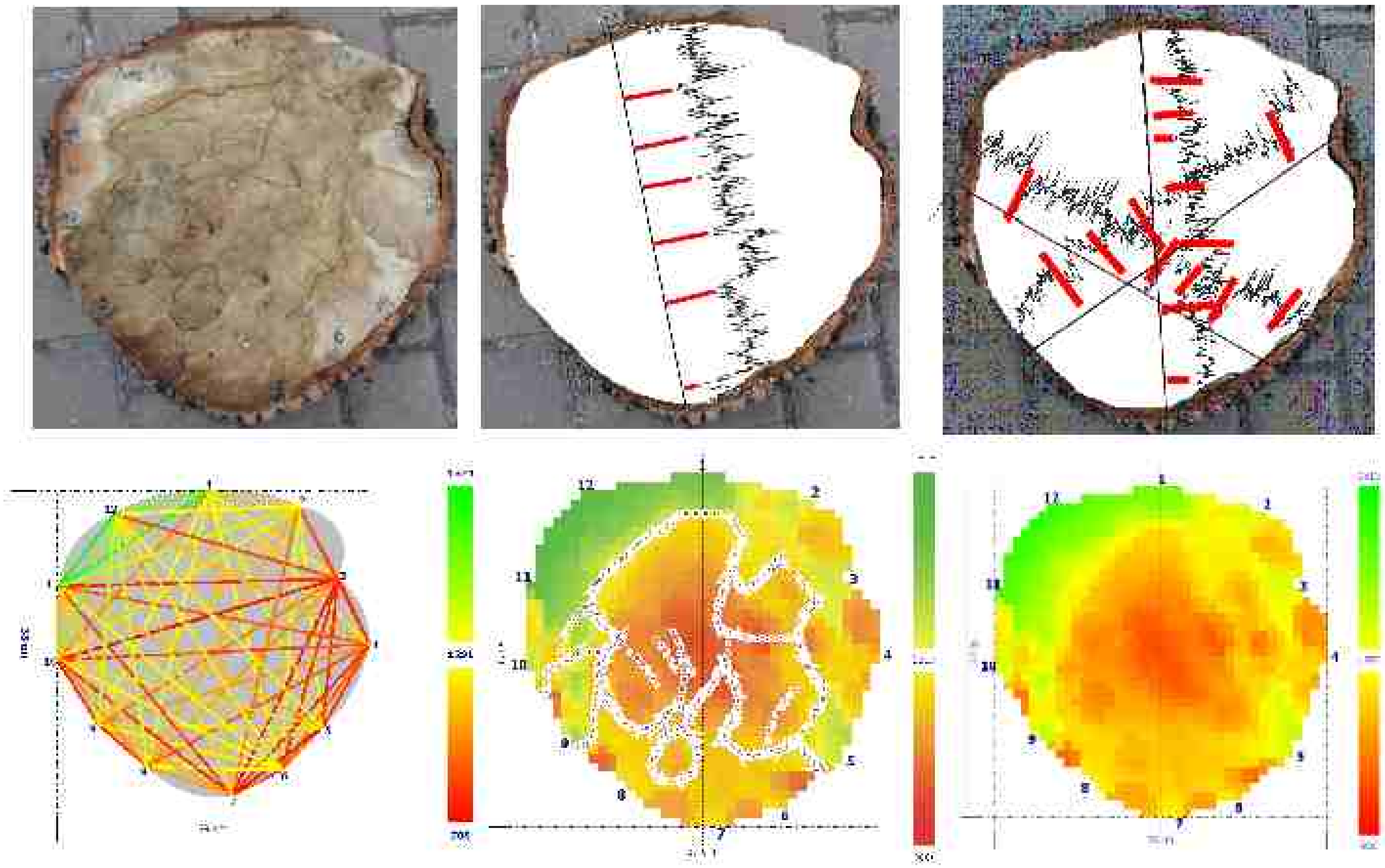




Colour determines our impresson



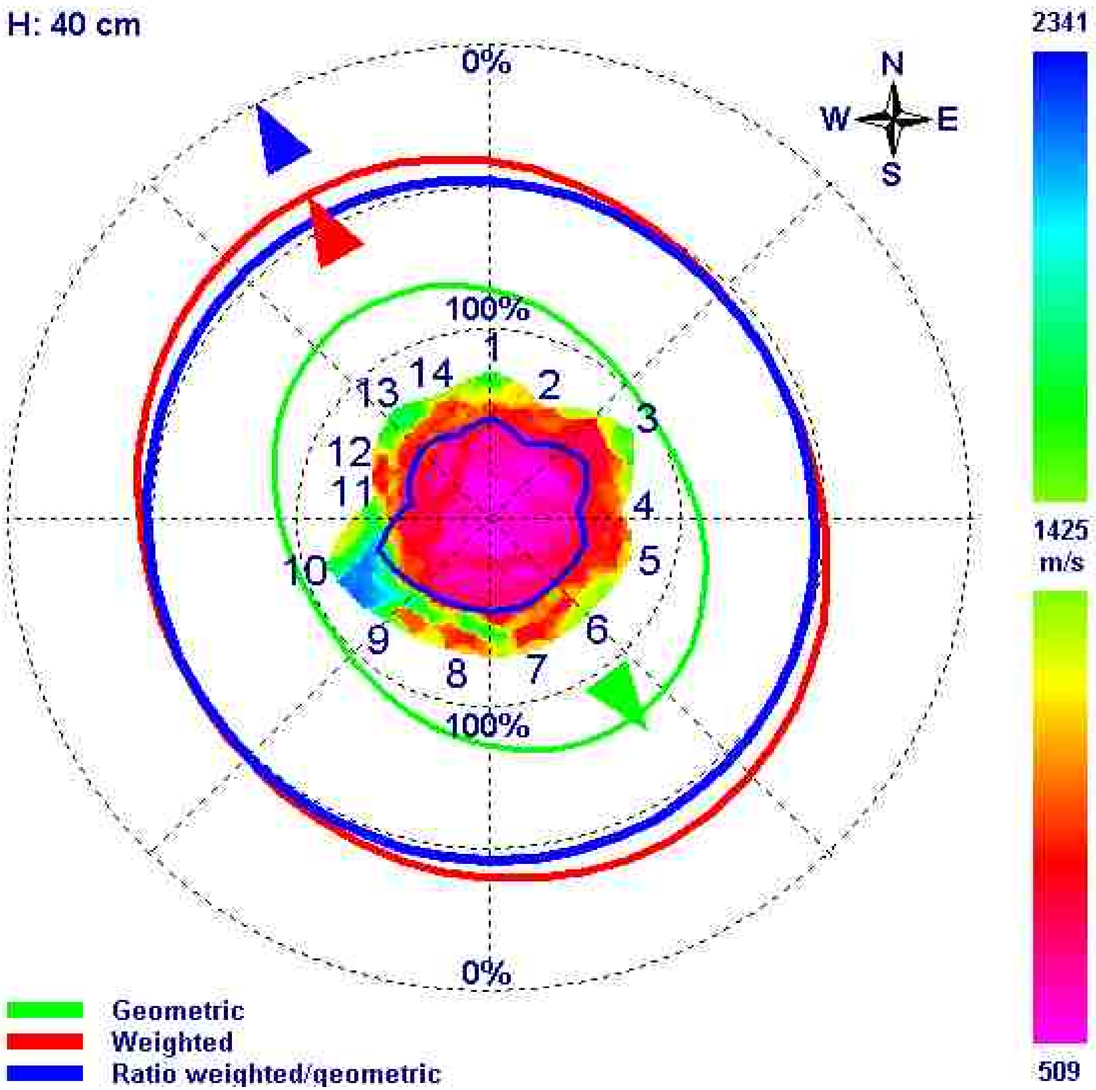
Sonic tomography reveals the remaining load carrying part of the cross-section. It cannot and dies not reveal wood condition!



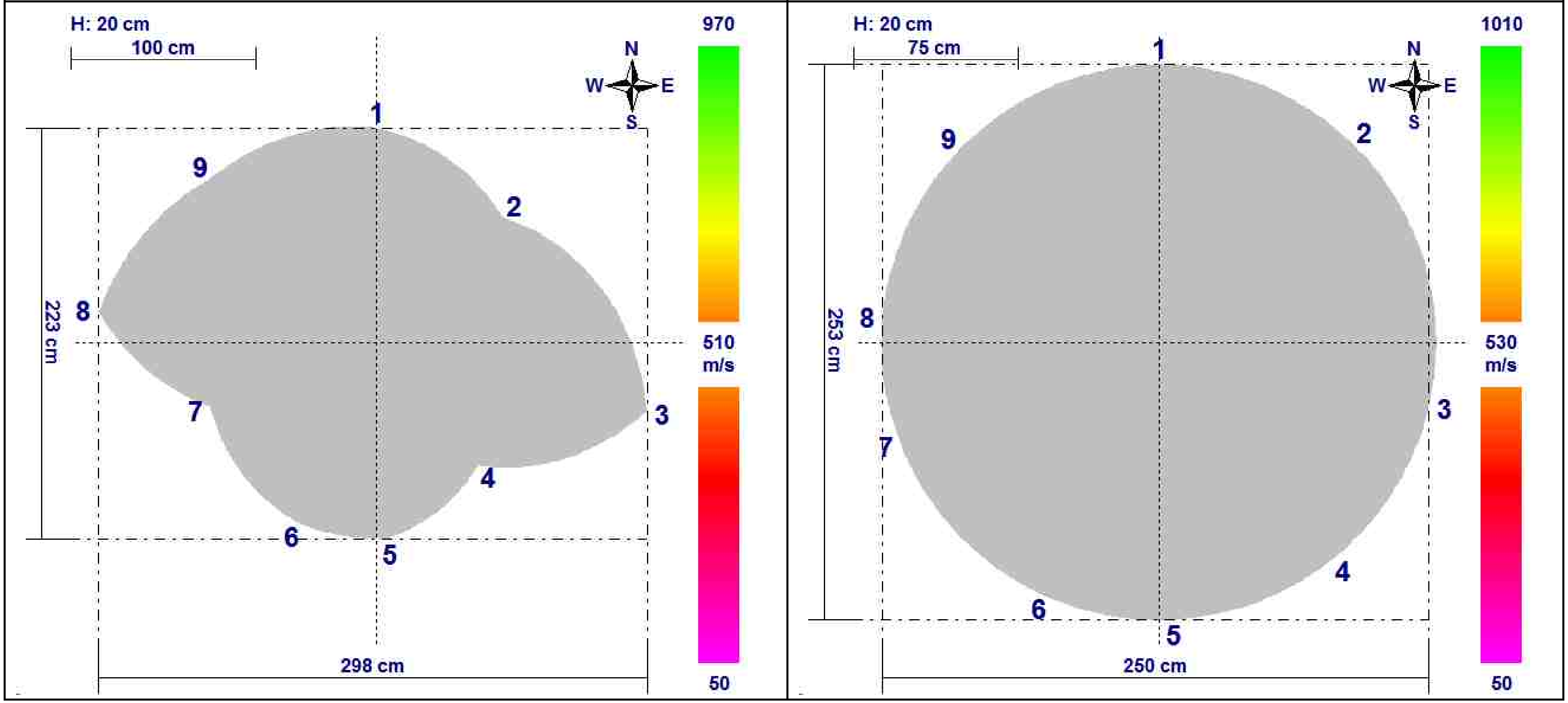
Main result:

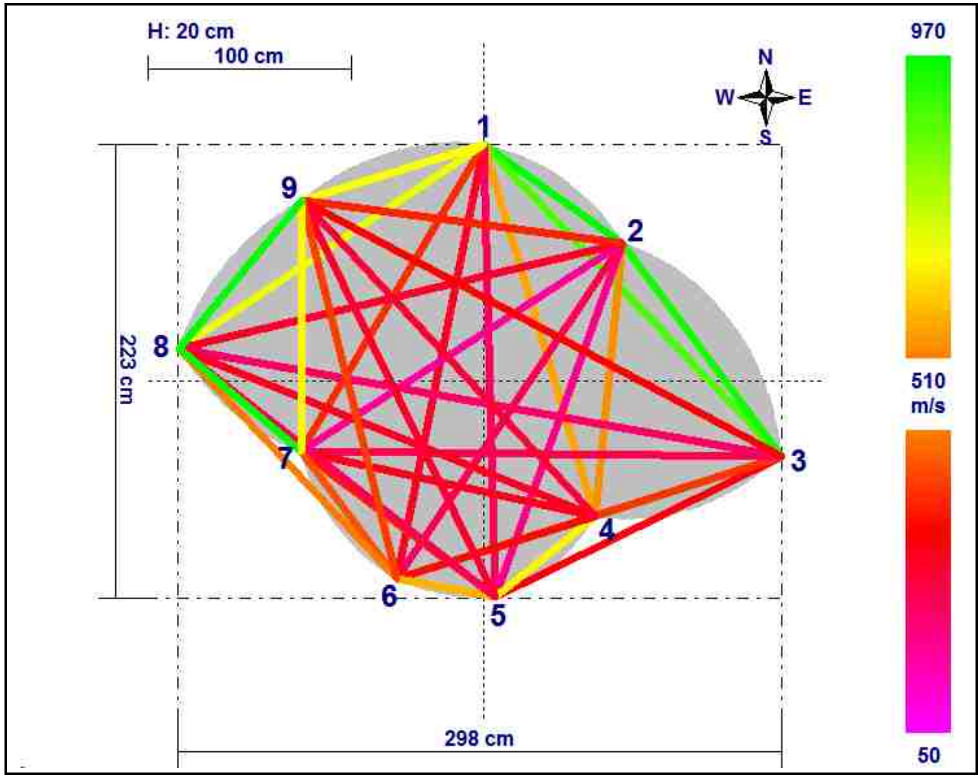
=>

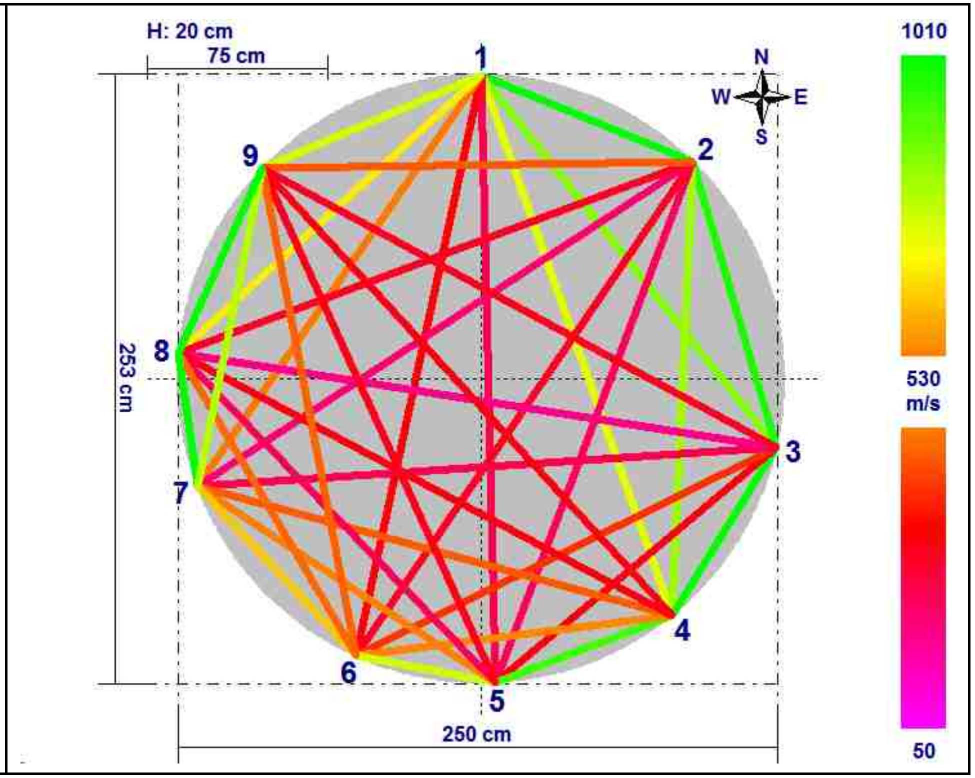
change in section modulus as a measure of strength loss calculated for all load directions.

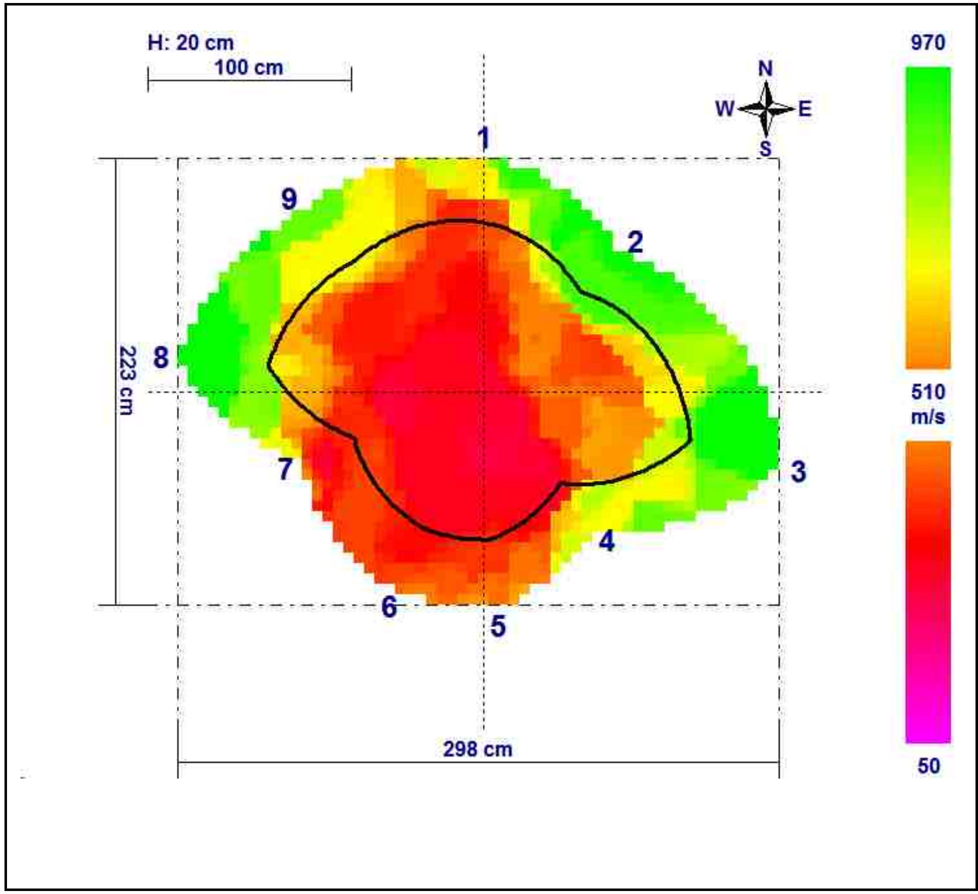


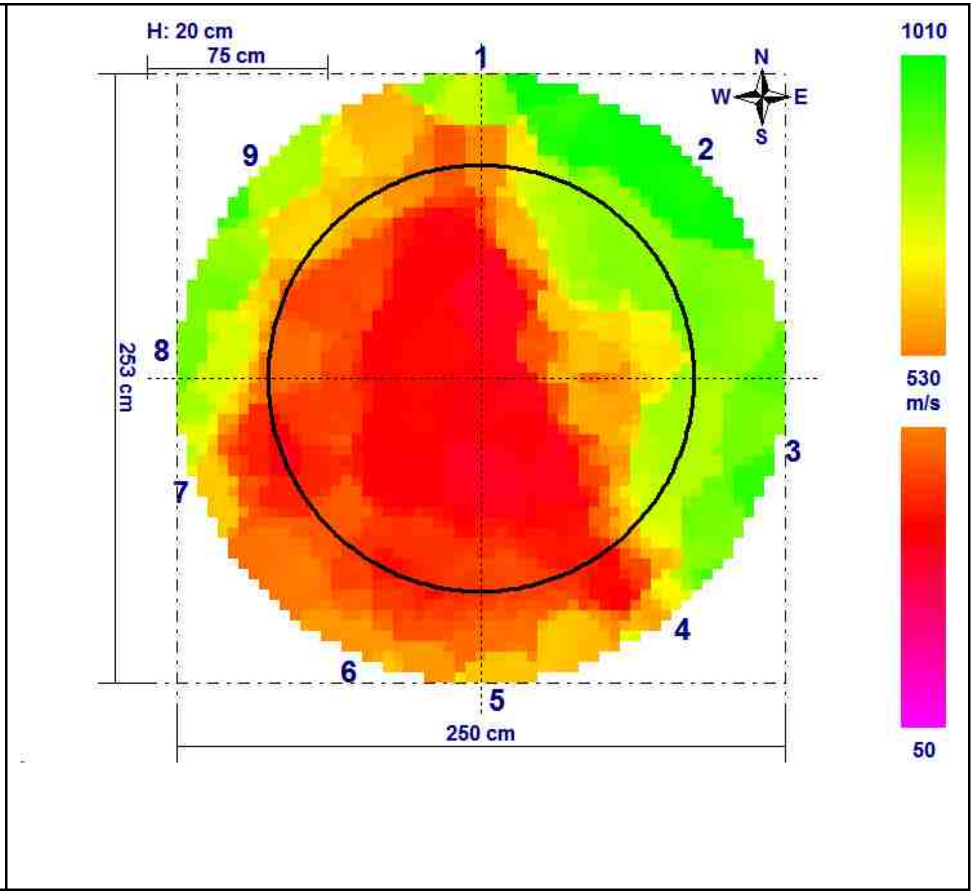
Is sensor position exactness critical for result of sonic tomography?

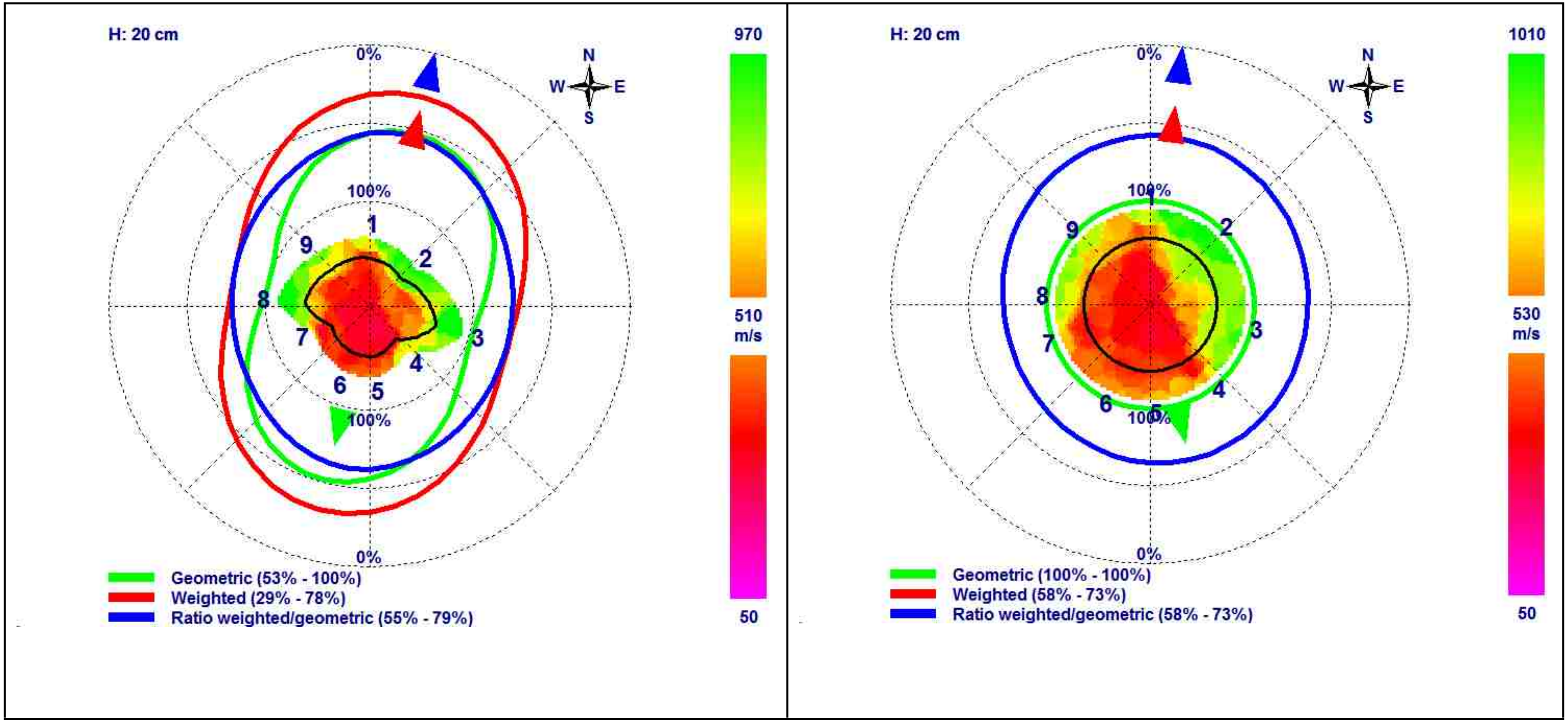



H: 20 cm
100 cm
970
510
m/s
50
N
W
E
S
1
2
3
4
5
6
7
8
9
223 cm
298 cm


H: 20 cm
75 cm
1010
530
m/s
50
N
W
E
S
1
2
3
4
5
6
7
8
9
253 cm
250 cm

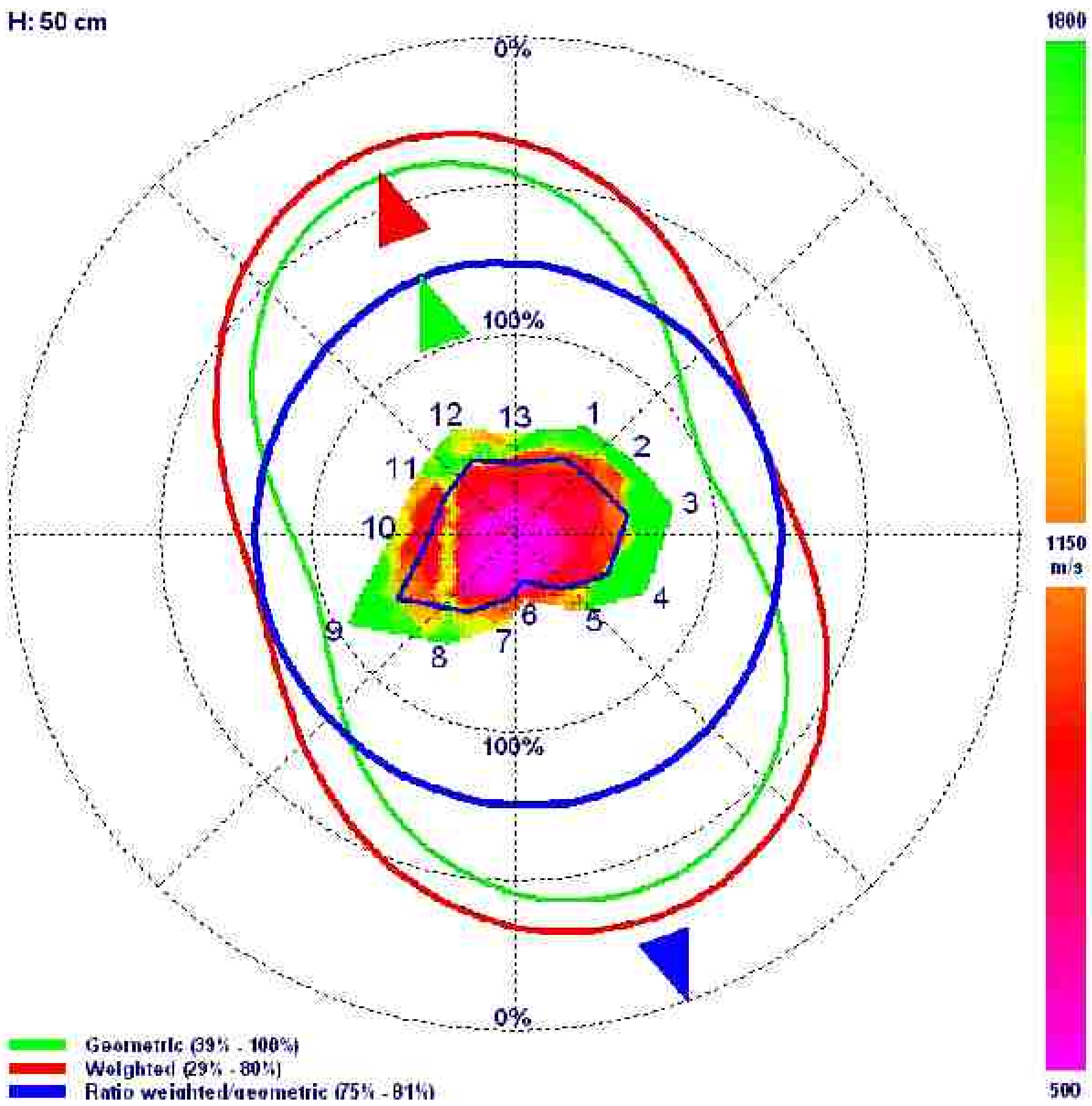

H: 20 cm
100 cm
N
W
E
S
970
510
m/s
50
1
2
3
4
5
6
7
8
9
223 cm
298 cm


H: 20 cm
75 cm
N
W
E
S
1010
530
m/s
50
1
2
3
4
5
6
7
8
9
253 cm
250 cm



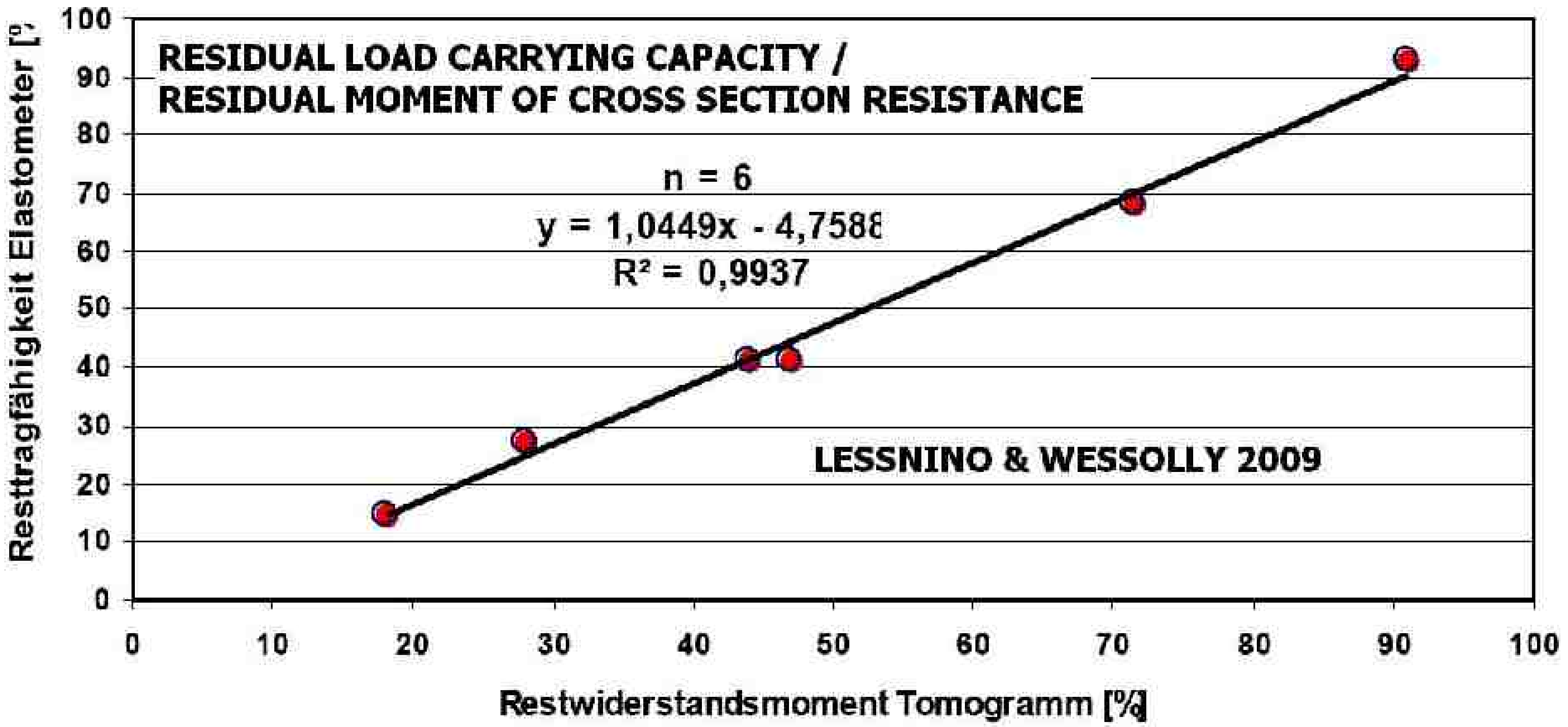
Even in this extreme case of completely ignoring the shape and making an irregular / oval cross-section circular, that means every sensor was mis-positioned both absolutely and relatively, the final result (relative strength loss) is nearly the same as before (ca. 79% to 73%).

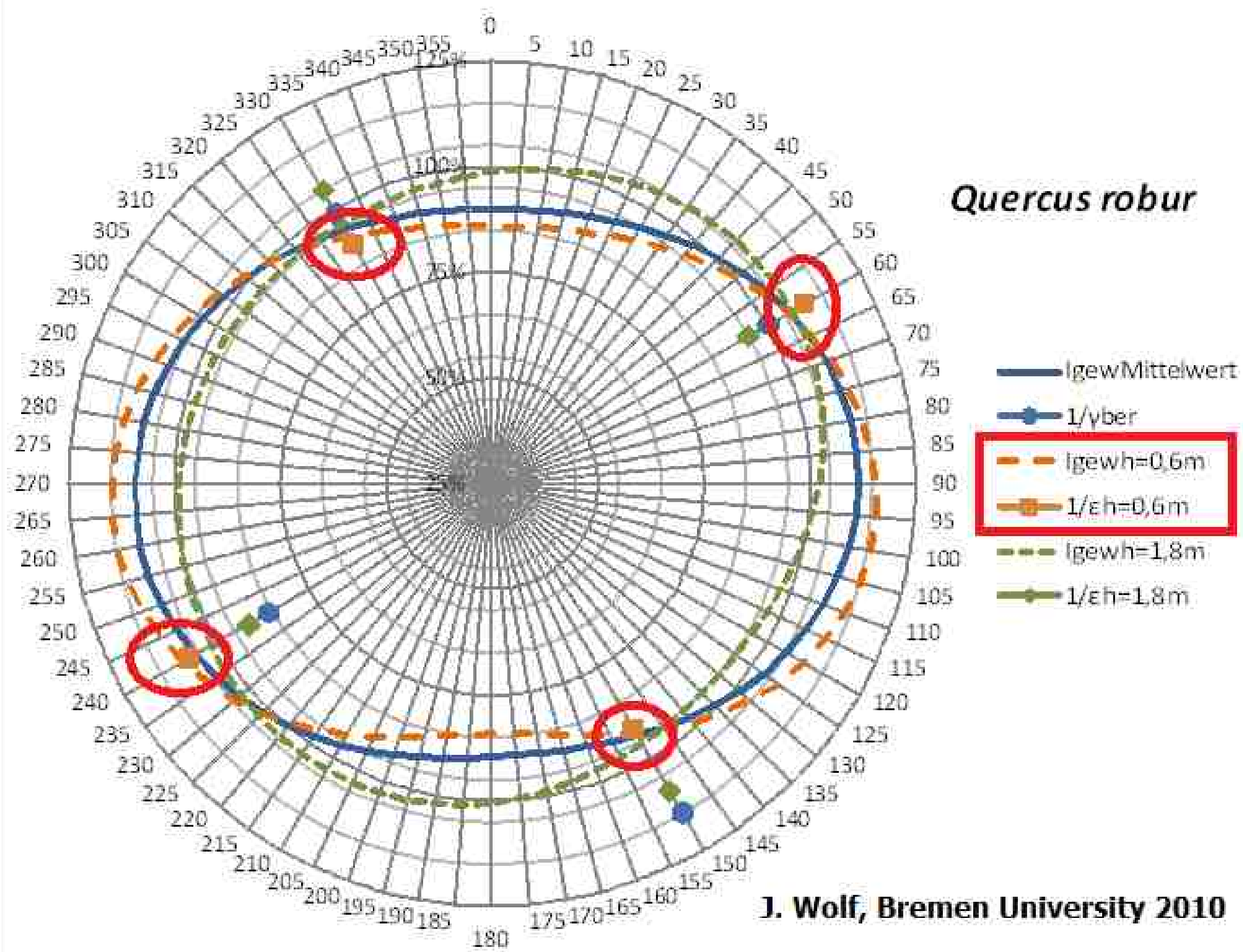
=> sensor positioning precision is important (for presentation and explanation) but not that critical!



What does this value of relative strength loss means?

Lessnino & Wessolly compared strength loss by tomography and static load tests =>


RESIDUAL LOAD CARRYING CAPACITY /
RESIDUAL MOMENT OF CROSS SECTION RESISTANCE
n = 6
y = 1,0449x - 4,7588
R² = 0,9937
LESSNINO & WESSOLLY 2009
Resttragfähigkeit Elastometer [%]
Restwiderstandsmoment Tomogramm [%]
0
10
20
30
40
50
60
70
80
90
100


Quercus robur
IgewMittelwert
1/γber
Igewh=0,6m
1/εh=0,6m
Igewh=1,8m
1/εh=1,8m
J. Wolf, Bremen University 2010

=> sonic tomography delivers values for bending / stability loss of trunk cross-sections similar to static pull-test, but for all load directions!

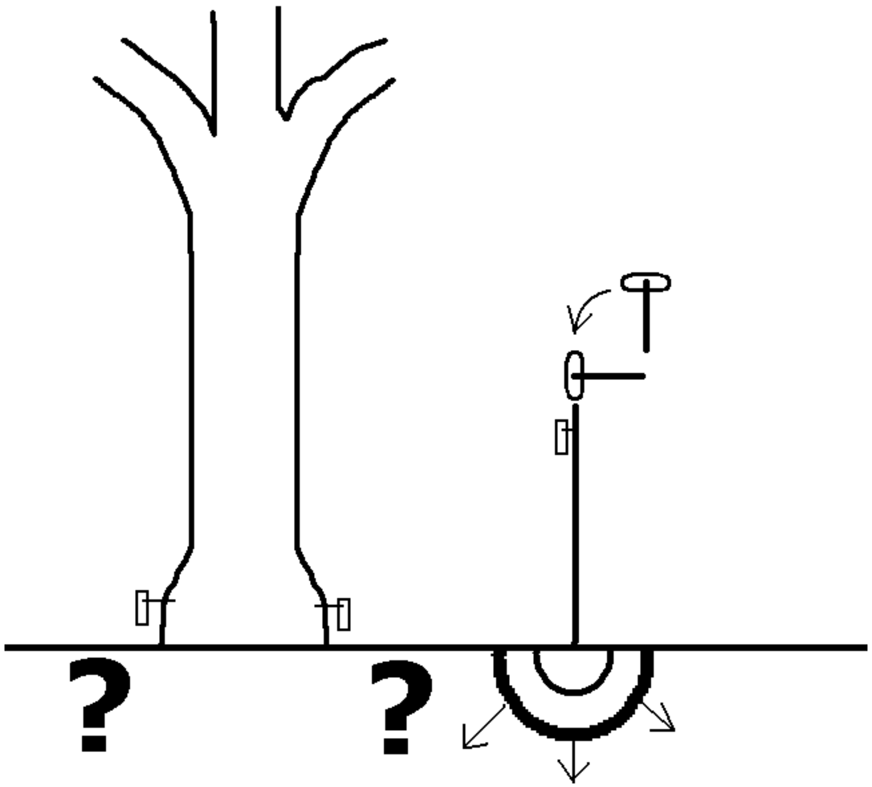
- delivers relative strength loss of cross sections
- does not reveal wood condition
- is low and limited in spatial resolution
- is not critical to sensor position in the main results
- can not give any information about future development of damages

=> this is one reason for resistance drilling

And the roots?

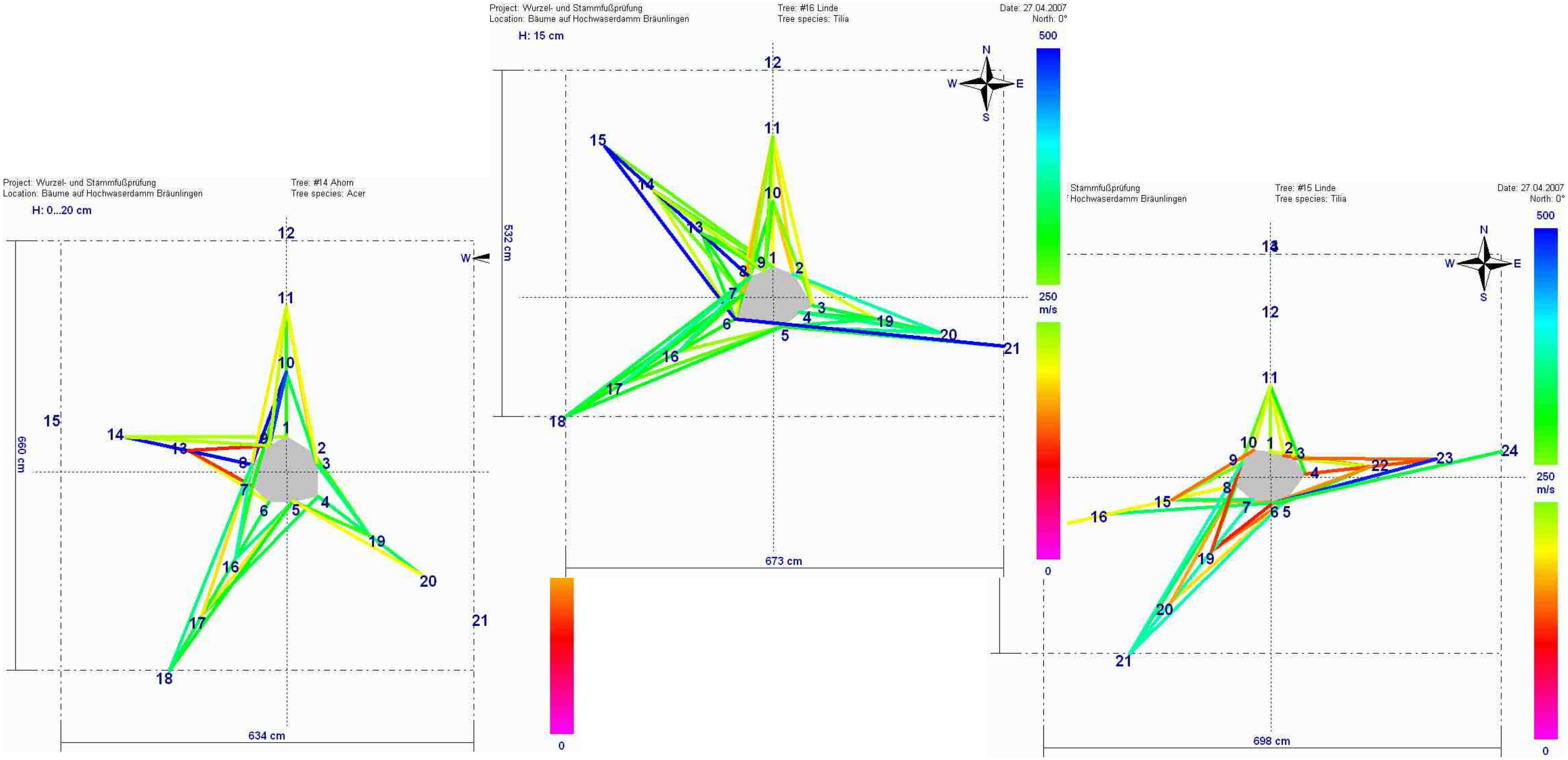
Root analysis by stress waves (in use since 2004)

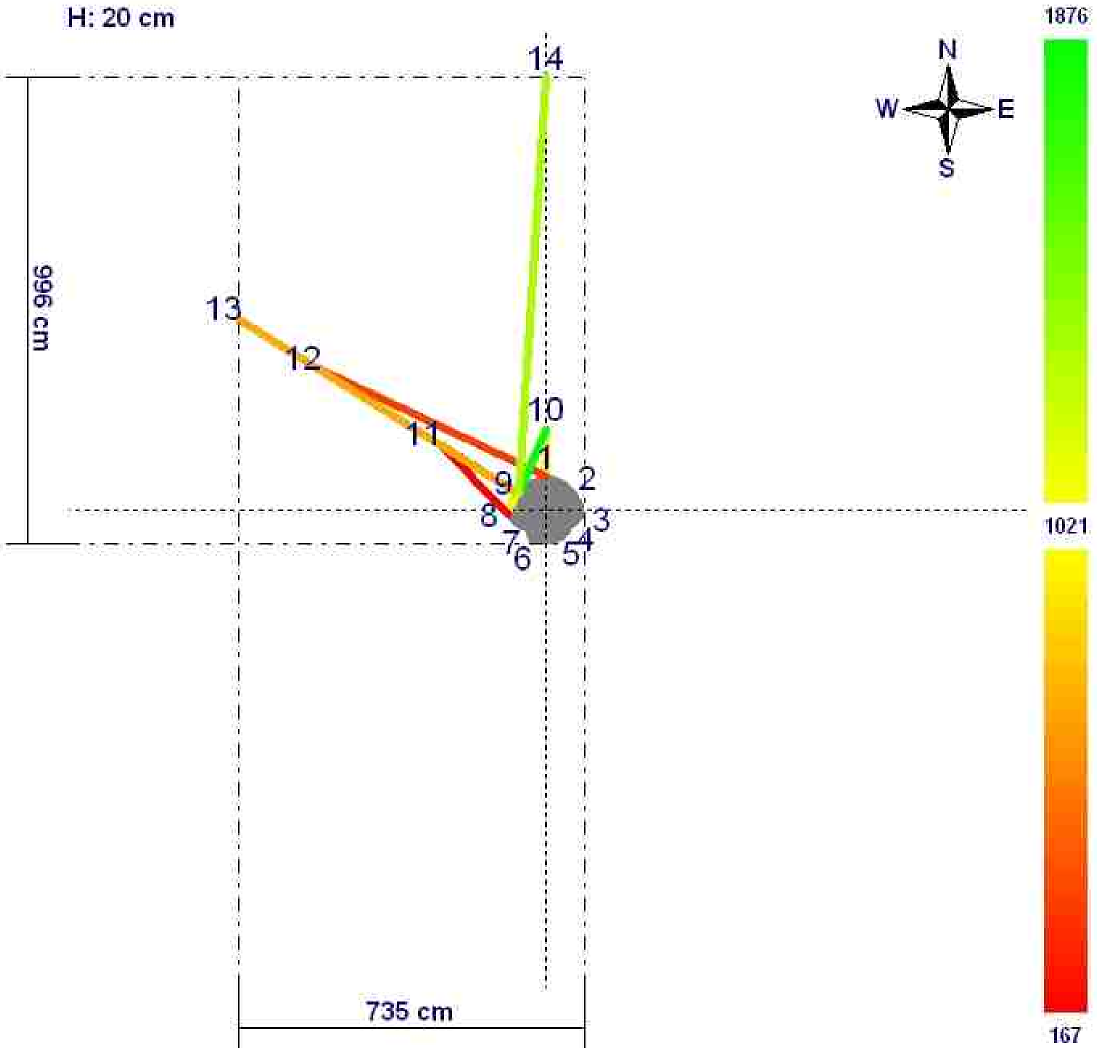
- Finding roots
  - to prevent damages by constructions
  - to check for damages by construction works afterwards
- Identifying the tree who is
  - responsible for damages to footpaths or walls or tubes
- Estimating anchorage weight for stability evaluation.



Application:

Typical results, sometimes difficult to evaluate.

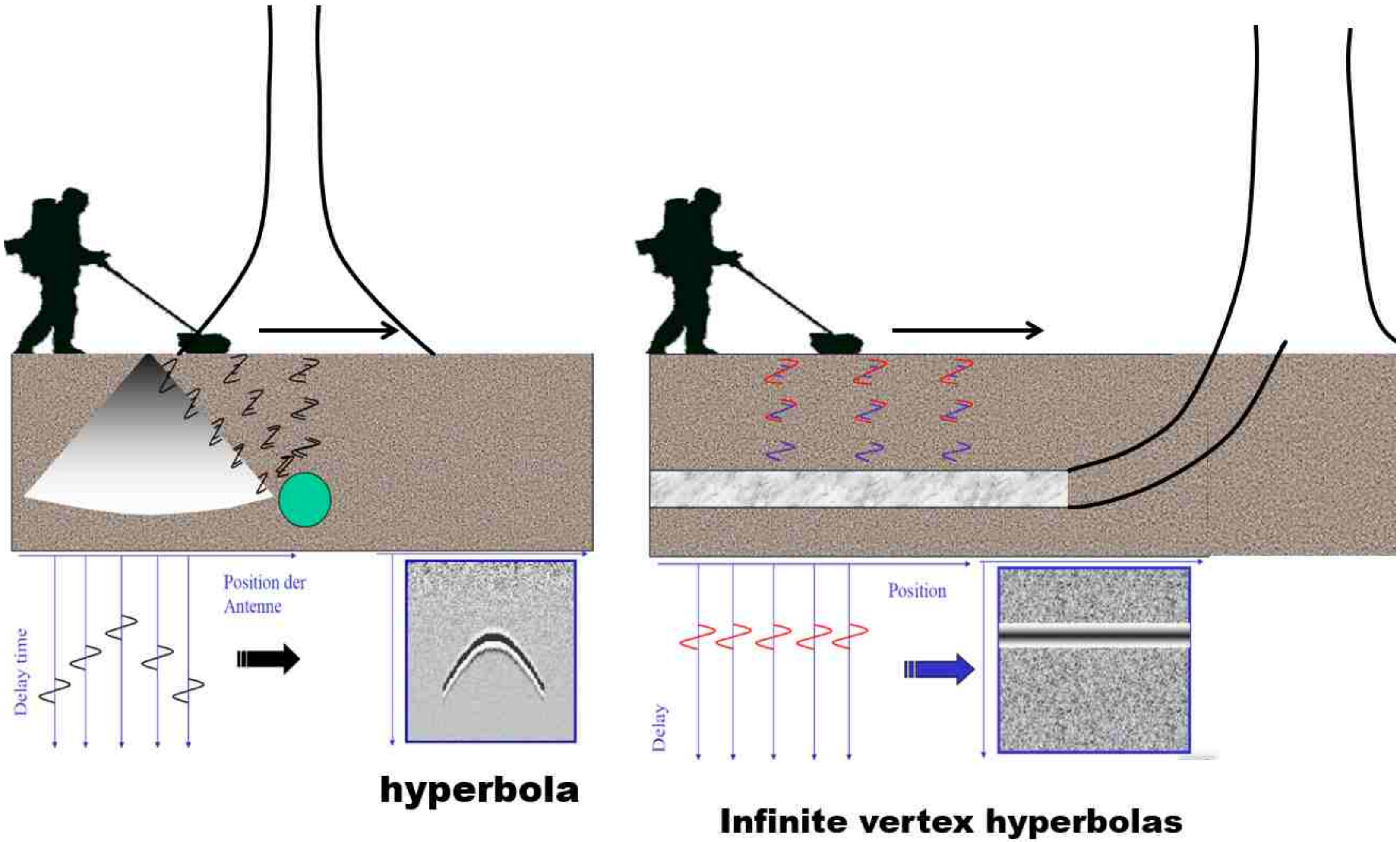




H: 20 cm
996 cm
735 cm
N
W
E
S
1876
1021
167
1
2
3
4
5
6
7
8
9
10
11
12
13
14

Comparison of Arboradix and Ground Penetrating Radar:

Principle of the measurement



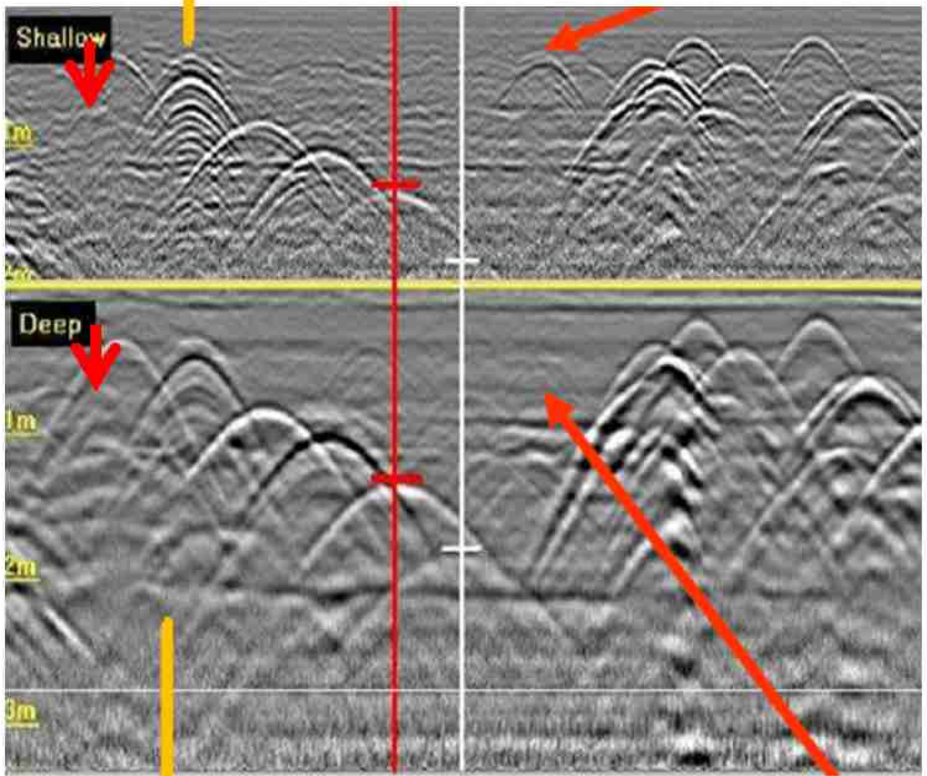
07.11.2013 Tree Biomechanics Week 2013 5

High resolution in different depths

Shallow

Visible pipe

2 frequence radar 250 + 700Mhz



07.11.2013

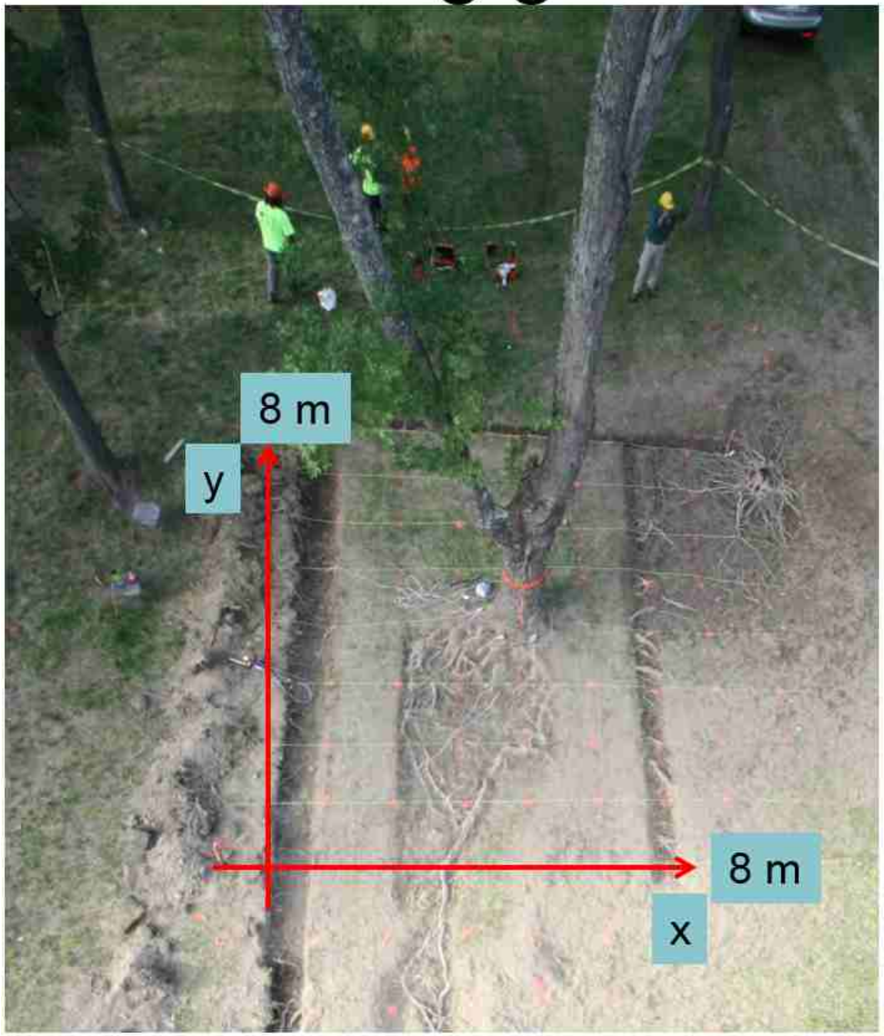
Deep

Tree Biomechanics Week 2013

Invisible pipe

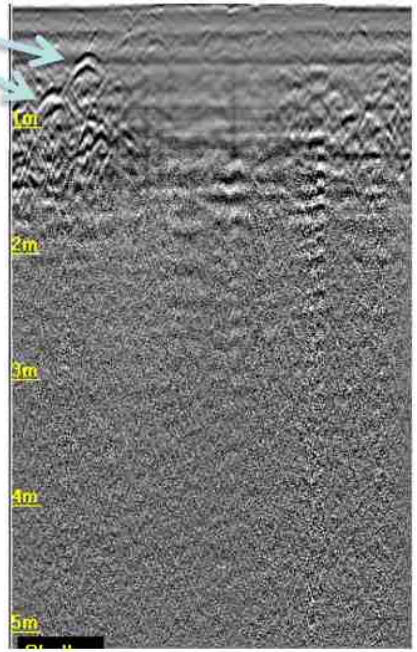
6

Measuring grid

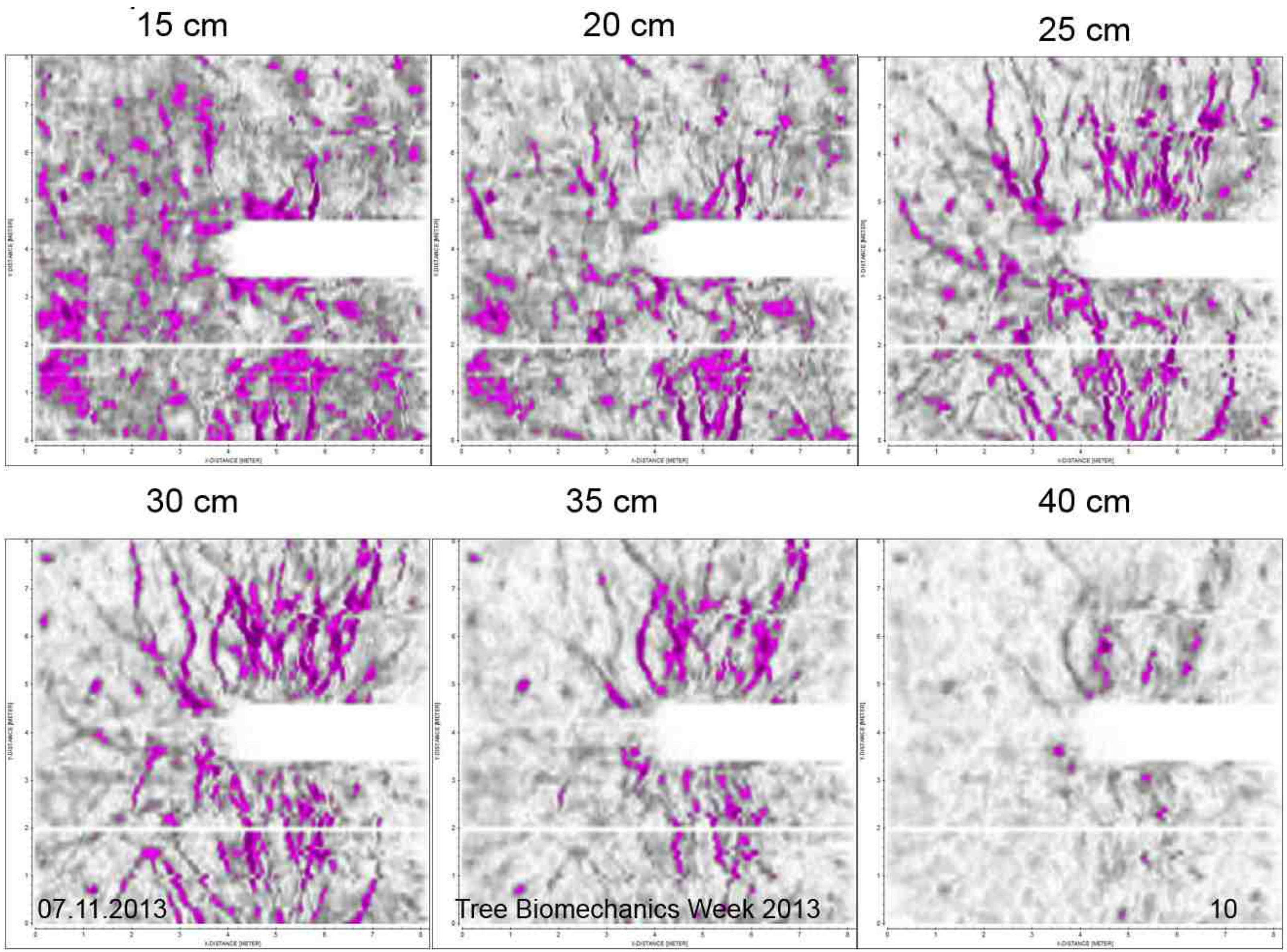


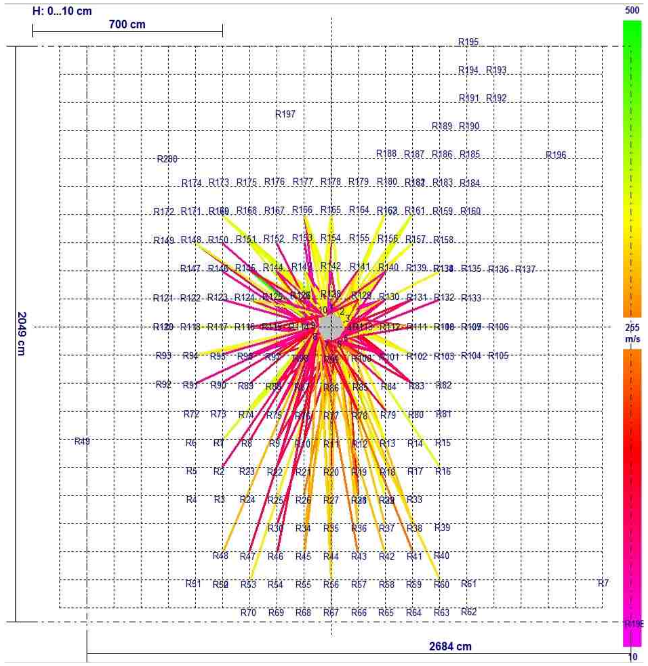
- 1 slice every 10 cm in x & y directions
- Total measuring distance of 1,3 km
- 160 pictures need to be „connected“

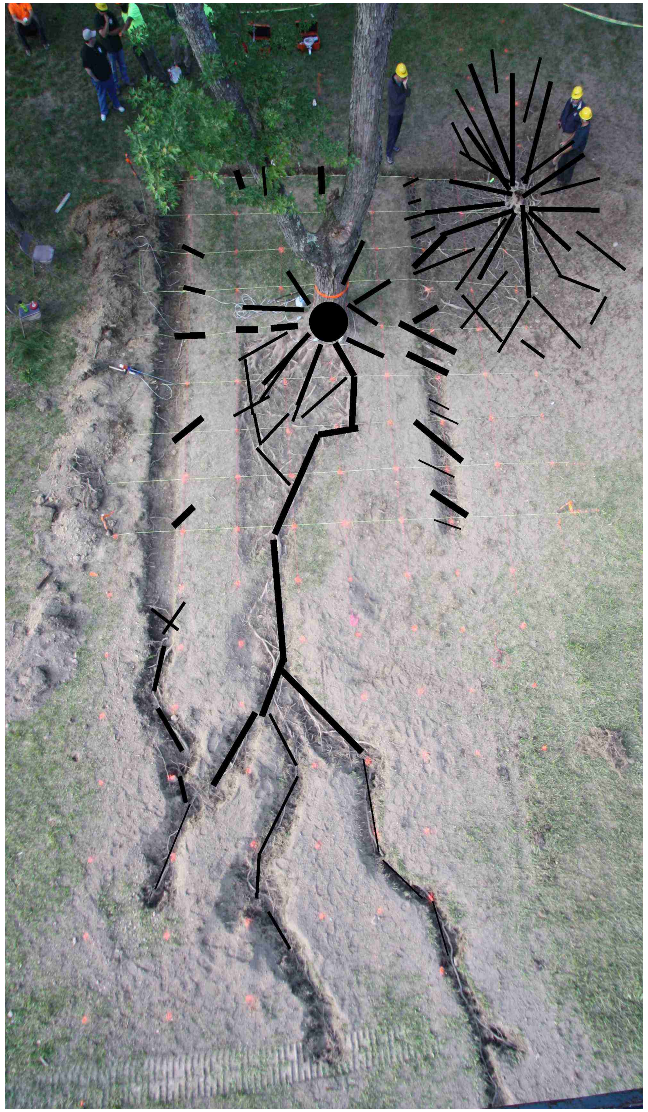
roots

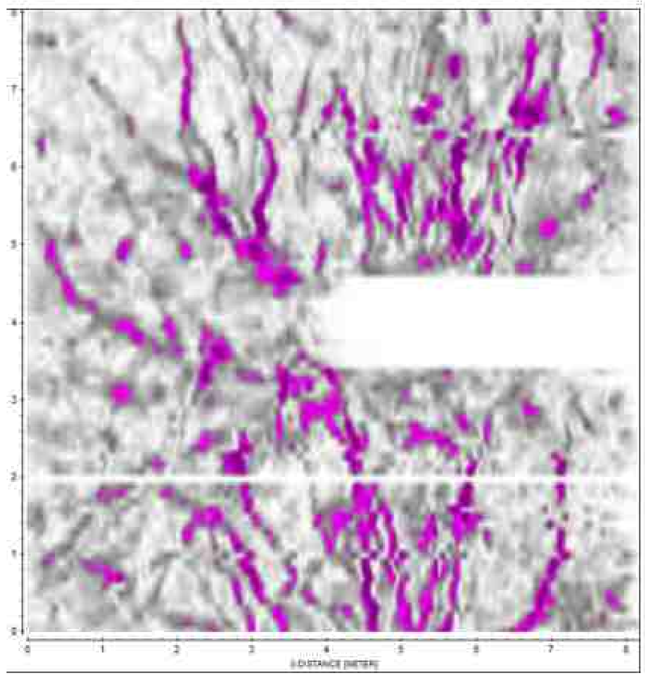


07.11.2013 Tree Biomechanics Week 2013


15 cm
20 cm
25 cm
30 cm
35 cm
40 cm
07.11.2013
Tree Biomechanics Week 2013
10


H: 0...10 cm
700 cm
500
255 m/s
2049 cm
2684 cm





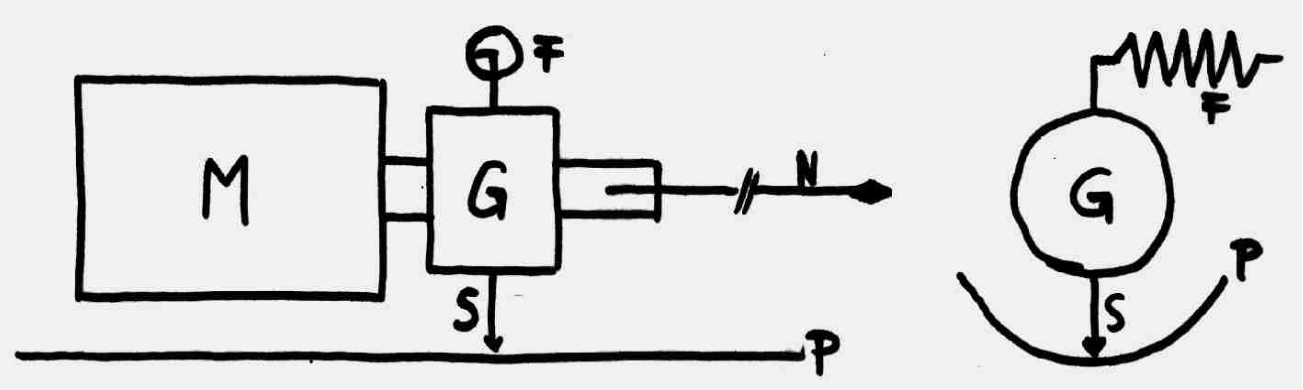
=>

- sonic root assessment reveals the area of soil mechanically bound by the tree
- this is can be compared with wind load but is not as precise as static load test
- sonic assessments show the current state
  - but no information on expected future developments

=> resistance drilling as an additional source of information!

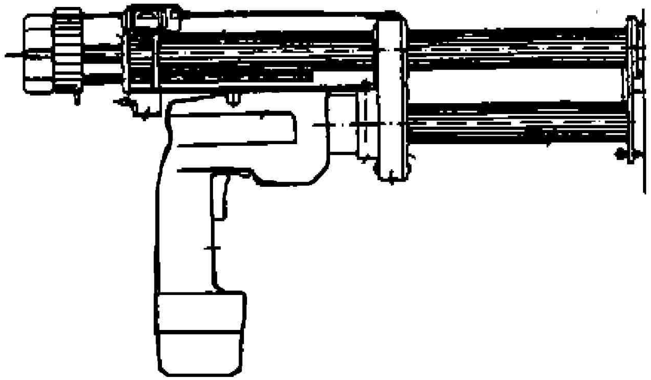
Resistance drilling

using thin needles



Kamm & Voß 1985

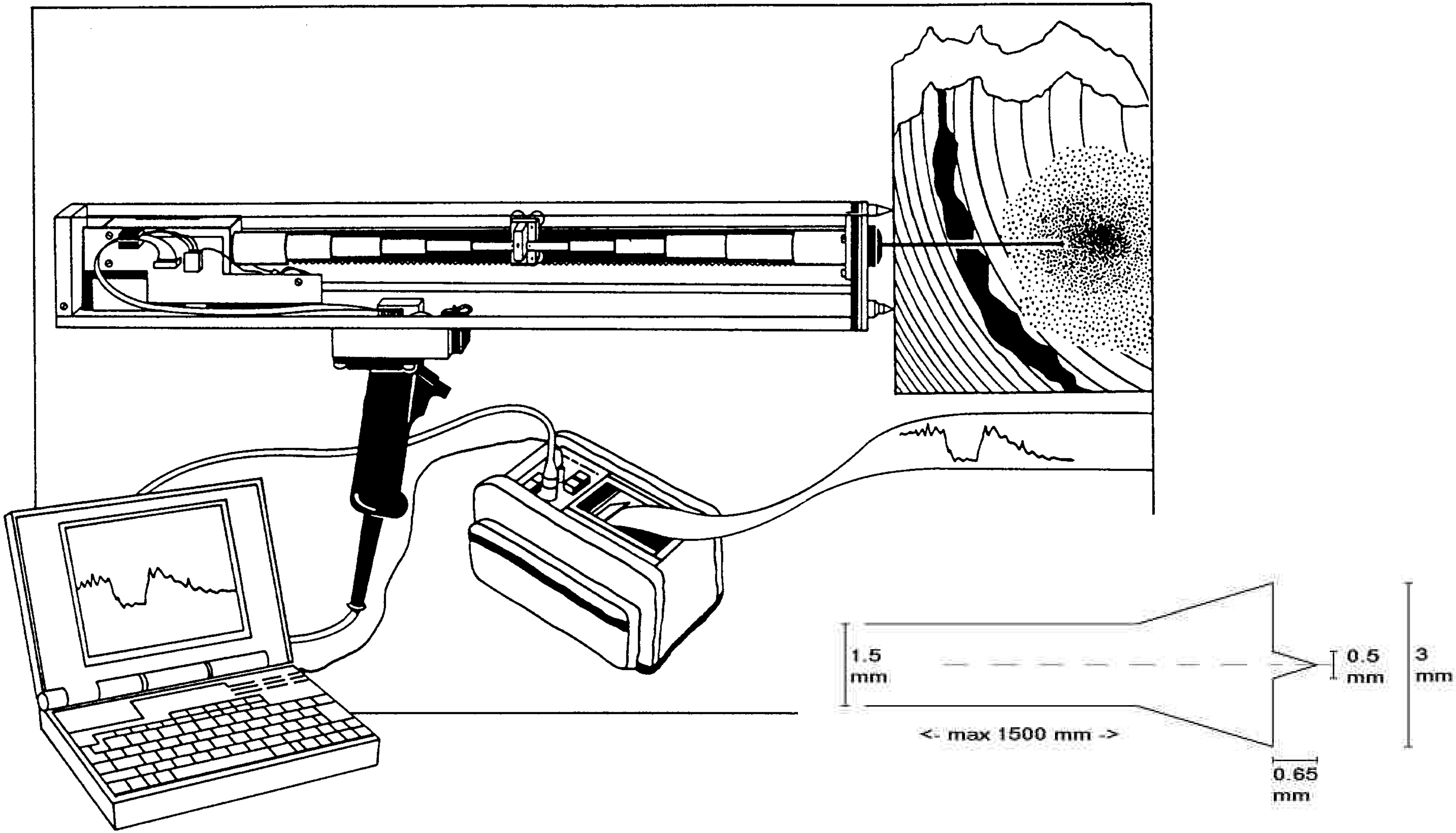
Rinn & FEIN 1987

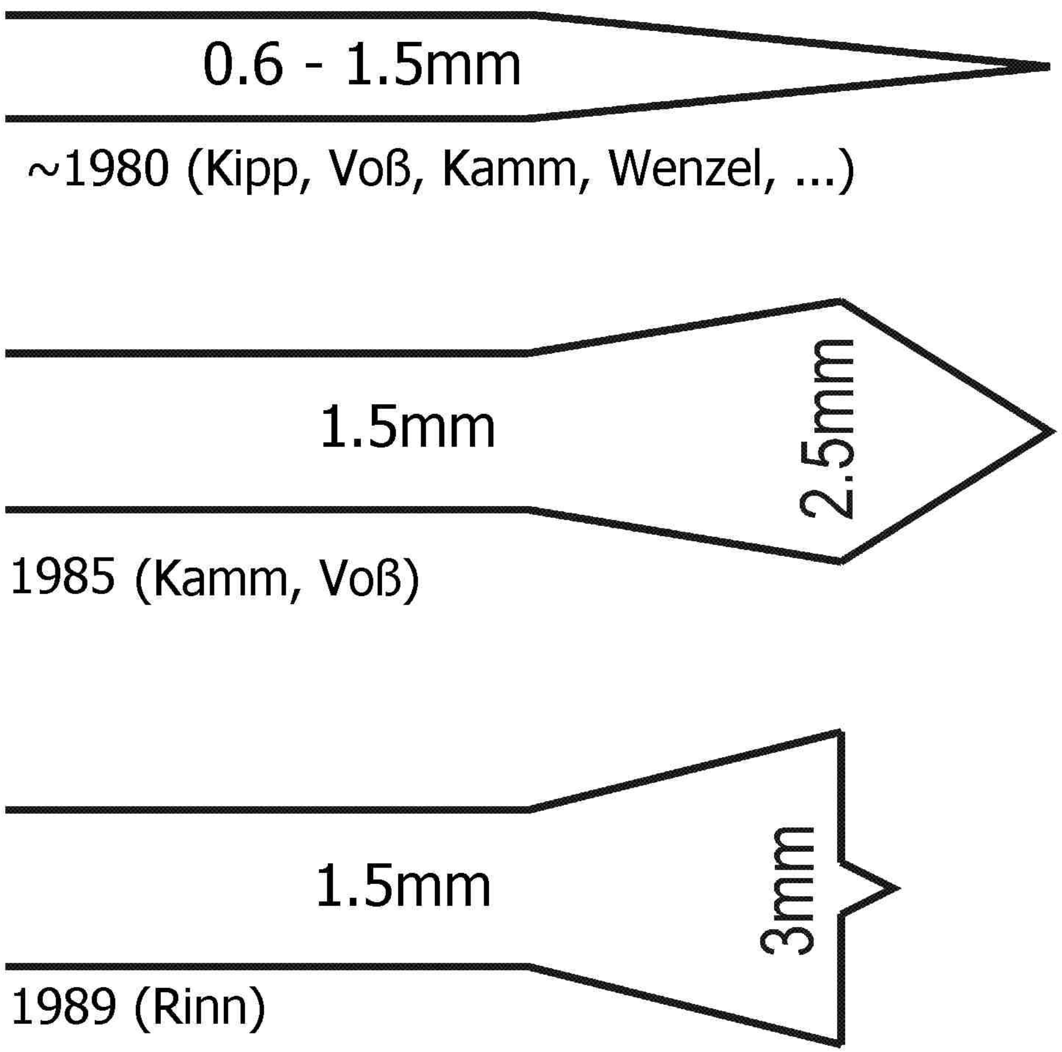


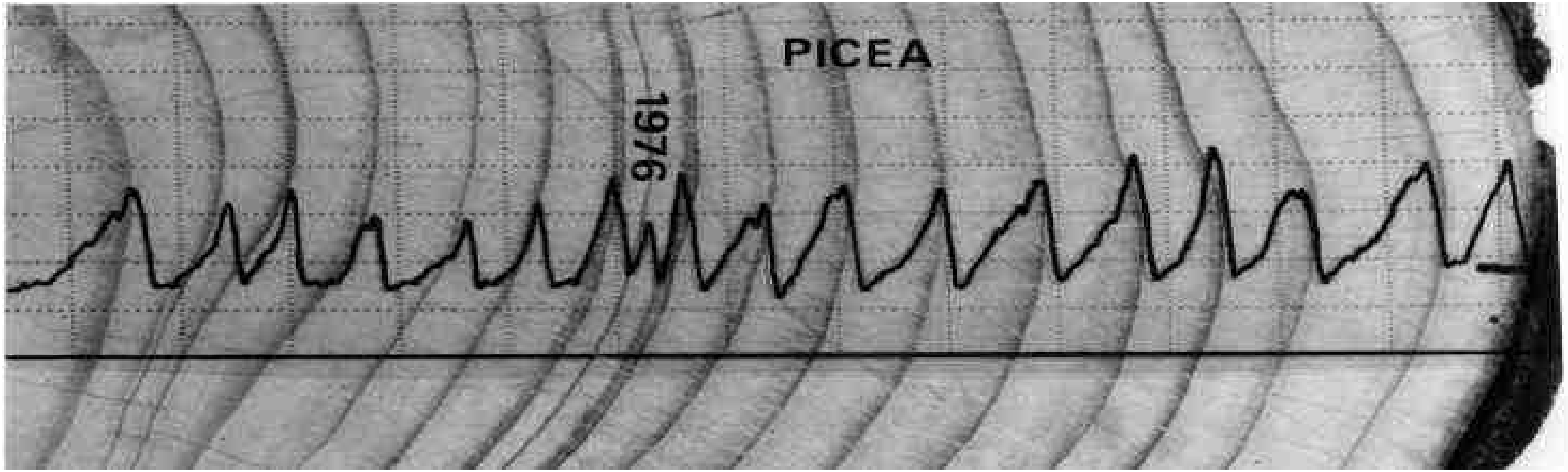
Kipp 1990

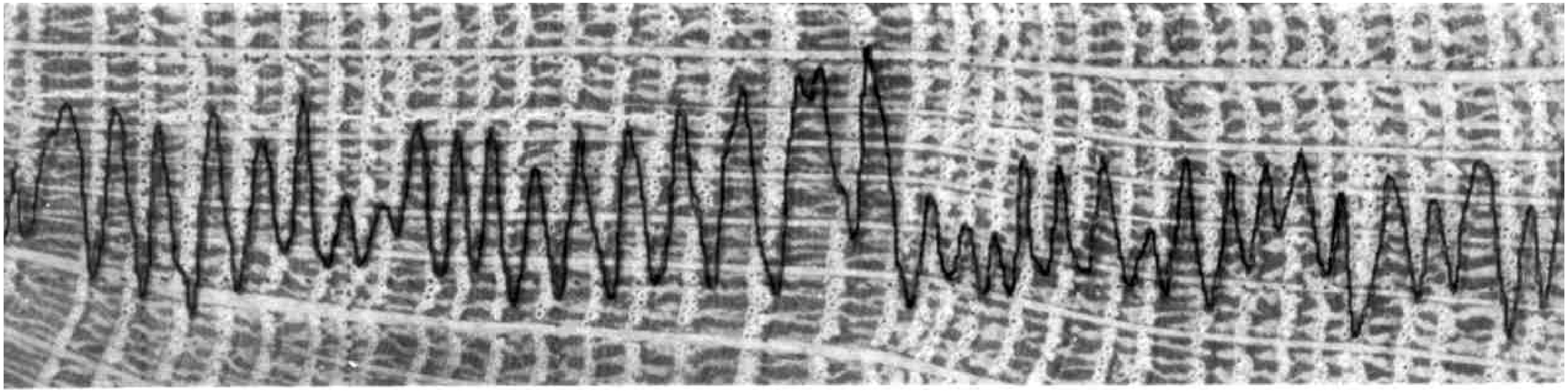
History and origin of the RESISTOGRAPH® drill-resistance method

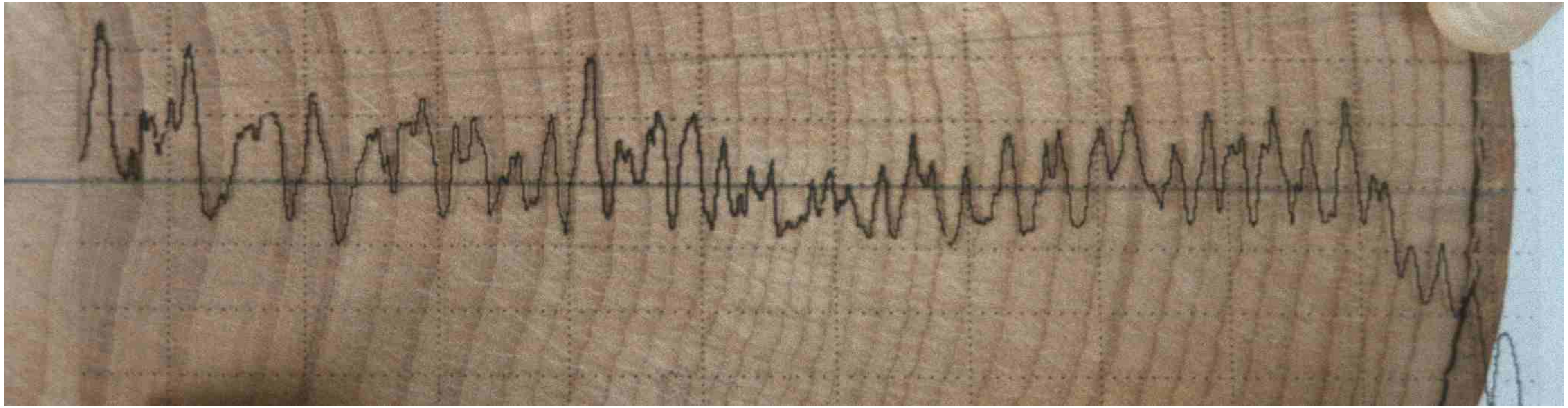
1970	Pin-penetration depth ~ wood density (Liechtenstein)
1972	Insizing of wooden utility poles => needle penetration resistance (Germany)
1973	Resistance drilling by torque-measurement of particle boards (Germany)
1978	Recording soil penetrometer (USA)
1983	Recording motor power as measure of mechanical resistance (Japan)
1985	Needle drill resistance by motor power (Germany)
1986	Diploma thesis: resistance drilling for tree-ring analysis (RINN, Heidelberg)
1987	First portable series of drills to inspect trees and timber (RINN & FEIN)
1990	Patent on electronic drill resistance measurements (RINN) and needle geom.
1993	RESISTOGRAPH as registered trademark (in more than 30 countries, RINN)
1999	First drill providing automatic feed rate adjustment to wood species

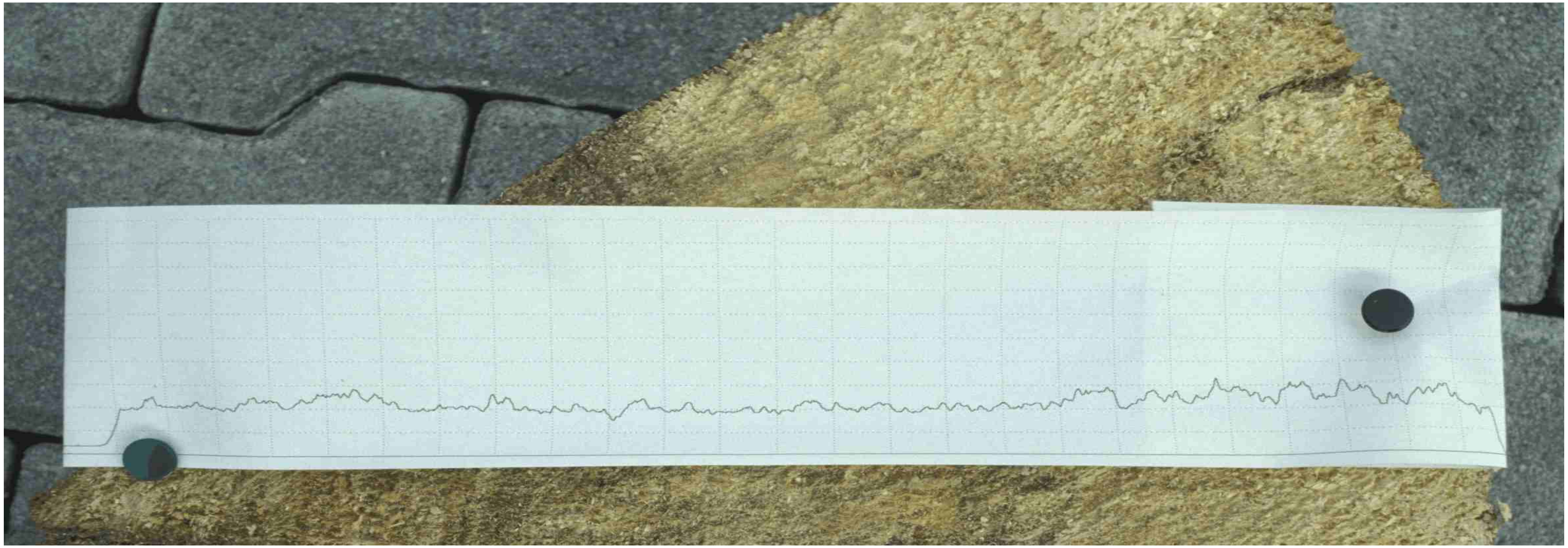

1.5
mm
0.5
mm
3
mm
<- max 1500 mm ->
0.65
mm

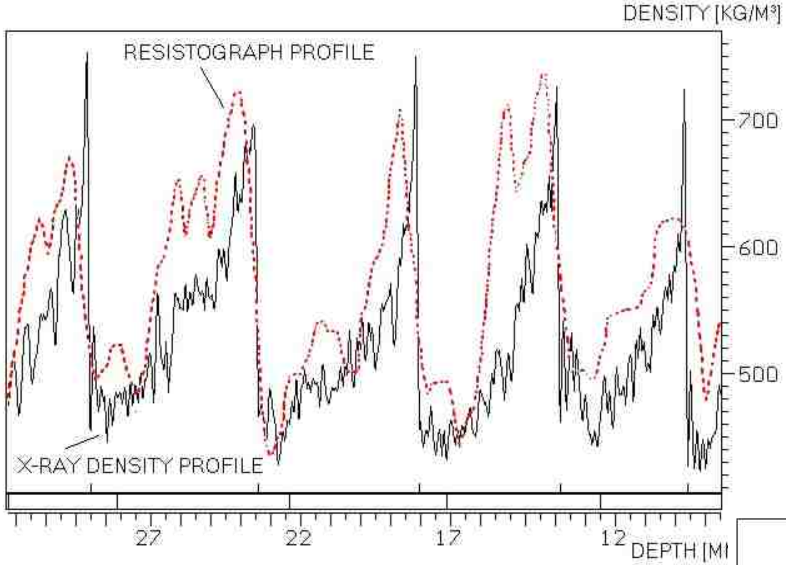

0.6 - 1.5mm
~1980 (Kipp, Voß, Kamm, Wenzel, ...)
1.5mm
2.5mm
1985 (Kamm, Voß)
1.5mm
3mm
1989 (Rinn)


PICEA
1976









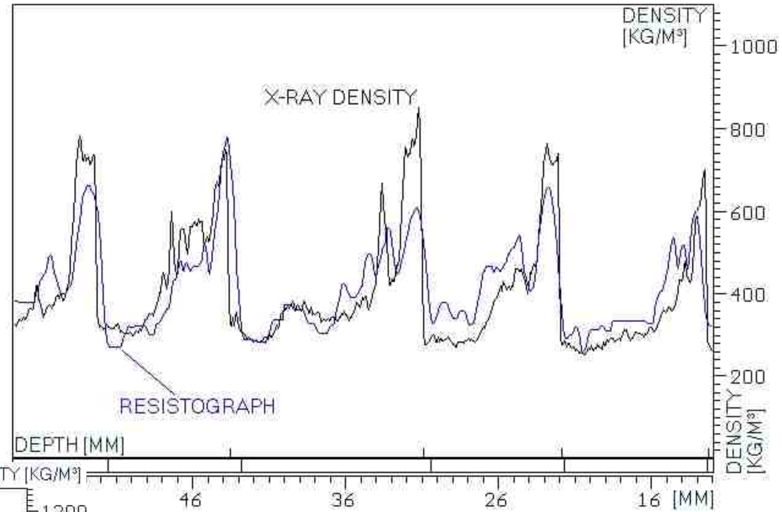
Tilia

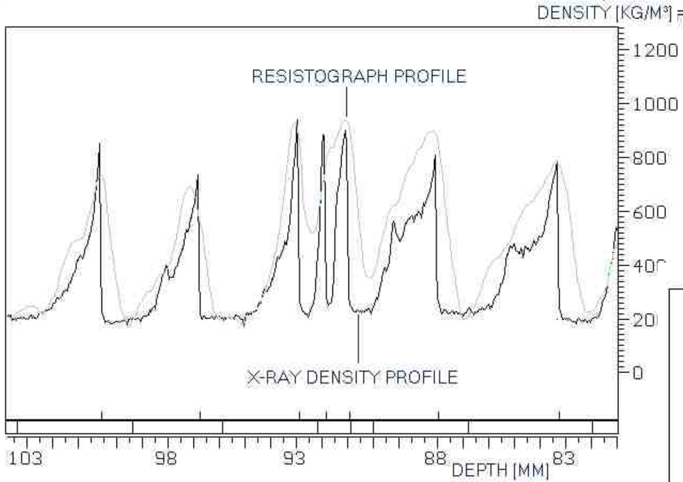
Larix

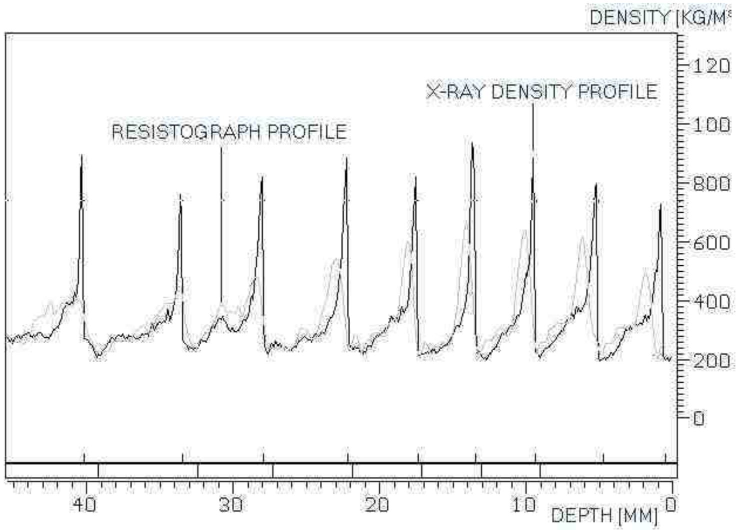
X-ray

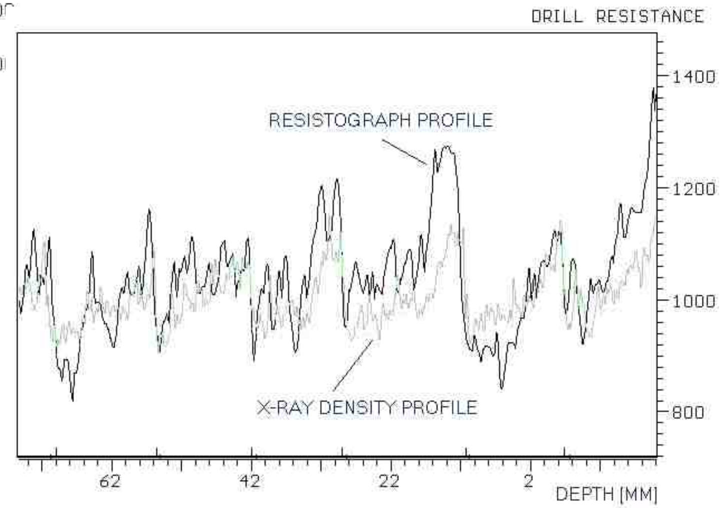
versus

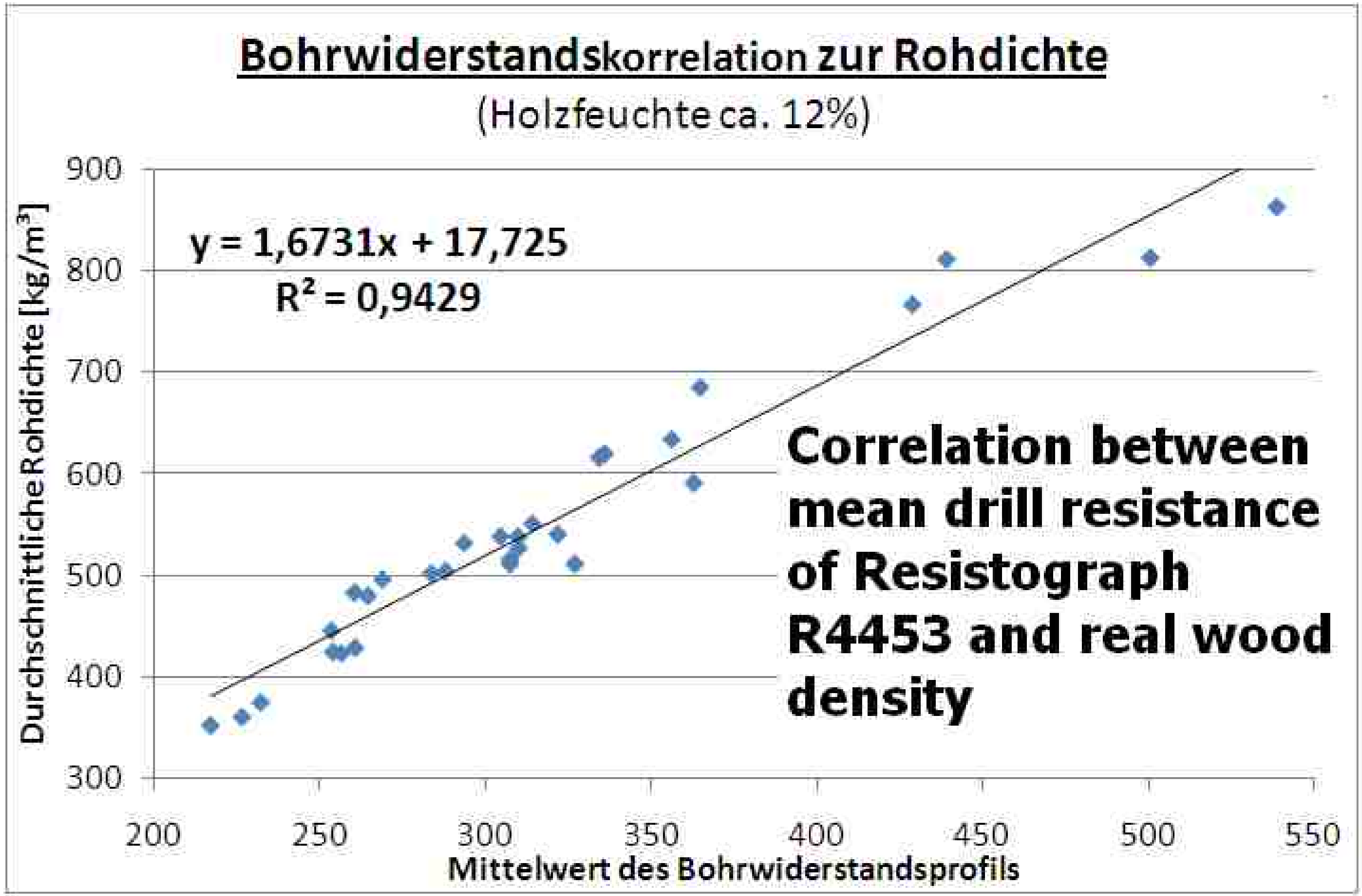
drill resistance

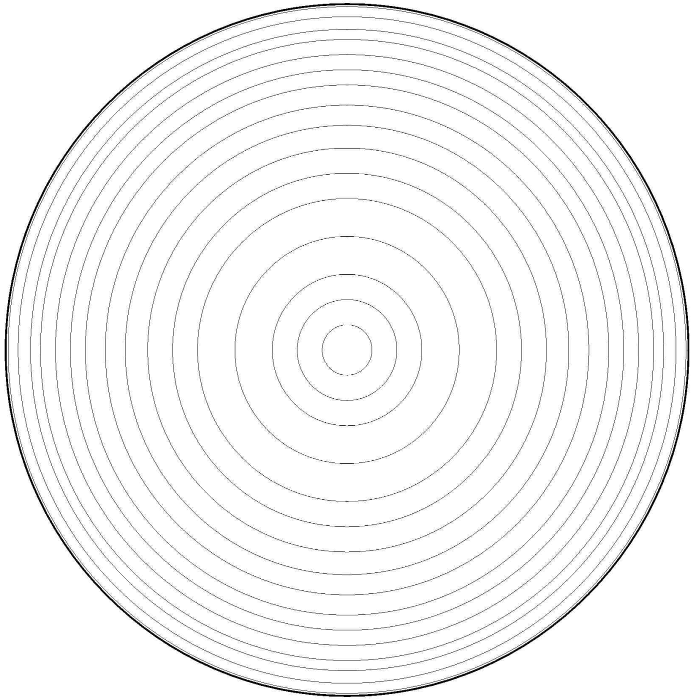




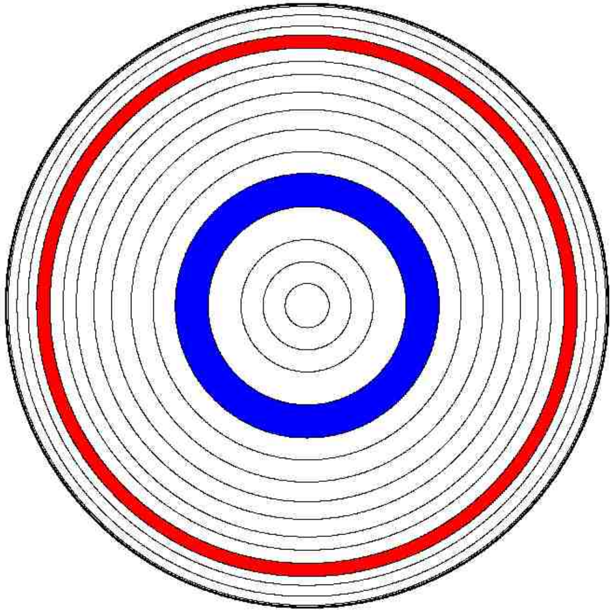


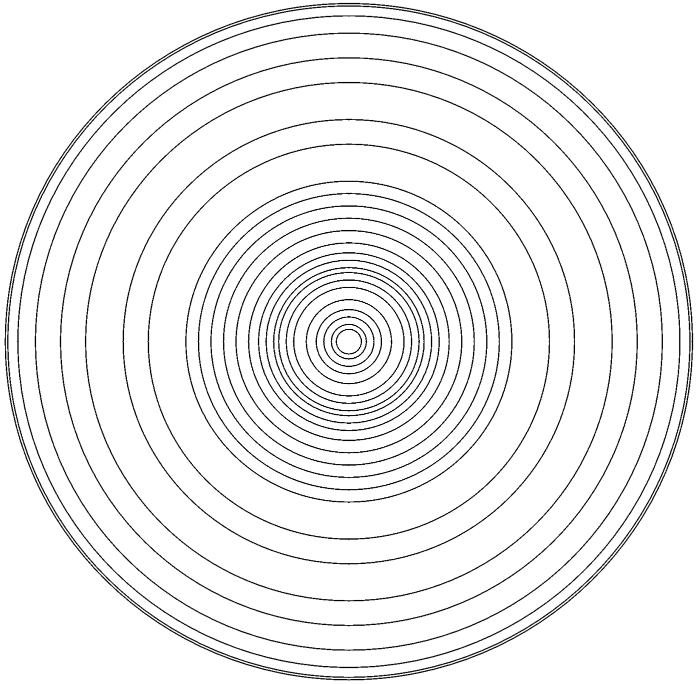


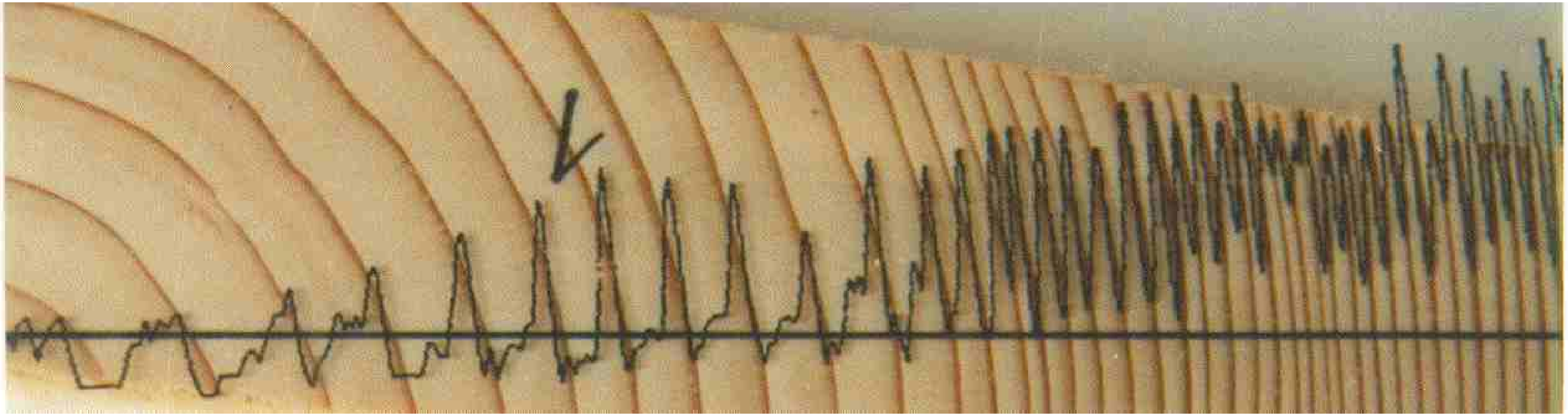

Bohrwiderstandskorrelation zur Rohdichte
(Holzfeuchte ca. 12%)
y = 1,6731x + 17,725
R² = 0,9429
Correlation between mean drill resistance of Resistograph R4453 and real wood density
Durchschnittliche Rohdichte [kg/m³]
900
800
700
600
500
400
300
200
250
300
350
400
450
500
550
Mittelwert des Bohrwiderstandsprofils

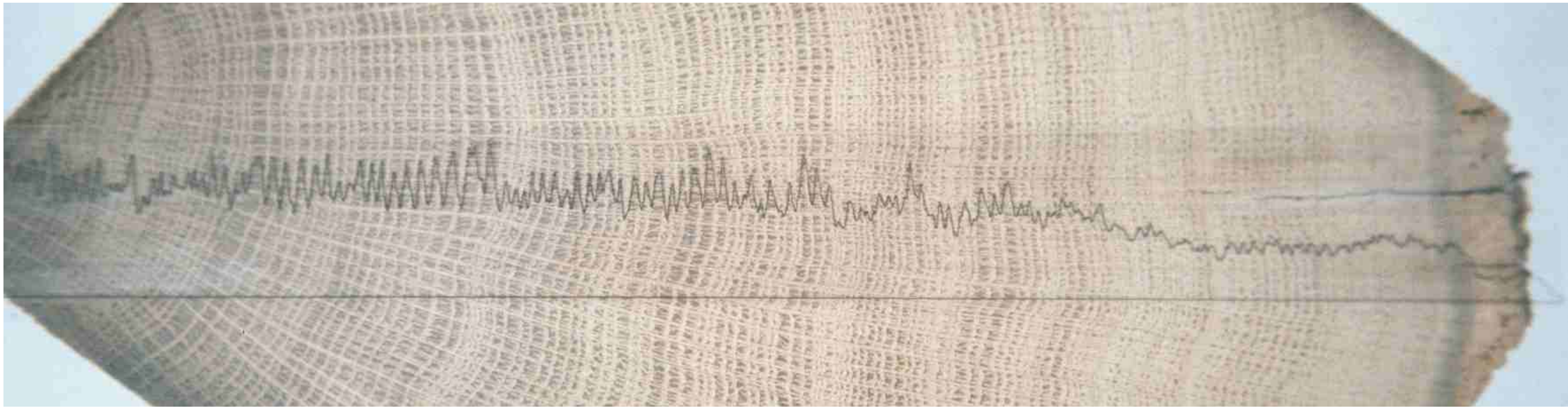


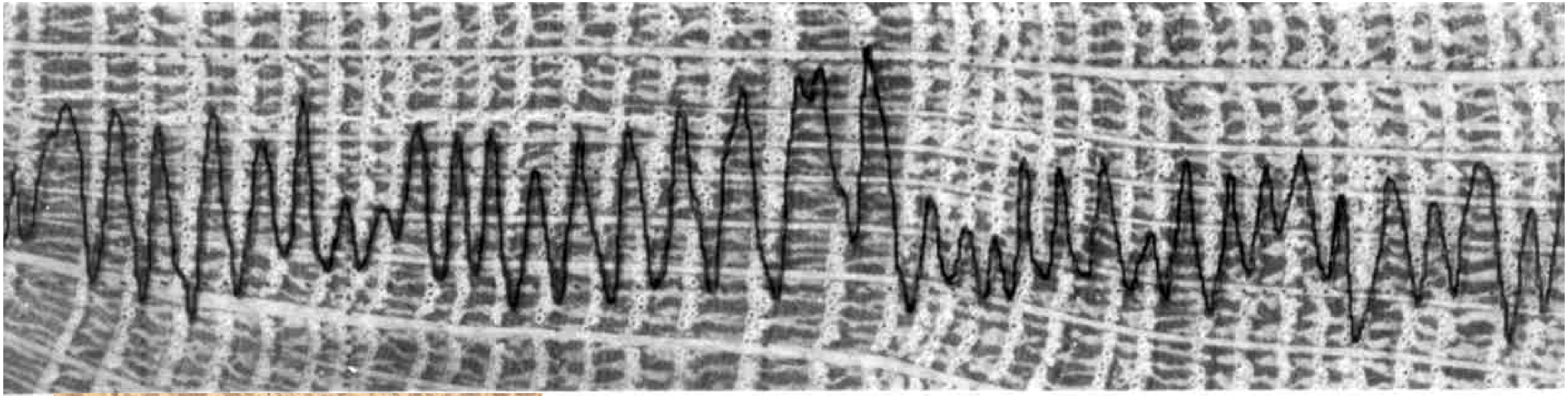
Age trend

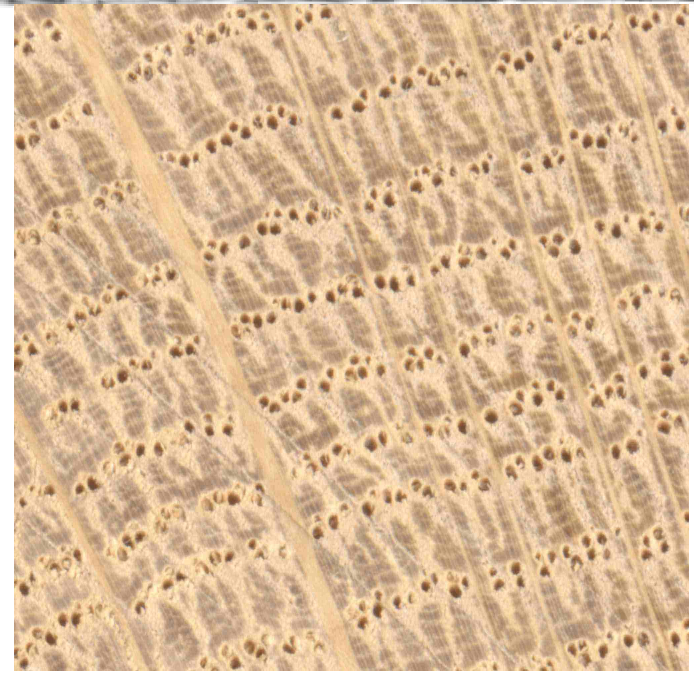




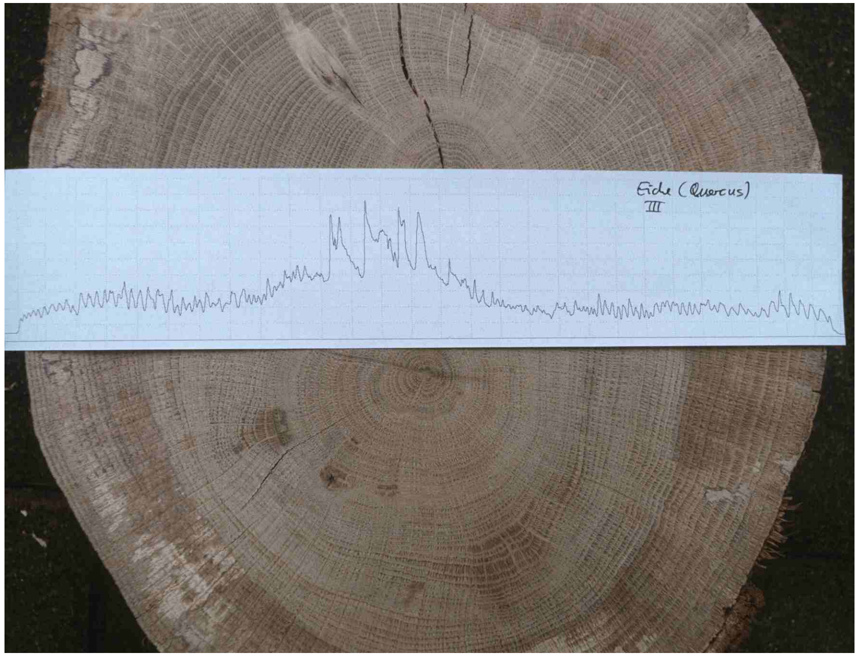


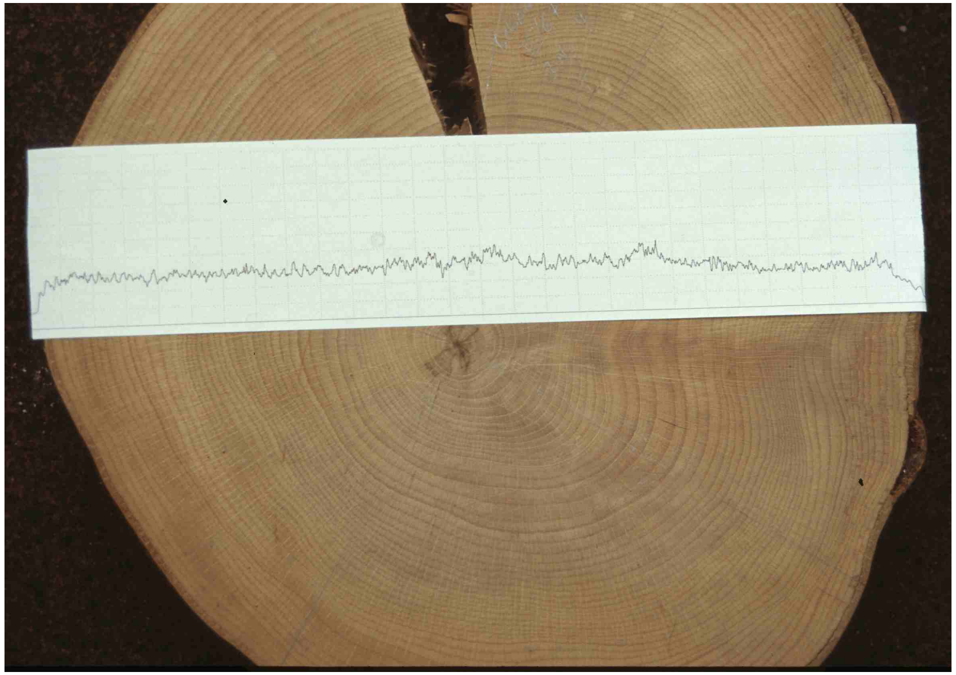


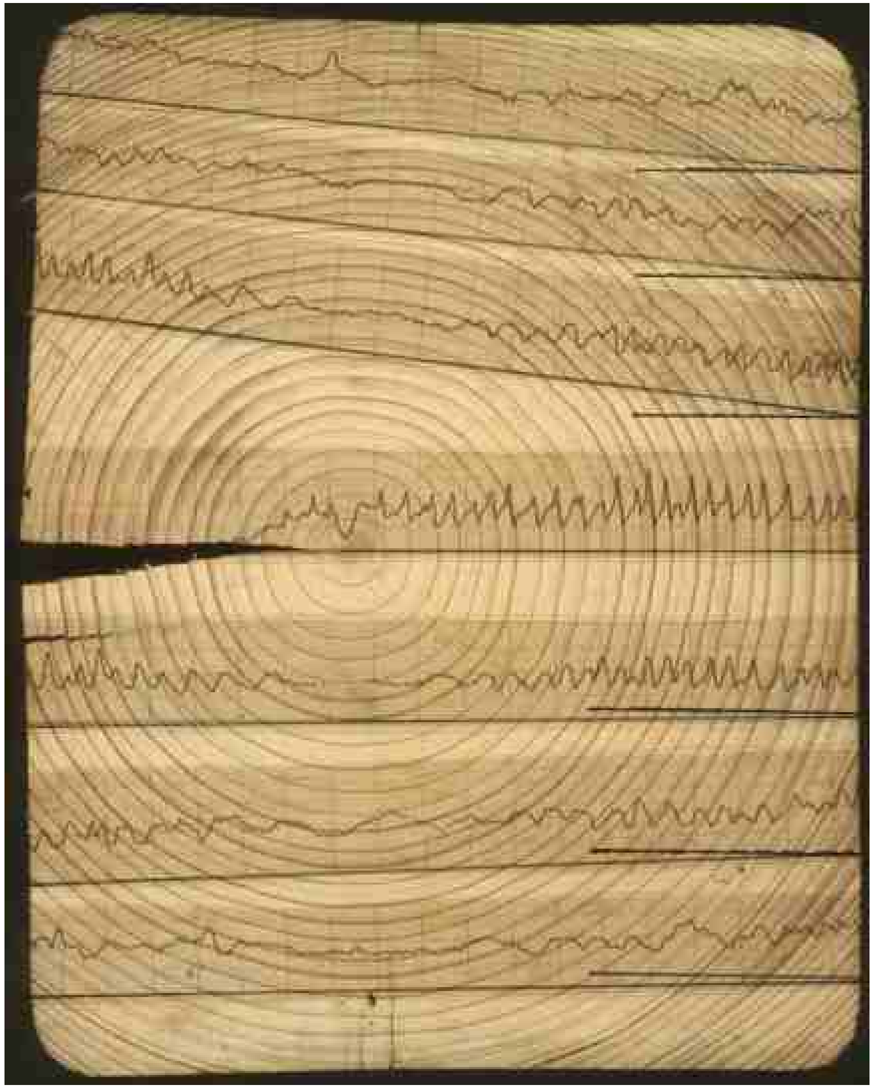


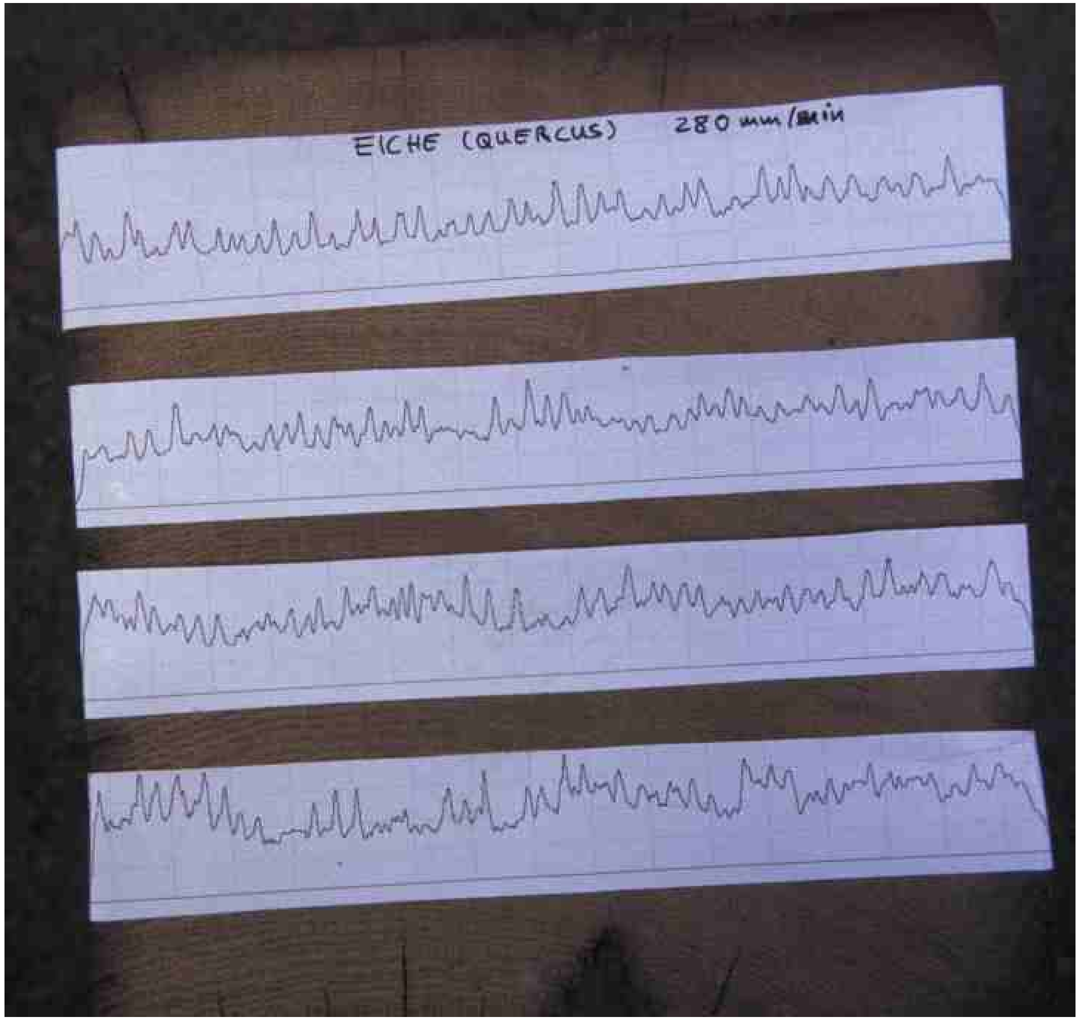


Earlywood width in oak shows small variations
=> bigger tree-rings are dominated by latewood
and provide higher spatial density
as shown in the resistance profile.

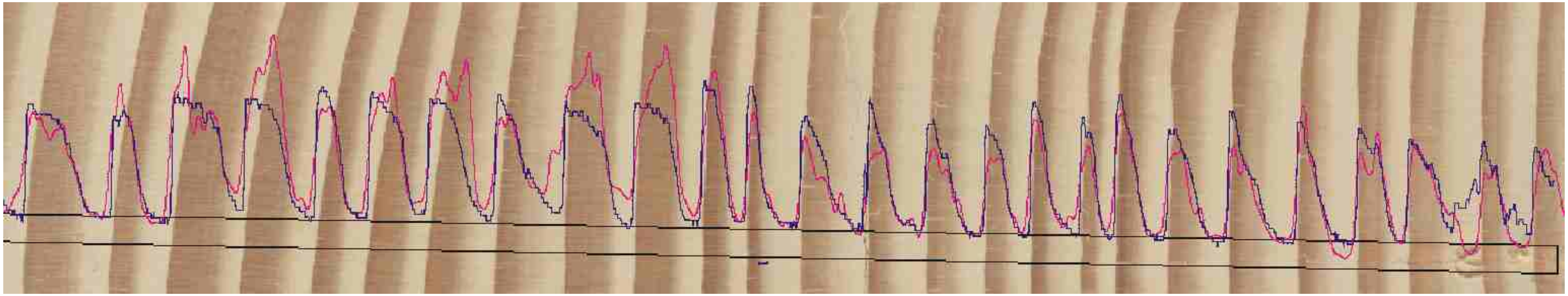

Eiche (Quercus)
III



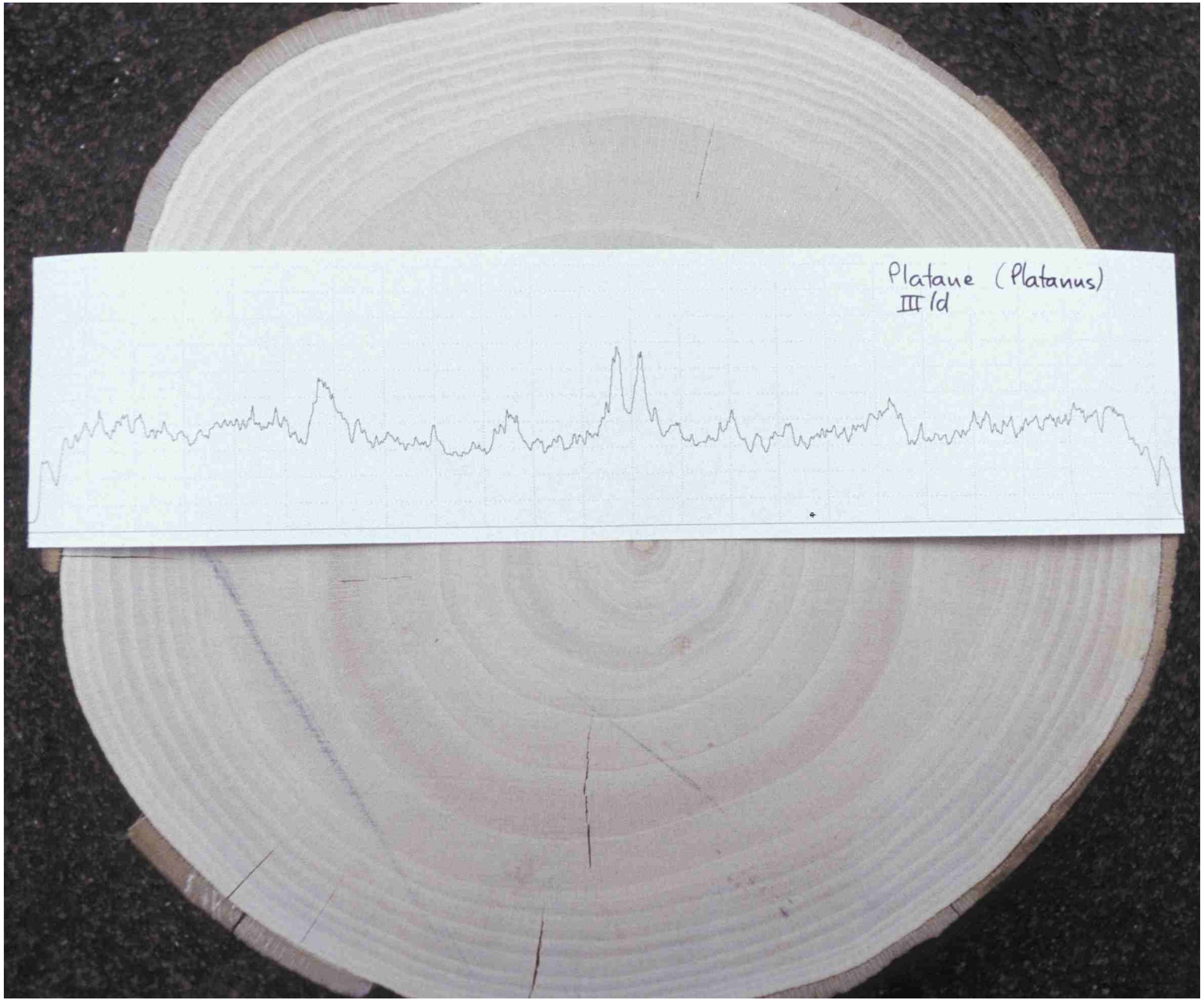


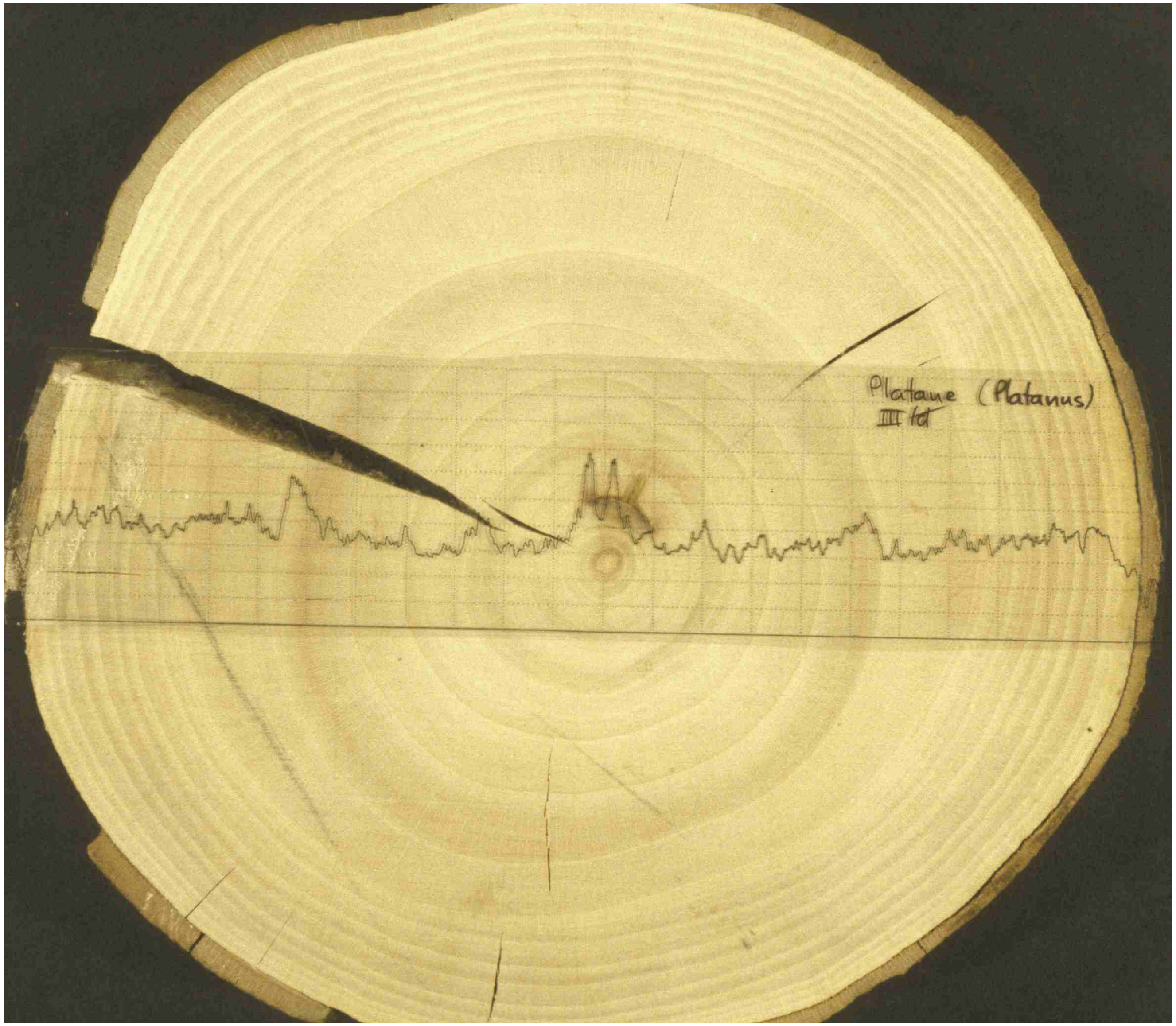

EICHE (QUERCUS) 280 mm/min

In clear conifer wood (no heartwood, no discolouration), the greyscale-profile reveals density and is proportional to drill resistance.



In compression wood, drill resistance is higher than the greyscale profile and both different from real density.

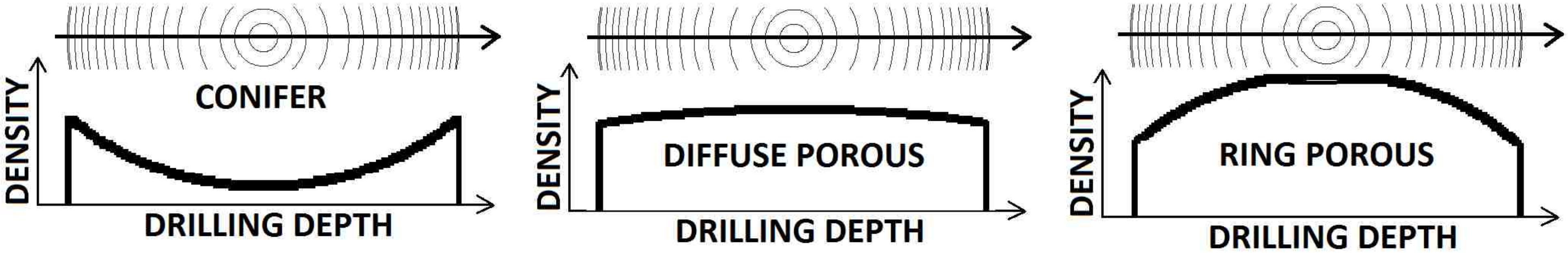

Platane (Platanus)
III/d

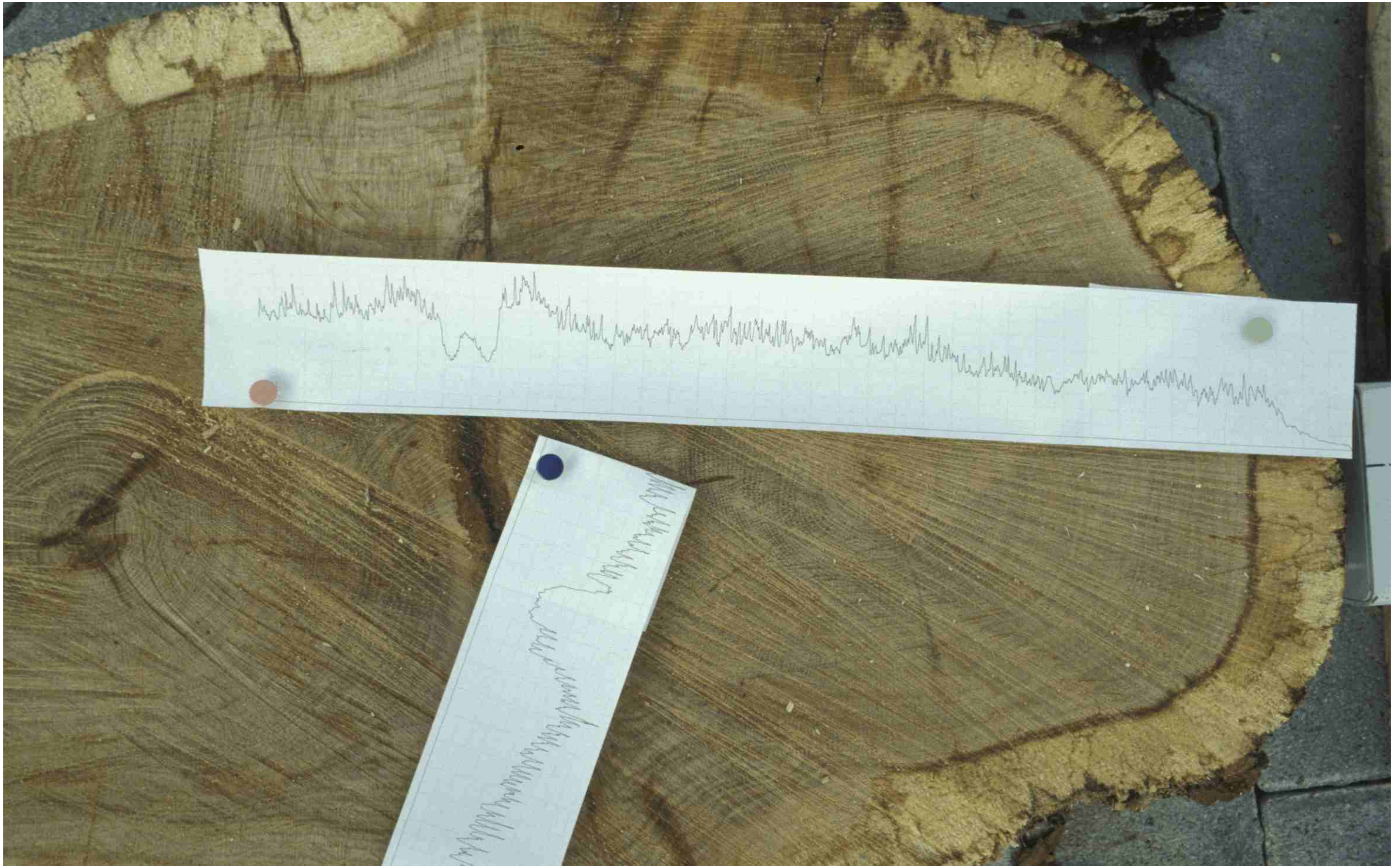

Platane (Platanus)
III ld

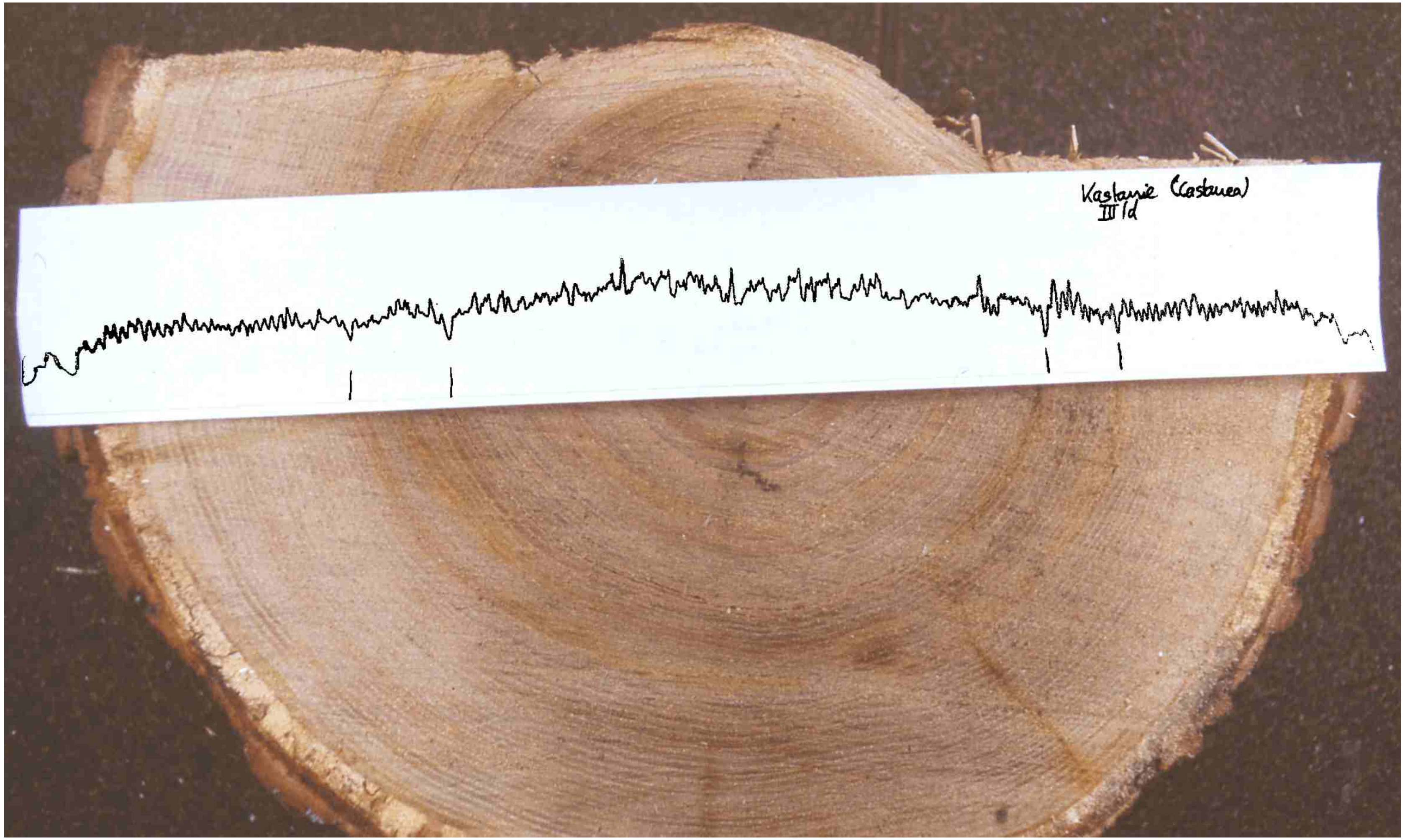
=> electronically regulated and linearly recorded

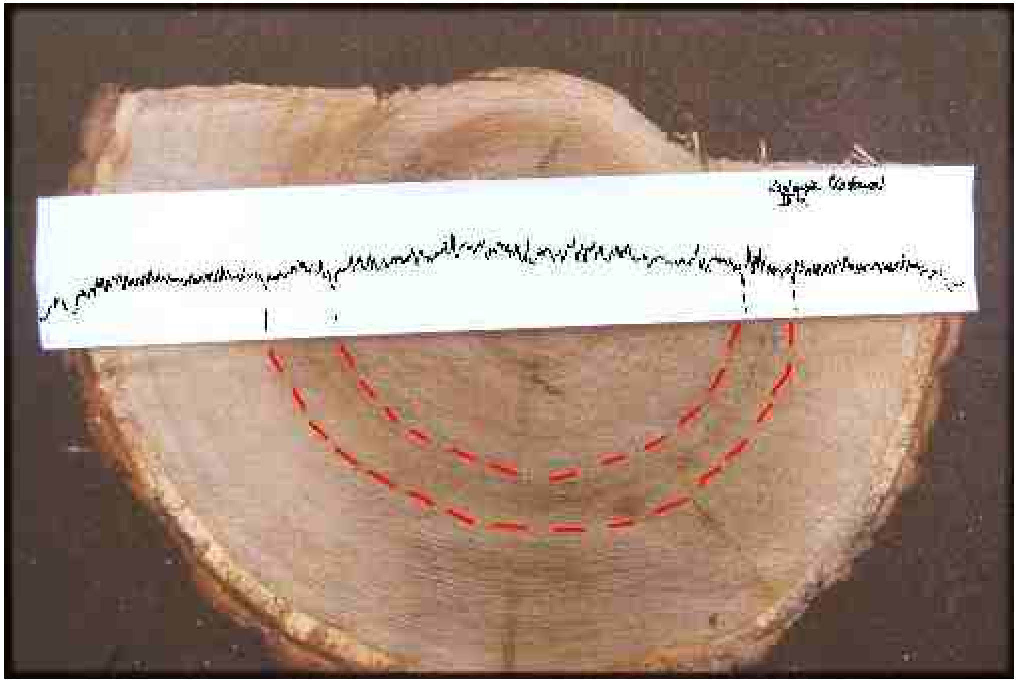
drill resistance reveals wood density

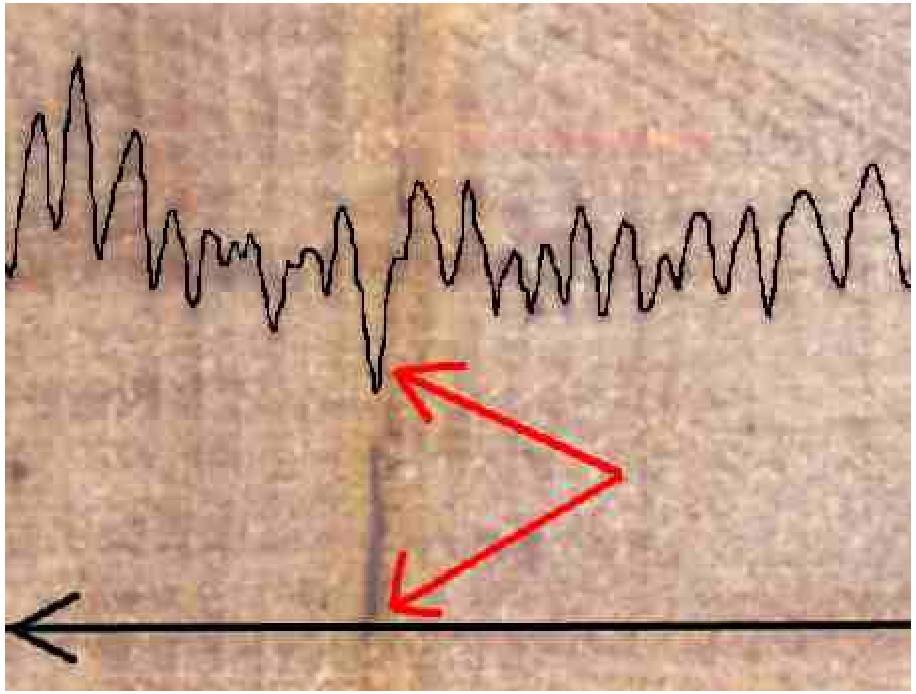
if needle geometry concentrates penetration resistance at the tip.

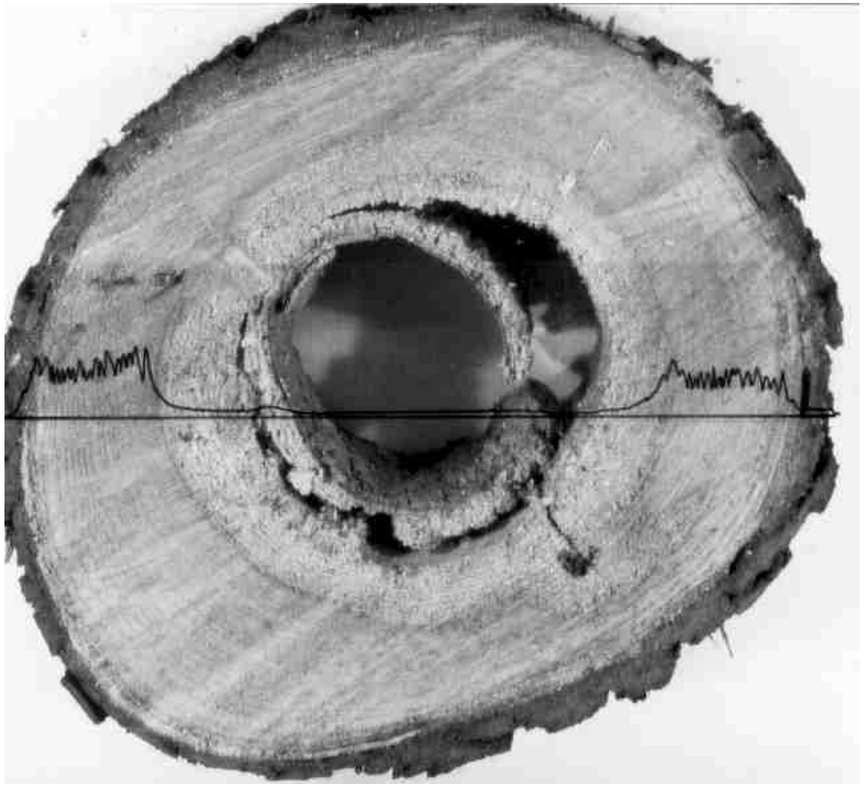


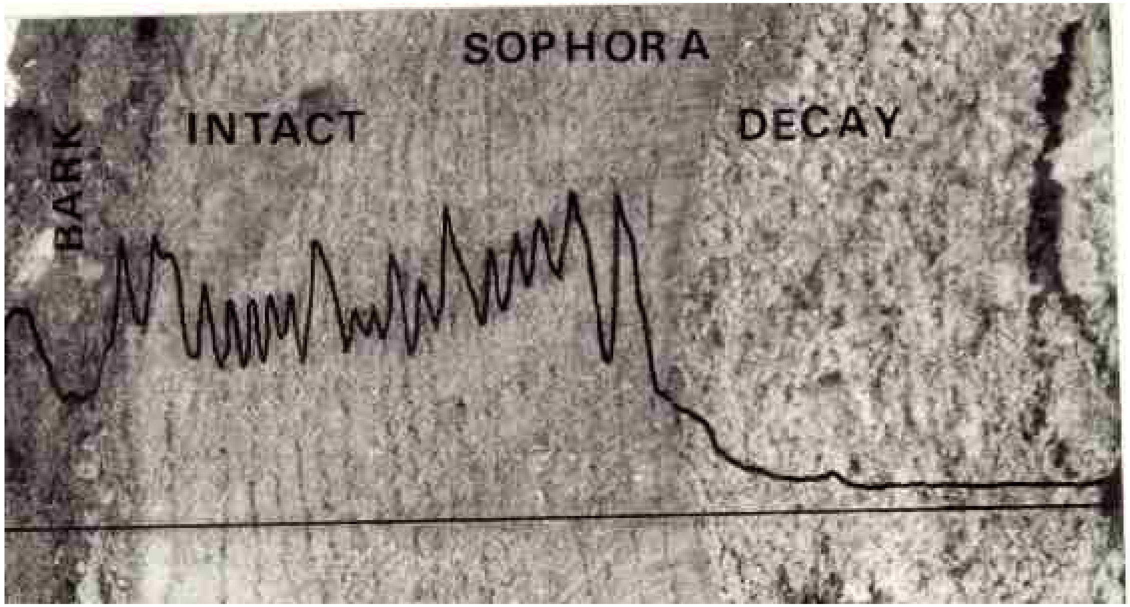


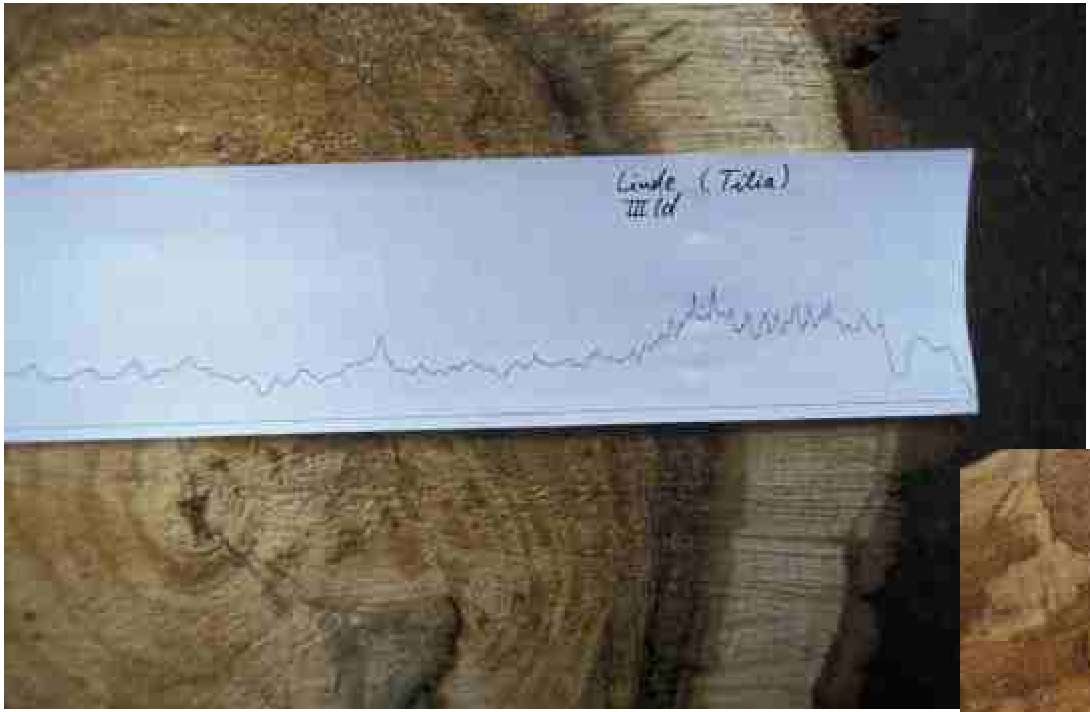

Kastanie (Castanea)
III/d

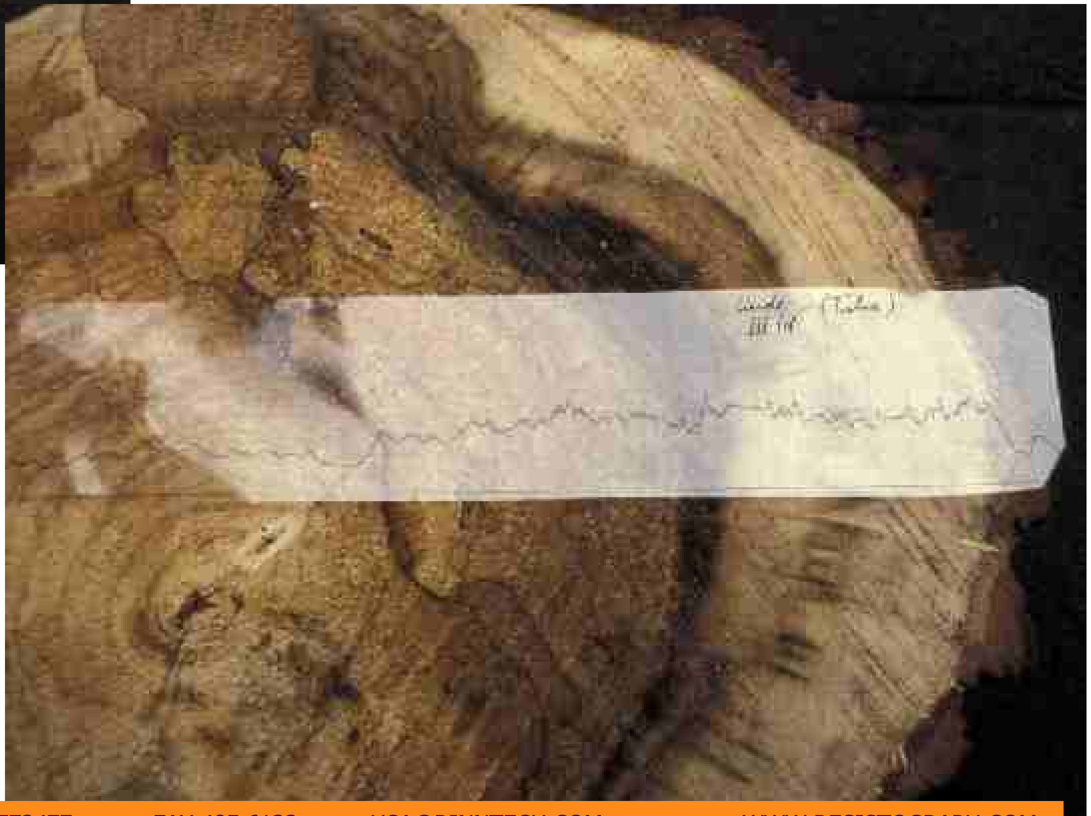


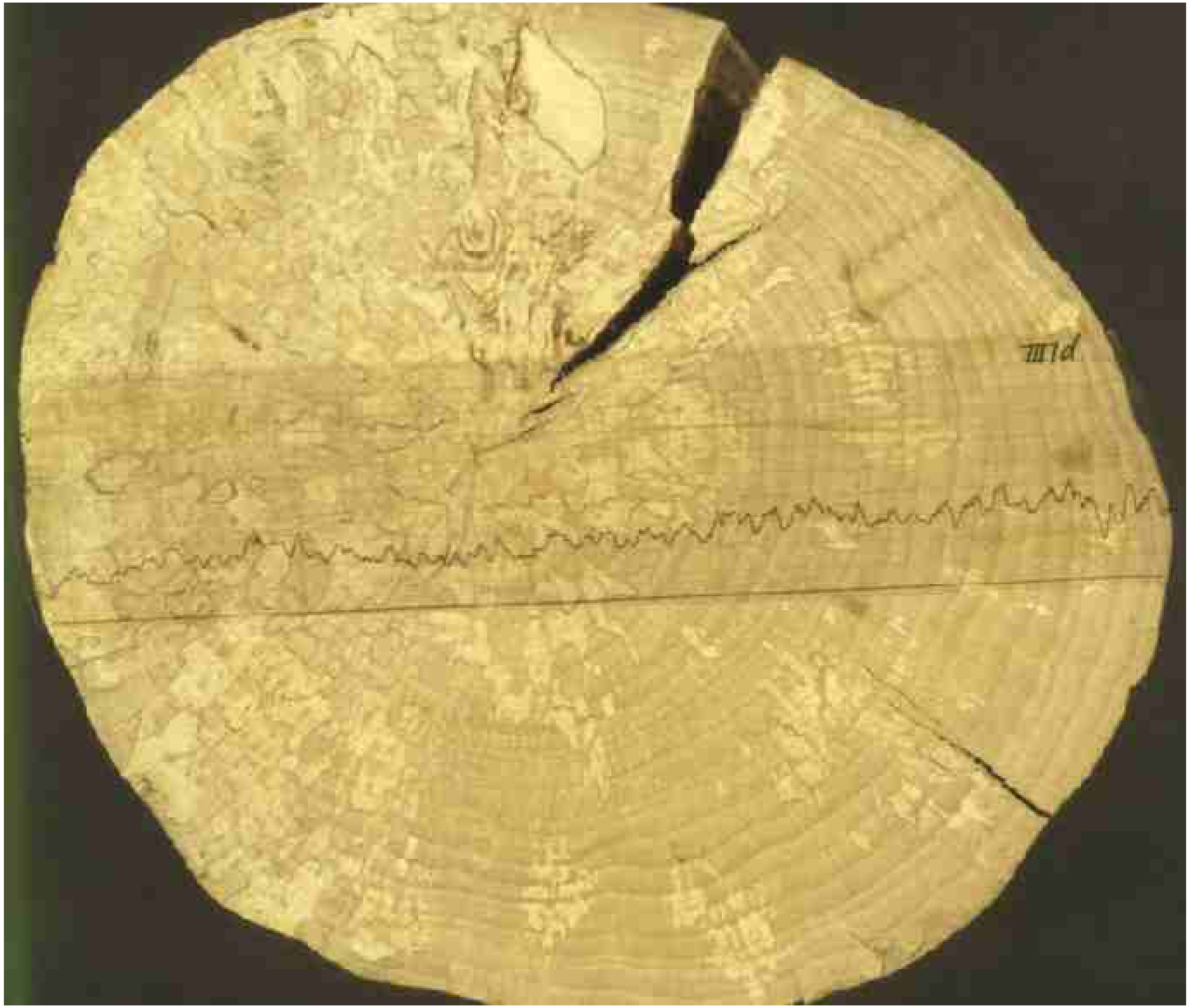


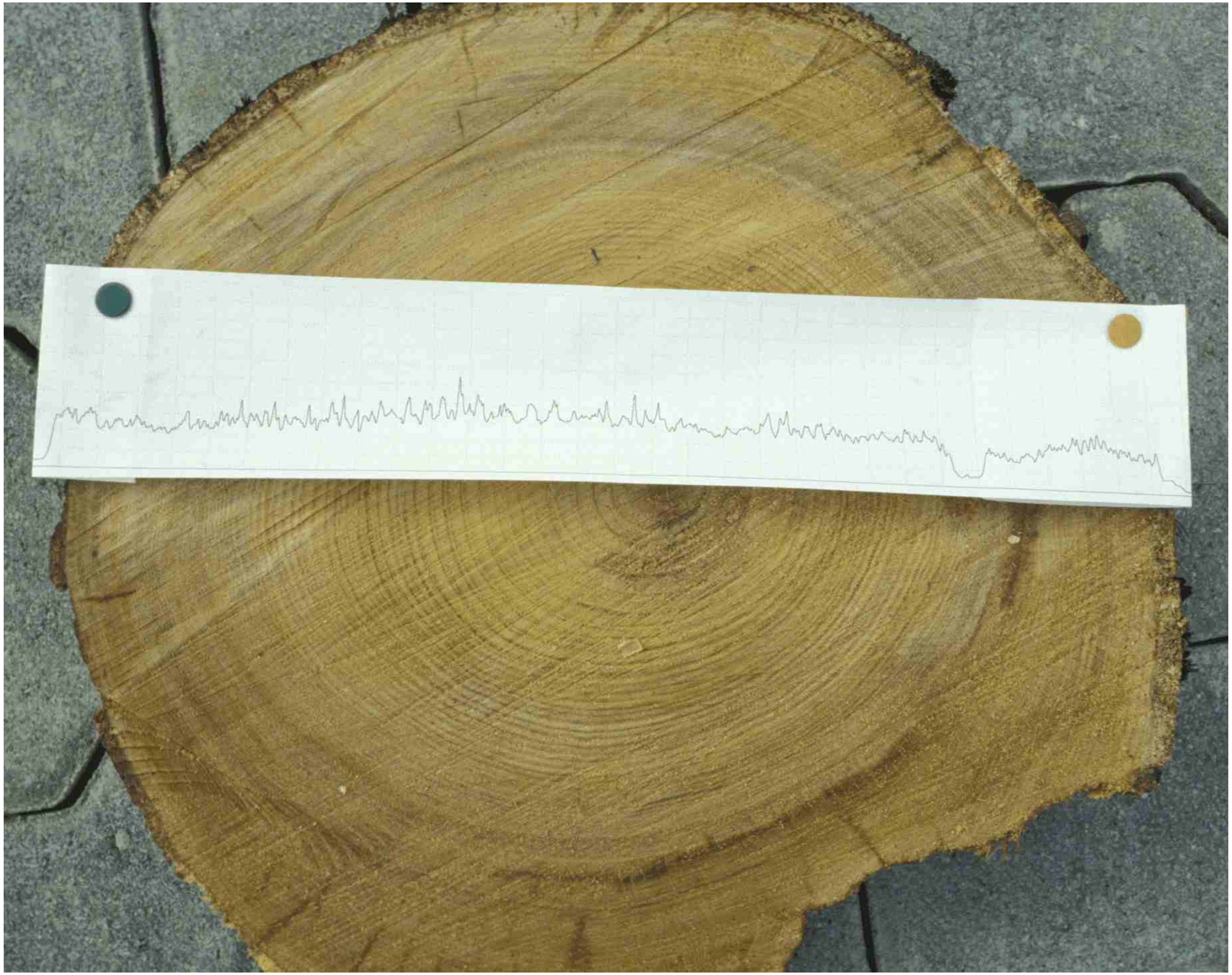


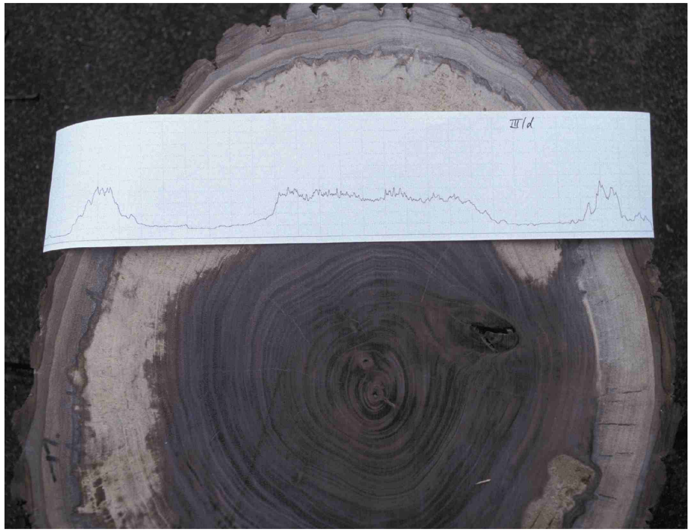

SOPHORA
BARK
INTACT
DECAY


Linde (Tilia)
III (d)

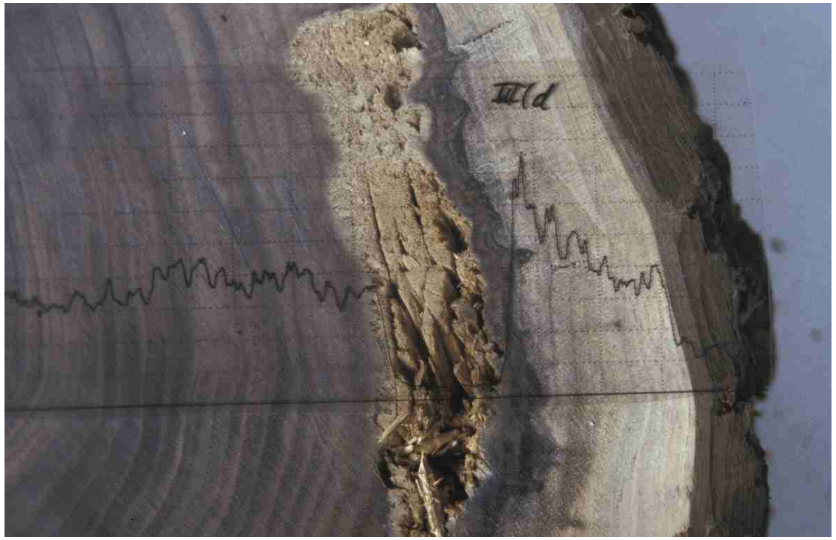


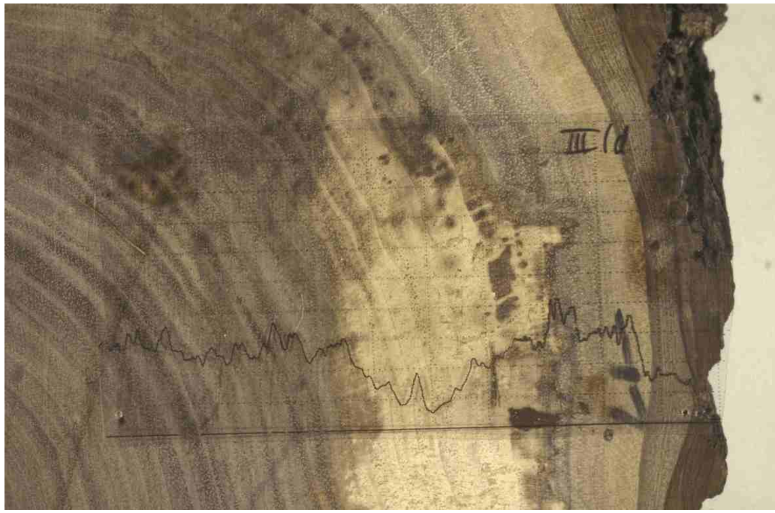

III 7d

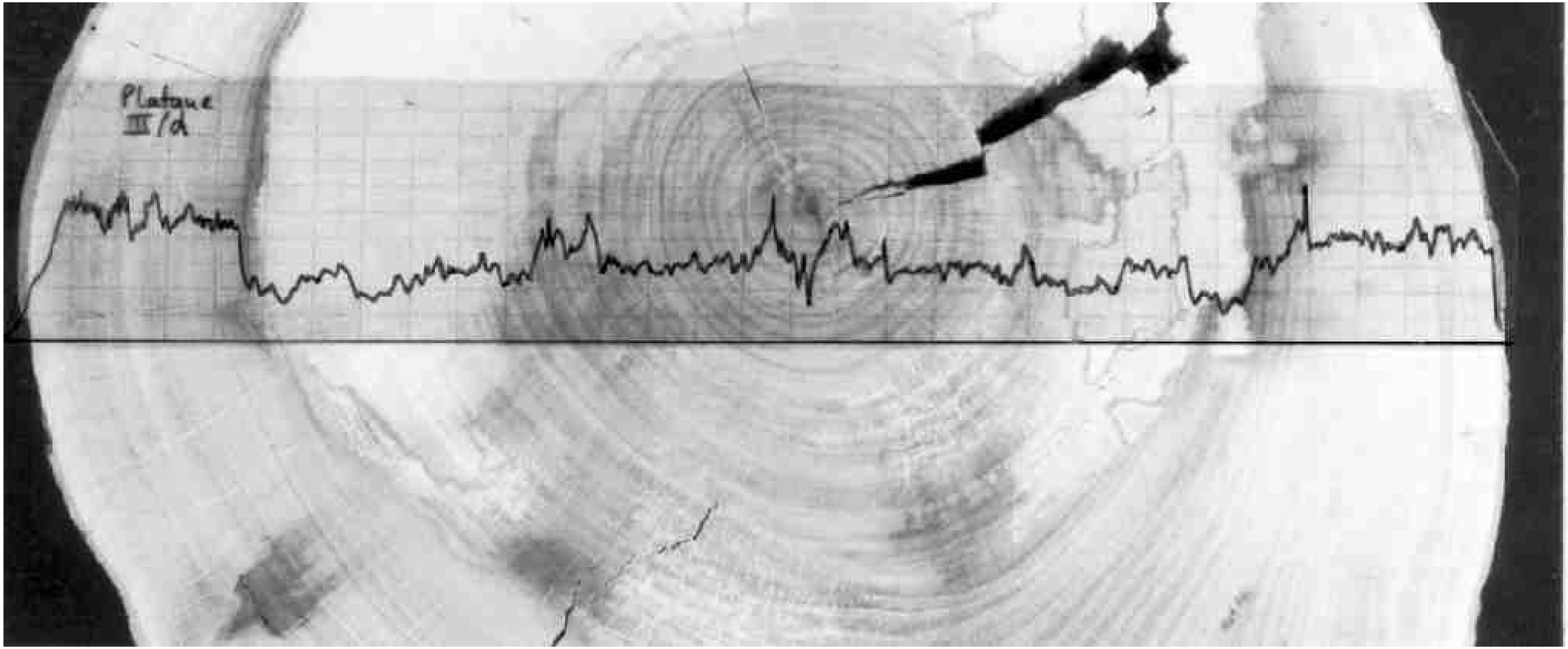


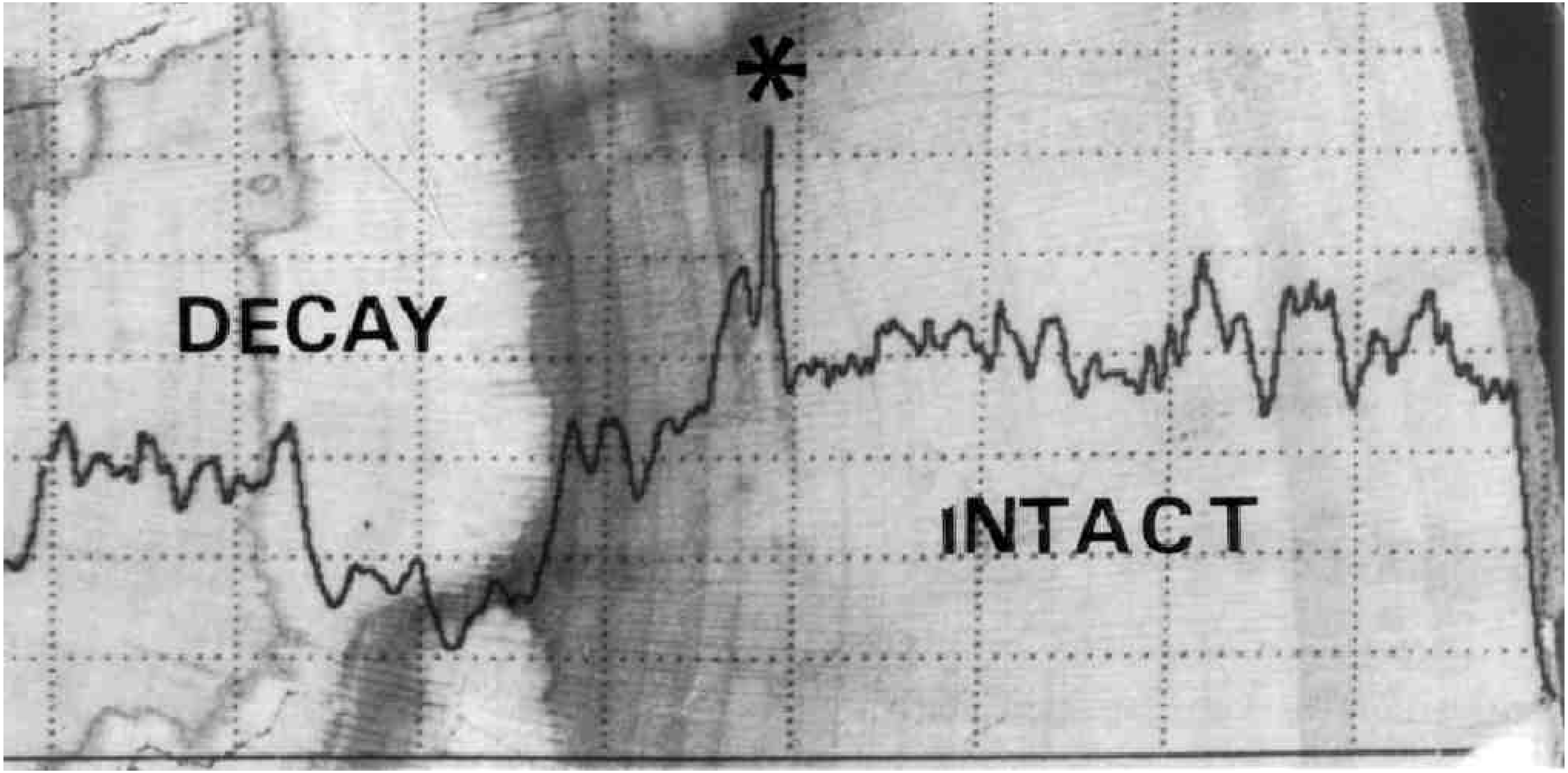

III/d

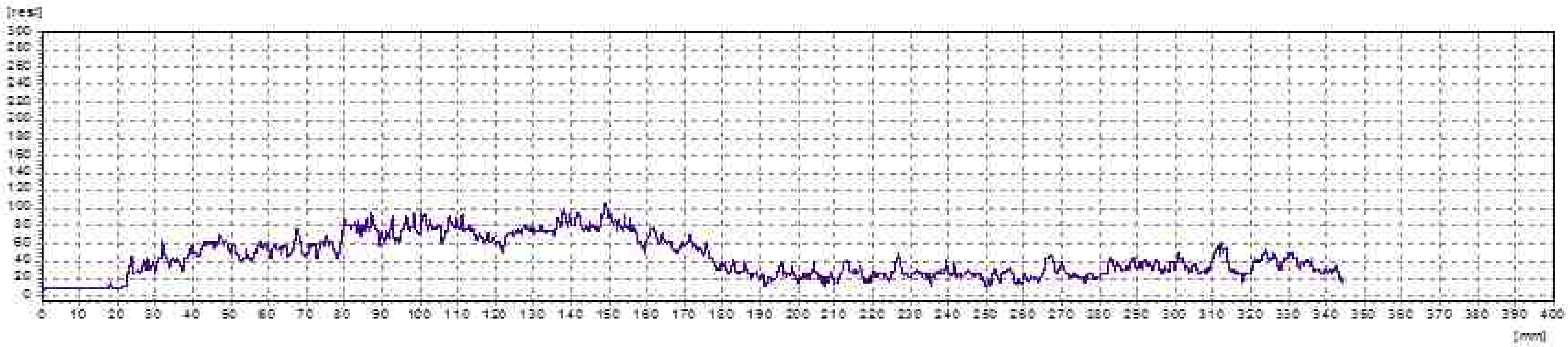

III/d


III/d


III/d

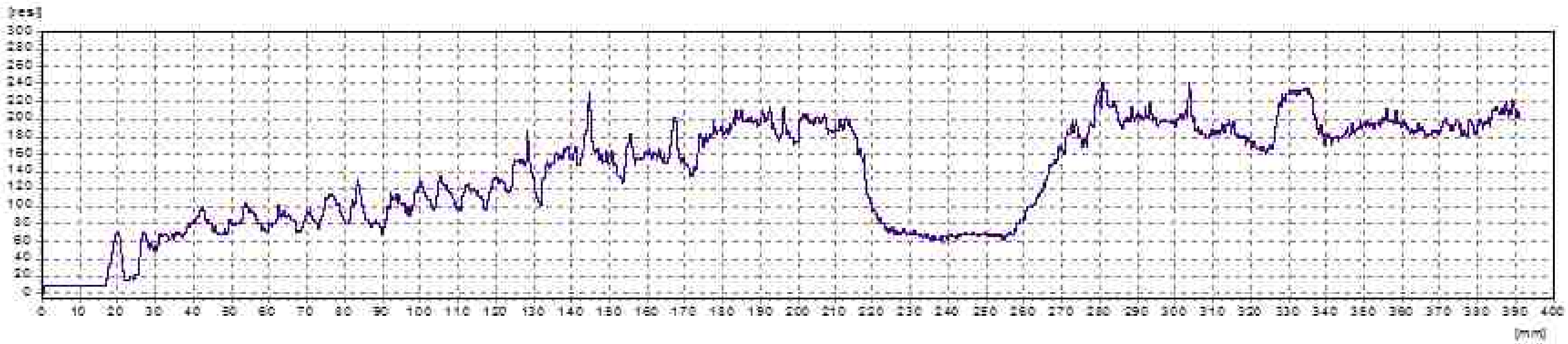

Platane
III/a


*
DECAY
INTACT



no compartimentalization and poor compensation growth => no future!

good compartimentalization and poor compensation growth => better perspective!



=>

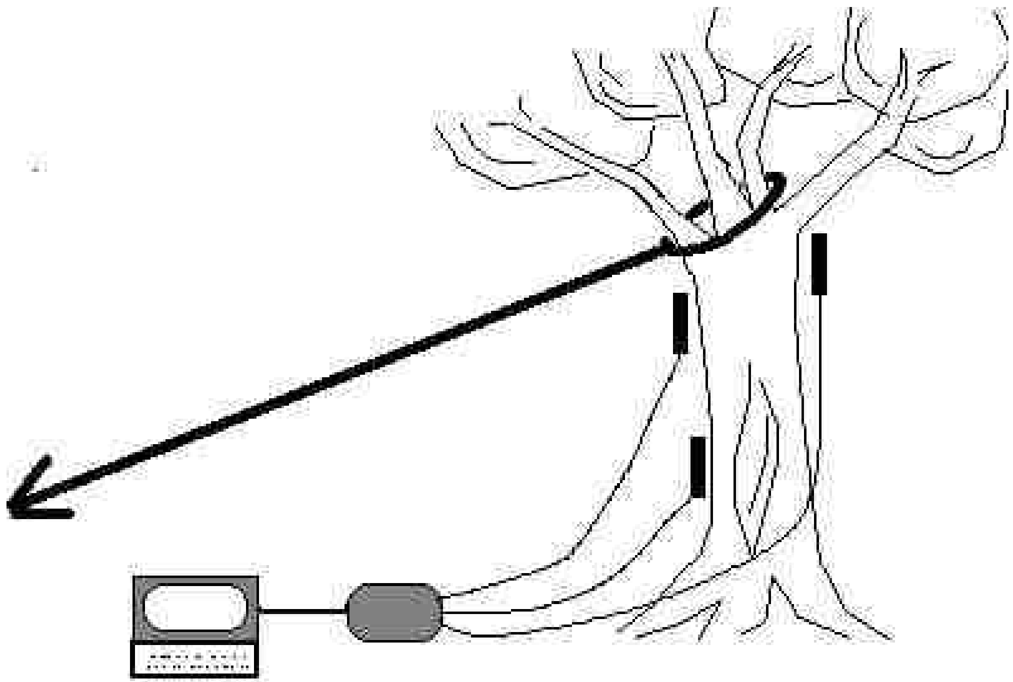
high resolution, electronically recorded resistance drilling provides

detailled information about
local wood condition

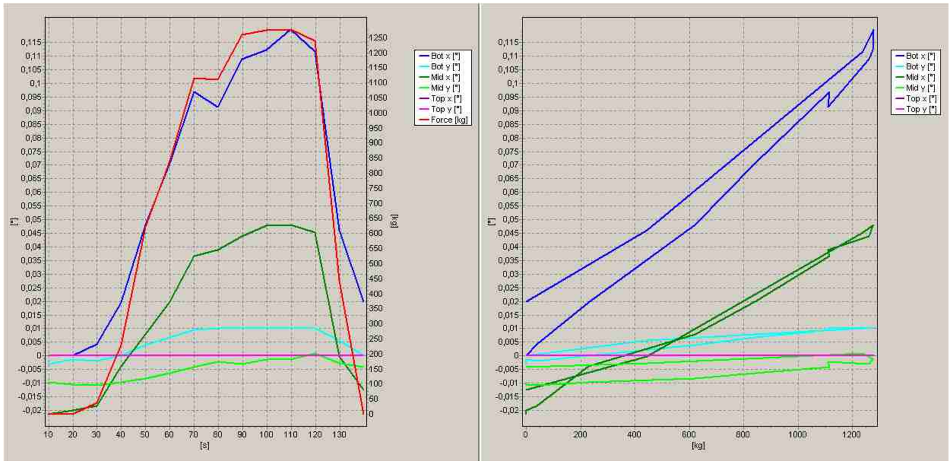
allowing trained users to estimate future developments of decay and compensatory radial increment growth!

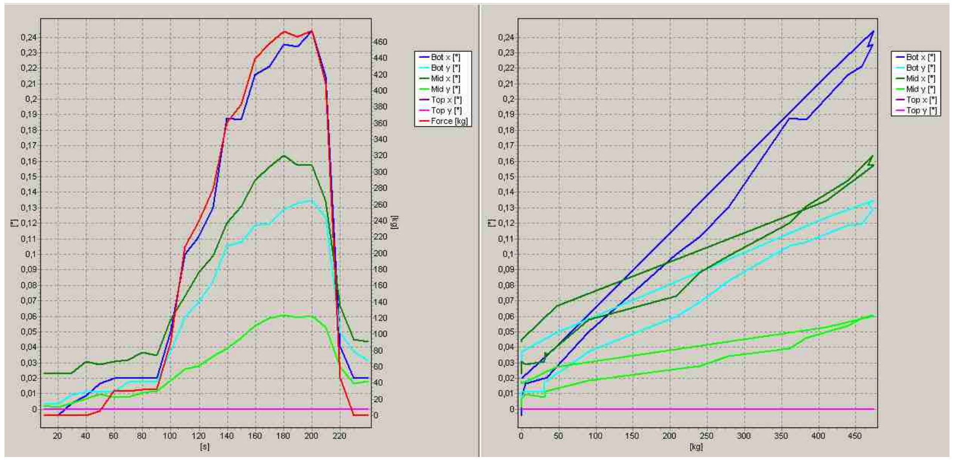
These features are not provided by the resistance drills of the first generation operating with a spring-driven recording mechanism because this kind of measurement recording delivered systematically wrong profiles!

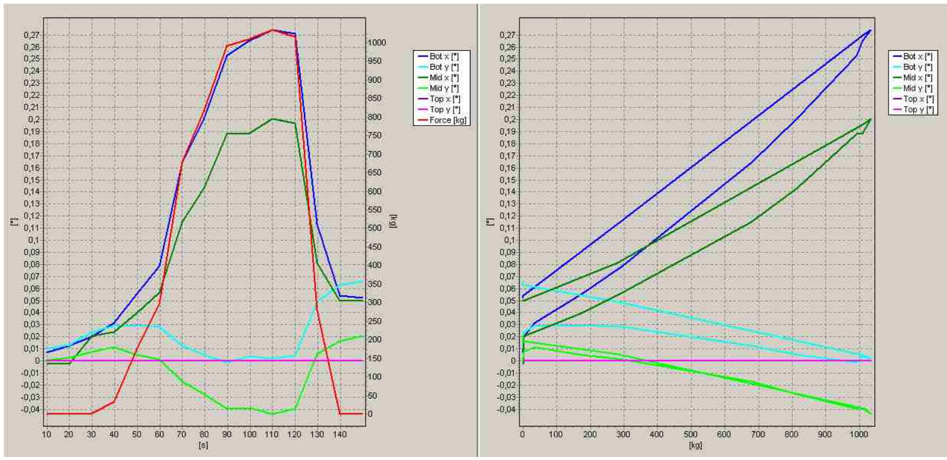
For important (for example ornamental) but strongly damaged trees with root problems or for trees with recently damaged/cut roots, the best instant diagnostic approach currently seems to be a static load test, often called "tree pulling". It is not precise but a reasonable approach, basically measuring stem strain and root plate tilt. Because trees in nature mostly fail under dynamic wind loads from changing directions (often in combination with torsion), a static pull test in one direction is highly limited in estimating the behavior of the tree in a real storm - but, this method seems to allow highly skilled experts the (currently) best possible estimate of reduction of uprooting safety due to root problems.

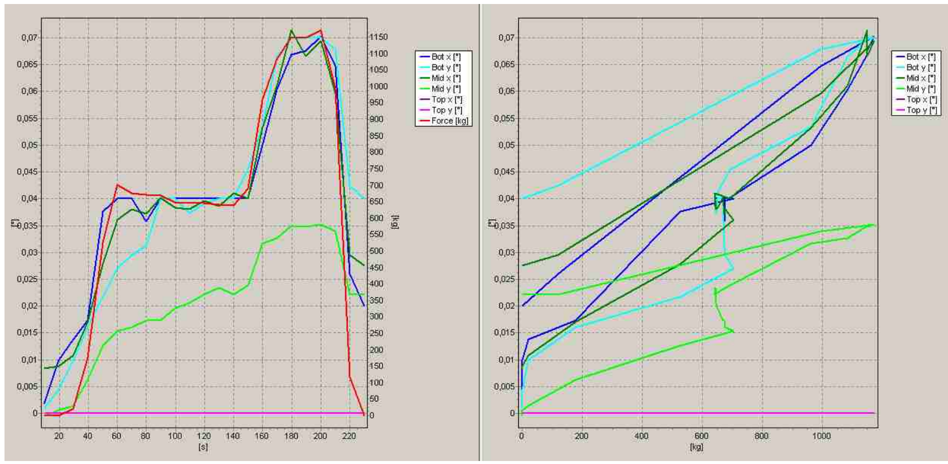


Inclination of sensors at base and top of major trunk section:









Conclusions, remarks, and recommendations

- Wood anatomy and internal tree structure strongly impact tree safety.
- Mature trees continuously gain safety by increasing girth (after crown size and thus wind load reached maximum) and need much less shell wall!
- The "1/3-rule" is correct for young trees with centrally rotten circular stem cross sections but is not valid for the typical mature urban tree that has to be inspected in terms of safety.
- There is no simple rule for evaluating breaking safety. Location of a defect is more important than its size! => Combination of sonic tomography and resistance drilling provide significant information.
- Tomographic approaches deliver significantly more information than localized assessments, such as drilling or strain-measurements, but low resolution and no information on trends and future.
- Proper static load tests are best approaches for uprooting safety.
- To become and stay a well educated and reliable expert, read books and papers, but question everything and everyone! Visit conferences, take seminars & TRAQ, and hurry up to pick up your bike...

[PDF-version of this lecture: send email to frank.rinn@rinntech.com]

Even the toughest guys finally realized that tree rings tell us a lot more than just age.

APPENDIX

The 'real story' of resistance drilling

is described on www.resistograph.com

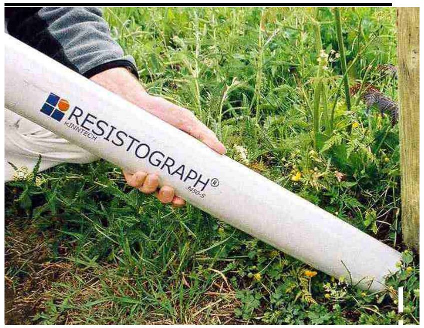
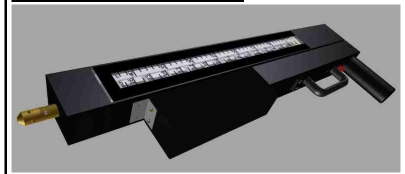
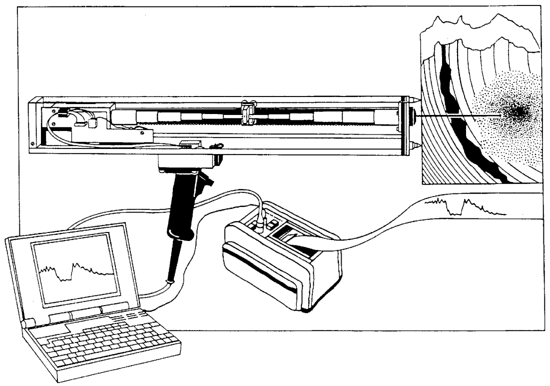
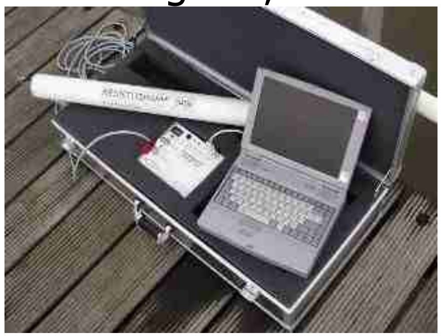
- To make wooden utility poles more resistant against fungi, a German engineering company started 1972 pushing thin needles into the wood in order to get the chemical preservatives deeper in. They and several other experts delivered ideas how to encounter the penetration resistance of needles, pins or borers into wood. Two retiring engineers of that company got the idea as a gift for being applied as a patent (although it was not their personal idea). The patent was later rejected by the German Patent Supreme court due to older publications describing similar devices.
- 1986-88, my physics diploma thesis at Heidelberg University checked if it is possible to obtain information about tree-ring density variations based on that patent application. It did not work in oak due to specific wood anatomical features. But the profiles showed tree rings in conifers and revealed differences between intact and decayed wood.
- ...

Origin of the name RESISTOGRAPH®

Since 1986, I am developing resistance drills in Heidelberg - based on preliminary ideas of several researchers and engineers. The first commercial portable versions, sold from 1987, I called "DENSITOMAT" but this name was not accepted for registration as a trademark because it was 'too much descriptive'. Thus the word DENSITOMAT was not protected by any formal registration. Because a competitor used "DENSITOMAT" for his resistance drills in 1992/1993, I looked for a name that could be registered as a trademark: in order to protect the image of a high-quality resistance drill that delivers reliable profiles because it is electronically regulating and measuring, delivering calibrateable values that are clearly correlated to wood density. In this process, I created the word RESISTOGRAPH®, did not find any such trademark registered, asked the Patent Office and got permission to register because this name was unique and not protected by anyone else. Subsequently, all of our resistance drills were named RESISTOGRAPH®. The German Trademark was extended to more than 30 countries.

WHAT IS A 'REAL' RESISTOGRAPH®?

Until today (2014), only these drills listed and shown here were officially licenced and thus allowed to be called and labelled "RESISTOGRAPH®":

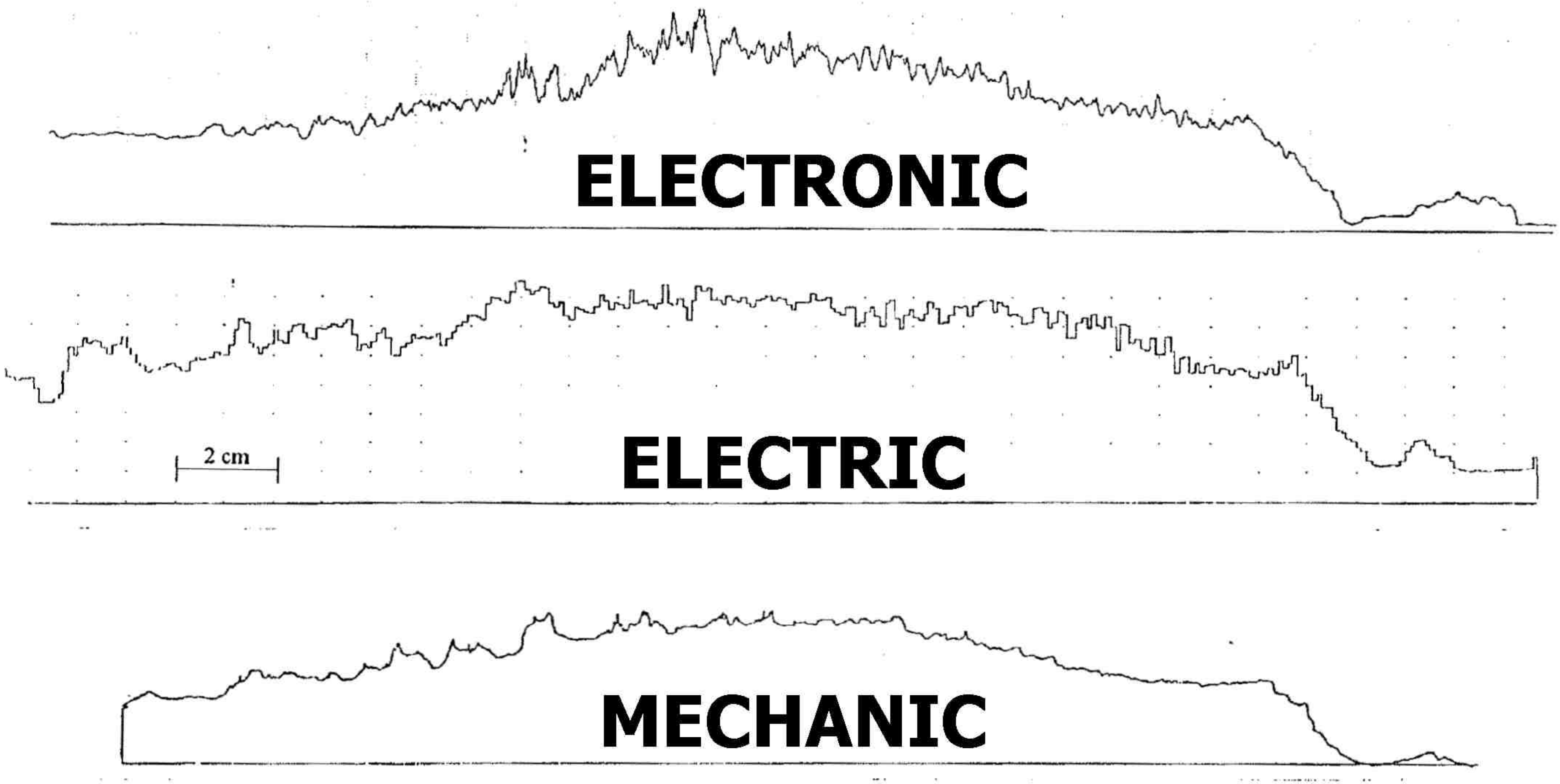
Series 1, Types 1280 or 1410	**Series 2&3: round**	**Series 4: square**	**Series 5: Prototype** since 2011
			
1992-1998	Type 2/3450: 1998-2005 Max. length 1,5m	2006-2014 Type 4452 Standard Type 4453 for tropical hardwoods	**Series 6: from 2014** 
		Versions: Professional + Scientific (highest resolution)	lighter, smaller, faster at the same precision and reliability level as before

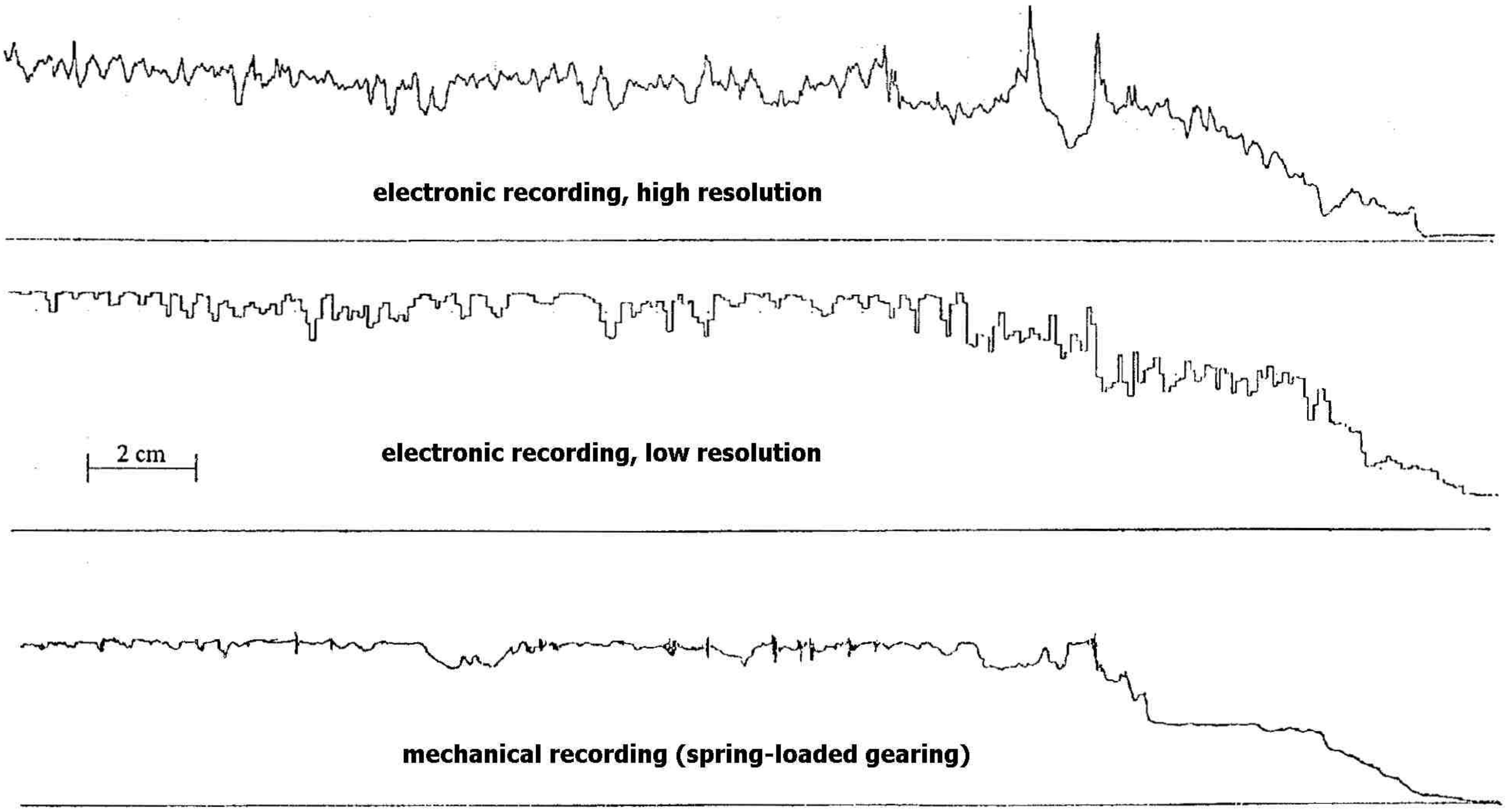
DIFFERENCES BETWEEN A 'REAL' RESISTOGRAPH® AND OTHER DRILLS

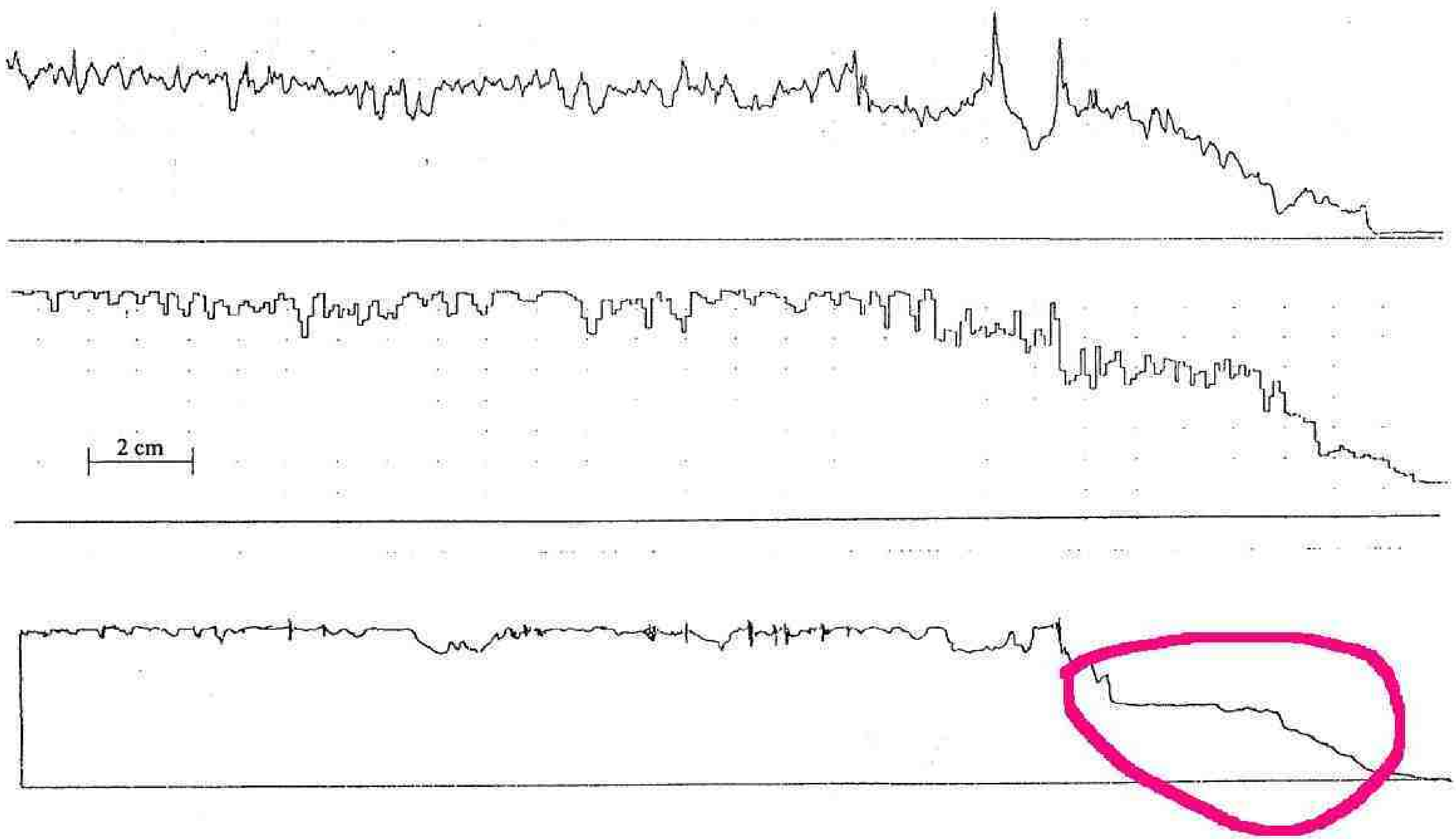
There are many differences between the different versions of resistance drills, both in handling as well as in precision, resolution, and reliability.

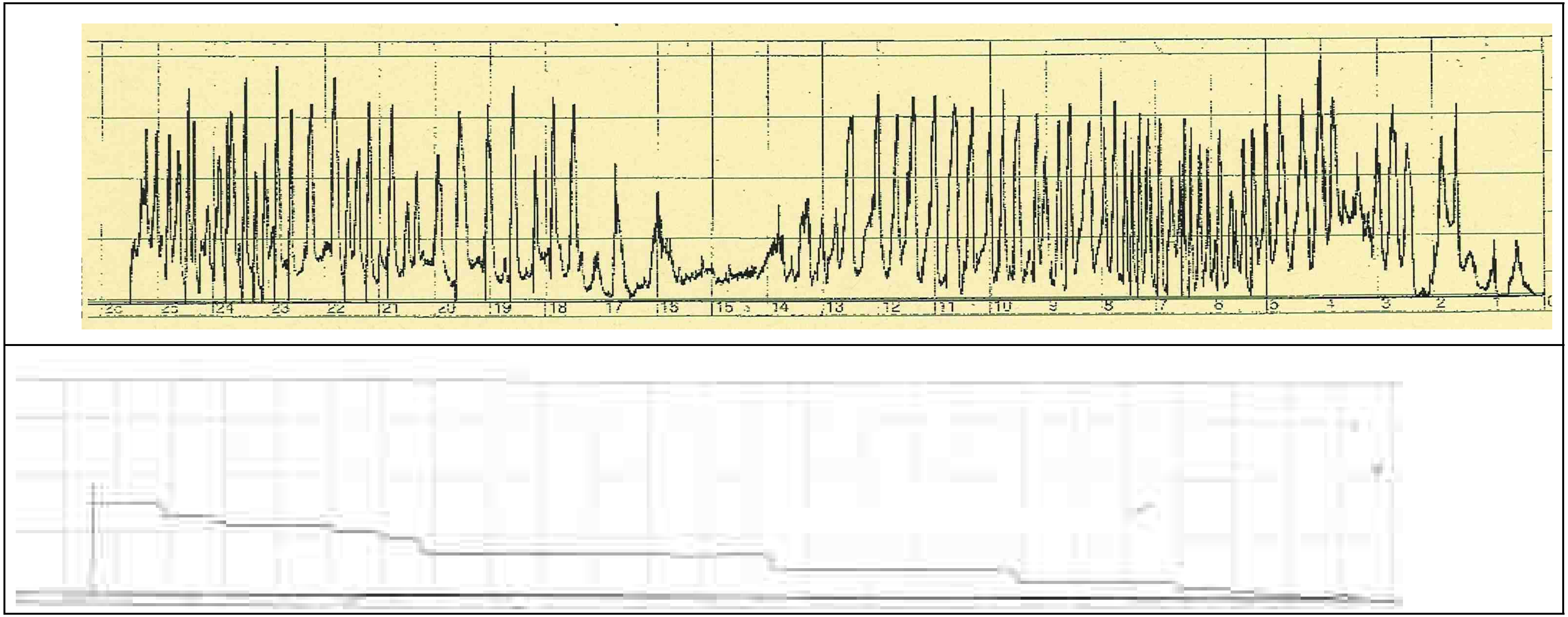
The profiles recorded mechanically with the first prototypes of around 1984 were found to be systematically wrong, either too high or too low, fluctuating too much in resonance or flat-damped. Early stages of decay could not be detected and soft but intact wood was revealed like being decayed. The following pages (Mattheck&Bethge 1995) show a comparison of resistance drilling profiles that have been measured and recorded mechanically, electrically or electronically. Only the electronically regulated and recorded profiles have been obtained with a real (and officially licensed) RESISTOGRAPH®. Because spring-driven mechanical recording was unreliable, the original inventors KAMM&VOSS developed an electrically recording resistance drilling prototype, applied for a patent and tried to sell it. This idea led to DENSITOMAT as a further development by Frank Rinn in 1986 and later to his RESISTOGRAPH®.

Subsequent graphs from Mattheck, Bethge, Rinn, CIS-Madeira.


ELECTRONIC
ELECTRIC
2 cm
MECHANIC


electronic recording, high resolution
2 cm
electronic recording, low resolution
mechanical recording (spring-loaded gearing)


2 cm



Typical resistance drilling profiles by mechanical recording showing systematically incorrect curves: (over-) fluctuating in resonance or flat damped. Such profiles cannot be interpreted correctly and thus the inspected tree or structure cannot be evaluated reliably based on such systematically incorrect profiles.

This profile drops down to zero in the center earlywood areas indicating decay although the wood is completely intact, but just soft. Thus, such profiles do not allow to reliably identify decay or insect damage:

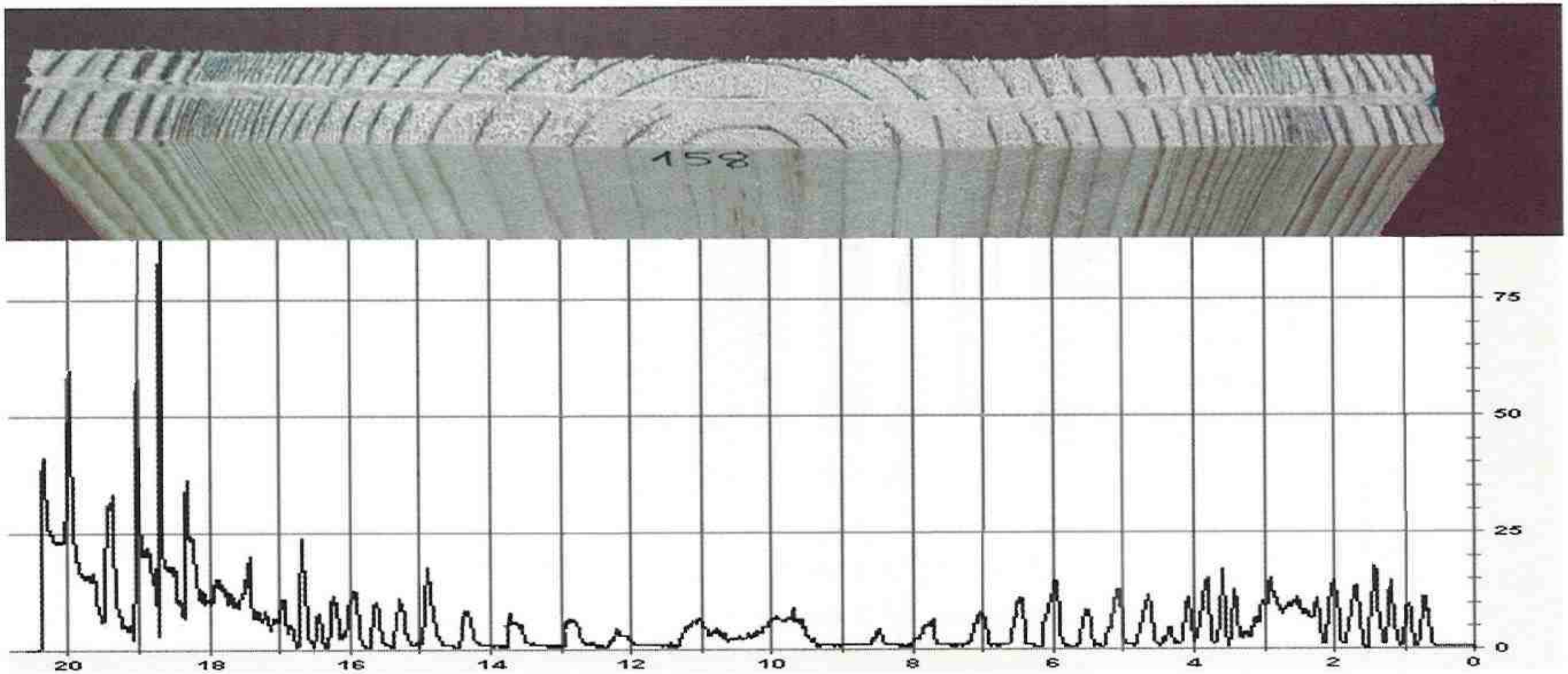


Figura 4.9. Correspondencia entre anillos y gráfica del resistógrafo

Appendix to a topic of tree safety research

One of the main problems of material research:

Load carrying capacity of structures can mostly only be assessed by loading them until failure!

=> The only way to check how good we can measure and estimate breaking safety of the typical mature urban tree of concern is to break such trees until failure!

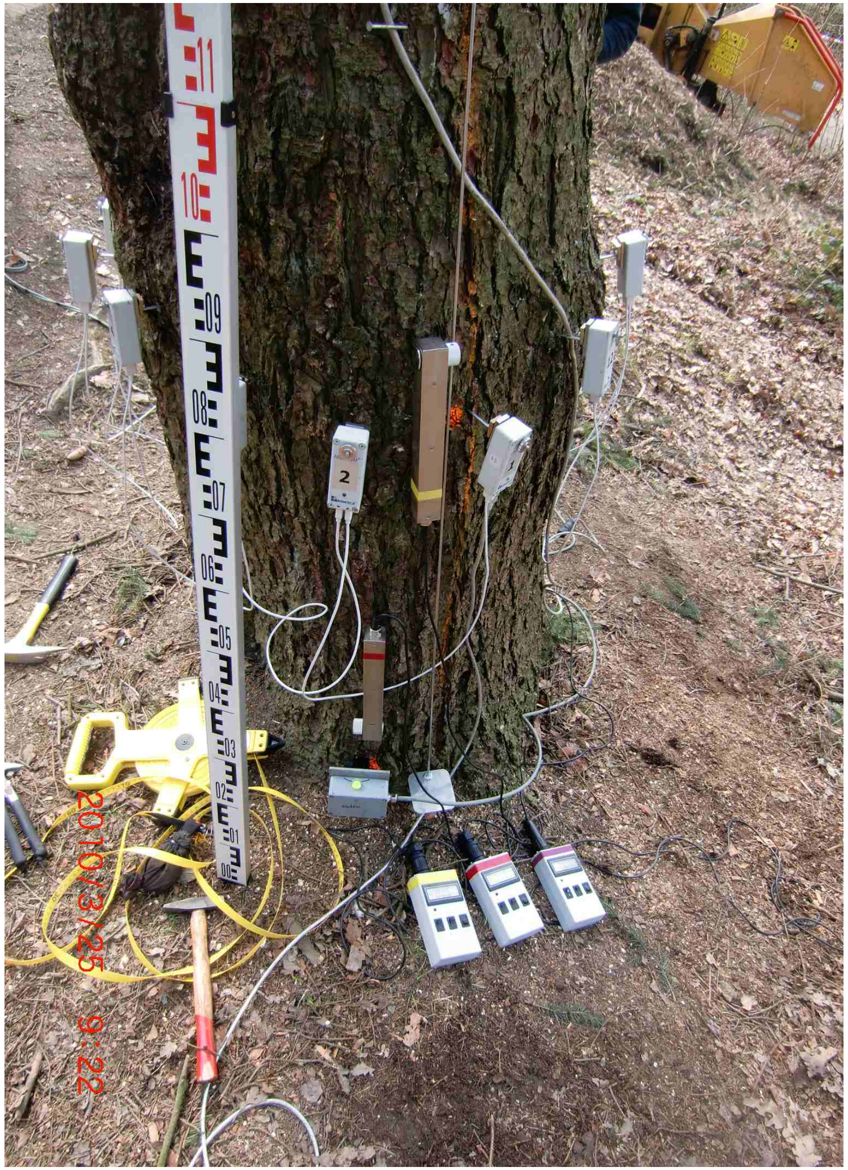
This was done by the German Society of Certified Arborist (from 2009) and later followed by ISA in the biomech-week. . . . . . . Please support these efforts!. . . . .

The German Association of Certified Arborists

Fachverband geprüfter Baumpfleger

started 2009 loading trees to failure after having inspected them with all available equipment.


PICUS
10
11
12


2010/3/25 9:22


2010/3/24 12:53