Biology of Wood Decay What you need to Know

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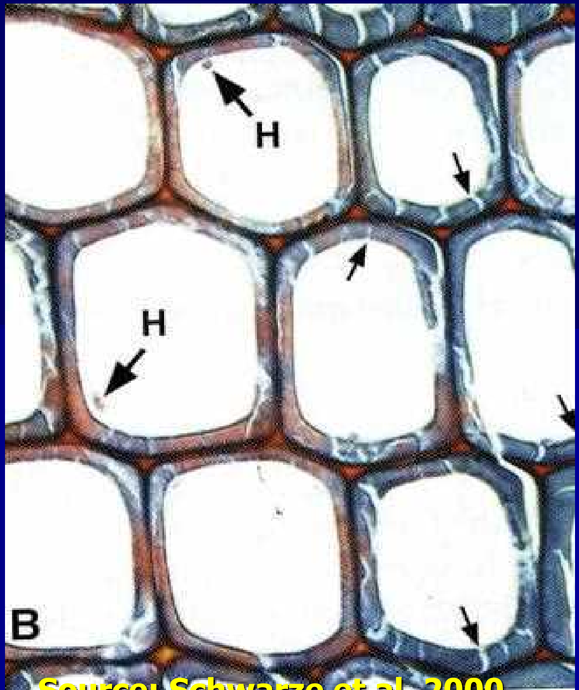
Decay

ling chi

- death by a thousand cuts
- Digesting cellulose and lignin
- Slow burn, 20+ years
  - More severe with age



Source: Schwarze et al. 2000

Decay does not cause fungi

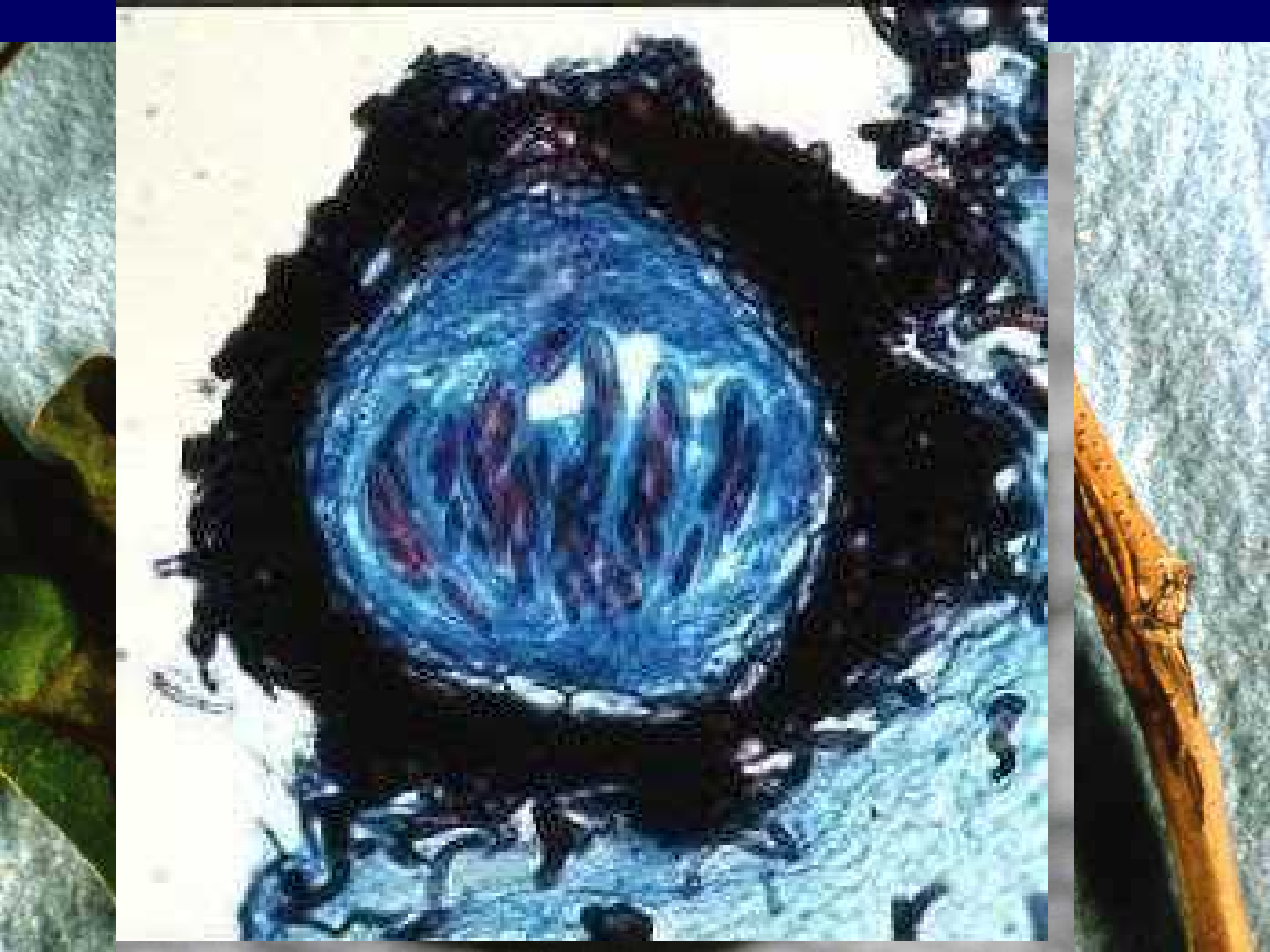
Robert Hartig, 1874

Father of Forest Pathology

All Decay is Caused by Fungi

Two Groups of Decay Causing Higher Fungi

- Ascomycetes (Ascomycota)
  - Much less common cause of decay
- Basidiomycetes (Basidiomycota)
  - Cause most of the decay in trees



Ascomycete Wood Decays

#1 *Kretzschmaria deusta*

Massaria of London Planetree
Splanchnonema platani
Massaria platani

- Canker and decay
- Upper side of branch
  - Point of attachment
- Decay occurs rapidly
  - Months
- Branch failure
  - Branch dieback +/-

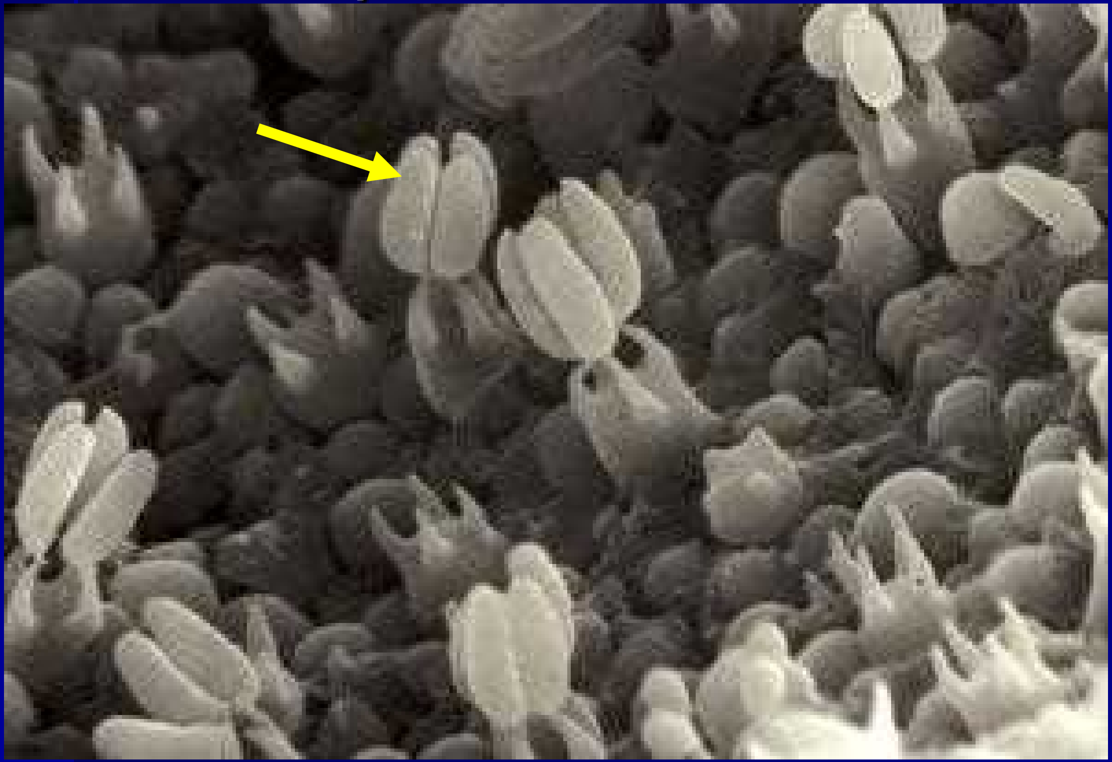
Widespread in NYC area

- Pointed cankers
- No woundwood
- Small fruiting bodies on bark
- Fungus reported from all over US since 1930's

Basidiomycota

Cause Most of Decay in Trees

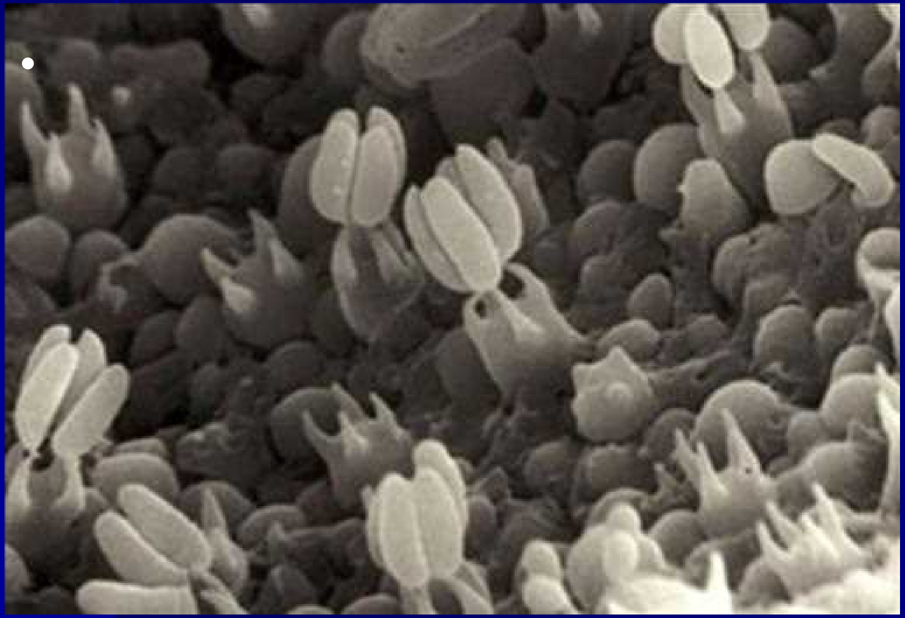
- **Basidiospores on a basidium**
  - Spores 5-10 microns
  - Basidiomycetes



Courtesy: R. A. Blanchette; UMN

Basidiomycetes

- Spores from sexual reproduction
- No spread from asexual reproduction



Chlamydospores-thick walled, dark colored resting spore

- *Ganoderma sessile*

Problem?

Non-pathogens on Soil

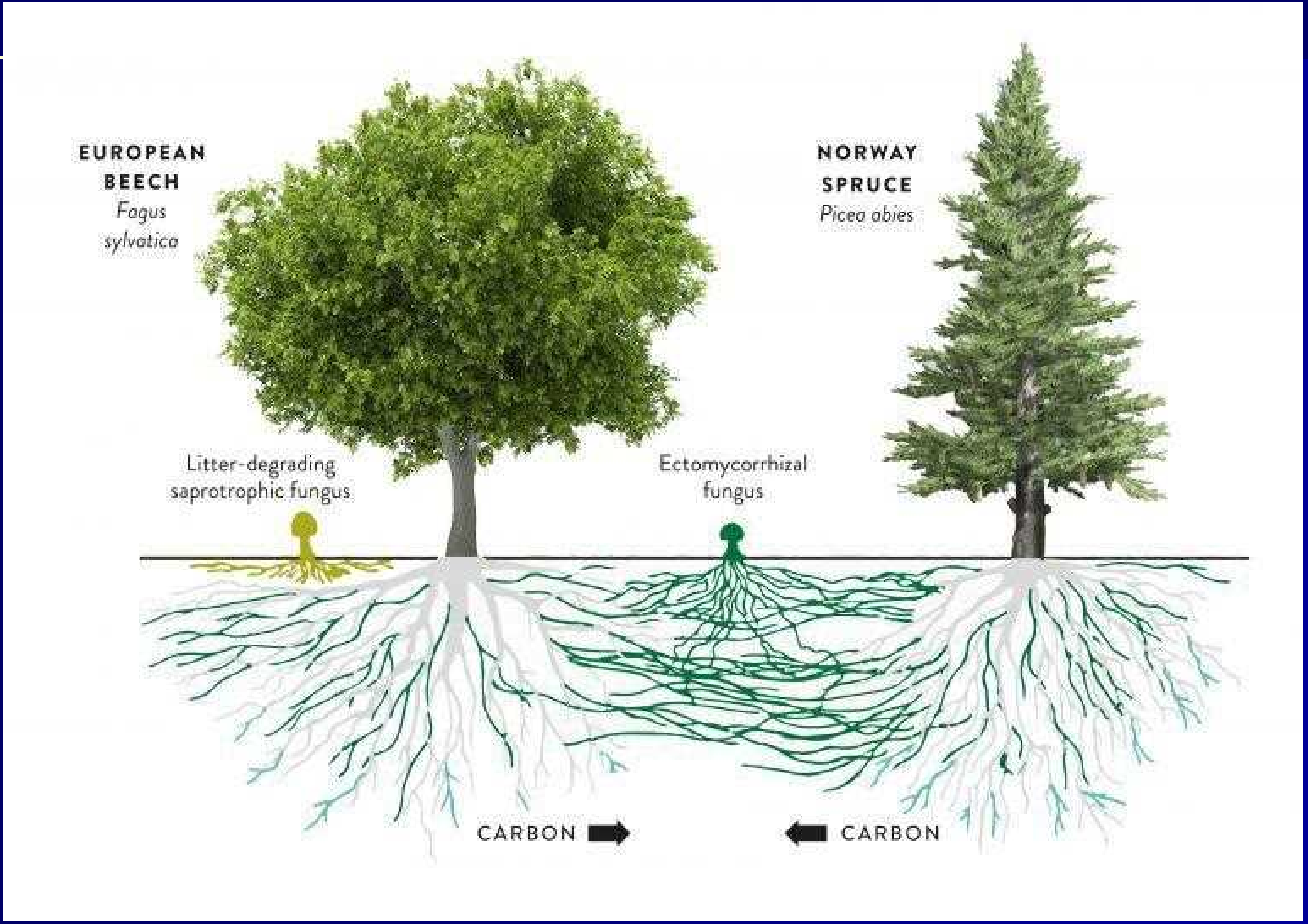
Not a decay fungus

- <u>Single</u> gilled/poroid mushrooms on soil near tree
- Fruiting in spring or summer/Fall
- Many are mycorrhizal

Amanita muscaria

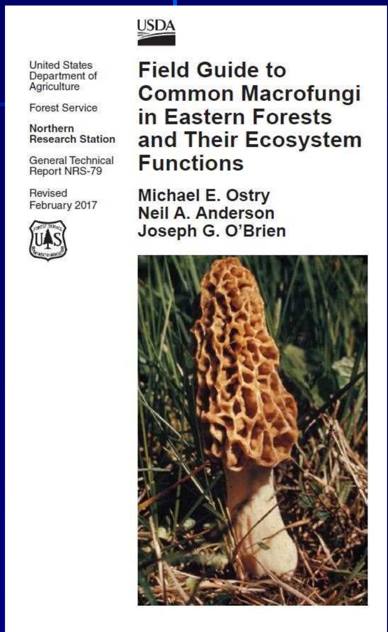
- Mycorrhizal
- Hallucinogenic
- Viking gummies

Mycorrhizal Symbionts



Phaeolus schweinitzii

Like the Nation Debt Trillions of Spores per Conk


USDA

United States Department of Agriculture

Forest Service

Northern Research Station

General Technical Report NRS-79

Revised February 2017

Field Guide to Common Macrofungi in Eastern Forests and Their Ecosystem Functions

Michael E. Ostry
Neil A. Anderson
Joseph G. O'Brien

Fungal note: The most common perennial wood decay fungus of dead and dying hardwood trees. A single conk can produce 1.25 billion spores each hour for 5-6 months each year.

Ganoderma applanatum

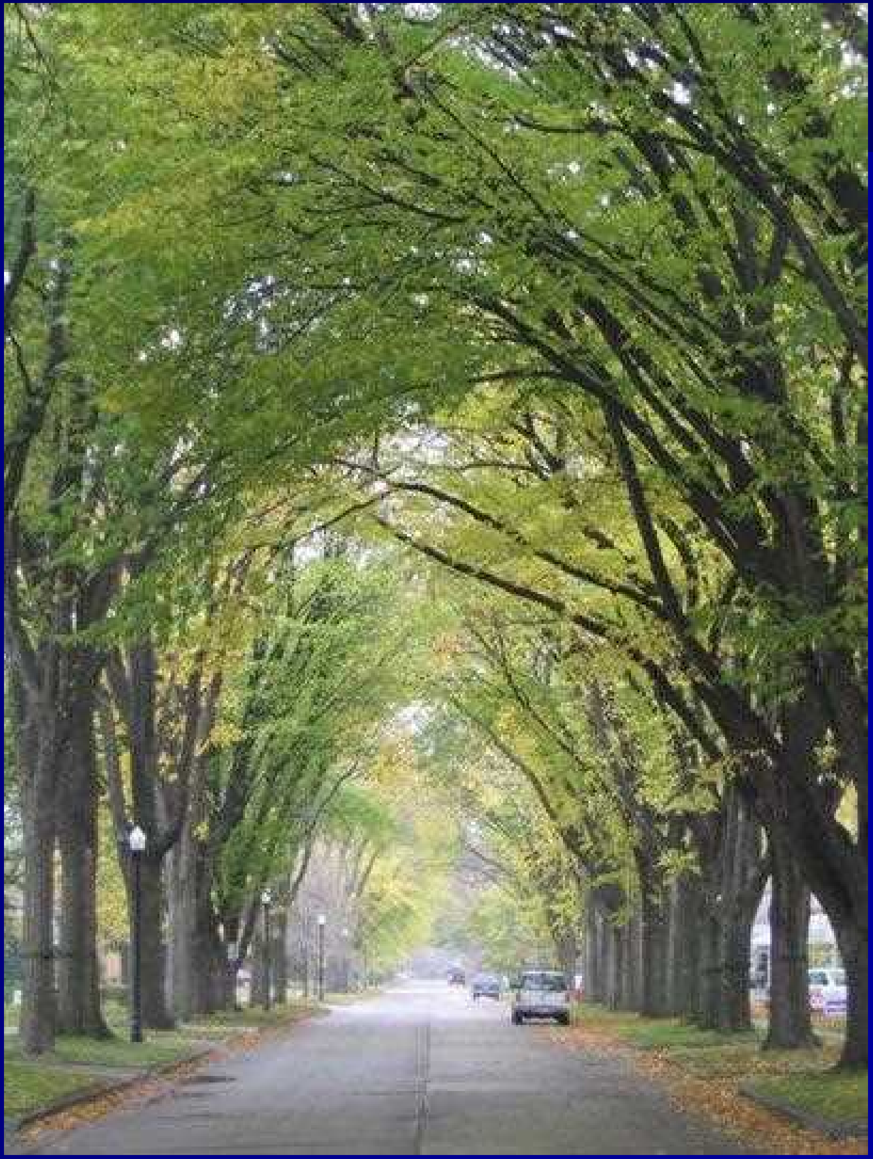
Sanitation

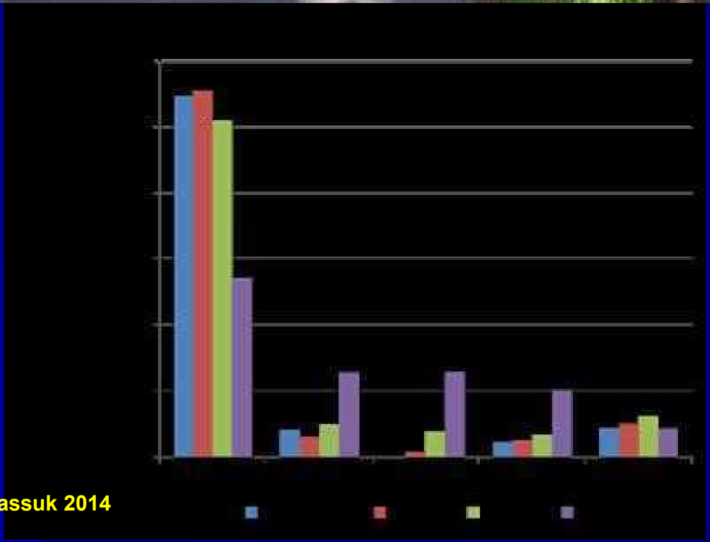
Remove stump and as many large roots as possible




Sanitation

Sanitation No Joke





Cowett and Bassuk 2014

Chaga
Inonotus obliquus

- Basidiocarps develop only after 5+ years!

Stewart Blackwell

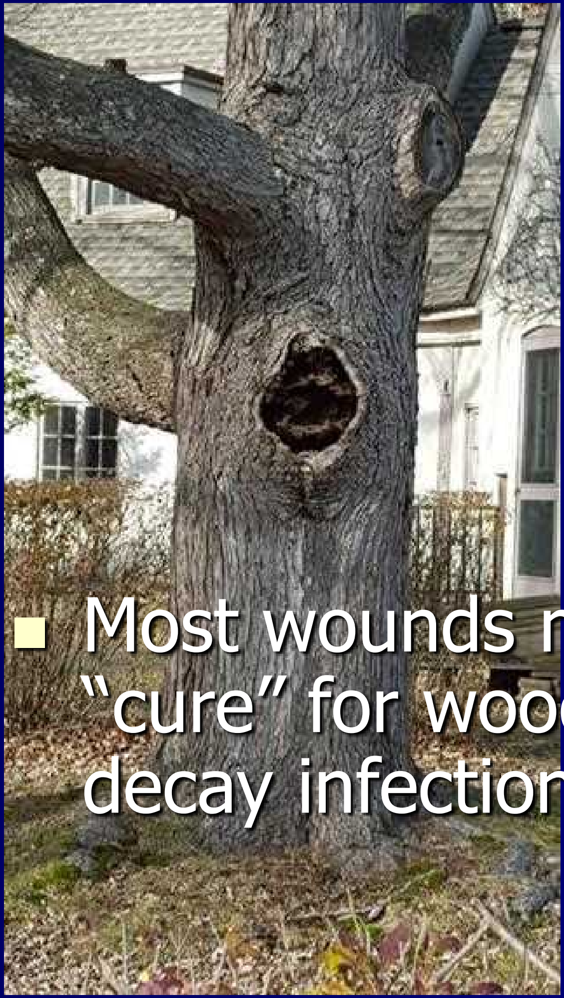
Common Terms
Sexual Fruiting Structures

- Conk = Annual or Perennial
- Bracket = Annual or Perennial
- Mushroom = Annual Fleshy
- Fruiting body = All
- Technical
  - Sporocarp, Basidiome, Basidioma, Basidiocarp

Life Cycle

- Most trees with decay do not develop basidiocarps
  - 3% of trees with decay have fruiting
- Two spore infections required for fruiting
  - Different mating types

Spores Infect Wounds



- Most wounds must "cure" for wood decay infection

- Decay fungi do not compete well with fast growing mold fungi
- Mold fungi use easily available carbohydrates

Heart Rot v. Slash or Sap Rot

- "Heart rot" pathogens
  - Wounds must cure for spores to germinate!

"Slash" Rots

-Spores germinate right after wounding

Decay Infections

- Most trees likely have more than one species of decay fungus
- Likely a succession of fungi in decayed wood

Veteran Tree Preservation

- Habitat for successional fungi that require decayed wood

Decay Pathogens

- Interested in the leading edge
  - Causing decay of “healthy wood”

Decay Pathogens as Endophytes

Able to detect RNA of decay pathogens in functional-healthy sapwood!

- David Parfitt, D. et al. 2010. Do all trees carry the seeds of their own destruction? PCR reveals numerous wood decay fungi latently present in sapwood of a wide range of angiosperm trees. Fungal Ecology 210:338-346.
- Boddy, L. 2021. Fungi and their complex relationships. Arboricultural Association. 306 p.
  - *Laetiporus sulphureus, Kretzschmaria deusta, Ganoderma australe, and others*

Decay Infection

- Exposed heartwood
- Large sapwood wound
  - Sapwood dies behind the wound
- Small sapwood wounds
  - Woundwood closes wound
  - "Included sapwood"
- Infection via roots
- Endophytically

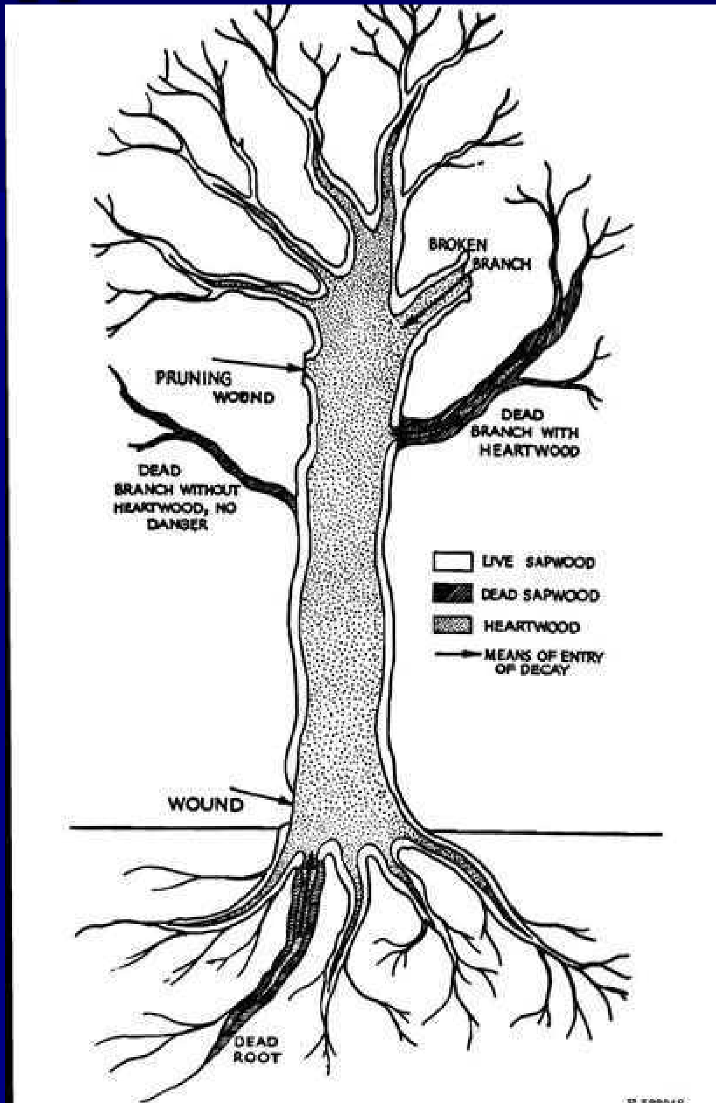


Figure 1 — Methods by which decay enters a tree.
From *Pathology of Trees and Shrubs*, by T. R. Peace, with copyright permission from the publisher.

Most Decay Starts with Wounds





Wounds of all Sorts

Woundwood or Callus?

- Both WW and Callus
  - Early in the wound sealing process

Woundwood
Normal wood eventually forms




Biology of Callus and WW

Chrisluleyphd.com

CONTINUING EDUCATION UNIT

CEU ISA™

Biology and Assessment of Callus and Woundwood

By Christopher J. Luley

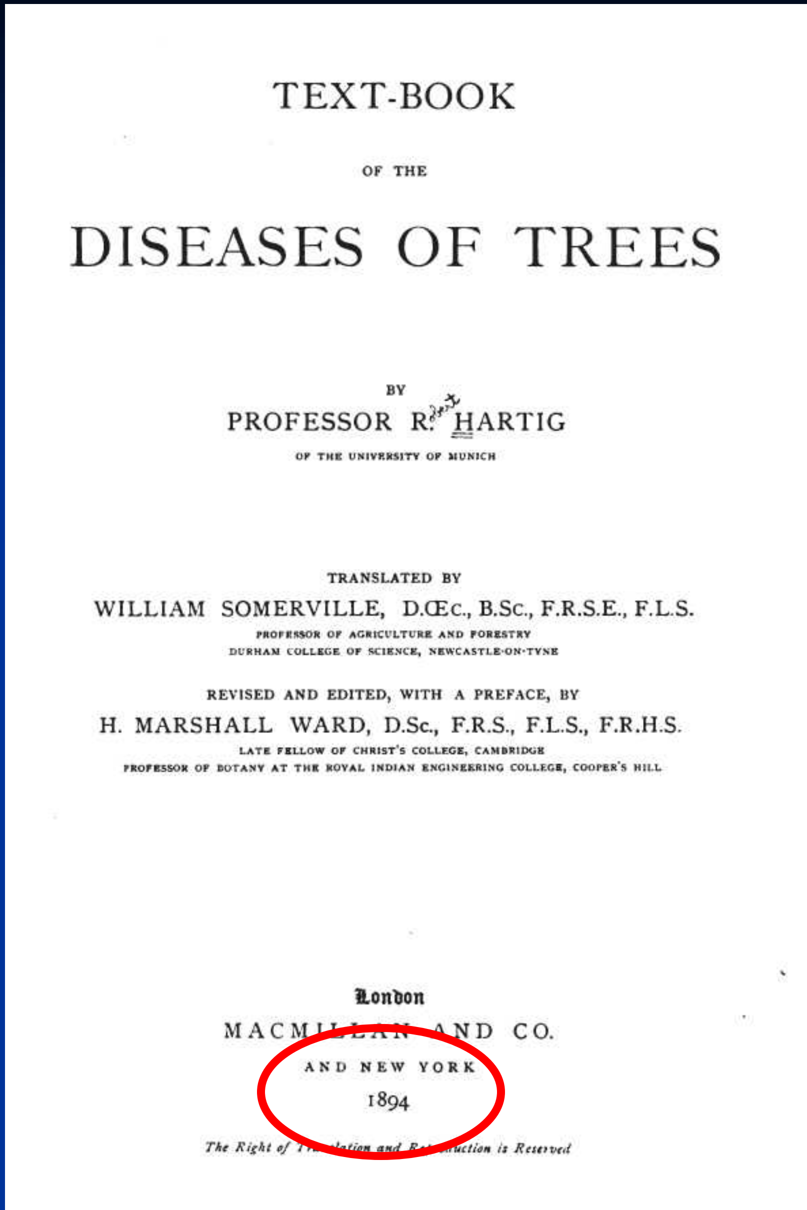
Objectives

- Explain the circumstances in which callus and woundwood are formed
- List the environmental and physical conditions that affect growth of callus and woundwood
- Understand the implications of callus or woundwood on tree risk assessment

CEUs for this article apply to Certified Arborist, Utility Specialist, Municipal Specialist, Tree Worker Climber/Aerial Lift Specialist, and the BCMA science category.

called upon to evaluate tree response to wounding in risk and Plant Health Care assessments (Figure 1).

Historically, wound response has been divided into wound closure (new growth formed after the wounding event and discussed in this article) and compartmentalization (various responses of pre-existing tissues) (Shigo 1984). Two terms have dominated the discussion of wound closure, *callus* and *woundwood*. Understanding these terms has been a source of confusion for both scientists and arborists. This article will review the biology of callus and woundwood formation, and demonstrate how this knowledge can provide diagnostic information about overall tree health, reaction to pathogens and insect pests, tree stability, and forensics.



TEXT-BOOK

OF THE

DISEASES OF TREES

BY

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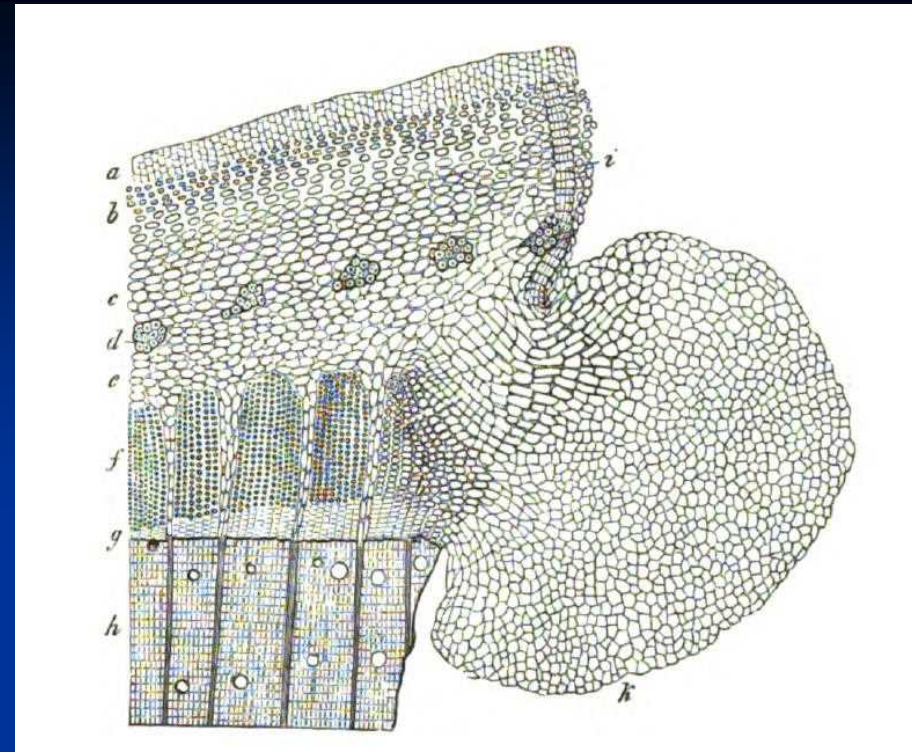


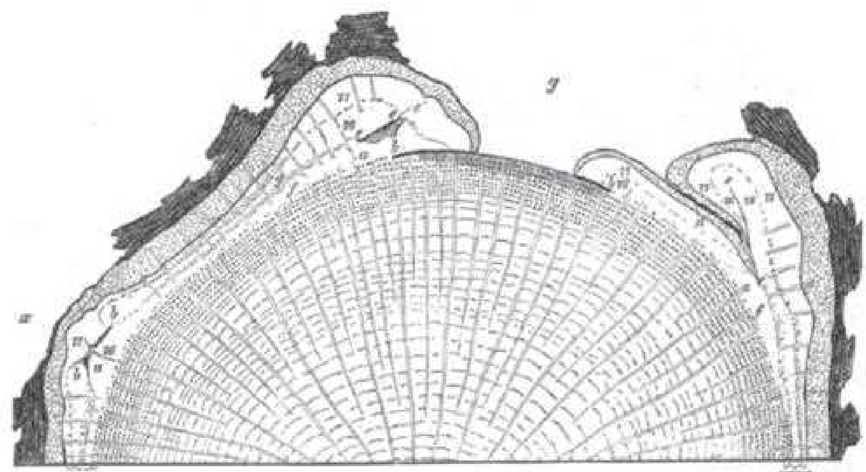
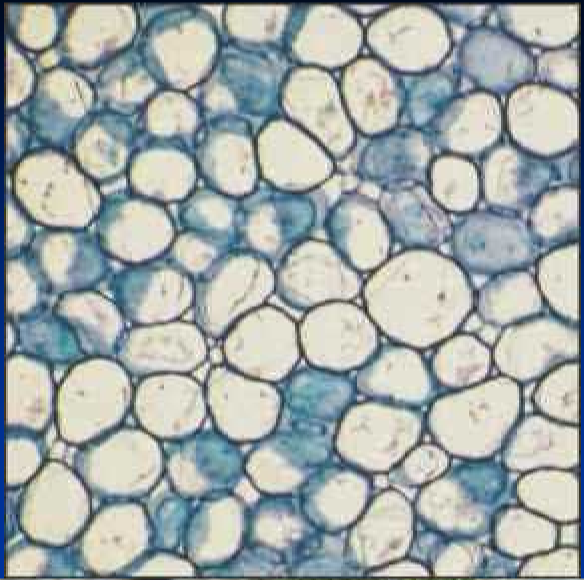


FIG. 134.—Cross-section of the stem of an oak which, two years before being felled, had ruptured at several places in the cortex in consequence of much-augmented growth. *x* and *y*, two places where the cortex had ruptured; *a* to *h*, new investing layers formed by occlusion with their cortex, *d*; *c*, callus; *e* to *e*, lower surface of the loosened cortex, the cambium of which has also produced new growth.

Parenchyma Cells

- Thin walled, living plant cells
  - Bark and sapwood
- Parenchyma-tissue made up of parenchyma cells
- Ray parenchyma-collection of living cells



Callus

- Thin walled, parenchyma cells that initially lack lignin
- Forms days/weeks after a wound
- Formed by
  - Vascular cambium
  - Sapwood parenchyma, and/or
  - Bark (phloem) parenchyma

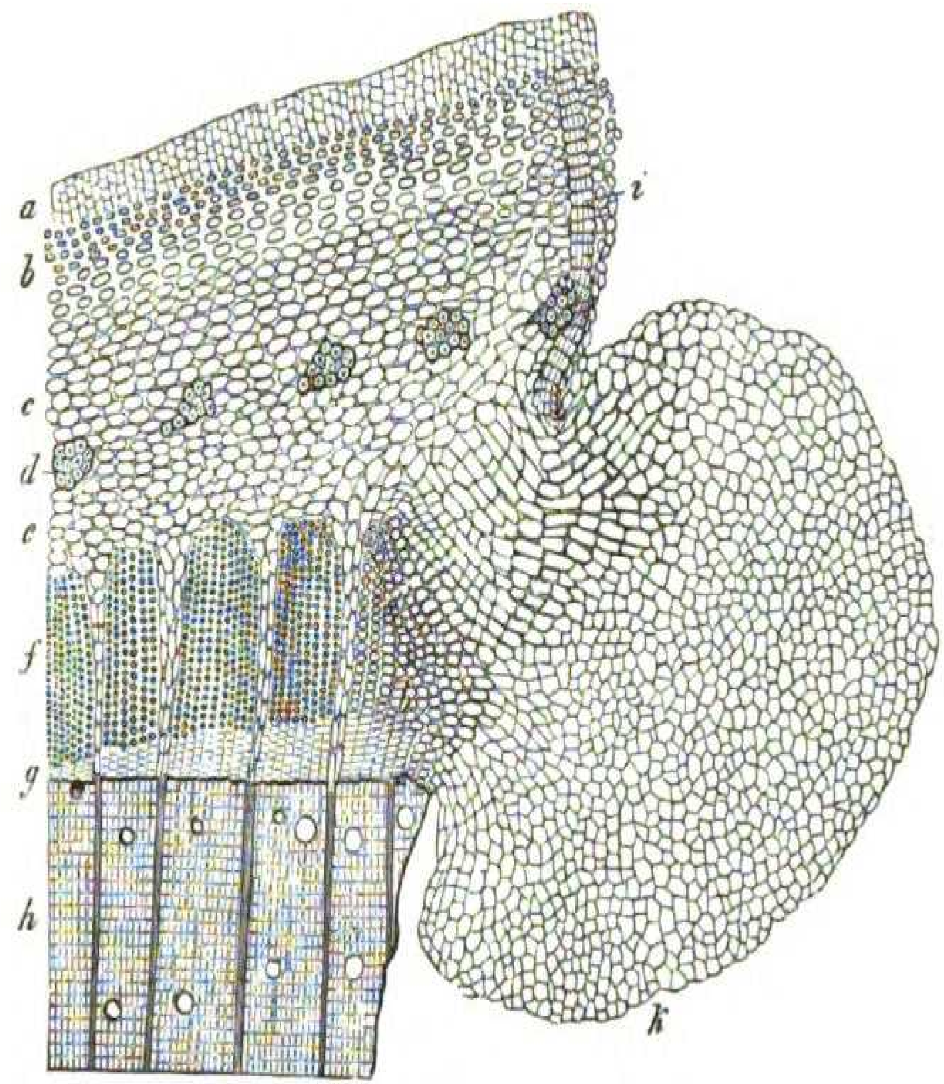
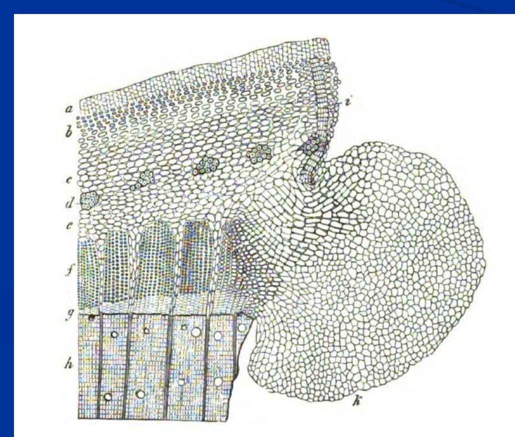


FIG. 132.—The formation of callus on the edge of a wound on an oak-branch. *a*, periderm ; *b*, collenchyma ; *c*, outer cortex ; *d*, primary bundles of hard bast ; *e*, cortical parenchyma ; *f*, soft bast ; *g*, cambium ; *h*, wood ; *i*, "wound-cork" formed by the outer cortex ; *k*, callus.

Callus
Totipotent

- **Blank slate**
- **Can form vascular cambium, roots, flowers, shoots or whole**

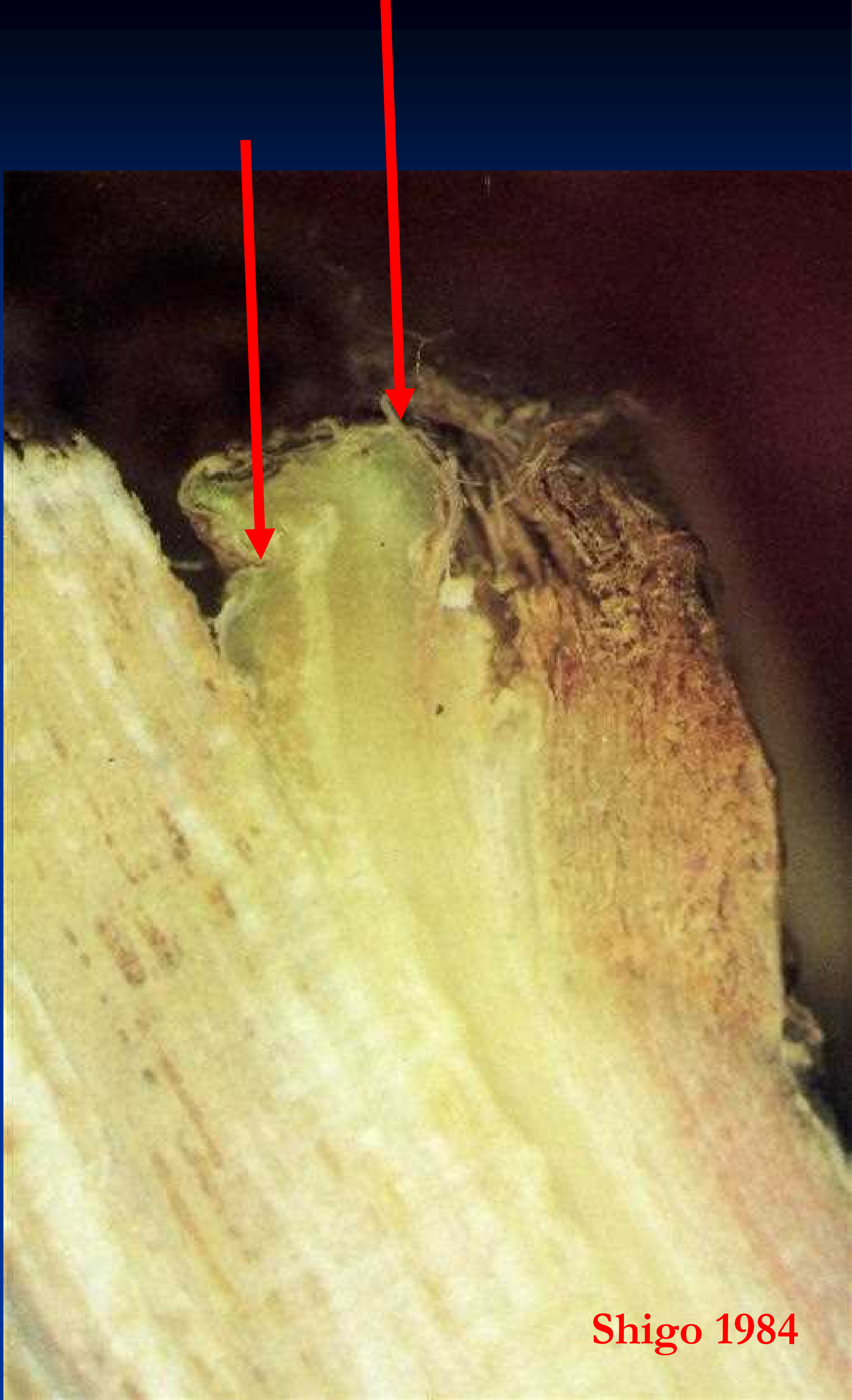


Callus Pad White Oak

Callus

1. May differentiate to form vascular cambium (VC)
2. Covers VC while VC regains function
3. May cover wound surface

- Short-lived
  - Becomes lignified and loses mitotic ability
  - Covered/Sloughed off as woundwood grows

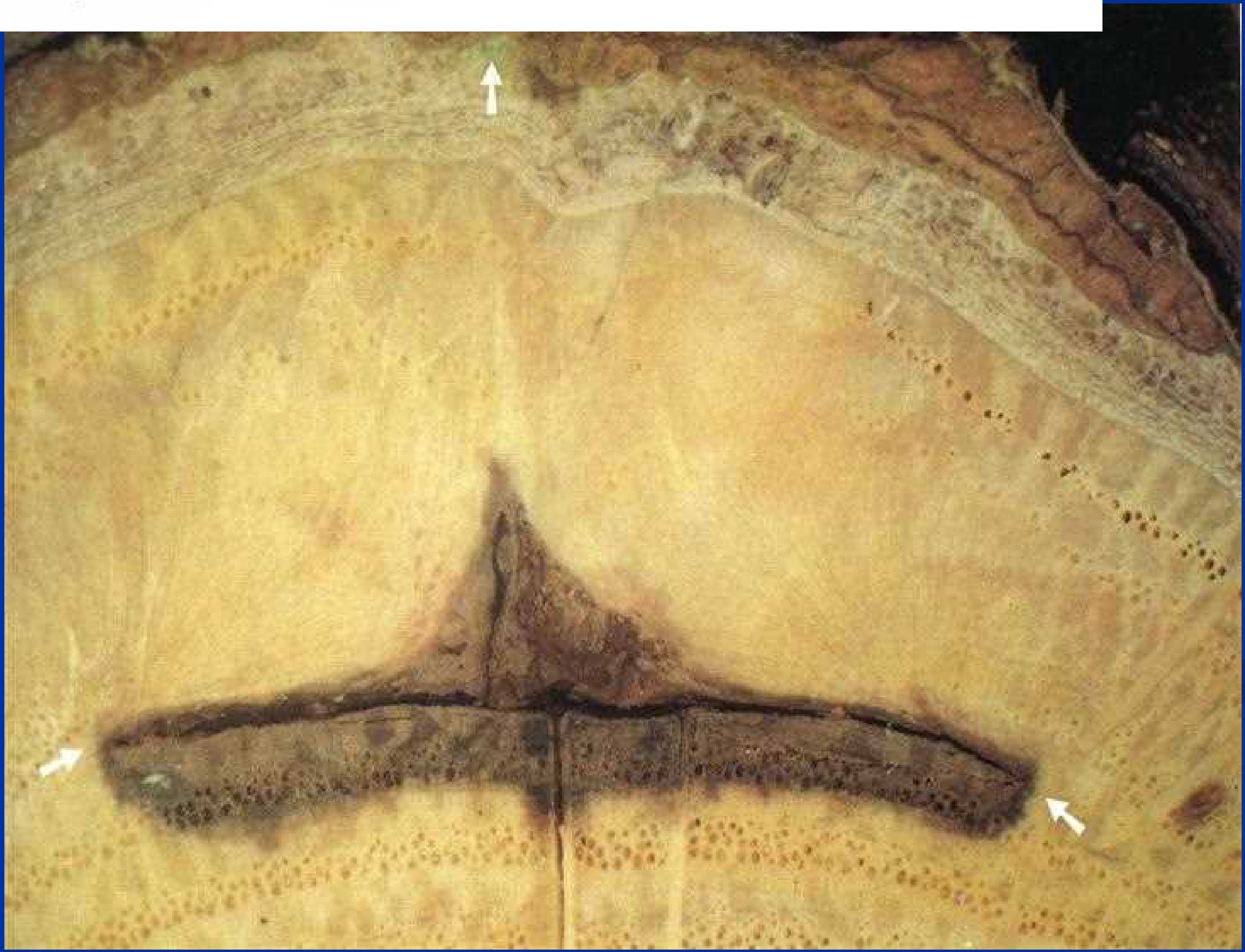


Callus can form vascular cambium which then forms wound wood directly

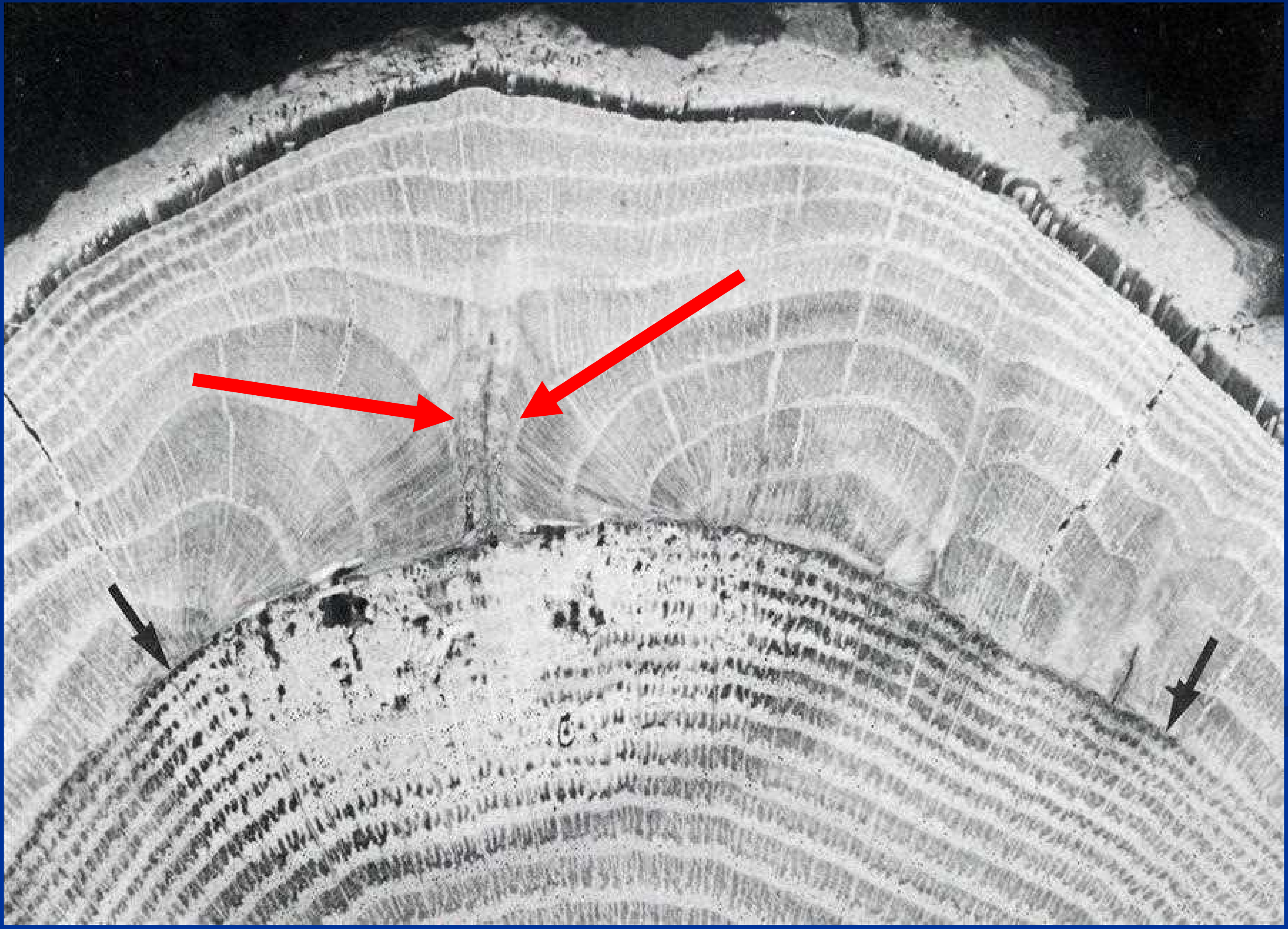
Wound-wood

Besides a thin walled, homogeneous callus parenchyma, many plants, after injury, produce tissues of other kinds, which become similar to wood tissue through a develpment of tracheal elements. The tissue resembling wood, which is formed after injury, is distinguished from normal xylem by its simple histology. We will term it wound-wood and for this reason add it to the list of kataplasms.

- Initially shorter, denser cells
- Less vessels
- Kuster 1913
  - Woundwood



Woundwood Seals a Wound
Sets the Stage for "Frost Cracks"



Callus and Woundwood Forms quickest when trees are actively growing

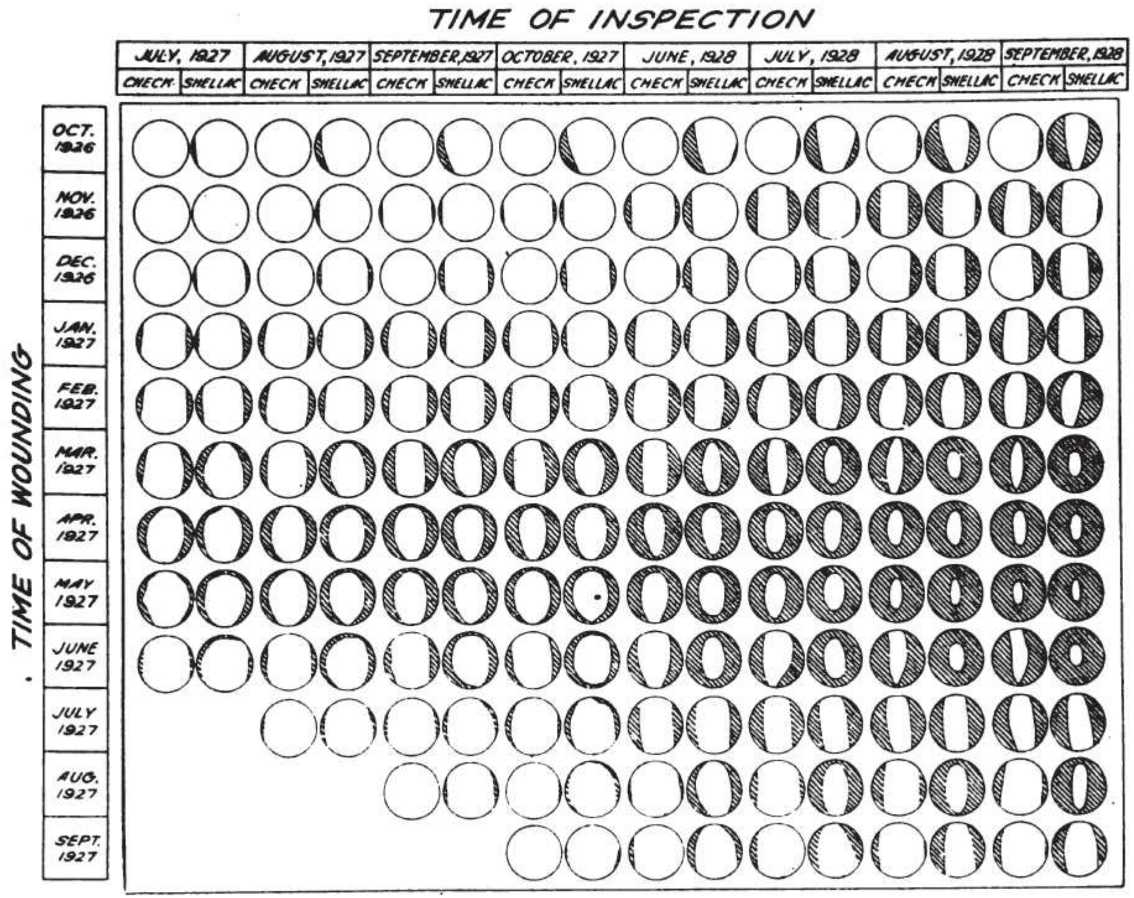
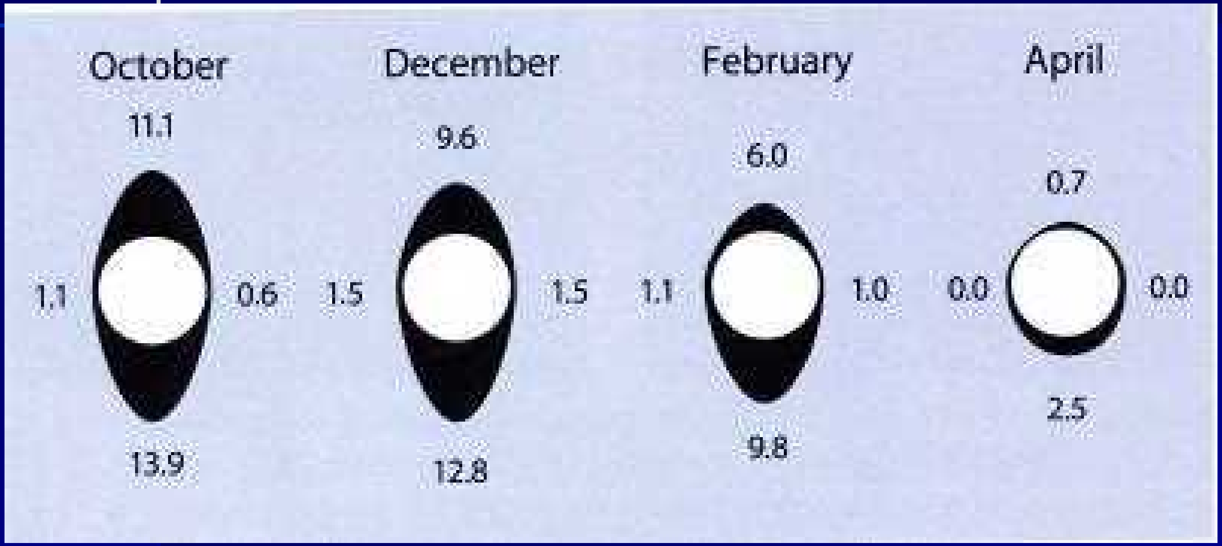


FIGURE 5.—Successive stages of callus growth for each wound on *Acer rubrum* No. 4

Marshall, R. P. 1931. The relationship of season of wounding and shellacking to callus formation in tree wounds. USDA Technical Bulletin 246. 29 p.

Impact of Time of year on Wound Closure



Dujesiefken and Liese 2014

- Wounds made in the fall seal slowest and may have dieback associated with the injury
- Avoid fall drilling and pruning of trees

Wound Sealing
High Humidity Protection
Promote Callus and Woundwood Formation

POLYETHYLENE PLASTIC WRAP FOR TREE WOUNDS: A PROMOTER OF WOUND CLOSURE ON FRESH WOUNDS

-McDougall and Blanchette, 1996

- **Effect goes away after 1 week**
- **Species effects present**

Non-Specific Spread of Decay Fungi

Possibly spreading n + n Hyphae

Spread by Insects

- **Some sap rot fungi**

Cerrena unicolor

Berry, 1969

Table 4.—*Relationship between infection courts and incidence of infection and volume of decay*

Infection court	Infections		Volume of decay	
	No.	*Percent*	*Cu. ft.*	*Percent*
Fire scars	128	26.12	99.20	31.98
Insect wounds	78	15.92	28.00	9.03
Dead branch stubs	69	14.08	31.13	10.03
Parent stumps	41	8.37	38.21	12.32
Open branch stub scars	31	6.33	39.95	12.88
Branch bumps	31	6.33	16.33	5.26
Damaged tops	23	4.69	16.48	5.31
Roots	22	4.49	6.68	2.15
Mechanical injuries	21	4.29	11.87	3.83
Woodpecker injuries	18	3.67	5.96	1.92
Miscellaneous	13	2.65	9.79	3.16
Unknown	15	3.06	6.61	2.13
Total	490	100.00	310.21	100.00




100% Chance of Decay

Supply Shadow

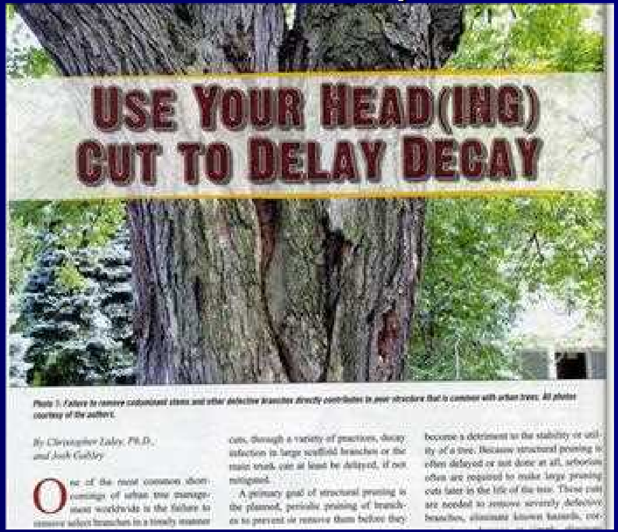
Supply Shadow

Preserve Branches where Possible

- Delay branch removal
  - Especially on main trunk or large diameter scaffolds
- Remove/partially remove at a later time as needed

-Delay making large cuts;
-Preserve branches where possible
-Remove at later time

- ANSI A300 Part 1-2017
- Heading cut
  - 7.4.1 To avoid making an unnecessary large branch removal where an appropriate lateral branch is not present






Heading Cuts

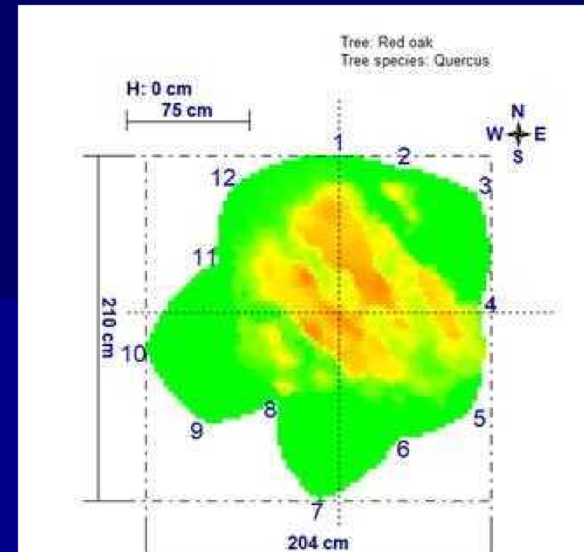
Heading Cuts

- Not for sugar maple!

Root Infections

- Root contact/grafts
- Armillaria via
  - Rhizomorphs
- Disease Centers

Under ground spread



Sporulation

Seasonal Progression

HERE COME the Basidiocarps: Seasonal Fruiting of Decay Fungi

BY CHRISTOPHER J. LULEY, Ph.D.

Just like the seasonal progression of flowering in higher plants, the annual appearance of fruiting (production of mushrooms, conks, brackets and other fruiting structures) of wood-decay fungi is somewhat predictable. When decay fungi appear during the year can be a significant aid to identification. If nothing else, the timing of fruiting can help confirm the identity of many common wood-decay pathogens.

For example, *Armillaria mellea* (shoestring root rot in the wide, taxonomic sense of the species) is an autumn fruiting mushroom. Mushrooms that appear in the spring or summer are almost always not *A. mellea*. However, *Armillaria tabescens* (ringless Armillaria) is a common summer-fruiting mushroom that is an important tree pathogen. Another common example is *Cerioporus (Polyporus) squamosus*, commonly known as Dryad's saddle. *C. squamosus* is one of the first wood-decay fungi to fruit in the spring, appearing often in early May. At the end of the growing season, *Hypsizygus (Pleurotus) ulmarius* (elm oyster) is often the last fungus to fruit, and new mushrooms may be seen as late as November

This synopsis represents my observations of the time during the growing season when wood decay fungi typically first appear. Most of my observations are from western New York (USDA climatic zones 5 to 6), so one should adjust the annual progression as needed, depending on where you live. In warmer climates, fruiting sequences may mean less because temperature is less of a limiting factor in restricting or promoting

When decay fungi appear during the year can be a significant aid to identification. If nothing else, the timing of fruiting can help confirm the identity of many common wood-decay pathogens.

fruiting. In addition, in southern climates some fungi may fruit well into the winter or at least continue to produce and release spores from fruiting bodies formed during the growing season.

Weather patterns in any given year greatly influence the fruiting of decay fungi. In general, wetter years are better for more fruiting of the annual fungi (mushroom or fleshy fruiting producers spores for only a short time period in a single growing season, and must fruit again the next year to produce spores again). Some trees that harbor annual fungi may have mushrooms or conks one year but not the next. Common examples are *Ganoderma sessile* (aka *G. lucidum*) and *Laetiporus sulphureus*.

Some decay fungi seem to be more consistent, like the root- and butt-decayer – and edible – hen of the woods, *Grifola frondosa*. Remember that the perennial fungi, such as *Ganoderma applanatum* or *Phellinus (Fomes)* species, produce a new layer of pores on the same conk each year. The hard, woody brackets of perennial conks can persist on trees for many years. Some perennial conks can ...

Cerioporus squamosus

First to fruit in spring

Pleurotus ostreatus

Fall fruiting

Armillaria mellea

Never in spring or summer

Edible Fungi on Living Trees

-Sulfur shelf
-Hen of the woods
-Lions mane
-Oyster mushroom

Lion’s Mane

Oyster Mushroom

The large print giveth, the small print taketh away

- Positive ID on any fungi you eat
- On trunk of living trees, “no” “poisonous” fungi
  - On ground around trees all bets off
- People react to new proteins

Medicinal Fungi-Living Trees!

Maitake

Grifola frondosa

Reishi

Ganoderma sessile

Medicinal Fungi

Ganoderma applantum

Artist Conk

Medicinal Fungi

Chaga on Birch

Inonotus obliquus

Lion's Mane On oak

Hericium erinaceus

Ganoderma sessile
Reishi; Ling zi

- 11 trees with conks
- .6% of trees with conks
  - **Sample projection 402 trees**
- Average SW/SR = .64
- SW/SR Range 0.24 to 1
- Decay often undetected in trunk!

Ganoderma lucidum Anti-Cancer properties

Ganoderma lucidum (Reishi mushroom) has shown promising anticancer properties in laboratory studies, primarily due to its bioactive components like polysaccharides and triterpenes. Key findings include:

- **Immune Modulation**: Polysaccharides, particularly beta-glucans, enhance the immune system by activating macrophages, natural killer cells, and T cells. This immune response indirectly targets tumor cells [1] [3].
- **Direct Cytotoxicity**: Triterpenes, including ganoderic acids, exhibit direct cytotoxic effects on various cancer cell lines and inhibit angiogenesis and metastasis [2] [3].
- **Inhibition of Cancer Pathways**: Ganoderma lucidum suppresses transcription factors such as NF-κB and AP-1, reducing tumor invasiveness by limiting cell adhesion, migration, and proliferation [1] [2].
- **Synergistic Effects**: Recent studies suggest that Ganoderma

- **Synergistic Effects**: Recent studies suggest that Ganoderma polysaccharides can enhance the effectiveness of conventional cancer treatments like Docetaxel [7].

Despite these findings, there is insufficient clinical evidence to confirm its efficacy as a standalone cancer treatment. It is considered a potential complementary therapy and requires further human trials to validate its therapeutic role [5] [8].

#3
Ganoderma sessile
Reishi; Ling zi

Cracking and Bleeding

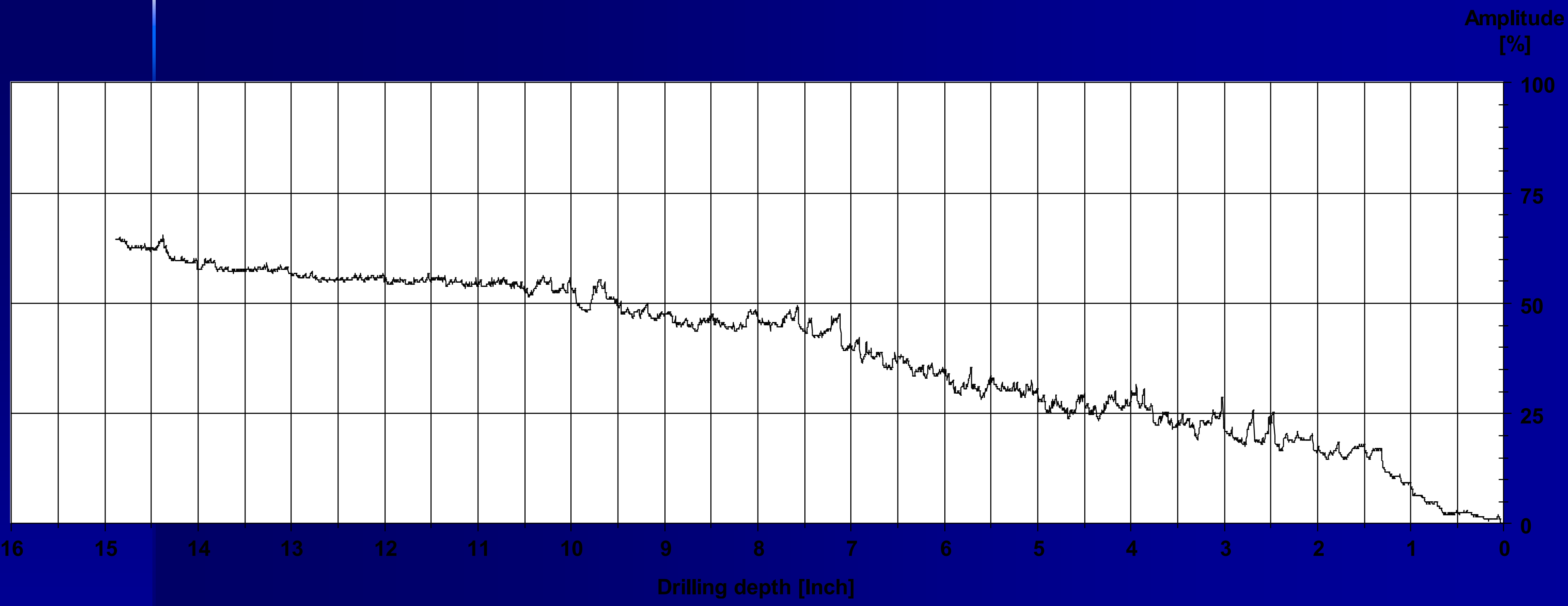
Phytophthora sp. Killing Bark and Cambium

Pocket diagnostics

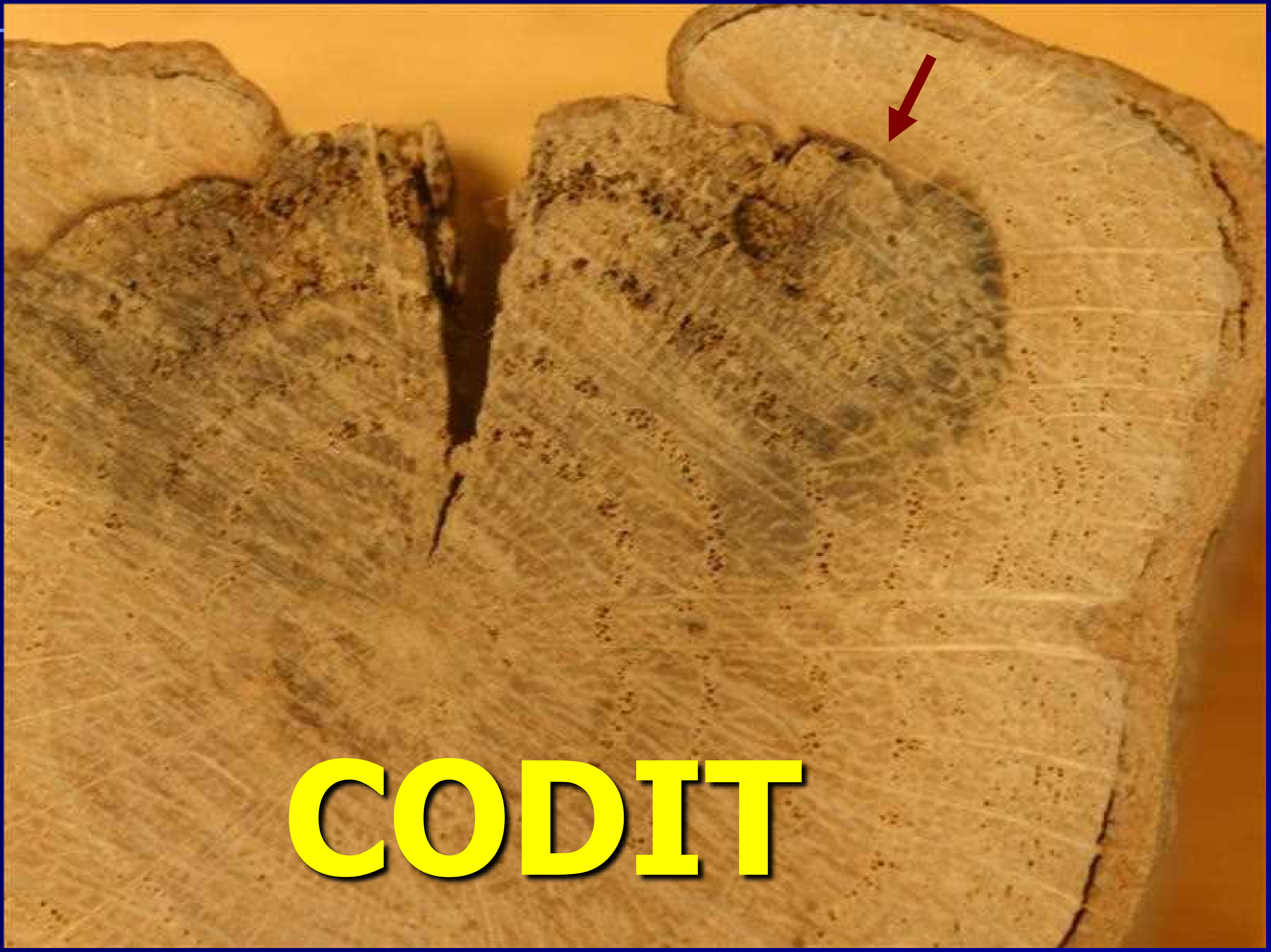
Phytophthora sp.

Grifola frondosa
Hen of the Woods
Maitake

Drilled 6 Times
No decay at conk or around tree



Host Reaction



Basic Wood Anatomy

1. Pith
2. Heartwood
3. Ripewood
4. Sapwood
5. Xylem
6. Rays
7. Vessels
8. Latewood
9. Tyloses
10. Cambium
11. Inner bark
12. Phloem
13. Bark Cambium or Phellogen
14. Outer Bark
15. Bark

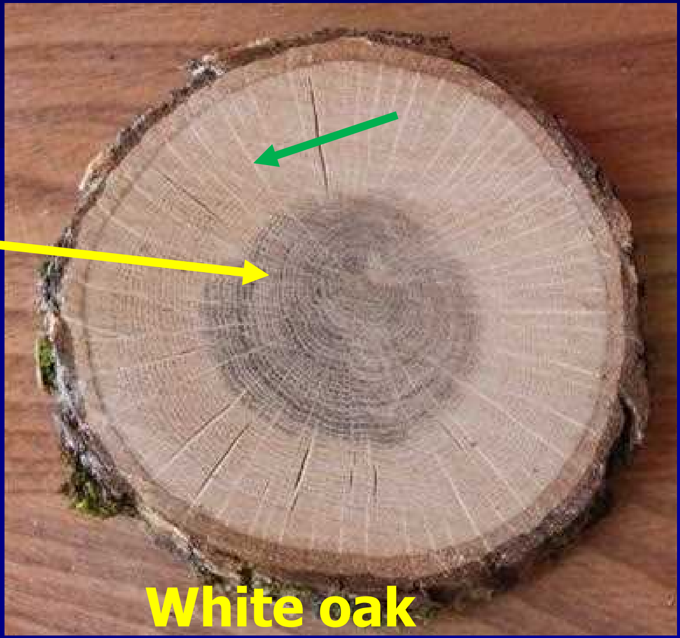
Basic Wood Anatomy

- Pith
  - Importance?

Heartwood and Heart Rot

Heartwood

- Non-living wood
  - No living parenchyma
  - Formation genetically controlled
  - May or may not be more resistant to decay
  - Non-conducting
- Ripewood
  - <u>Heartwood</u> that is light colored and is not more resistant to decay



Ripewood- heartwood but no darker colored extractives

- Some conifers
- Birch, Acer
- Many species wrongly classified or unknown

Some Conifers

White pine

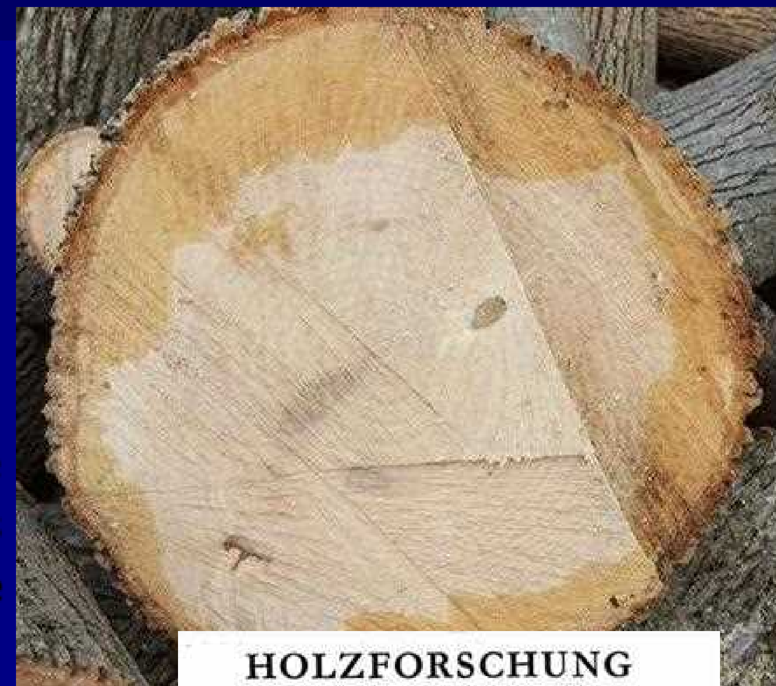
Ripewood – <u>heartwood</u> that is not different colored then sapwood

Red Spruce

White ash?

White ash heartwood

An exception to this unfavourable state of affairs is encountered in ash (Fraxinus excehior). This timber produces coloured heartwood only if the moisture content of the trunk core exceeds 55% and if oxygen is present (Bosshard 1953, 1955)· These conditions not being fulfilled, the ash tree produces colourless heartwood. When a coloured heartwood is lacking, the ray parenchyma of the uncoloured heartwood contains colourless droplets of phenols; in the sapwood and the transition wood, no such compounds seem tö be accumulated. Sufficient moisture presupposed, those phenols will be oxidized and will polymerize to a dark brown pigment.



HOLZFORSCHUNG

MITTEILUNGEN ZUR CHEMIE, PHYSIK, BIOLOGIE UND TECHNOLOGIE DES HOLZES

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Cytology of the Ray Cells in Sapwood and Heartwood*)

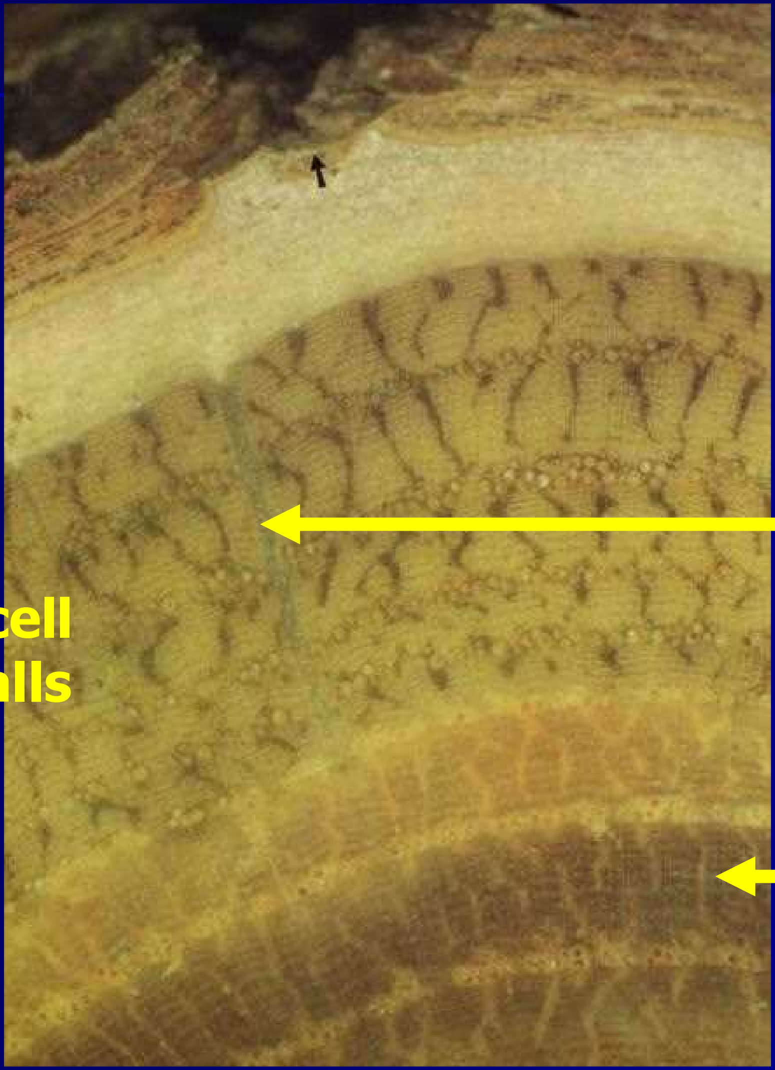
By A. Frey-Wyssling and H. H. Bosshard

Department of General Botany and Laboratory of Microtechnological Wood-Research, Swiss Federal Institute of Technology, Zürich

Sapwood Conversion to Heartwood

-Living parenchyma converted to biochemicals

-Deposited in cell lumens and walls



Shigo 1994

Inner Sapwood

- <u>Not all trees form heartwood</u>
  - Diffuse porous species
    - *Acer*
    - *Fagus, Betula, Populus* (Sinclair and Lyons, 2005)
  - May have living cells all the way to the center of the tree
- Discolored wood in the center of a tree (WID)
  - Not necessarily heartwood
  - False heartwood

Sugar Maple

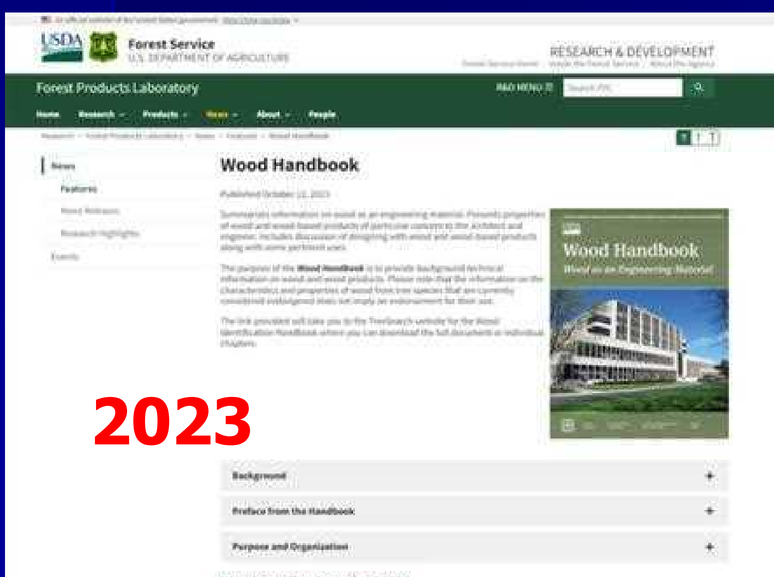
Heartwood

- Lists/descriptions of heartwood for species that probably do not form heartwood

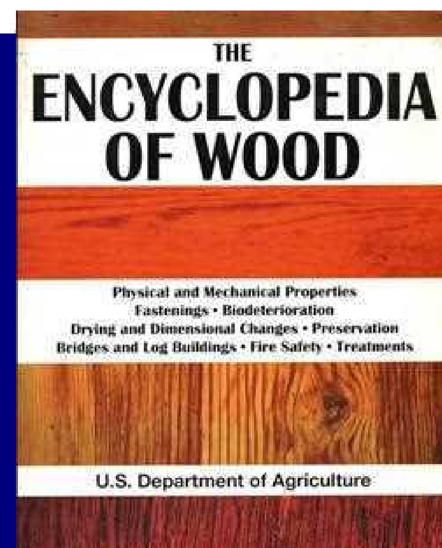
FPL-0153, 1967

Table 1.--Comparative decay resistance of the heartwood of some common native species

Resistant or very resistant	Moderately resistant	Slightly or nonresistant
Baldcypress (old growth)[1]	Baldcypress (young growth)[1]	Alder
Catalpa	Douglas-fir	Ashes
Cedars	Honeylocust[2]	Aspens
Cherry, black	Larch, western	Basswood
Chestnut	Oak, swamp chestnut	Beech
Cypress, Arizona	Pine, eastern white[1]	Birches
Junipers	Pine, longleaf[1]	Buckeye[2]
Locust, black[3]	Pine, slash[1]	Butternut
Mulberry, red[3]	Tamarack	Cottonwood
Oak, bur		Elms
Oak, chestnut		Hackberry
Oak, Gambel		Hemlocks
Oak, Oregon white		Hickories
Oak, post		Magnolia
Oak, white		Maples
Osage-orange[3]		Oak (red and black species)[2]
Redwood		Pines (most other species)[2]
Sassafras		Poplar
Walnut, black		Spruces
Yew, Pacific[3]		Sweetgum[2]
		Sycamore
		Willows
		Yellow-poplar



2023



Pathology of Decay Fungi

Shortle and Dudzik 2012

<u>Obligate Saprophytes</u>

- Can only attack dead wood
  - Heartwood
  - Damaged/dead sapwood

<u>Facultative Pathogens</u>

- Can attack
  - Heartwood
  - <u>Healthy Sapwood</u>
    - Dead or damaged also
  - Cambium and bark

Wood Types in a Tree

Table 1. Wood types within the living tree.

Wood type	Color	Decay resistance	Representative genera	Implications
Heartwood	+++	+ to +++	*Quercus*, *Pinus*, *Carya*, *Ulmus*, *Robinia*, and many others.	Easy to see but color does not confer decay resistance.
Ripewood	0 to +	0 to +	*Picea*, *Fagus* (Boddy 2021), and *Fraxinus* (Frey-Wyssling and Bosshard 1959).	Hard to confirm visually, as it appears similar to sapwood.
Sapwood	0	0	All species	Decay resistance due to living cells that respond to invasion of healthy sapwood and maintain sapwood water conductance and high moisture content.
Inner sapwood	0	0	Mostly diffuse-porous species such as *Acer*, *Betula*, and *Populus*	Mostly non-conducting sapwood that retains living cells on non-heartwood forming species. Difficult to separate in the field from conducting sapwood.
Wound Initiated Discoloration (WID)	+ to +++	– to 0	All species	May be incorrectly interpreted as heartwood.
Decayed Wood	0 to +++	0	All species	Early stages may be difficult to distinguish visually from WID.

0 Denotes concolorous with normal sapwood
+ Denotes slight color different relative to normal sapwood
+++ Denotes distinct color difference relative to normal sapwood

Prescribe Pruning Dose based on Heartwood Presence

Heartwood in Roots

- Roots form heartwood but only in roots near the trunk or stem

T. Draves

Decay in Heartwood

- Often has minimal or no impact on tree biological health

Heartwood and Heart Rot, Part 1: Are they Important to Arborists?

Photo 1. Man has used the increased resistance of heartwood of some tree species for wood in service. Here, black-locust fence posts and white-oak rails have resisted decay in service for more than 20 years. Unless otherwise noted, all photos courtesy of Christopher Luley.

BY KEVIN T. SMITH, PH.D., CHRISTOPHER J. LULEY, PH.D., AND TOM DEAVES

Tree care professionals frequently assess or estimate the strength of wood within a living tree or standing snag. This is often quite informal, with training and experience that guides decisions to remove or retain a major stem, or where to tie off lines and place a felling hinge. This article will look at the importance of heartwood and how it can impact decisions where wood strength and decay status might affect tree care practices.

Long before modern arboriculture and an understanding of tree biology, humans benefited from the resistance to decay of heartwood found in some tree species. People recognized that the heartwood of certain species (e.g., cedar, black locust, osage orange, white oak) greatly resisted decay when used as fenceposts or in contact with soil. (Photos 1, 1A) Decay-resistant heartwood of western red cedar provides a contemporary example of a product that extends the service life of outdoor furniture and decks.

Heartwood formation can be accompanied by a dramatic change in wood color. This is true for black walnut and black cherry, highly prized by furniture manufacturers. This color change is frequently, but not necessarily, associated with increased resistance to decay.

Photo 1A. In this section from a dead white oak, the sapwood is extensively decayed while the heartwood is largely sound. Note that the heartwood in this tree occupies a large volume of the stem.

Despite common knowledge about heartwood, the terms heartwood and heart rot have long been confused in both the popular press and scientific literature. Heartwood has been ambiguously defined both on the basis of position (wood in the central core of the stem or branch) and/or visible properties (lack of sap conduction, dark coloration). In this article, we suggest that the hallmark of heartwood formation is a genetically pre-programmed

CONTINUING EDUCATION UNIT

Heartwood, Part I

Biology, Formation, Identification, and Importance

By Kevin T. Smith and Christopher J. Luley

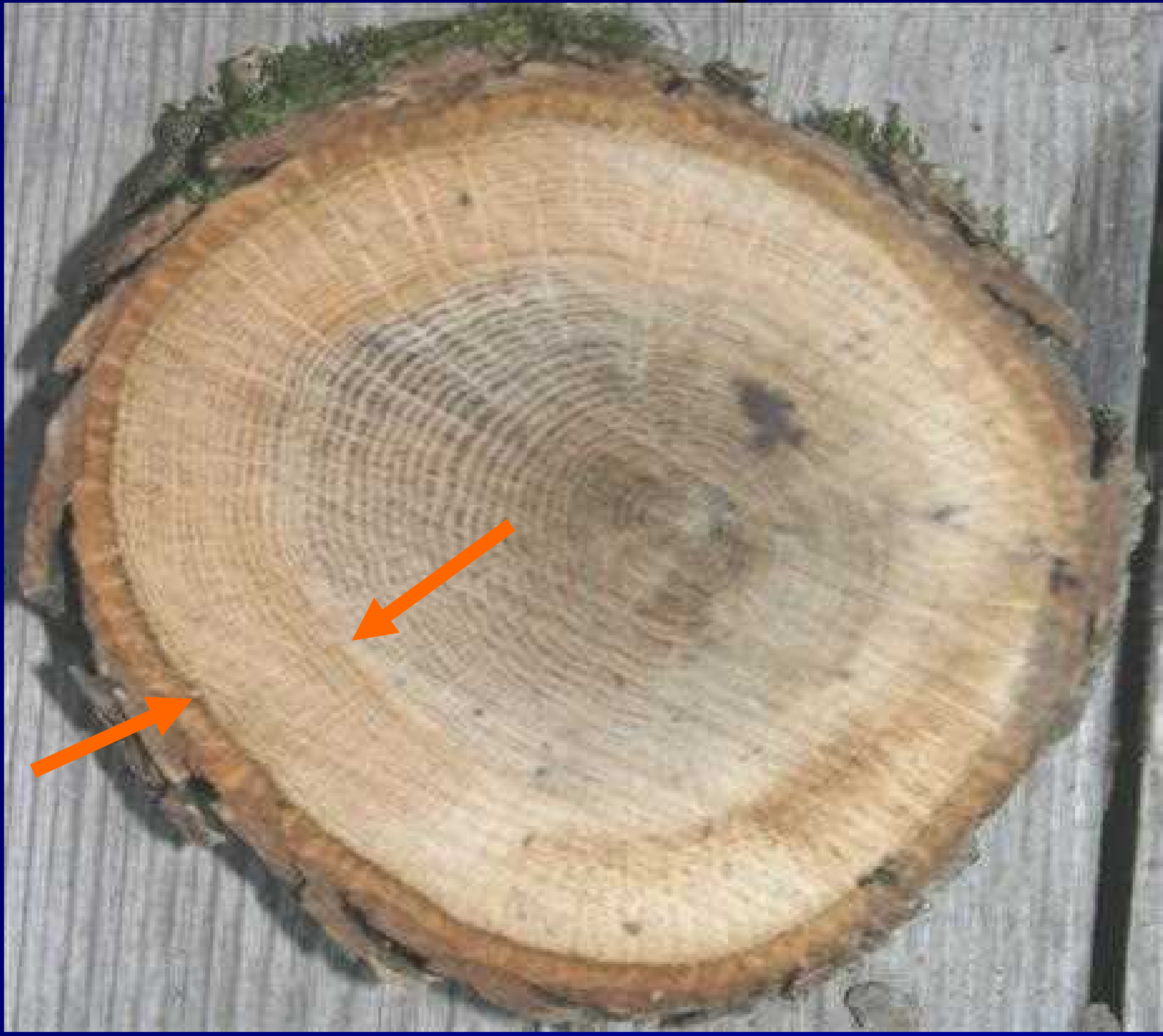
Learning Objectives

- Understand the differences between sapwood, heartwood, and wound-initiated discoloration and how each is formed.
- Review the relative decay resistance of select North American tree species.
- Understand the importance of being able to distinguish between sapwood, heartwood, and wound-initiated discoloration for the purposes of arboricultural operations.

CEUs: A, U, M, T, L, Bs

Basic Wood Anatomy

- Sapwood or
  - Xylem
    - Vessels
  - Fibers
    - Parenchyma
  - Not inherently resistant to decay
  - Resistance due to living parenchyma cells



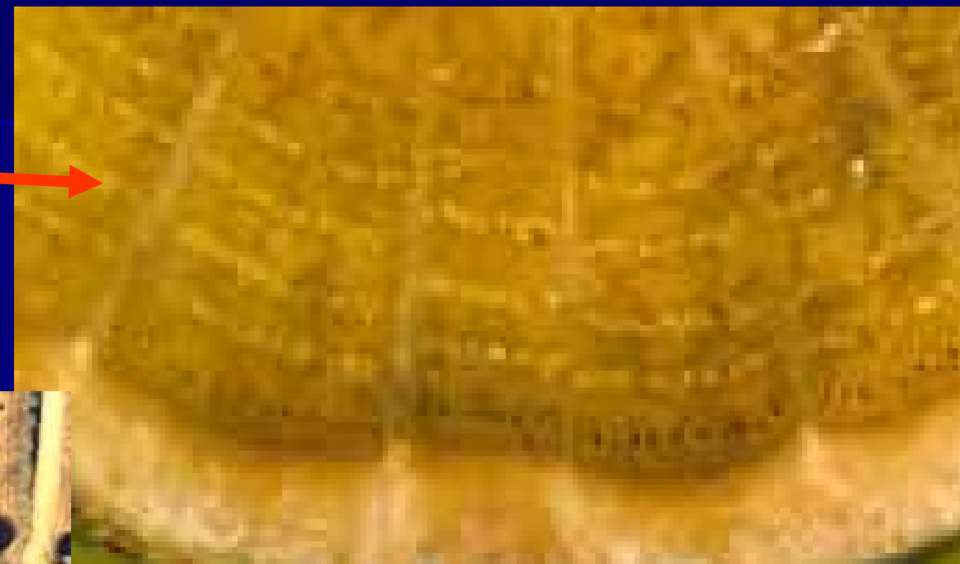
Sapwood in Sugar Maple

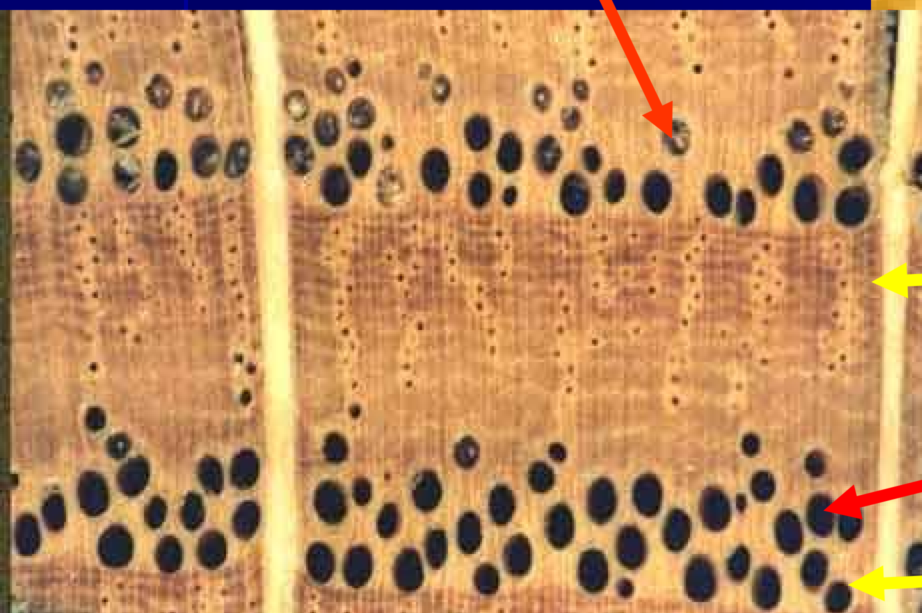
- Living cells maybe found all the way to the center of the stem ~150 yo
- Conducting sapwood in outer rings
- Sapwood slowly changes color as it ages

WID

Vessels-conducting water

Tyloses





Latewood

Vessel

Springwood

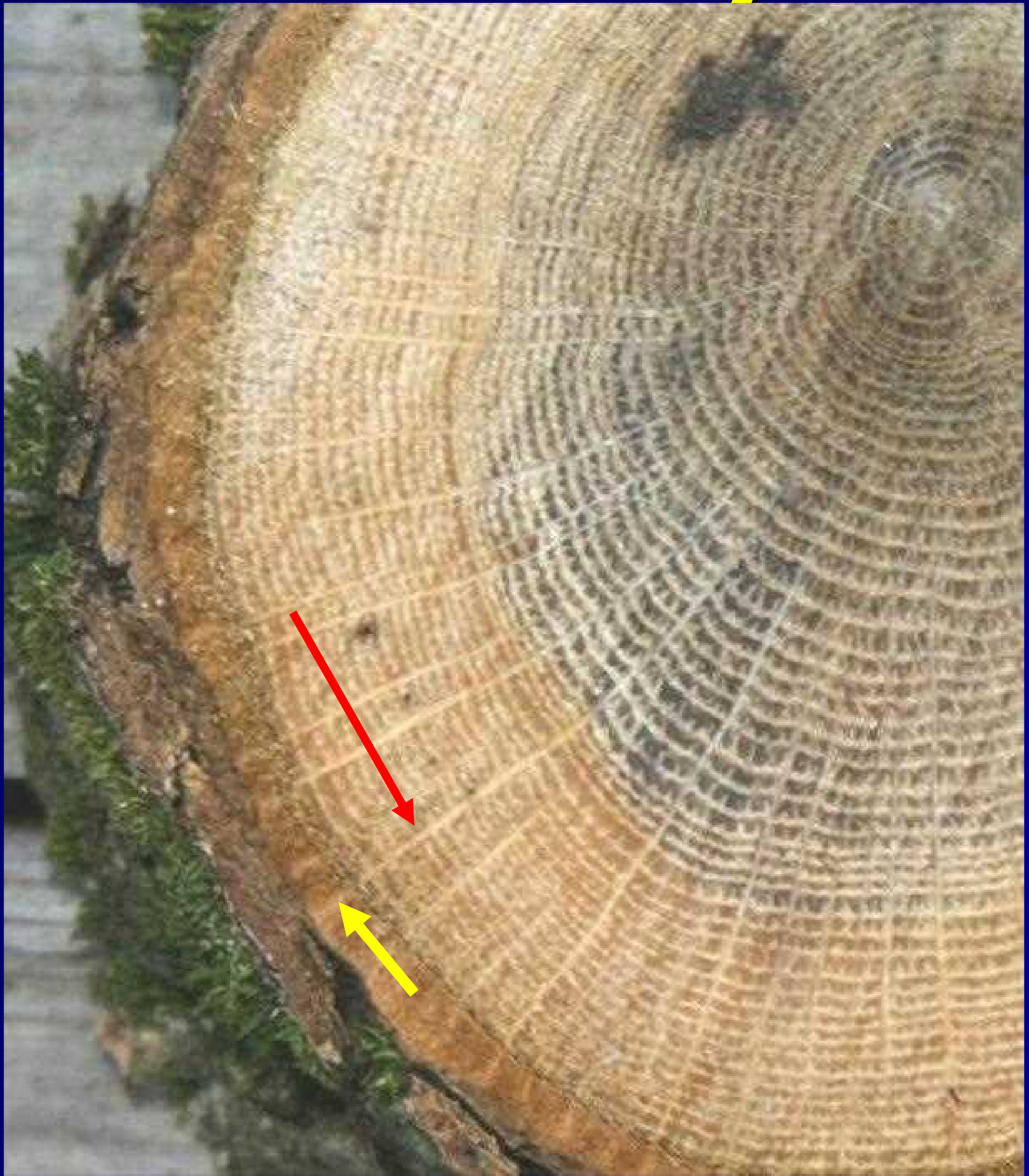
Sapwood

1. Conducts water
   – Tracheids and Vessels
2. Stores energy
   – Via living cells
     - Parenchyma
     - Fibers – some fibers remain alive
3. Provides support
   – Apoplast- non-living cells that provide support
   – Tracheids

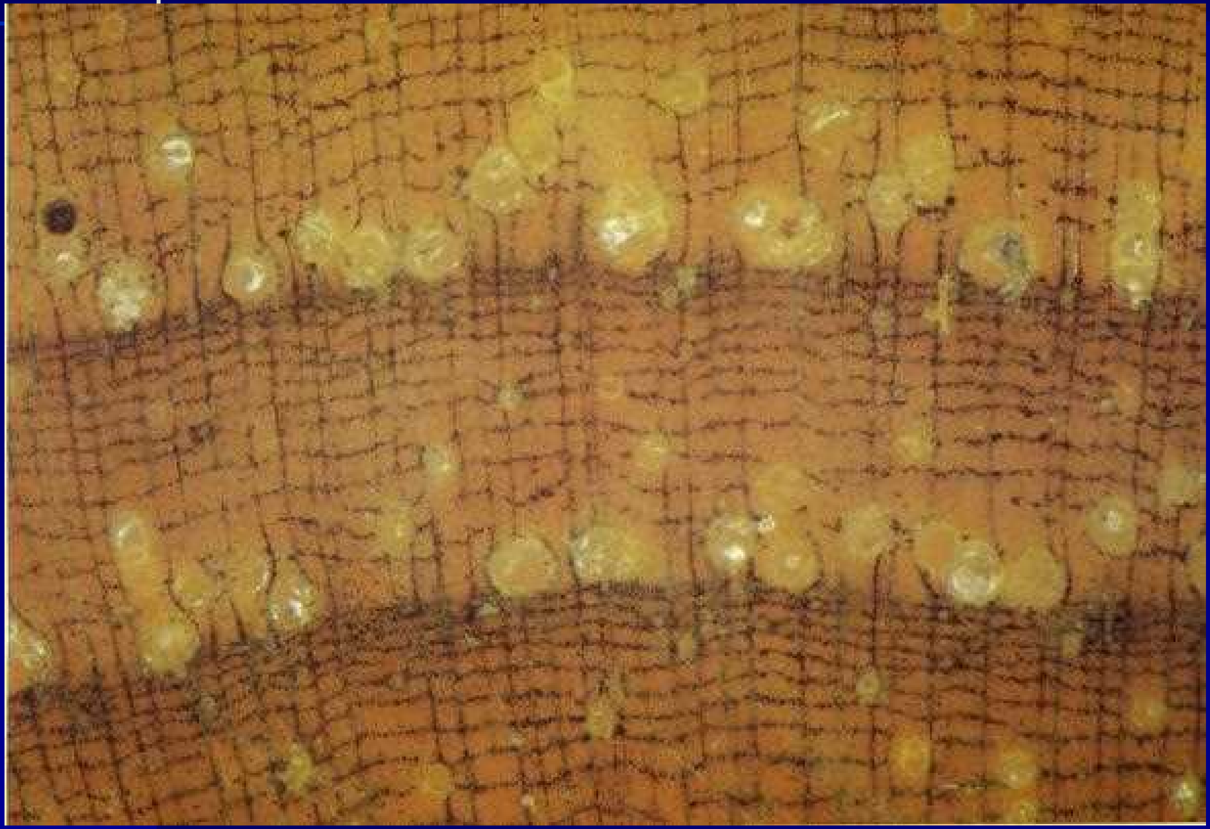
Black Locust

Basic Wood Anatomy

- Rays-
  - Living parenchyma cells
  - React to decay fungi invasion
  - Attached to phloem and sugar source!



Parenchyma Cells Stained with Iodine-Living sapwood

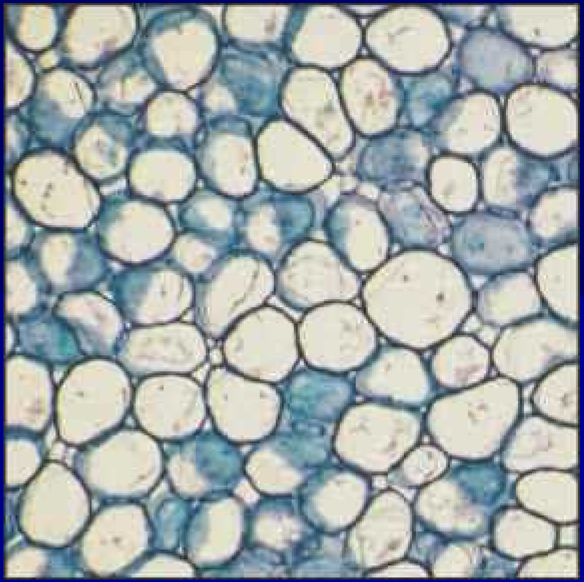


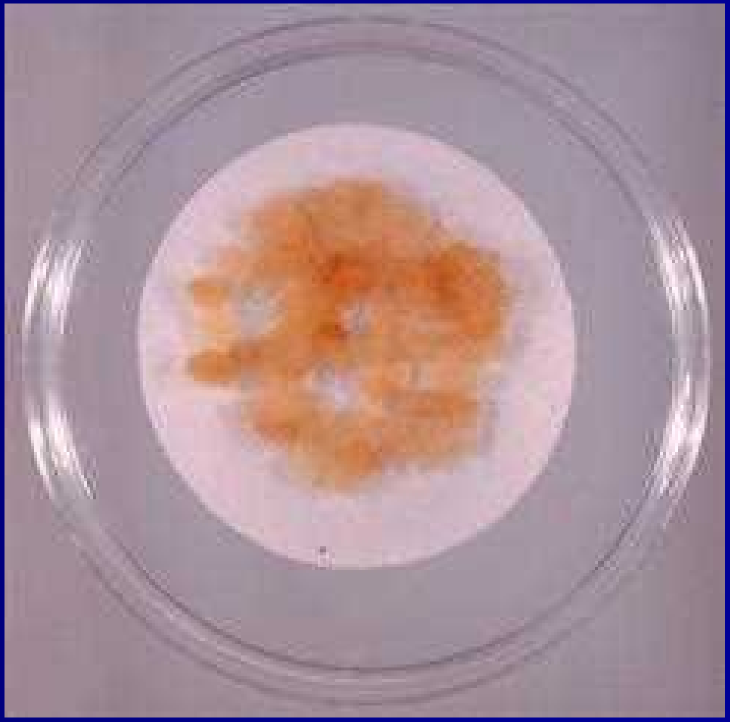
Shigo 1994

- Symplast-connection of living cells

Parenchyma Cells

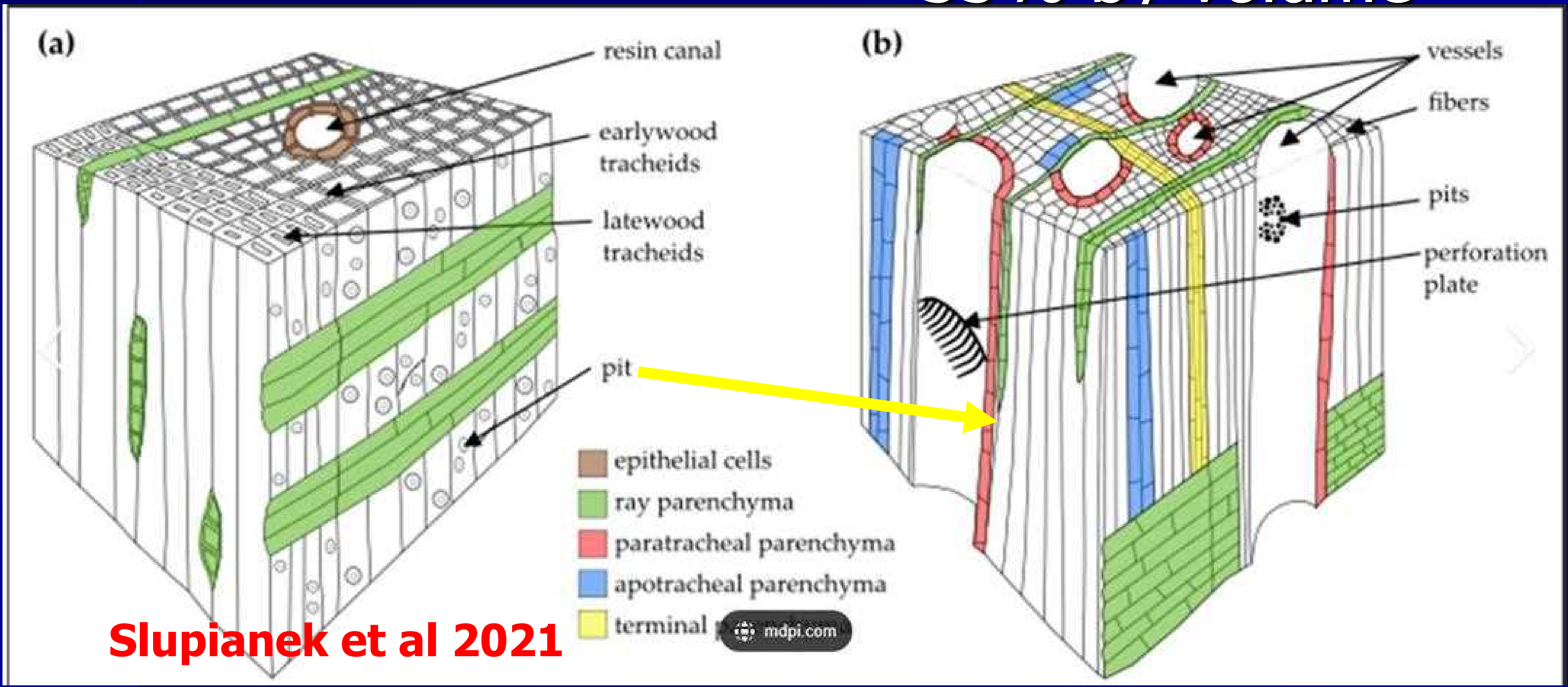
- Thin walled, living plant cells
  - Bark and sapwood
- Parenchyma-tissue made up of parenchyma cells
- Ray parenchyma-collection of cells





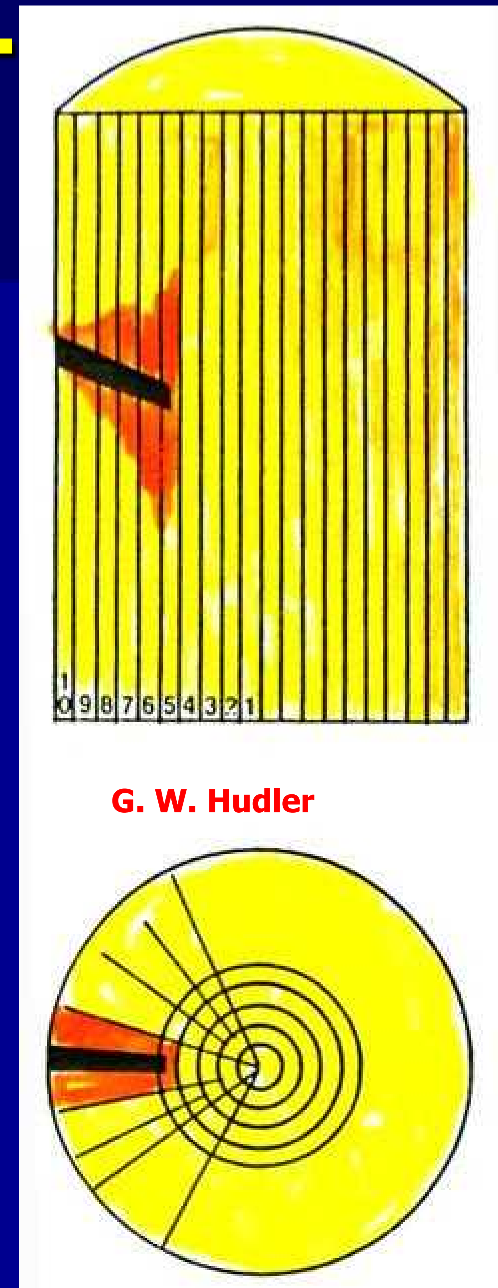
Parenchyma – Active reaction to decay fungi invasion of sapwood

- Conifers 5-8% by volume
- Deciduous 10-35% by volume



Slupianek et al 2021

Living Parenchyma – Reaction zones



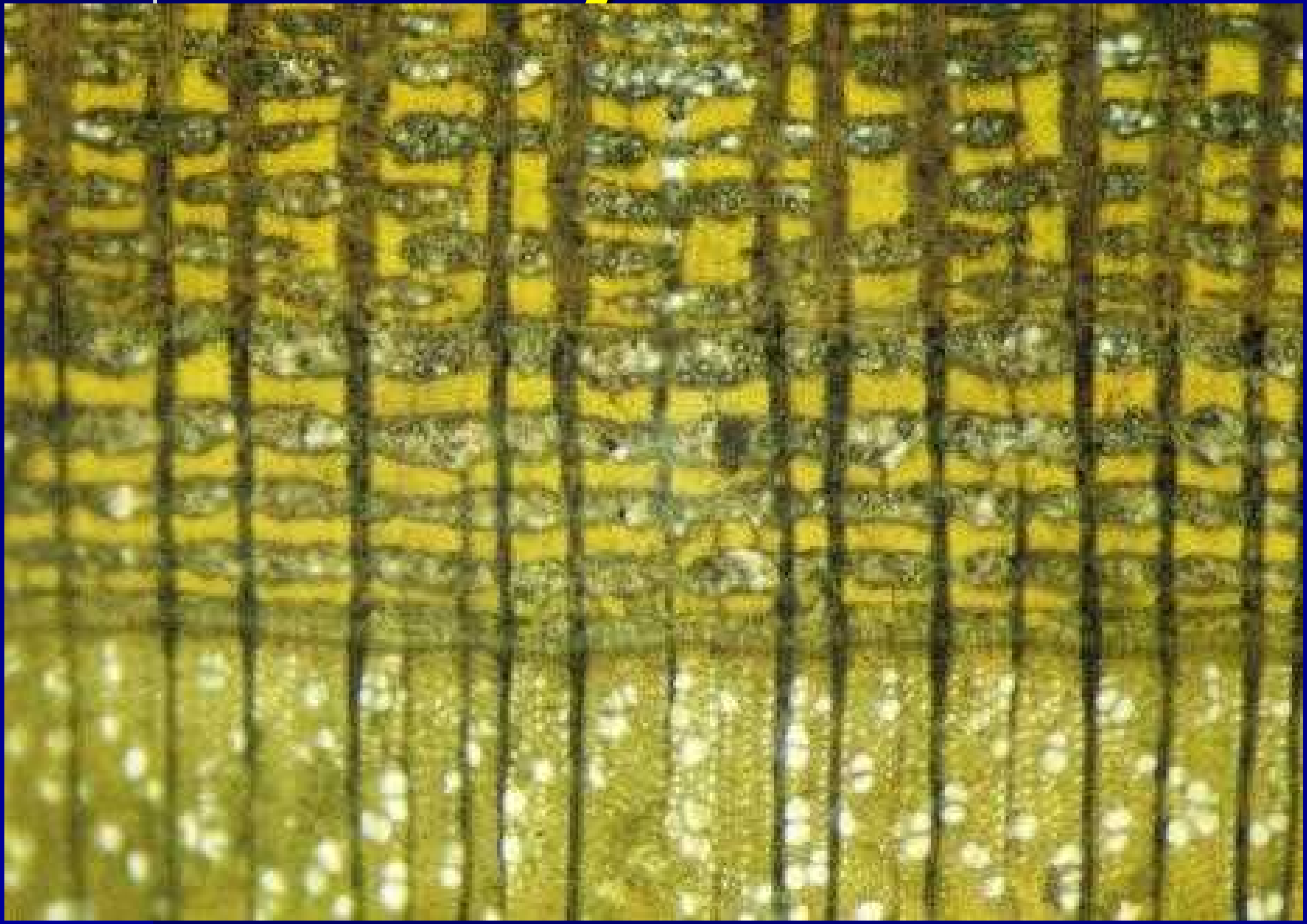
Basic Wood Anatomy

- Cambium
- A couple cells thick

Basic Wood Anatomy

- Phloem
  - Inner bark
  - No structural importance
  - Note lighter color

Rays extend into Phloem Wood's Connection to Carbohydrate Source

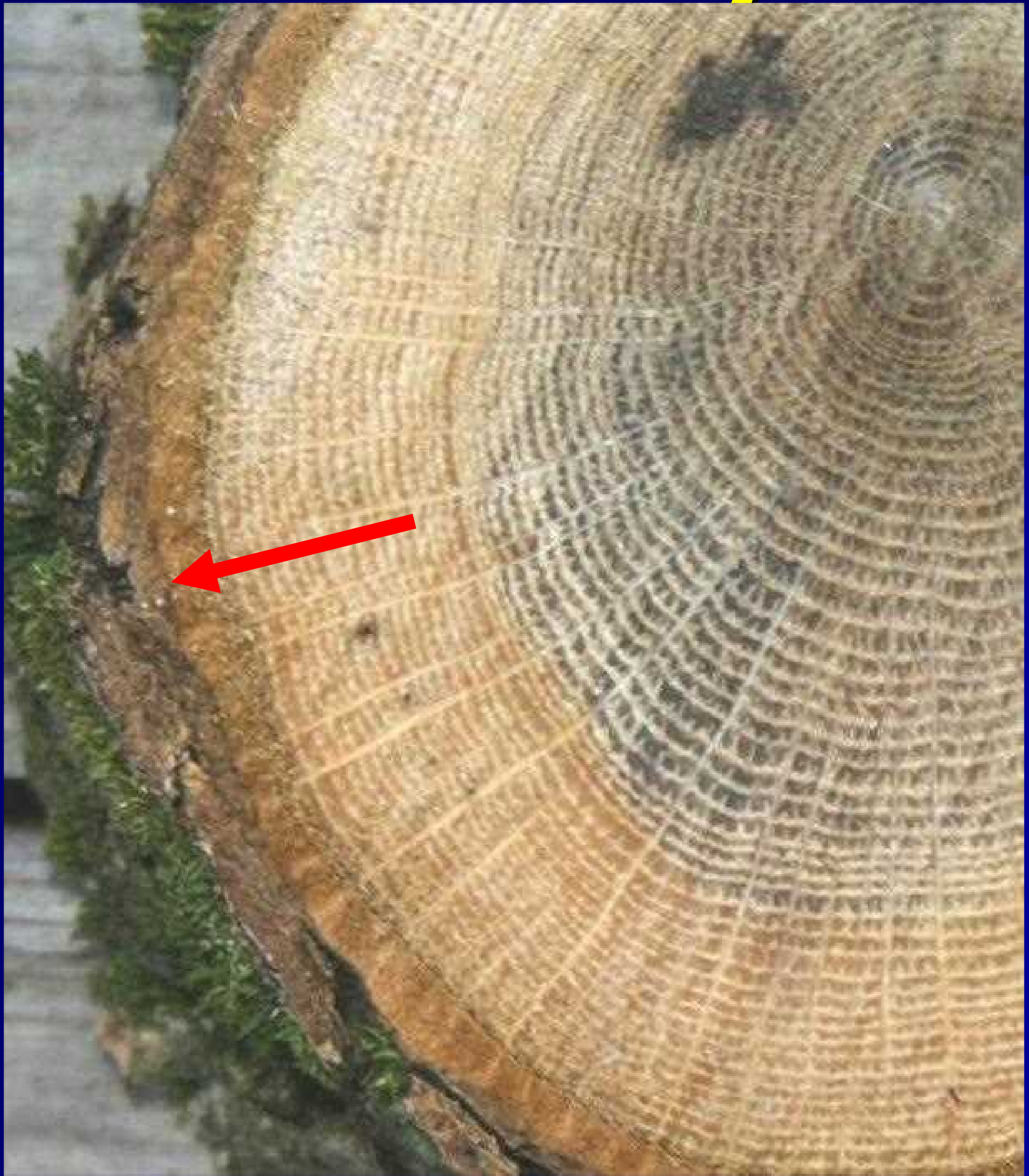


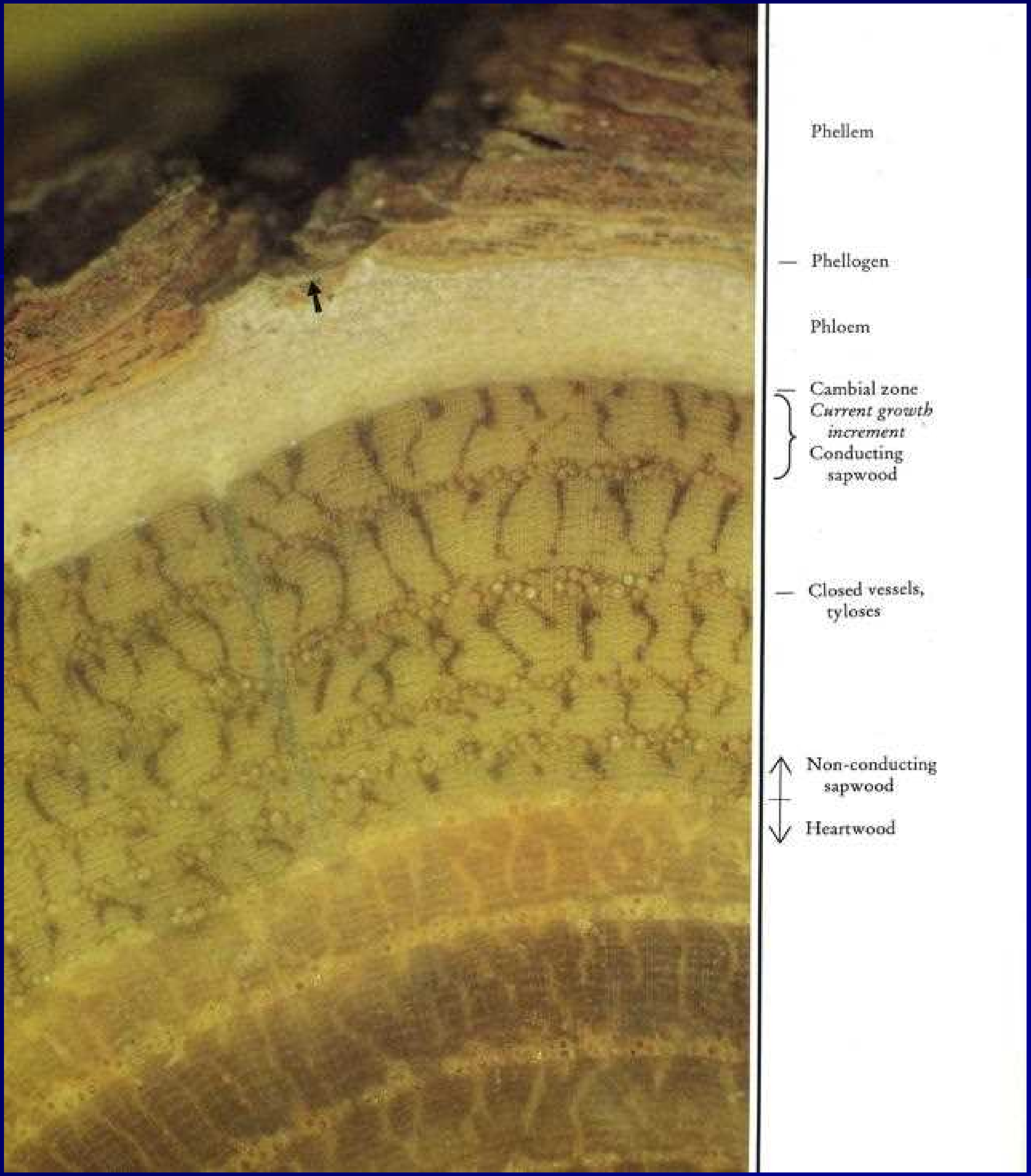
- Symplast
- Connection to tree biological health

Shigo 1994

Basic Wood Anatomy

- Bark
  Cambium
  - Trees have 2 cambial layers
  - Phellogen

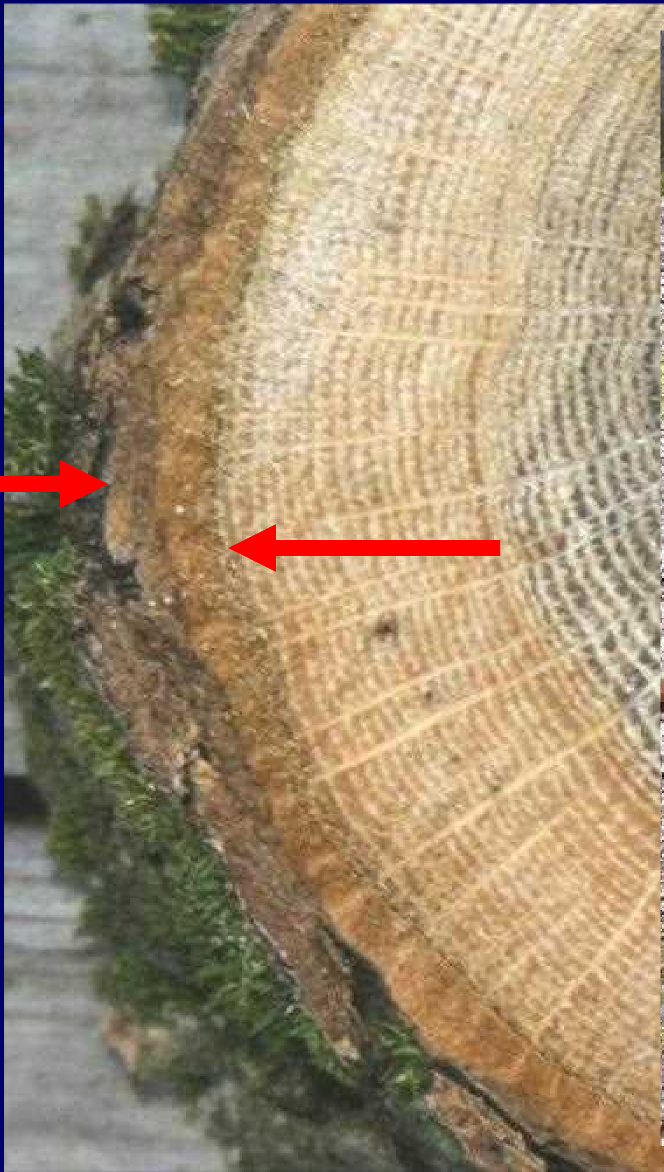



Phellem
Phellogen
Phloem
Cambial zone
Current growth increment
Conducting sapwood
Closed vessels, tyloses
Non-conducting sapwood
Heartwood

Shigo 1994

Basic Wood Anatomy

- Bark
  - –Inner and Outer bark



Bark Rot
Dendrothele candida

Black Oak

Dendrothele species Typically Host Specific

- Widely distributed
- Some host specificity
- Able to degrade suberin
- Most trees species have one
- Basidiomycetes/
  - Agaricales

Dendrothele species

Pignut hickory

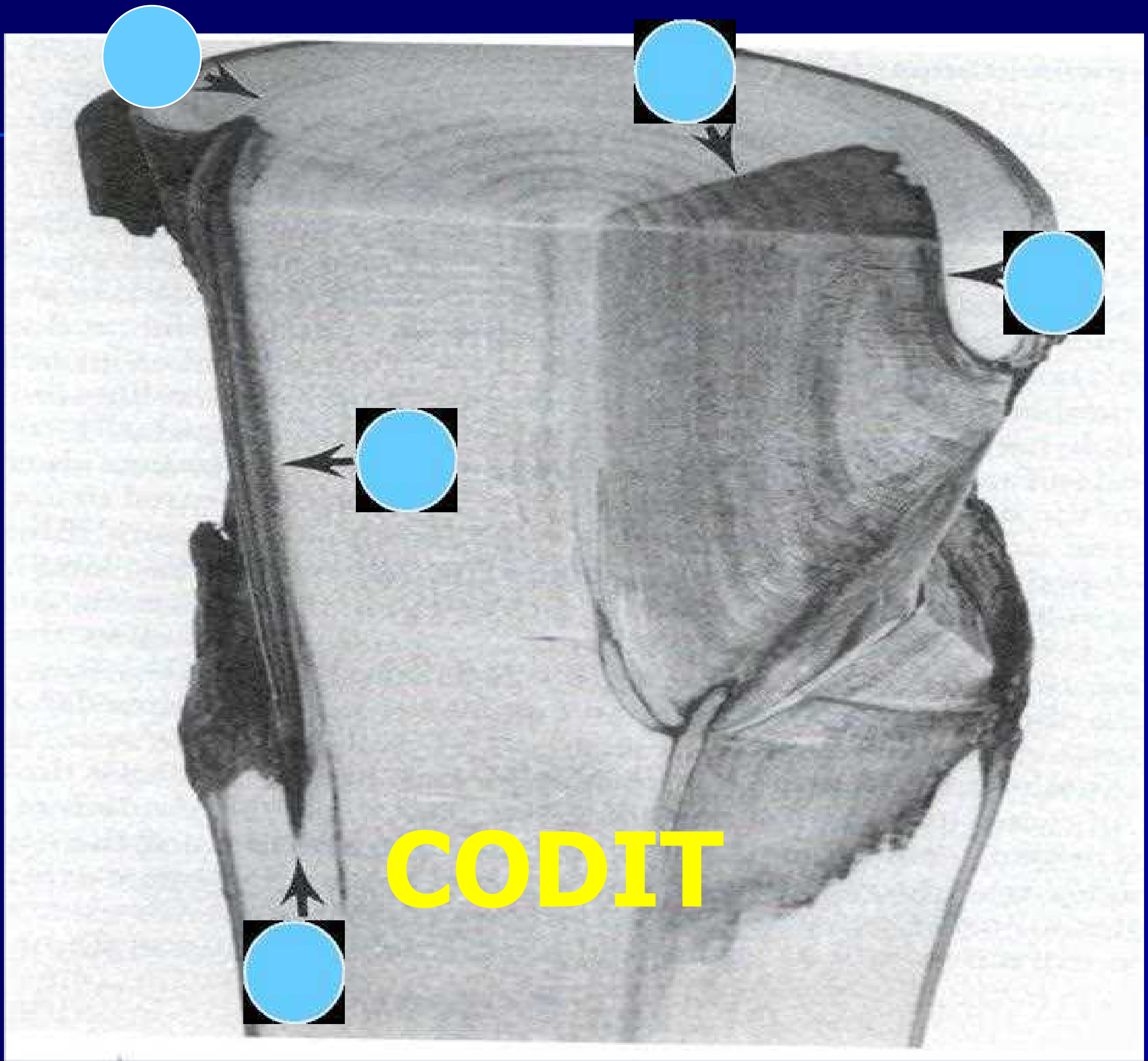
White oak

Smooth Patch
Aleurodiscus (oakesii) wakefieldiae
Basidiomycete

Smooth Patch or Bark Rot? Decaying outer bark and Inhibiting Phellogen or Bark Cambium

Compartmentalization of Decay in Trees

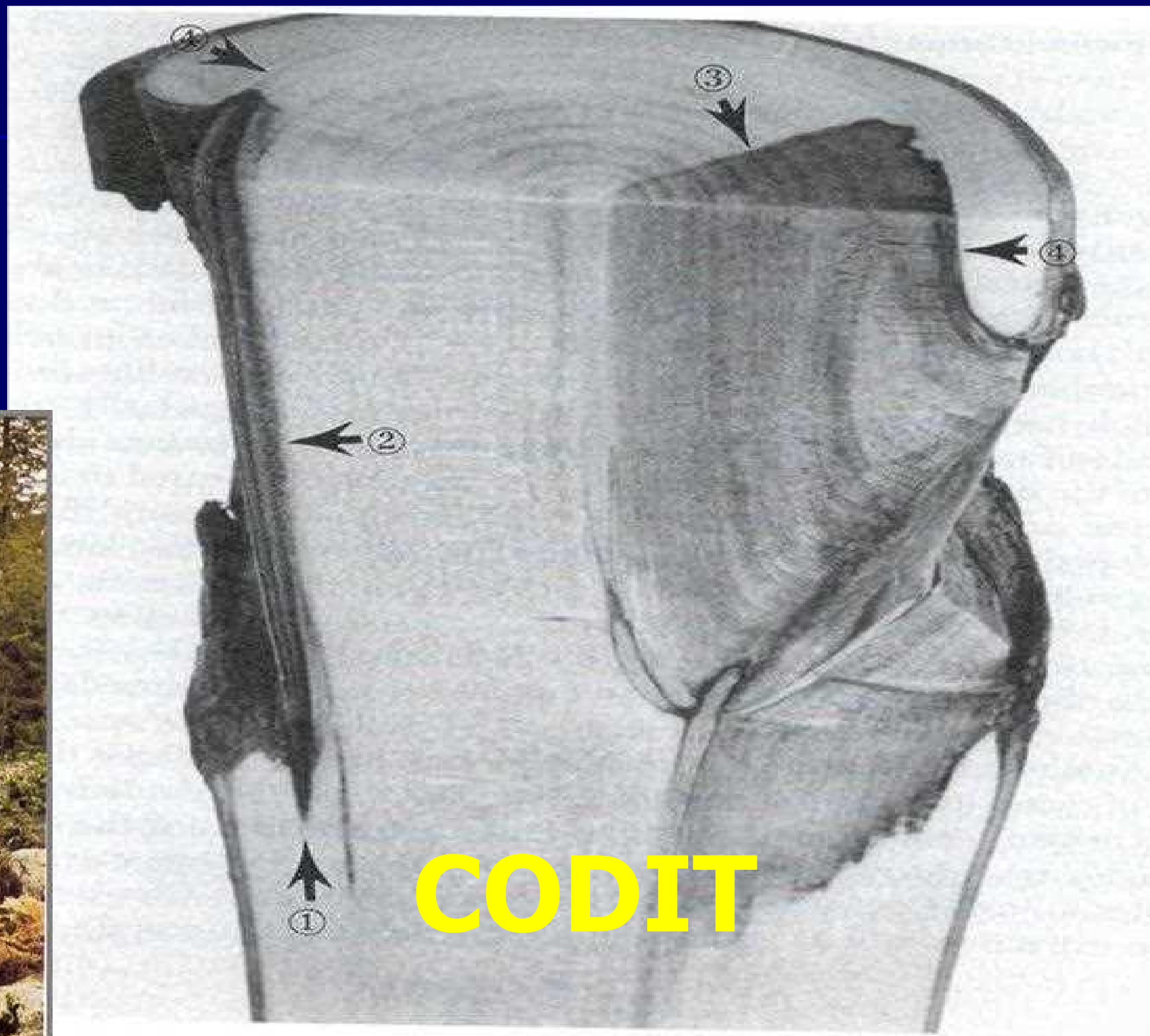
Label the CODIT Walls and List in order of Resistance to Decay



CODIT

Strong to weak

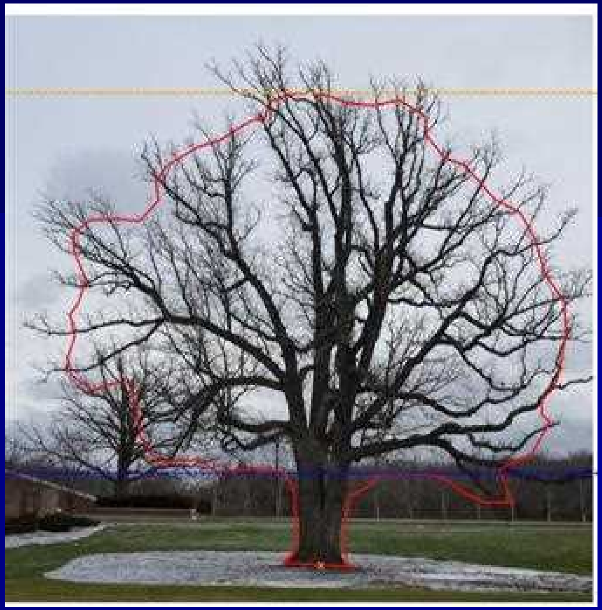
1. Wall 4
2. Wall 3
3. Wall 2
4. Wall 1

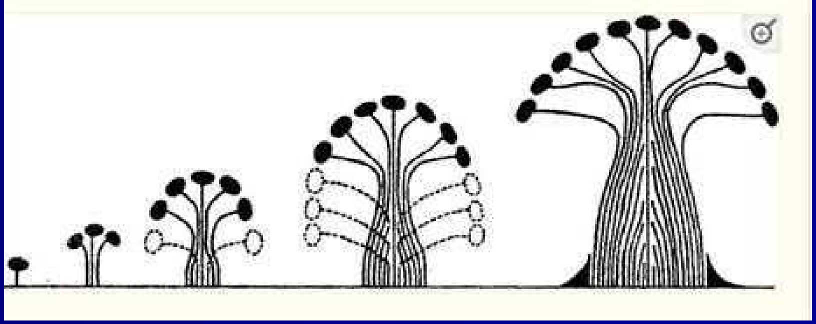


Sapwood Moisture Camp

- **Boddy and Rayner 1983. ORIGINS OF DECAY IN LIVING DECIDUOUS TREES: THE ROLE OF MOISTURE CONTENT AND A RE-APPRAISAL OF THE EXPANDED CONCEPT OF TREE DECAY**
  - Boddy 2021
- "High water content of functional xylem"
- Wood Decay Fungi cannot grow in "aquatic milieu"
  - Oxygen is extremely low
- D in CODIT should be Dysfunction or Damage and not Decay

- Crown reduction reduces functional sapwood
  - Pipe Model Theory
- Allows spread of decay
  - Drying of sapwood
  - Drought

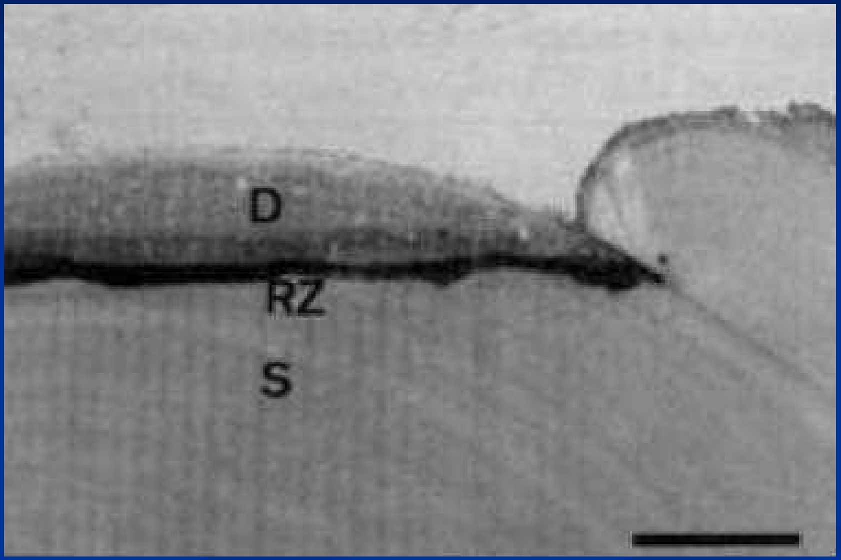




Wall 1-Weakest
Tyloses in Vessels
Formed by Axial Living Parenchyma

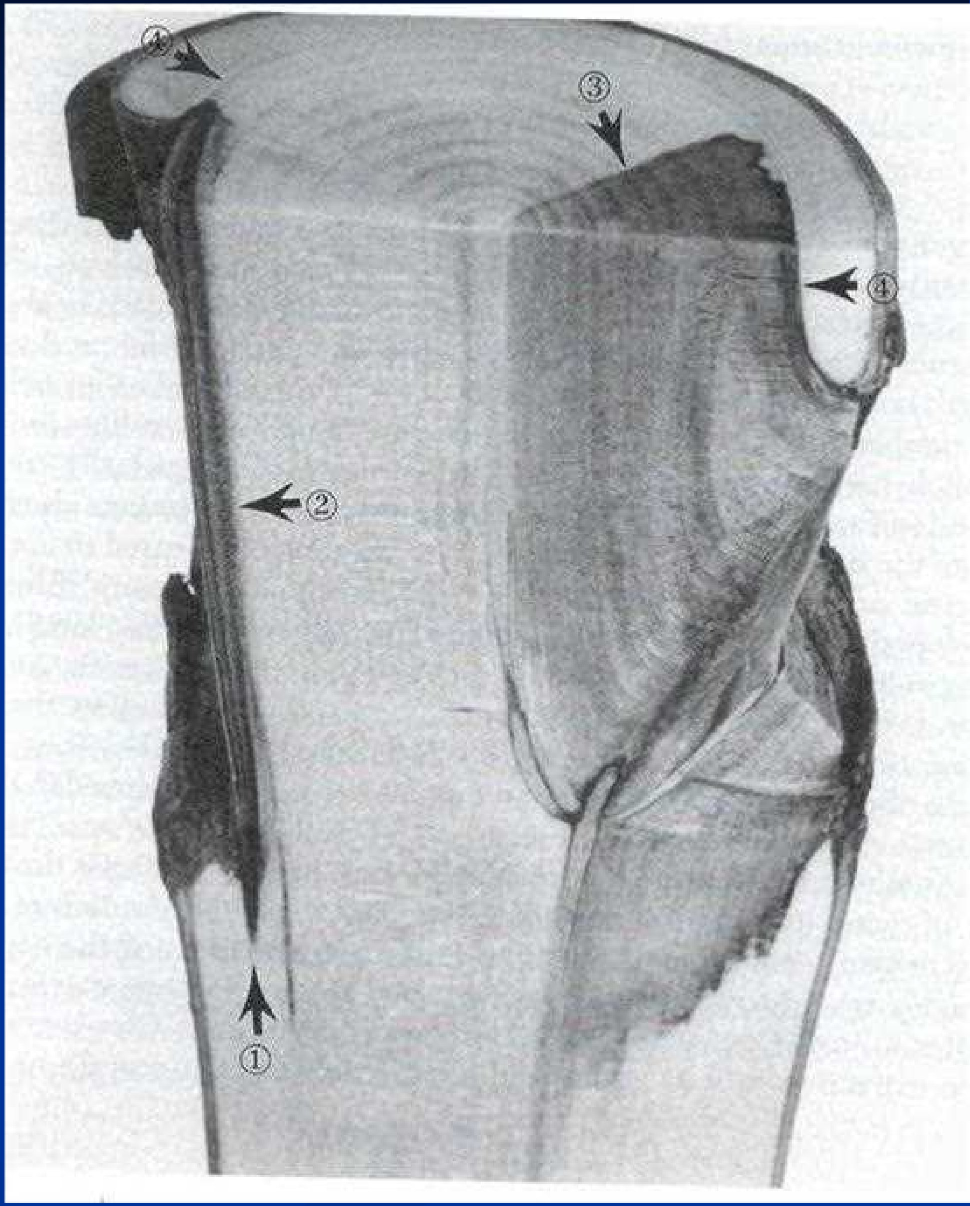
Wall 2 CODIT Details

- Second weakest wall
- Annual rings
  - Latewood
  - Thick walled and highly lignified
- Reaction zone in sapwood when Wall 4 fails
- Heartwood
- Sapwood moisture



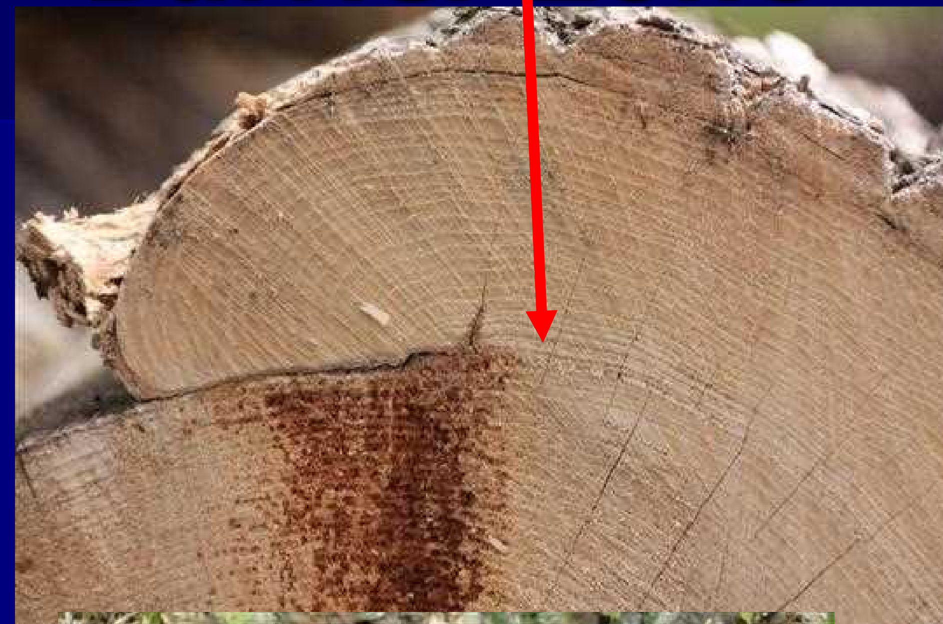
Wall 3
CODIT Details

- Ray Parenchyma
  - Radial
  - Axial
- Second strongest wall
  - Phenolics and free radical
- Will reform along with Wall 1 and 2 if breached
- Strength directly affected by tree health?



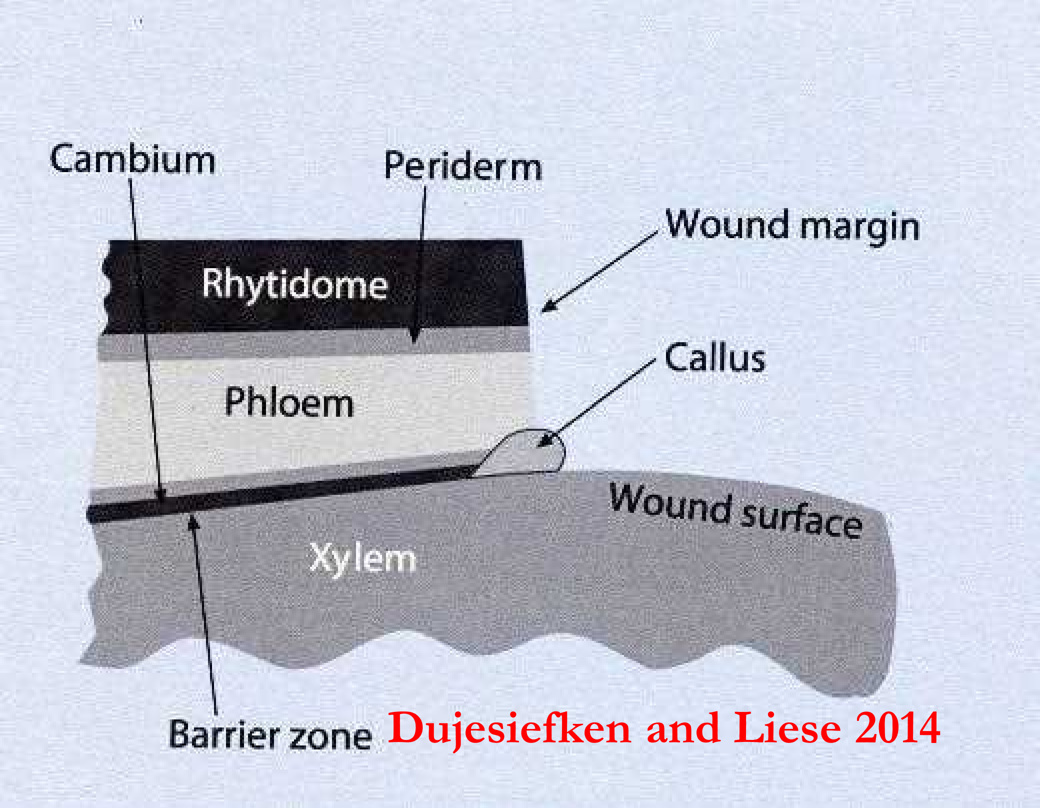
- **WALL 4**
  - **Formed de novo by cambium**
- **Strongest protection layer**
- **Designed to keep new wood free of decay**
  - **Physical boundary**
  - **Chemical boundary**

Barrier Zone



Barrier Zone-formed by cambium Only forms once at a wound site

- High density of parenchyma cells
- High suberin content

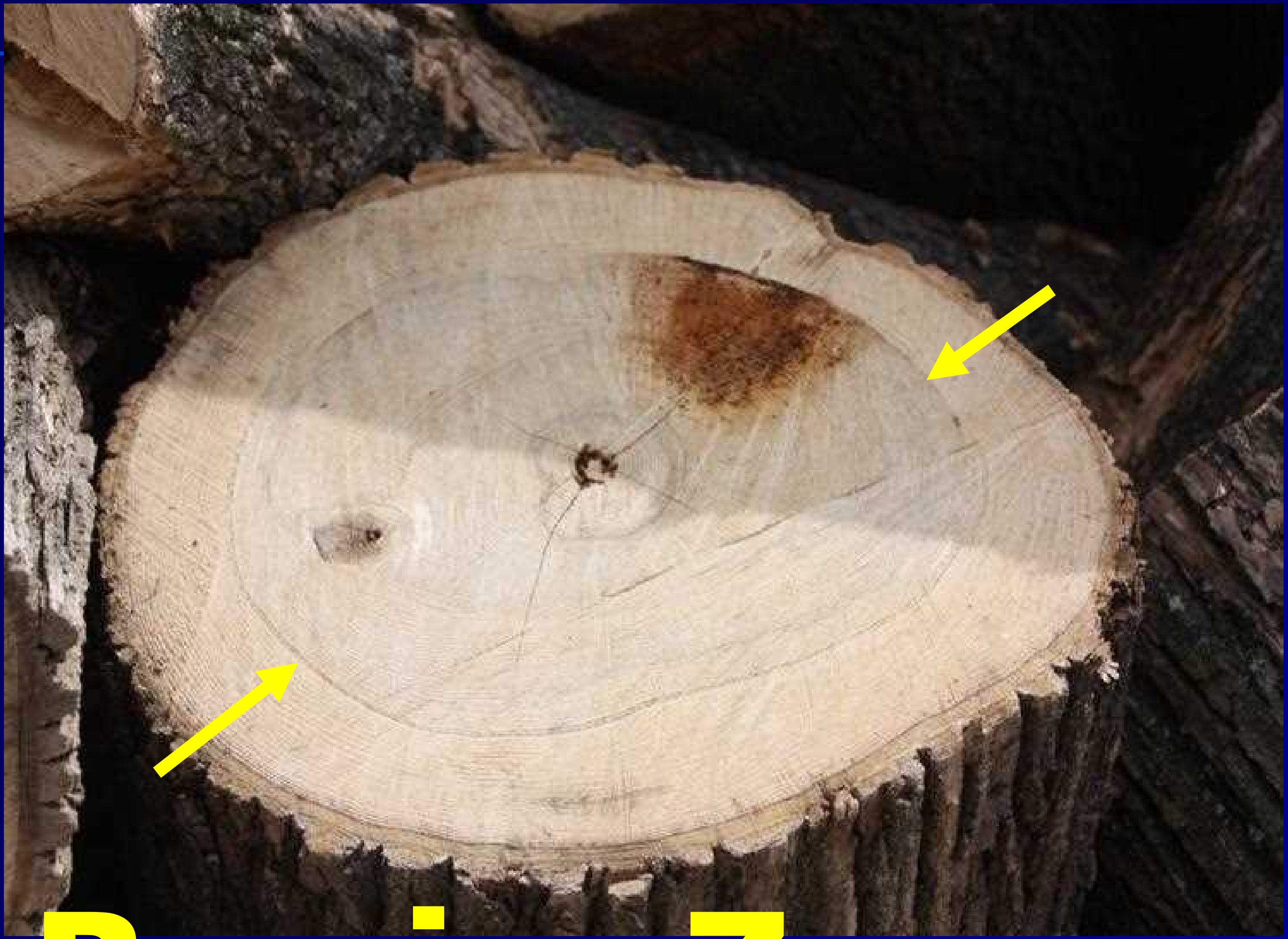


Dujesiefken and Liese 2014

Barrier Zone

- Formed in annual ring present at the time of wounding
- If dormant forms in next ring

Chemically Strong Physically Weak



Barrier Zone

Chemically Strong Physically Weak

Barrier Zone

Barrier Zone Protective Sheath

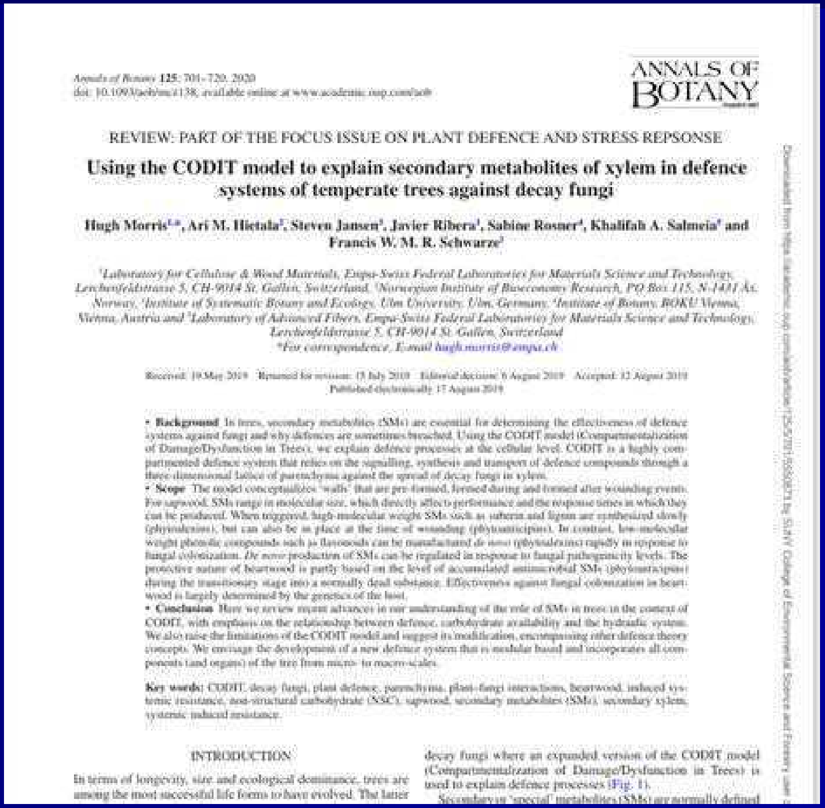
- Highly reactive because of parenchyma cells
  - Produce phenols
- Physical barrier
  - Suberin
- Stronger than reaction zones
- **<u>Most decay fungi can't breach barrier zone</u>**

Most Fungi Cannot Breach Barrier Zone

"Heart Rots"

Levels of Pathogenicity

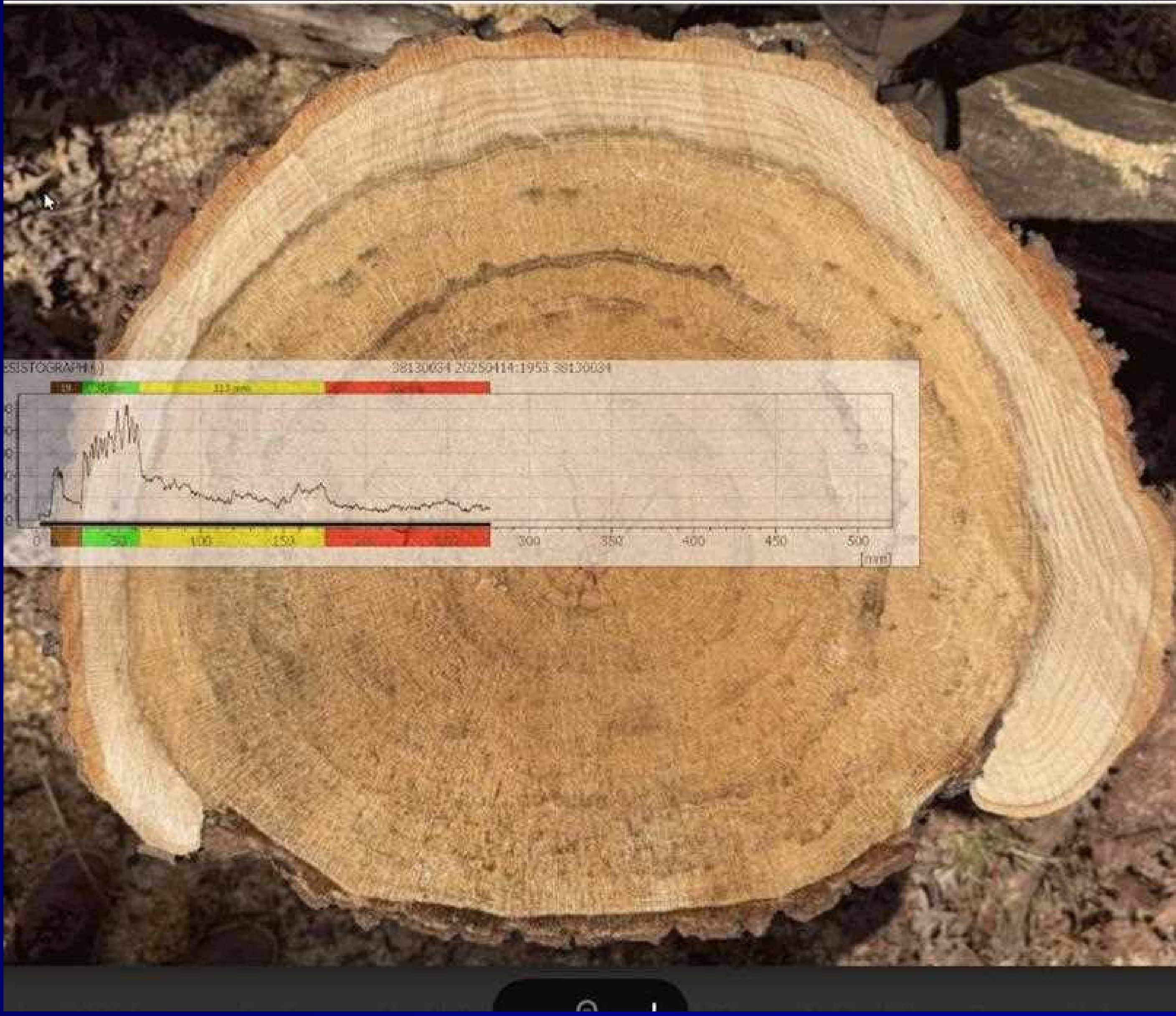
- High level – ability to breakdown *de novo* suberin in parenchyma cell walls or resin in conifers;
  - “Barrier Zone”
- Moderate – the ability to degrade phenols or terpenoids stored and released from vacuoles in parenchyma or the ability to circumvent phenolic compounds by growing in the cell wall in soft rot mode
  - “Reaction zones”
- Low – the inability to breach reaction zones or the barrier zone under normal circumstances.
  - Heart rots or dead sapwood
  - Saprophytes



Inonotus hispidus

- Wall 4 without wounding

-Barrier Zone
-Wall 2

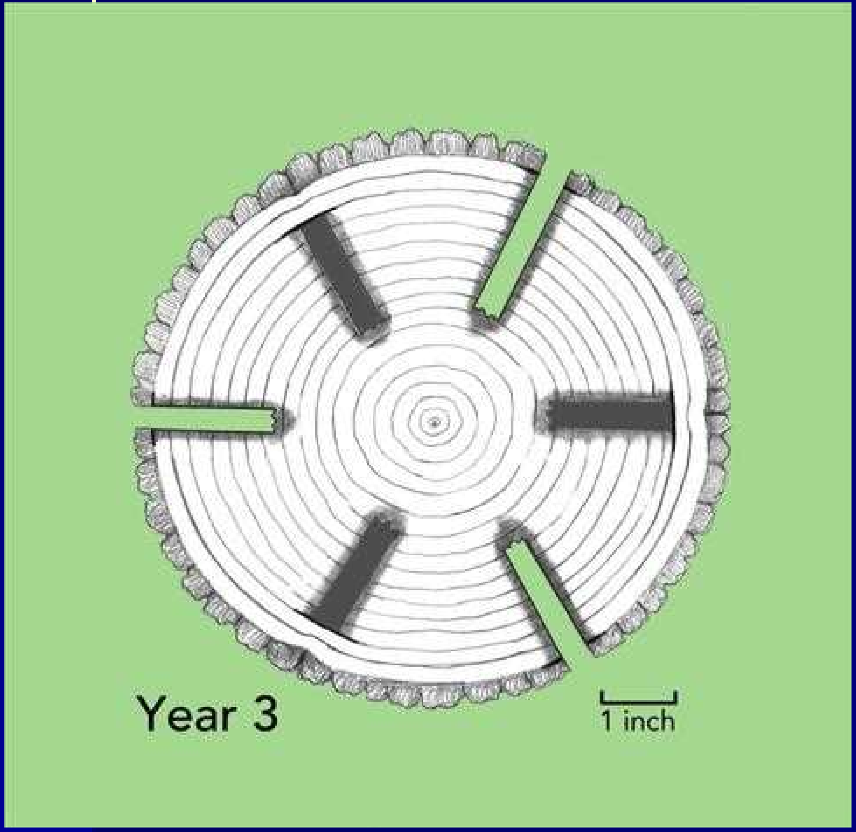


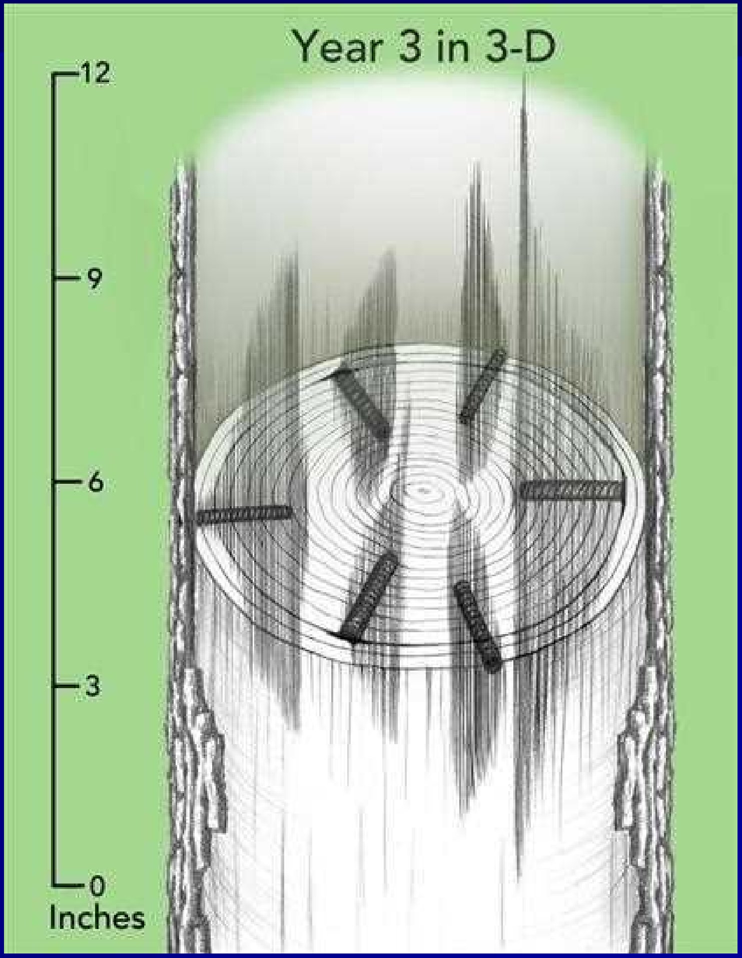
Biological Health
Barrier Zone Strength
Importance of Plant Health Care

Breaching the Barrier Zone can Spread Decay

Tom Smiley, Bartlett Tree Experts

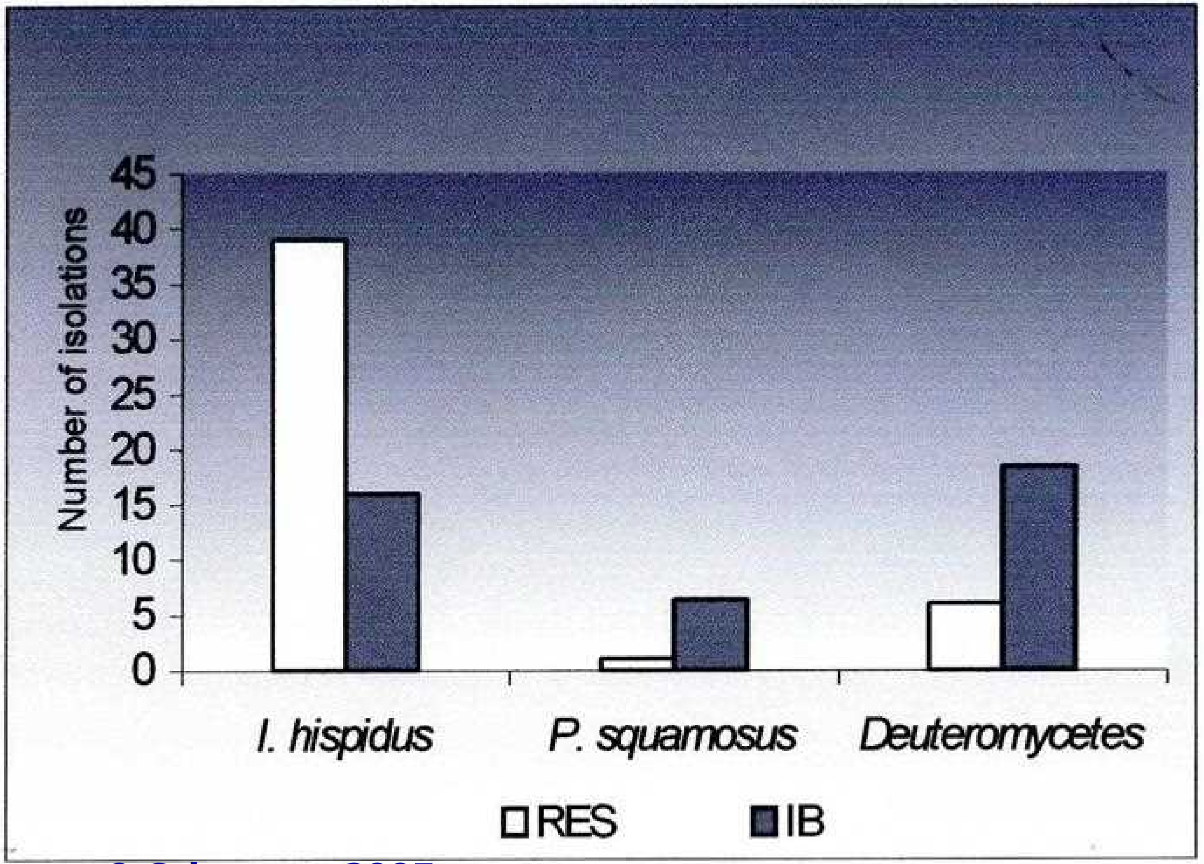
Reaction Zones Tree Injection





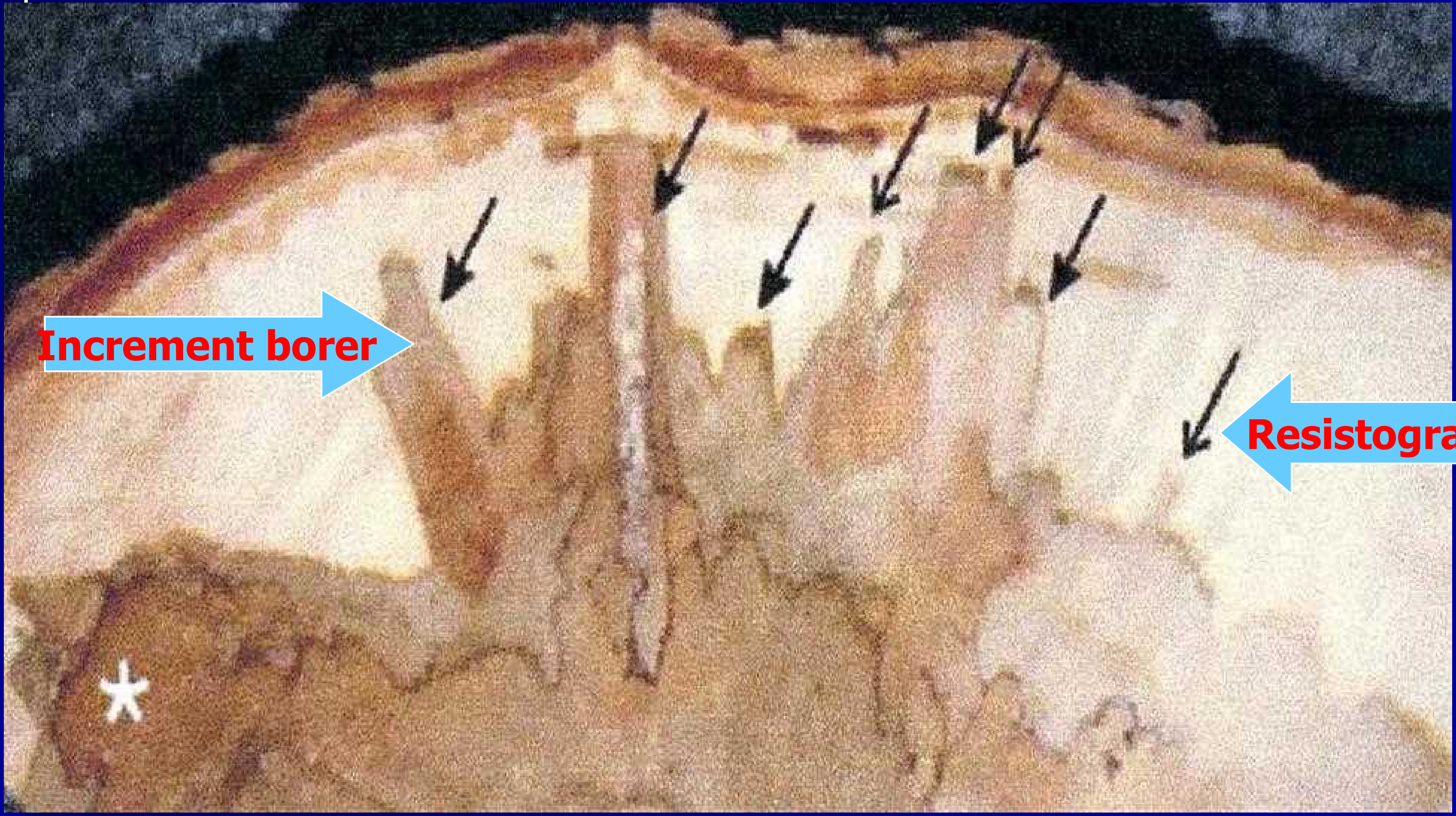
Decay Spreading to Injection Sites

Decay Spread Ash and Plane Tree



Kersten & Schwarze, 2005

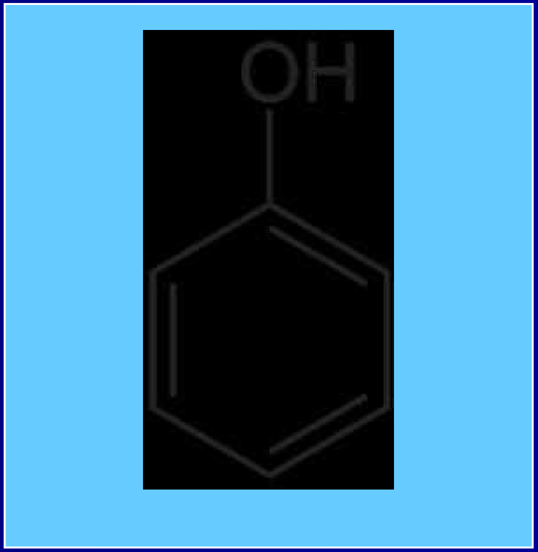
"*Ustulina*" infected tree



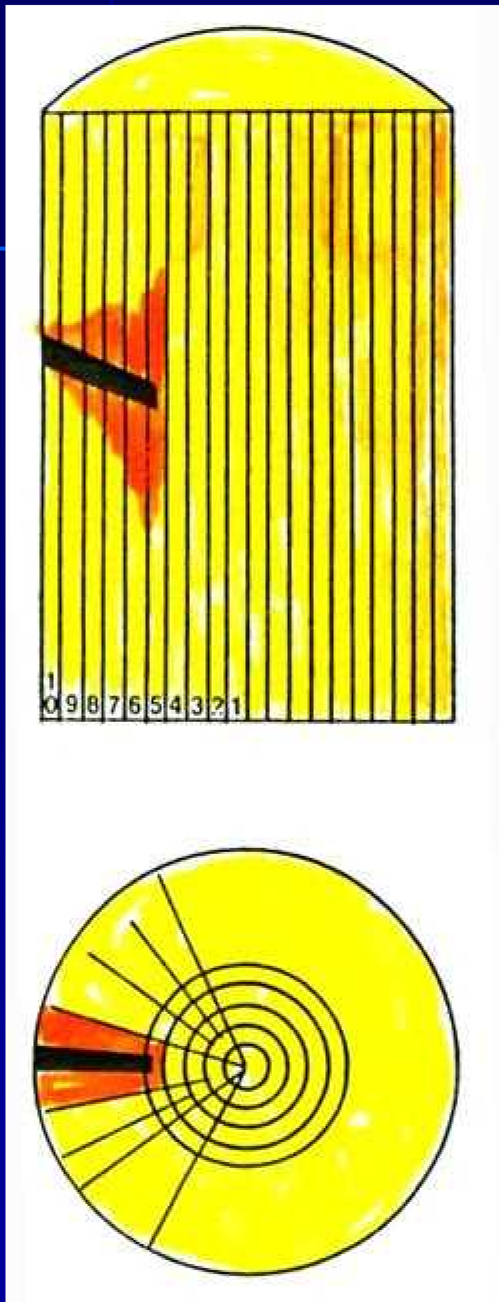
Source: Mattheck C. Undated. Excessive drilling

Reaction Zones

- Formed by parenchyma cells
- Discolored wood
- High concentrations of polyphenolics

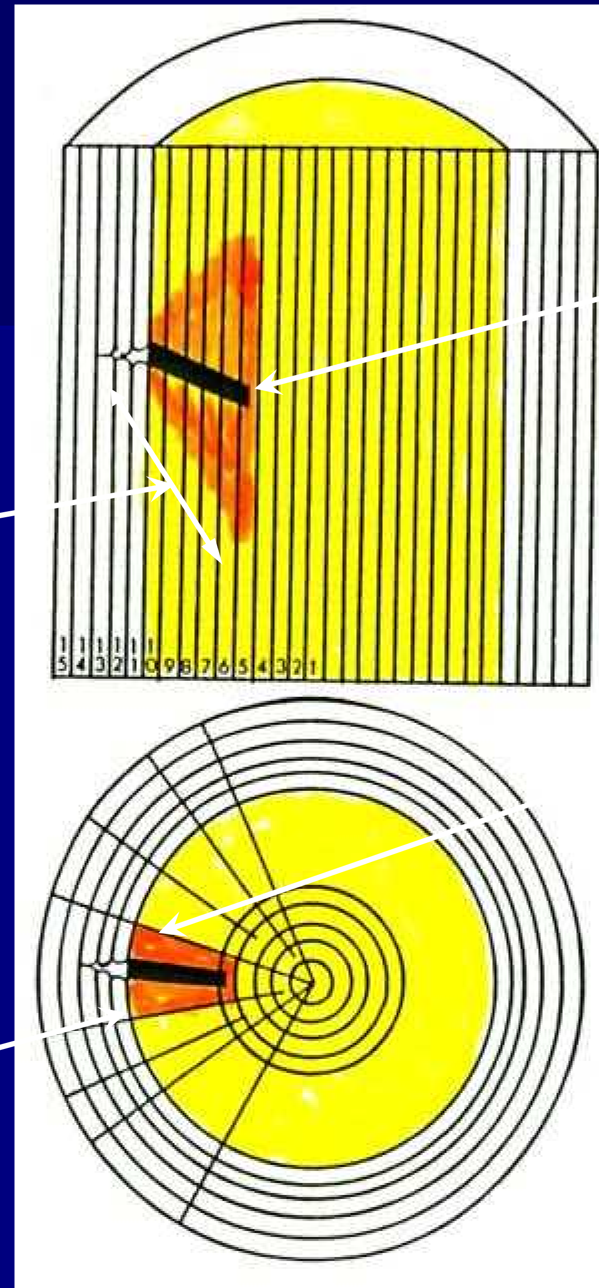


Reaction Zones



Wall 1:
Plugs in
Vessels &
tracheids

Wall 4:
Cells produced
Right after
wounding

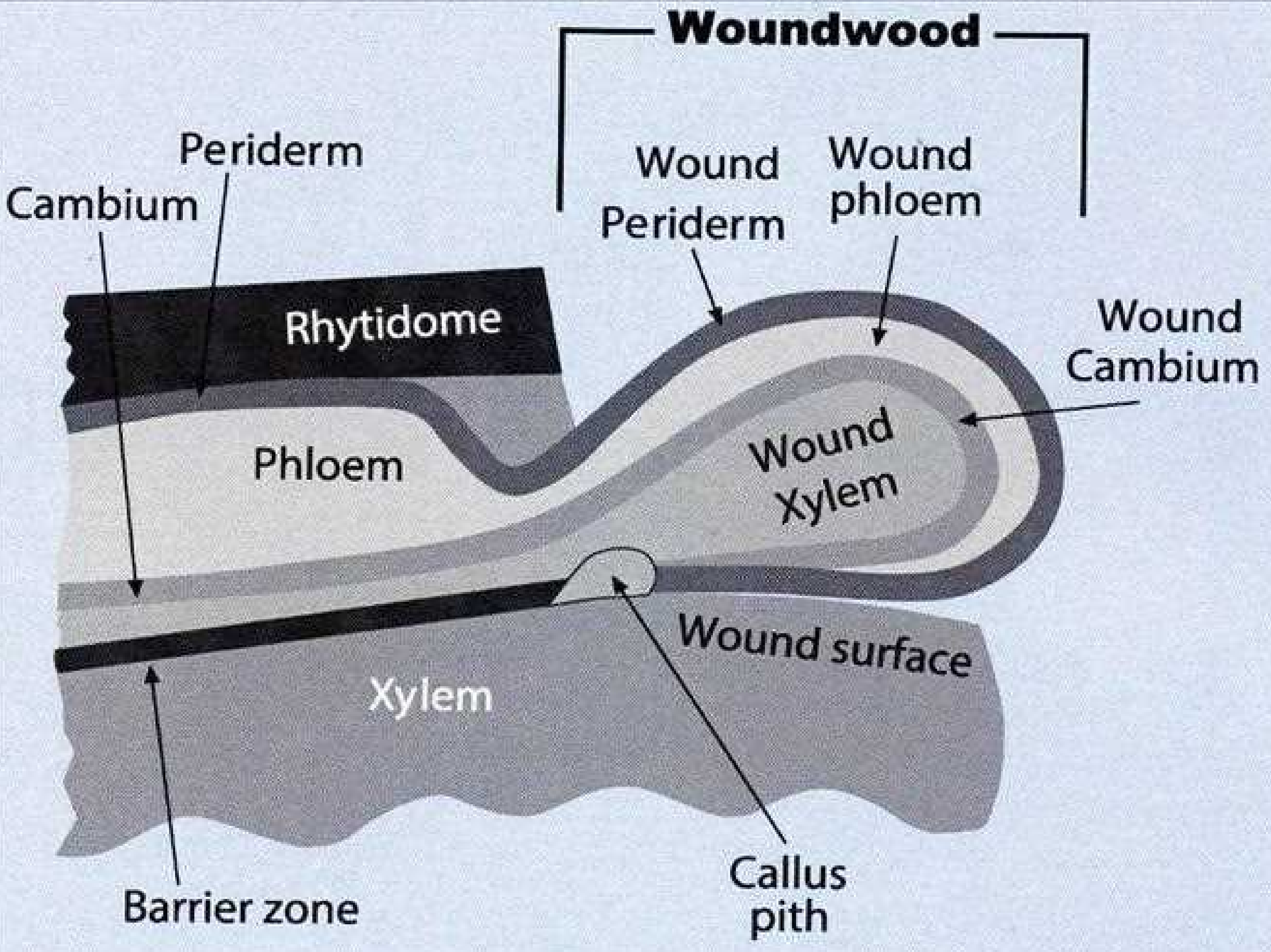


Wall 2:
previous
growth ring

Wall 3:
Rays

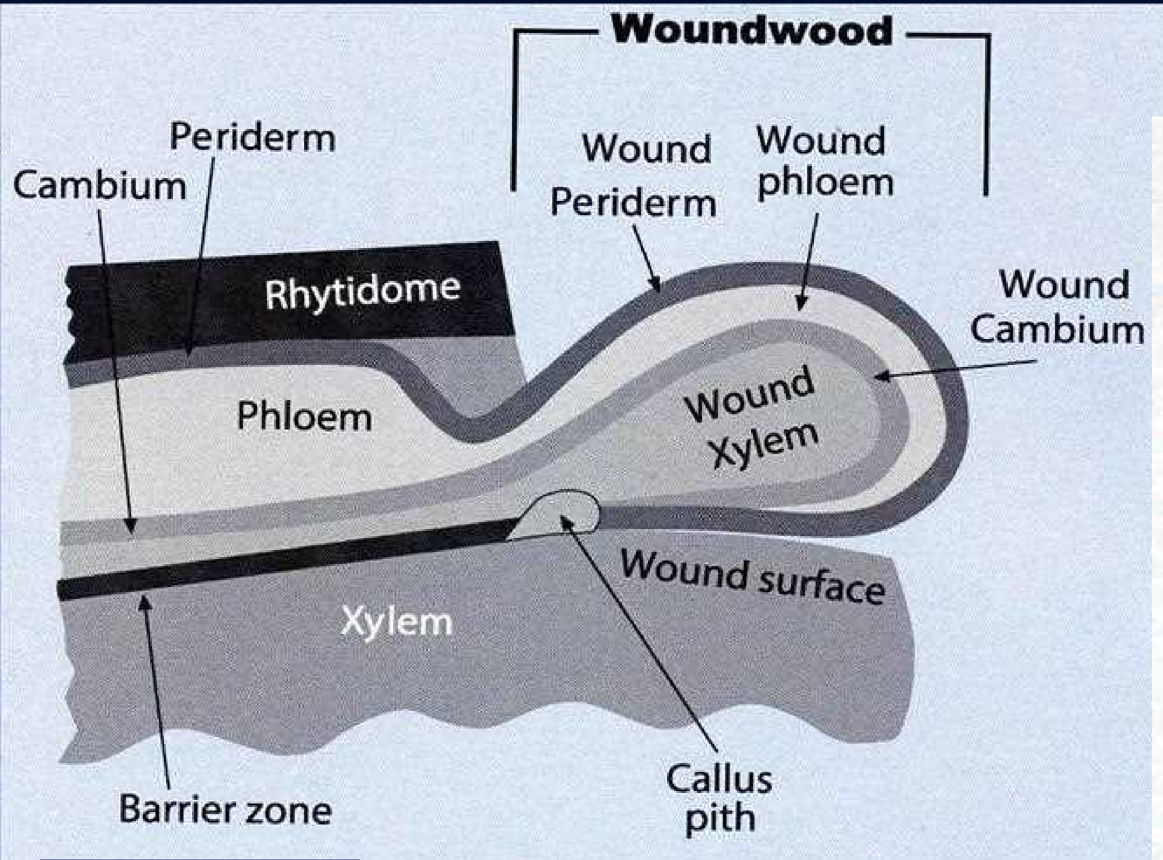
Reaction Zones of a “good compartmentalizer”

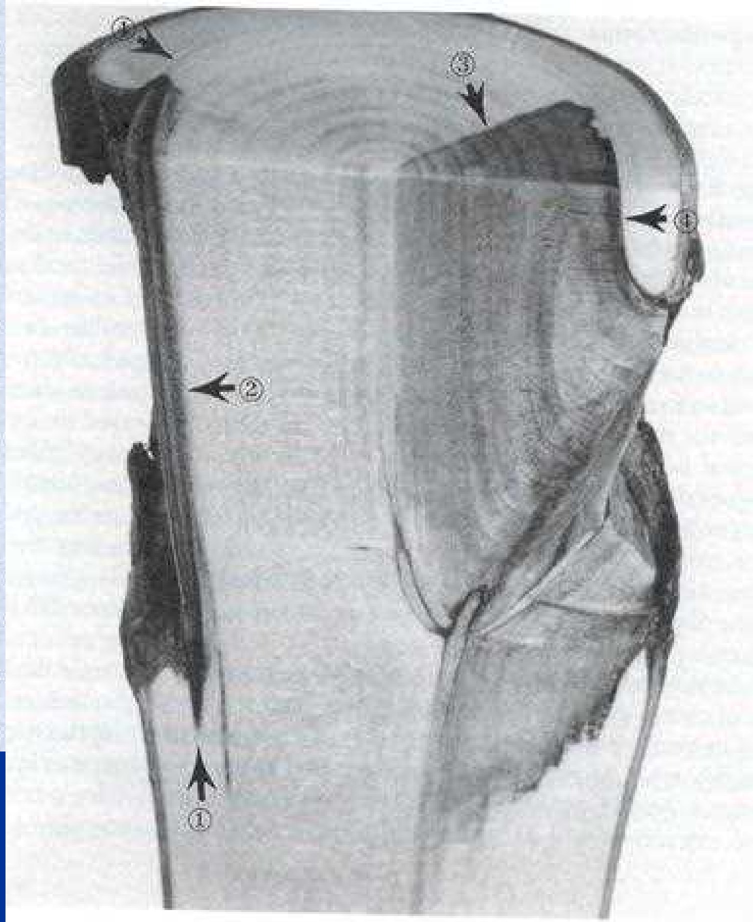
G. W. Hudler

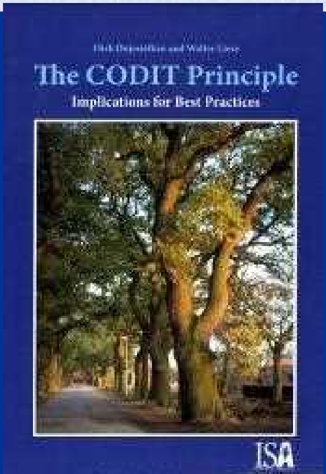

Woundwood
Periderm
Cambium
Wound
Periderm
Wound
phloem
Rhytidome
Wound
Cambium
Phloem
Wound
Xylem
Wound surface
Xylem
Barrier zone
Callus
pith

Decay Management
CODIT and Wound Closure are supported by Biological Health

Absence of Woundwood

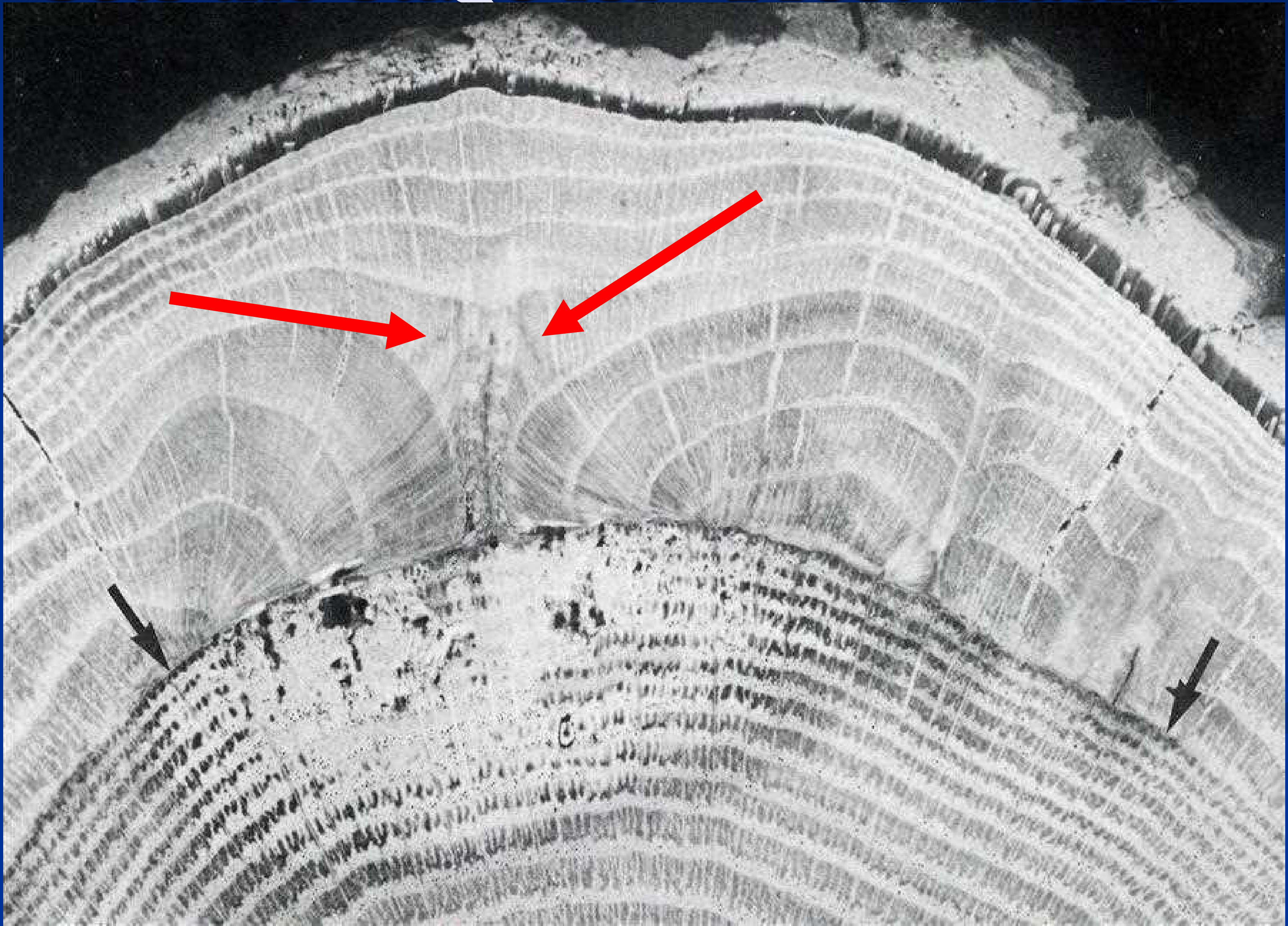

Woundwood
Periderm
Cambium
Wound
Periderm
Wound
phloem
Rhytidome
Wound
Cambium
Phloem
Wound
Xylem
Wound surface
Xylem
Barrier zone
Callus
pith




The CODIT Principle
Implications for Best Practices
ISA

Diagnostics Absence of WW

Woundwood Seals a Wound
Sets the Stage for “Frost Cracks”



Aging Wounds-How about this one?

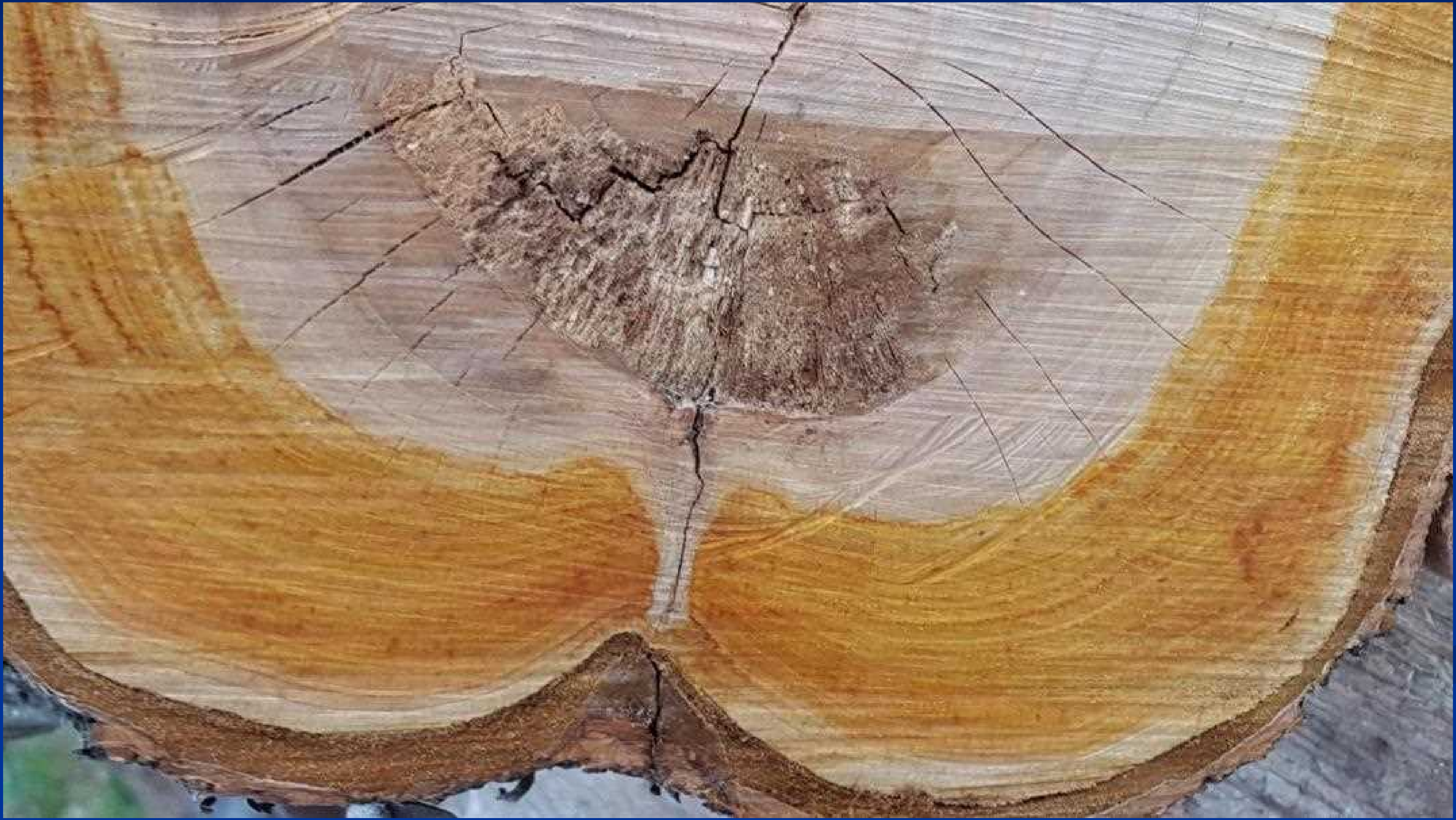
- Small wound 204 years ago
- Tree was estimated to be 600+
- Nicely compartmentalized

Aging of Decay Columns

Wound 23 years ago

- The tree tells the truth

Cracked



“Frost Crack”

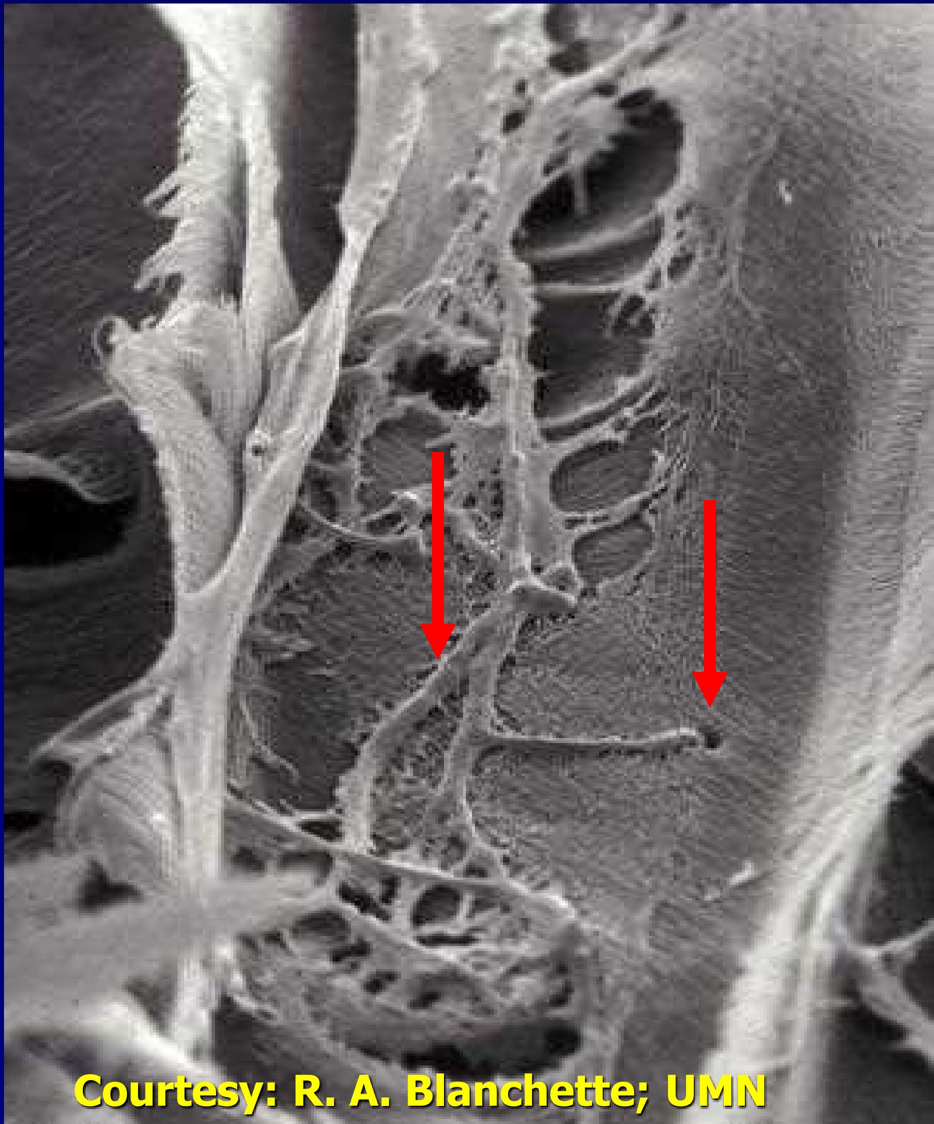
Ribs and “Frost Cracks” Related to old wound and WW Indicate an internal defect, possibly decay

Decay Attack

- Enzimatically digest wood
- Different types of enzymes used by
- White, Brown and Soft Rot

Hyphae + Enzymes

- Decay fungi move in wood via hyphae
- Hyphae secrete enzymes
- Hyphae are 2-5 microns



Mycelium-mass of fungal hyphae

Mycelial mats or felts

Type of Decay

White Rot
Remove Lignin

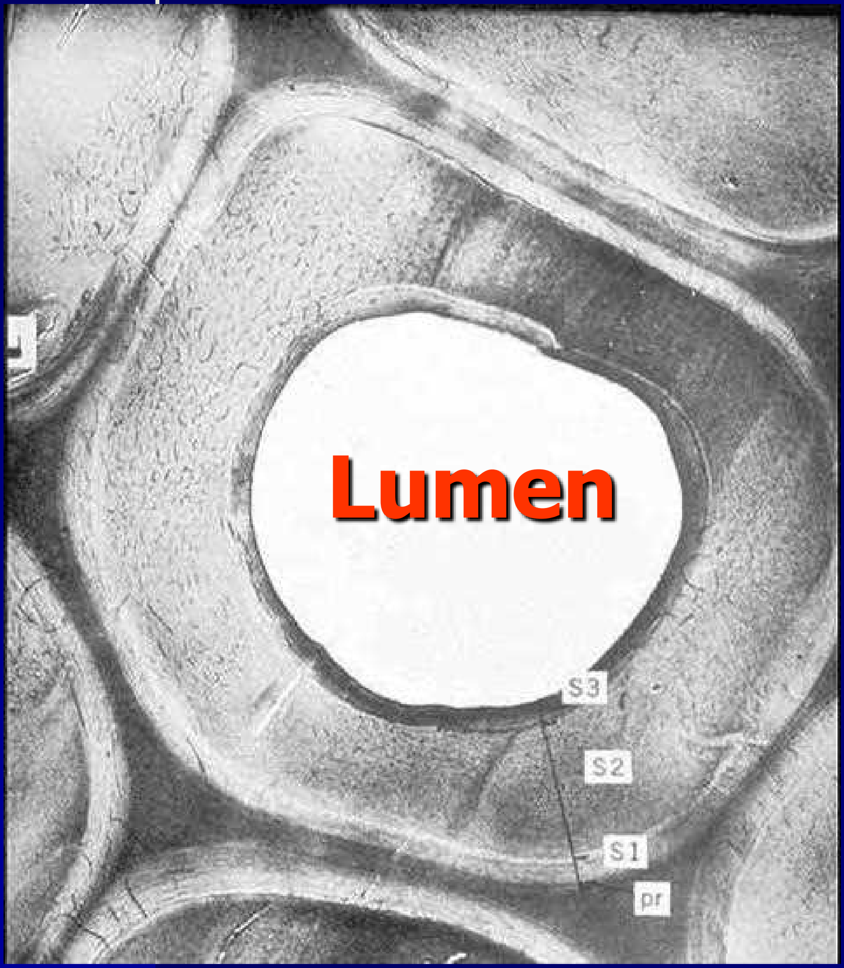
Brown Rot
Remove Cellulose

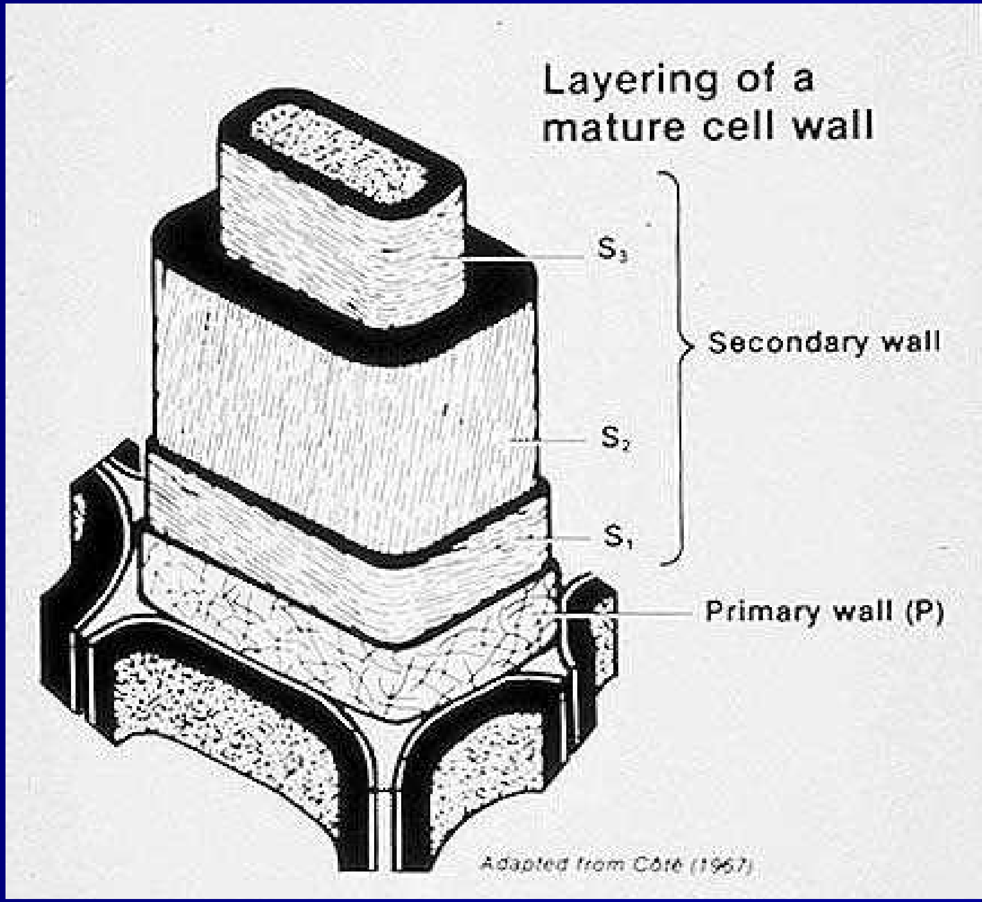
Decay Fungi Attack Woody Cell Wall

~50% Cellulose = long chains of glucose

~25% Hemicellulose = shorter chains of glucose

~25% Lignin = a polyphenol





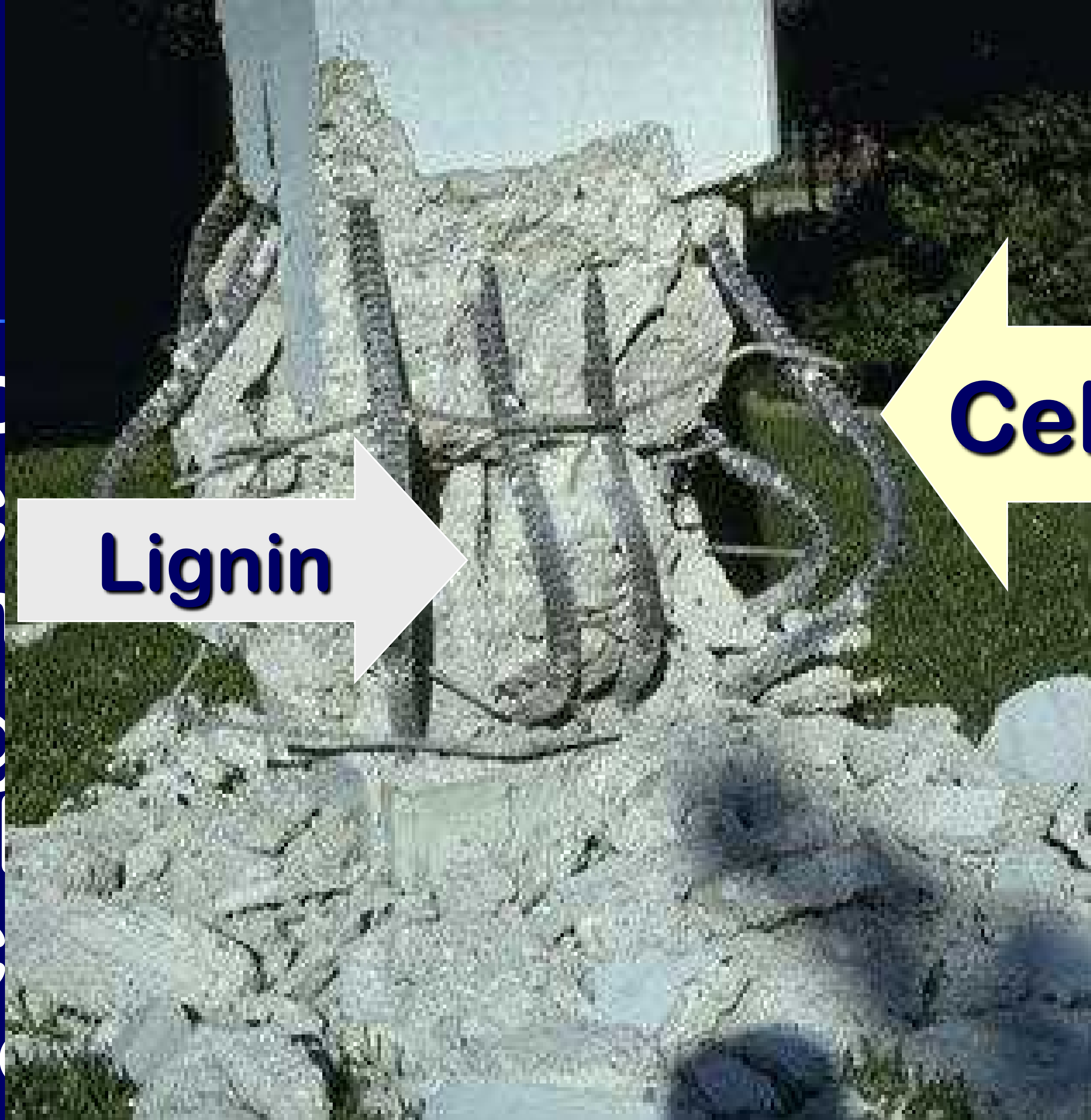
ay

■ Wo

–C ... rong in ... rope

■ Lig ... n cel

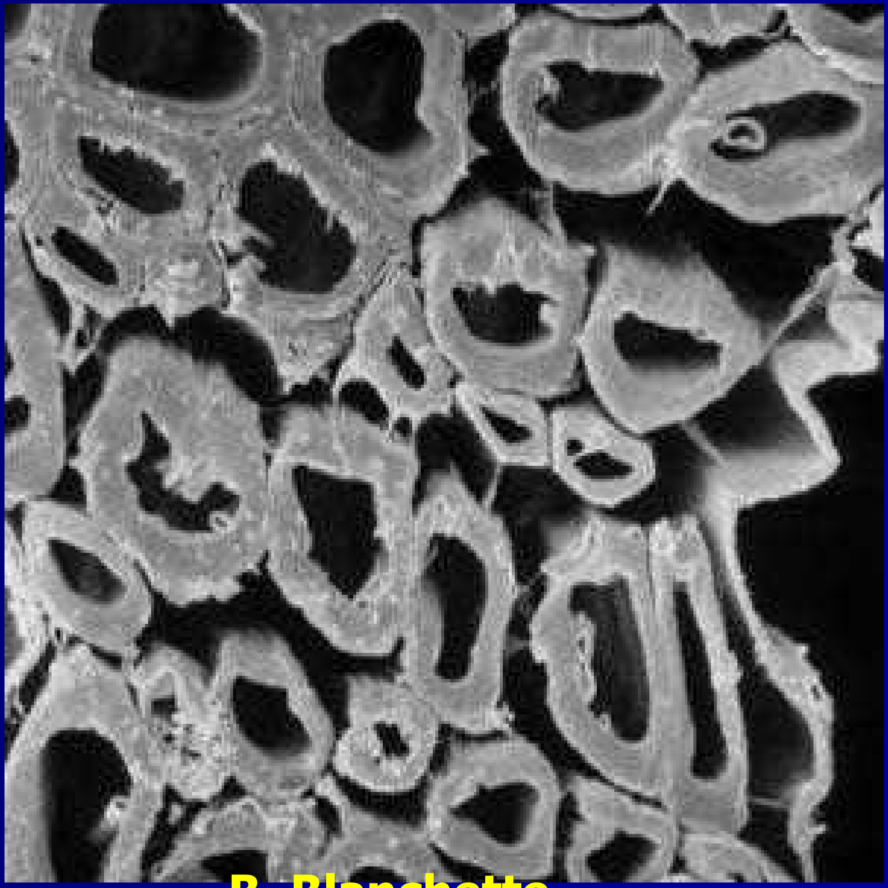
–C c



White Rot Fungi

Remove lignin (brown and stiff)
Secondarily attack cellulose; end of molecule
Reduces compressive strength

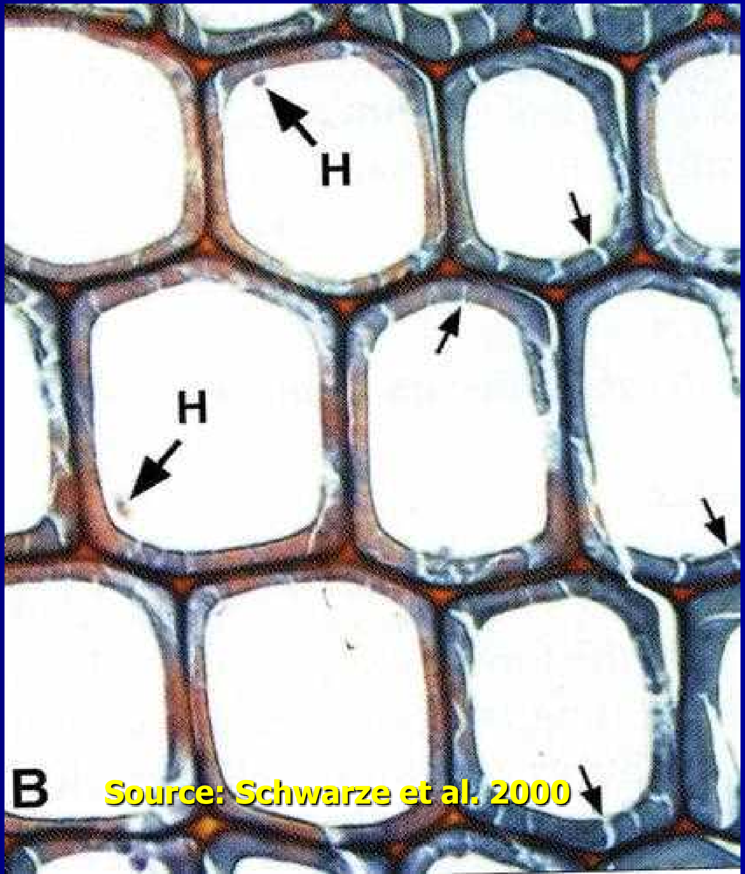
Wood retains some strength in Tension



B. Blanchette

Brown Rot

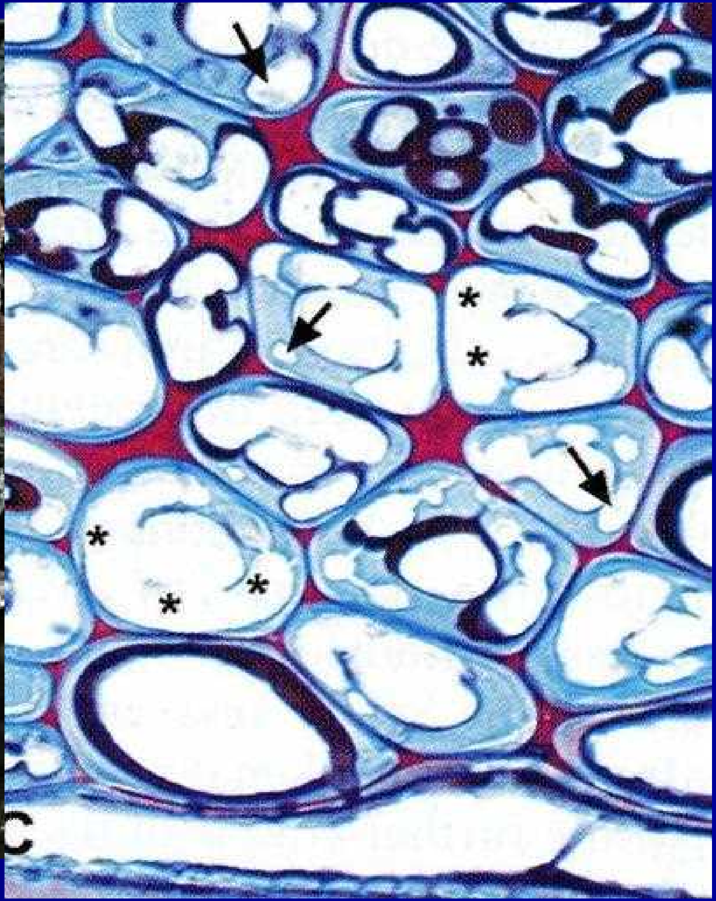
Removes Cellulose-Leave Lignin
Reduce Tensile Strength
Wood Becomes Brittle



Soft Rot Fungi (Ascomycetes)

Removes Cellulose-create bore holes

Reduce Tensile strength



Source: Schwarze et al. 2000

Soft Rot Decay Type

- Chemically similar to brown rots
- Visually similar to white rot
- Mostly caused by ascomycetes
- But also known from some basidiomycetes

Decay Type Significance

- Significant amount of strength loss occurs before wood loses 10% of its weight (Incipient decay)
  - Microscopic detection levels (Wilcox, 1978)
  - Especially brown rots (85% strength loss)
- Most tools are unlikely to detect insipient or early stage decay despite strength loss
  - Especially so for brown rots
- Soft rot is more difficult to detect with resistance drilling

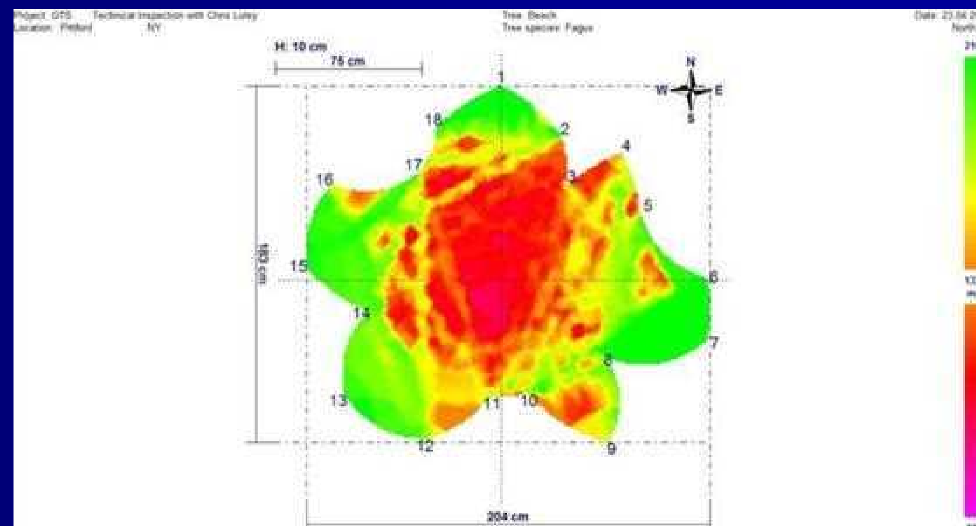
Decay Type Significance

- Trees are more likely to show response (adaptive) growth to white rot decay
- White rot-most common on deciduous trees
  - 1700 wood rotting species
  - 90%+ are white rots
- Brown rots
  - Most common on conifers
  - Coevolution with conifers
  - Seldom see adaptive growth

White Rot on Conifer?

- *Porodaedalea pini*

Seldom Show Adaptive Growth to Brown and Soft Rot



Decay Types

- May occur together
- Simultaneous decayers
  - Remove lignin and cellulose
  - *Meripulus sp.*

Naming Decay in Trees

- Decay is named by location it occurs in the tree

N l

- Simpl
comm nks
are p
- Biolog

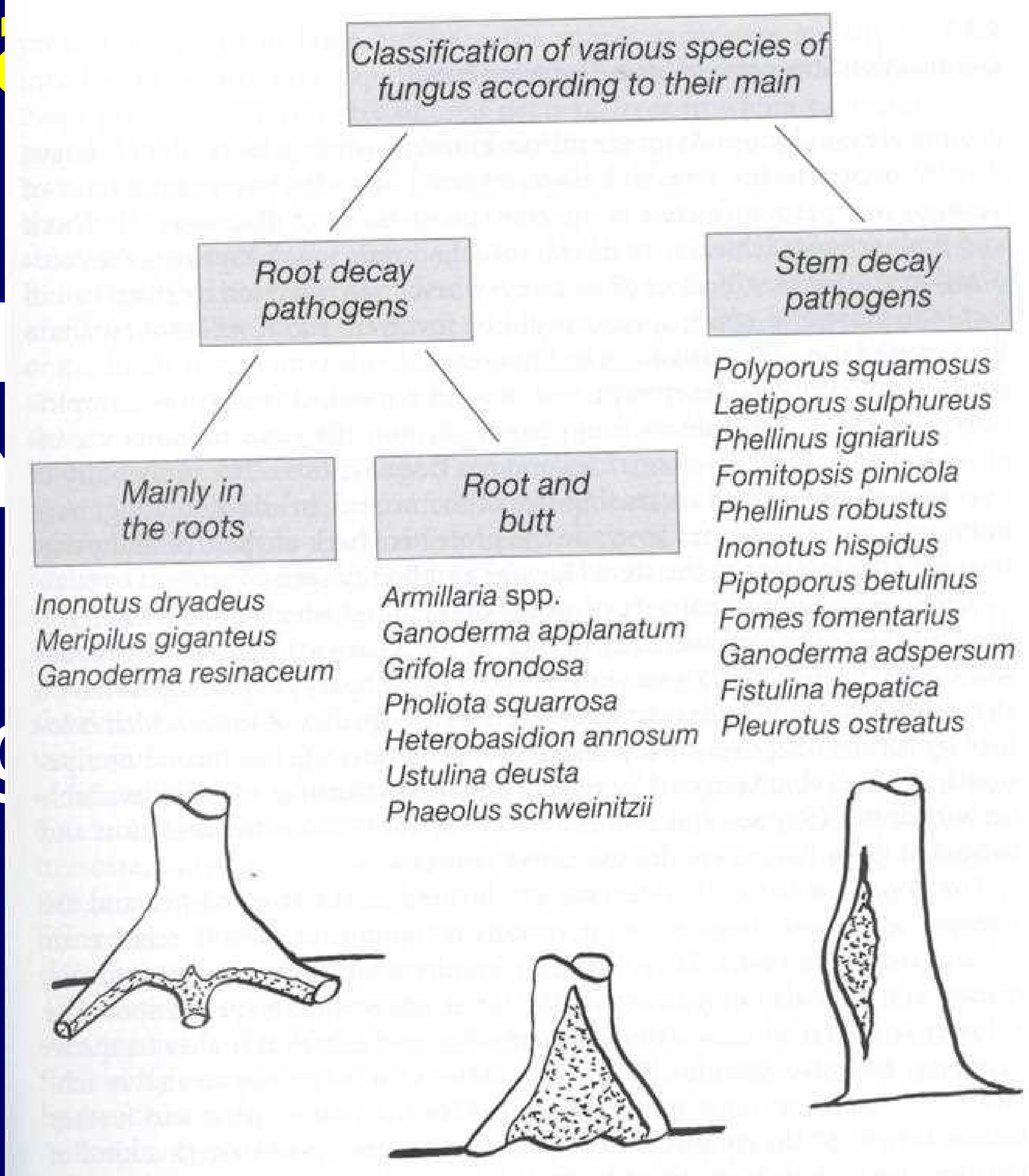


Fig. 17. Classification of various species of fungus according to their main occurrence in the tree

Basic Identification Key
Location of Decay and Conks

s

The following summarizes the individual species of decay fungi in this manual by the portion of the tree the fungus is primarily found decaying and fruiting. The fungi also are presented in order of appearance in the manual. This is a subjective breakdown, as the fungi show general tendencies to attack a particular part of a tree, but at times can be found transitioning to adjacent tree tissue.

Green text = fungi primarily found on conifers; Red text = an ascomycete; and Bold text = one of Big Five.)

Root Rots

Armillaria mellea
Desarmillaria tabescens
Ganoderma curtisii
Pseudoinonotus dryadeus
Meripilus sumstinei
Omphalotus illudens
Xylaria polymorpha
Nonpathogenic on Soil

Root and Butt Rots

Kretzschmaria deusta
Ganoderma sessile
Phaeolus schweinitzii
Climacocystis borealis
Bondarzewia berkeleyi
Grifola frondosa
Laetiporus cincinnatus
Niveoporofomes spraguei
Fistulina hepatica
Pholiota species
Inocutis ludoviciana

Butt and Trunk Rots

Ganoderma applanatum
Laetiporus sulphureus
Fistulina hepatica
Oxyporus populinus

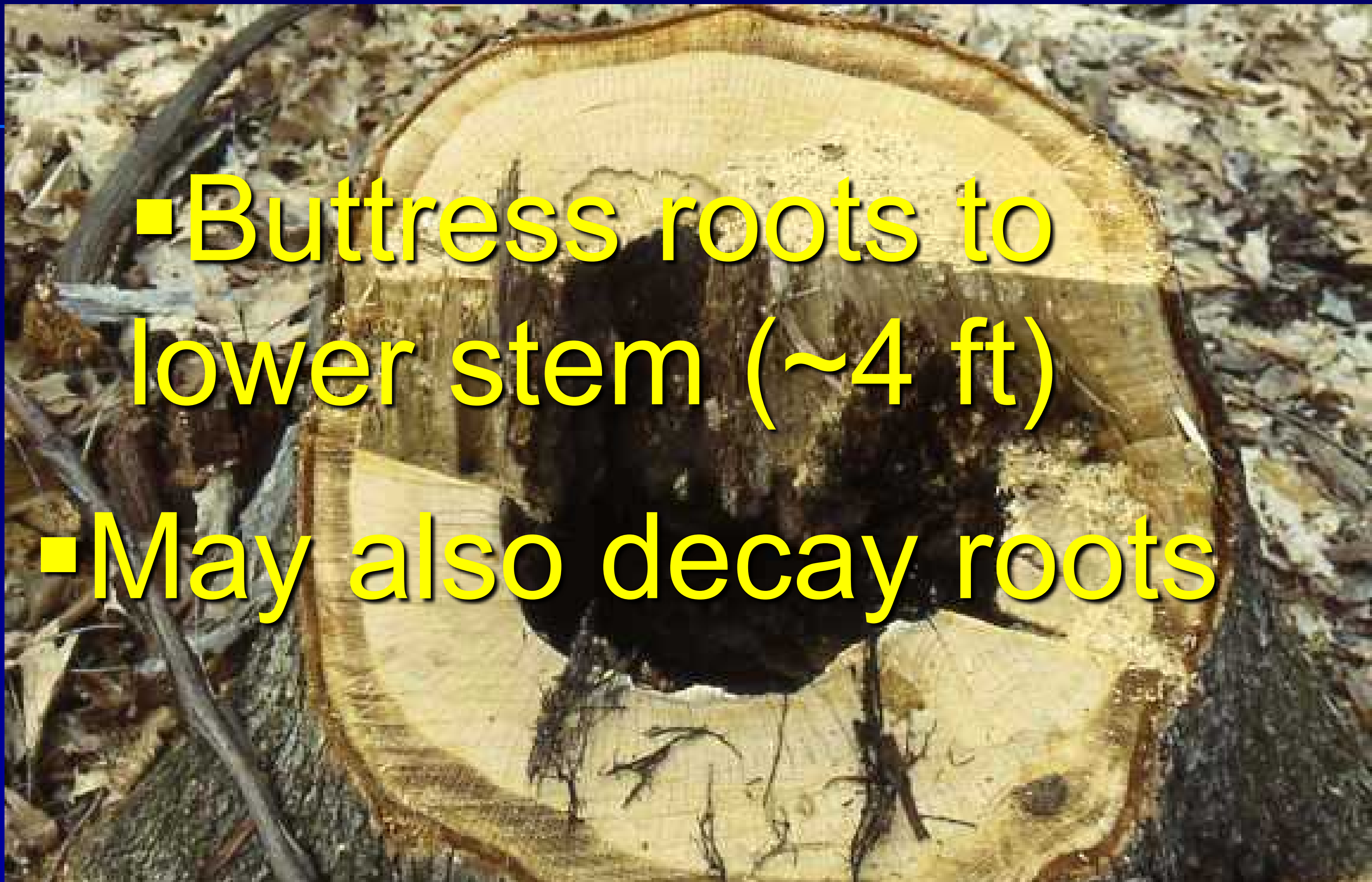
Trunk and Stem Rots

Climacodon septentrionalis
Cerrena unicolor
Daedalea quercina
Globifomes graveolens
Hericium erinaceus
Irpiciporus pachyodon
Inonotus hispidus
Fomes fomentarius
Porodaedalea pini
Inonotus obliquus
Ischnoderma resinosum
Fulvifomes everhartii
Phellinus igniarius
Phellinus tremulae
Fulvifomes robiniae
Pleurotus species
Cerioporus squamosus
Hypsizygus ulmarius
Saprophytes on Living Trees (*Daldinia childiae; Volvariella bombycina; Bjerkandera adusta*)
Saprophytes on Dead Trees (*Fomitopsis betulina; Cryptoporus volvatus*)
Bark Inhabitants (*Aleurodiscus wakefieldiae* and *Dendrothele* species)

Branch and Sapwood Rots

Irpex lacteus
Schizophyllum commune
Splanchnonema platani


▪Restricted to Roots
▪Most also decay butts



- Buttress roots to lower stem (~4 ft)
- May also decay roots

Trunk Rot

- Main trunk and larger diameter branches

Branch Rots

Significance of Conks

- All conks are <u>positive</u> indicators of decay