UNIVERSITY OF GEORGIA
Warnell School of Forestry & Natural Resources

Publication WSFNR-22-82C

November 2022

Tree Anatomy: Xylem Increments

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Trees show periodicity in growth. Root and shoots tend to take turns elongating and expanding in episodes during times of favorable growing conditions. As different parts of a tree elongate, other parts are actively initializing growing points and consolidating resource transport corridors. When above ground and below ground environmental conditions are not favorable for growth, resting criteria are placed over tissue activity. Sensors and timers continue to function as long as cells are living and connected to all other living cells within a tree.

Seasonality

Favorable growing conditions are essential for effective tree growth. Conditions in the atmosphere and below the soil surface are very different under the same climatic changes. The idea of a growing season is used to show when trees are elongating or expanding tissues. Usually a growing season is used to symbolize visible activity in above ground portions of a tree. The opposite of a growing season for a tree top is a dormant season. Growing season and dormant season alternating periods are primarily caused by warm / cold and wet / dry climatic cycles over four months to several years.

Defining a tree growing season requires an appreciation of the diversity of sites under highly variable condition where tree forms grow. Tree growing seasons are composed of intermittent periods of growth (coordinated longitudinal and radial expansion of woody tissues) among rest periods, with growth episodes caused by rain / dry, warm / cold, and/or internal dormancy / activity cycles. Seasonal elongation of twig and root tips, and seasonal expansion in girth by all woody tissues and periderm, are the most easily seen and mesured aspects of tree growth.

Rings

One easily visualized growth measure of a tree is girth expansion of woody tissues through activity of a vascular cambium. A history of this circumference / diameter expansion can be seen using increment cores or by cutting cross-sections perpendicular to the longitudinal axis (axial) of any woody tree component. The resulting view is a two dimensional approximation (biological shadow) of a three dimensional growth increment surrounding and over the last growing season's growth increment. Figure 1. For a given diameter, the wider an annual increment appears in cross-section, the greater growth and assimilation of growth resources it represents.

Transitions

In any cross-section, the largest conducting vessels can be either clearly visible to the unaided eye or can be minutely small. Due to shoot growth rates and timing, and leaf expansion periods, different growth conditions affect vessel size and xylem composition. Xylem formed under the influence of rapid shoot growth and leaf expansion tends to have larger-sized components.

The first xylem developed in a growth period is considered "earlywood." As growth slows and environmental constraints initiate changes within a tree, later xylem components may rapidly decrease in cross-section size, gradually decrease in size, or stay roughly the same throughout the growing season. This later formed xylem is considered "latewood." Visible features differentiating earlywood from latewood within a single growth increment cross-section is the basis for xylem porosity classifications in *Angiosperms.* Old, inaccurate, and improper terms for earlywwood and latewood have been lightwood / densewood, and springwood / summerwood.

Boundary

The transition between earlywood and latewood withn one growth increment defines xylem porosity forms. The forms are separated from each other by how slowly or abruptly vessel diameters change from the beginning of growth to the end of growth for any growing season. Transitions within one growing season's xylem growth increment, between earlywood and latewood, can be summarized into five boundary types. The boundaries between earlywood and latewood can be described as:

1) sharp boundary in ring porous *Angiosperms*; (Figure 2)
2) relatively sharp boundary in semi-ring porous *Angiosperms*;
3) relatively gradual boundary in semi-diffuse porous *Angiosperms*;
4) no discernable boundary in diffuse porous *Angiosperms*; (Figure 3) and,
5) any type of boundary in non-porous *Gymnosperms*.

Ringed

A seasonal (annual) xylem growth increment, where initial growth is composed of large diameter vessels quickly changing to small vessel diameters producing a distinct beginning and end are called ring porous. The ring porous term is reserved for *Angiosperms* although some *Gymnosperms* (like Southern yellow pines) with strict determinant growth may generate distinct earlywood and latewood xylem increments. Example ring porus trees include: <u>Castanea</u>, <u>Catalpa</u>, <u>Celtis</u>, <u>Fraxinus</u>, <u>Gleditsia</u>, <u>Morus</u>, <u>Quercus</u>, <u>Robinia</u>, and <u>Ulmus</u>. Figure 4.

Diffused

Annual xylem growth increments, where little or no differential in vessel cell diameter occurs throughout a growing season, are called diffuse porous. The diffuse porous term is reserved for *Angiosperms* although many *Gymnosperms* present little or no diameter difference in tracheid diameters across a growth increment. Example diffuse porous trees include: <u>Acer</u>, <u>Betula</u>, <u>Carpinus</u>, <u>Fagus</u>, <u>Liriodendron</u>, <u>Platanus</u>, <u>Populus</u>, and <u>Pyrus</u>. Figure 5.

The Middle

In *Angiosperm* trees there are two intermediate forms of seasonal xylem growth increment shown in earlywood / latewood transitions. The first intermediate increment transition form is called semi-ring porous.

Semi-ring porous increments have few large earlywood vessels gradually declining in diameter across the increment into latewood. Example genera with semi-ring porous growth pattern include Juglans, Sassafras, and Diospyros. Figure 6.

The second intermediate increment transition form is called semi-diffuse porous. Semi-diffuse porous transitions have many small diameter earlywood vessels which decline gradually in diameter to even smaller diameter vessels into latewood. Example genera with semi-diffuse porous growth pattern include Populus and Salix. Figure 7.

Not The Same

The type of growth increment porosity and associated shoot growth form, carries some adaptive advantages and have been genetically selected for over time. Porosity type is not necessarily the same throughout a tree. Because growth ring width is highly correlated with water availability, and a ring-porous growth form is associated with survivability under summer droughts and cold winter temperatures, (i.e. water transport is up to ten times faster in ring porous trees versus diffuse porous trees) ring-porous growth increments can be found in above ground portions of some trees.

These same ring-porous trees may have variously porous roots. Cellular types and proportion may stay relatively stable from shoot tip to root tip, but ring-porous architecture of shoots may grade into diffuse porous architecture of roots near root ends.

Non-Porous

The fifth form of seasonal xylem growth increment is found only in *Gymnosperms* and is called non-porous. *Gymnosperms* have no true vessels or pores (only trachieds) visible in cross-section and are considered to be non-porous regardless of xylem increment cross-section appearance. Some Southern yellow pines, for example, have distinct early and latewood boundaries, but are still termed non-porous.

Resin ducts or canals can be associated with both axial and radial parenchyma, but are not to be confused with vessels. Some resin ducts are common vascular features, while some are initiated by injury. Pitch pockets, usually associated with increment terminations may appear like large vessels.

Endings / Beginnings

Because trees generate new seasonal growth increments to the outside and over the top of past growing season growth increments, girth continues to increase with time. The thickness of each seasonal xylem increment is dependent upon many factors of tree health, environmental constraints, and availability of resources. The width in cross-section of a seasonal xylem growth increment depends upon its location.

To count seasonal xylem growth increments, each increment must be visually distinct from the previous and next increment. Determining the end of one growth increment and beginning of the next can be shown by vessel porosity changes (vessel diameters) within each growth increment and by the uniqueness of each terminal boundary layer between growth increments.

There are three terminal boundary layers most common in trees summarized as:

- A) a flattened line (squashed elliptical-shaped, radially flattened cells);
- B) fat line (cells with thicker than normal walls); and,
- C) different cell bands (high concentrations of axial parenchyma (marginal apotracheal parenchyma band), or thick-walled fibers with normal or compressed appearance.

Increment Width Anomolies

There are two relatively common seasonal xylem growth increment anomalies. The first is called false ringing. A false ring (growth increment) is one seasonal growth increment formed in a multiple shoot growth period (and associated multiple cambial growth spurts) which generate multiple xylem increment growth periods within one growing season. Insect attack and recovery, flood and drought, and strong fluctuations in growth resources several times within a growing season can cause false rings. False ringing is most prevalent in branch-wood and near the base of the living crown. It is rare in trunks, but can occur. False rings make growth increment counts (aging) highly inaccurate.

A second increment anomoly is called a mini-ring. Mini-rings occur in growing seasons with extremely poor growth conditions when only a thin truncated growth increment is generated (only the first set of cells divide and expand), or when no growth increment at all is visible in marginal branches, rapidly declining trees, cambial damage areas, or growth regulation disruption / destruction zones.

Reactivity

One feature of new xylem generation is its modification in strength and resistance to mechanical loads. The vascular cambium, as it is twisted and flexed around ray initials, can change the mixture of cell types and cell forms generated. One common structurally modified xylem form produced is called reaction wood or mechanically adaptive wood. Mechanical strategies differ between evolutionarily older *Gymnosperms* and newer *Angiosperms* in producing reaction wood. Figure 8.

Gymnosperm trees generate predominately compression wood in response to gravity and wind loads. This xylem type is generated on the underside of branches and stem leans with lignin-rich cells. Lignin is like an epoxy resin placed to resist deformation in compression.

Angiosperm trees generate predominately tension wood in response to gravity and wind loads. Tension wood is generated on the top / upper side of branches and leans in stems. Cells are structurally fortified with large amounts of cellulose strands. Cellulose resists deformation in tension, acting as carbon fibers. When large amounts of cellulose are deposited inside a cell, the cell interior may appear slick or wet, called a gelatinous layer under a microscope.

Shaking

Several types of wood faults or cracks can be visible in xylem. A crack in xylem can be called a shake, rupture, or check. These begin with gaps or openings formed between xylem cells. There are three major forms of cracks or shakes in tree stems: ring shake (wind derived) is formed along annual increment boundaries (also called cup or round shakes); radial shake (also called heart shake or rift crack) is formed radially through xylem along rays paths; and, star shake is multiple heart shakes radiating from the pith to form a radiating star pattern. Figure 9.

Shakes usually occur along old compartmentalization walls. They can be minute spaces or huge extensive cracks. Tree tissue growth over a shake may appear at the surface of a stem or branch as a raised seam or as open cracks. Trees attempt to minimize expansion and propagation of a shake. Many times internal faults remain hidden from external visual assessment until catastrophic failure or cutting.

Knotty

Many people recognize knots in lumber as old branch / stem confluence zones. Because of disruption of wood grain (longitudinal fibers), these branch connection zones can be weaker than surrounding wood, and prone to stress concentration and failure. The stem / branch confluence zone contains both stem and branch tissues. Branch tissue grows into the stem and turns downward, while stem tissue grows a flange interlaced with, and over the top of, branch tissue. This form of connection allows a branch to be flexible and disposable, while allowing for a strong defensive zone to develop in the confluence area.

Usually the term "knot" is used in wood products such as lumber. This term is occasionally used in tree growth descriptions. A knot is a conical shaped branch protection zone / stem flange area where stem tissues have parted or seperated surrounding branch base tissues. A loose or encased knot is derived from dead branch base tissues grown over by the stem flange in the stem defensive zone. An intergrown or tight knot is derived from live branch base tissues grown around and interlaced with the stem flange.

Keloid

Moving ropes, hot equipment, and tissue crushing injuries around the circumference of a branch or stem generate a specific set of tree responses, depending upon depth of damage. Shallow injuries usually produce a "keloid" (which means a claw-mark-like scar). A keloid is defined as a tree response which generates an abnormal proliferation of raised woody tissues and wound periderm over and around a shallow injury. In simple terms, a keloid is a peripheral lesion with wound wood and wound periderm present.

This type of injury and tree response can leave a tree open for pest entry, initiate vascular abnormalities, and generate mechanical load focal points leading to further damage. Long term tree health and structure can be compromised. Because of tree response and functional recovery processes, once tissue is injured it is not repaired or replaced, but sealed off and grown over — once injured is forever injured. Prevention of tree injury is the best and most effective means of ensuring a productive tree life.

Figure 10 provides a list of potential periderm damage assessment points (i.e. Coder Periderm Damage Assessment System). The greatest potential for damage to tree periderm is centered on the intial periderm of twigs which is smooth or thin, peeling or soft, during the leaf expansion period of Spring under hot, wet weather conditions. Areas already damaged by injury, hardware, heat, fire, abrasion, or along the path of wetwood or cavity drainage are predisposed to further damage.

Sap-Heart

Larger diameter and older branches and stems can be composed of one or two ages of xylem tissues, generally divided between sapwood and heartwood. Figure 11. Sapwood is xylem tissue containing living cells, usually around the outside circumference of a tree cross-section. Heartwood may or may not be present. Heartwood is xylem tissue without any living tree cells, usually occupying the center of stems and branches. For many temperate trees, there is a color difference between sapwood and heartwood.

Sapwood is the active component of xylem tissues. Less than 10% of sapwood cells are actually living. Most are dead but functional, concentrated in the last growth increment. Young sapwood transports water and materials from roots to shoots, and is dead when functional. Young sapwood rays (radial parenchyma) and axial parenchyma are alive when functional in storing carbohydrate and defending xylem tissues. Because of living tissues, carbohydrate stores, and lack of secondary defensive compounds and extratives, sapwood easily decays.

Callused

Around injuries and wounds, new tissue development can be seen as part of (or initiating) sapwood. On surfaces of a sapwood wound, meristatic tissue from the cambium zone, or initiated by rays cells, will push out onto the surface. These cells will limit oxidation, minimize water loss, and disrupt surface infection / colonization as part of beginning a compartmentalization process. The undifferentiated cell mass initially seen at a wound surface is termed "callus." As the tissues differentiate from callus into functional layers, the xylem tissue developed is termed "wound wood."

To The Heart

Heartwood is the passive, non-functional component of the xylem. It can have many materials deposited or generated at the sapwood / heartwood interface which can render it more decay resistant than sapwood. The transition zone between sapwood and heartwood can appear sharply defined, but on a cellular scale is wide and filled with unique processes of preparation and material conversions.

Heartwood transformation involves many steps including: programmed death of parenchyma (axial & radial); decrease in metabolic rate; starch depletion; accumulation of extractives and other compounds; and, tyloses are set. The transition area becomes less permeable to water and can cause changes in xylem moisture contents. The transition zone is irregular and does not follow one growth increment's boundary or remain in the same relative position from tree top to bottom.

The three cross-sectional transition patterns between sapwood and heartwood are usually categorized into:

1) distinct / sharp / abrupt;
2) semi-gradual; and,
3) gradual (thin transition zone <½").

Sand-Bags

Within cells of the sapwood / heartwood transition zone there is a gradual buildup of waste and specialized chemical precursors with a rapid accumulation / conversion at the boundary. These materials are remains of modified cell contents, including any carbohydrate (starch), chemically reduced into sometimes bio-toxic compounds generally called extractives. Deposition of extractives help set compartment boundaries and slow invading organisms, like decay and discoloration, and minimize oxidation of wood.

Heartwood Differences

There can be four primary types of heartwood or protection wood visible in a tree cross-section. In all types there are no living tree cells. Xylem tissue appearing like heartwood could include: (Figure 12)

A) True heartwood is an age-altered wood, but it can become transformed into wetwood or discolored wood;

B) False heartwood is xylem tissue altered by tissue shedding and compartment development;

C) Discolored wood (i.e. pathological heartwood) is sapwood killed and altered by wounds, injury, infection, and sudden tissue death; and,

D) Wetwood is xylem tissue altered by microbes (primarily bacteria and yeast) which colonize a xylem area increasing pH, increasing water content, and lowering oxygen ($O2$). Wetwood usually begins as an infected sapwood compartment but will survive as true heartwood is generated around the site.

The xylem tissue types appearing to be heartwood, but not true heartwood (i.e B, C, & D above) are all associated with injury, compartmentalization, and tissue infection.

Heartwood usually begins to form 3-9 feet high in a stem and tapers like a cone down and up along stem center increments. Heartwood is usually found in roots only near the stem base. First formation age of heartwood ranges from 5 years old (example = *Eucalyptus* spp.) to >100 years old (example = *Fagus* spp. – beech), depending upon species. True heartwood expands with tree age if no other injury or infection occurs – expanding more rapidly under tree stress and expanding more slowly under better growth conditions.

Changing Formation Rates

The rate of sapwood area growth and diameter expansion is great during good growing conditions. During these same good conditions, heartwood area still expands but at a reduced rate. Sapwood area growth is reduced during environmental stress and site constraints. During these poor growth conditions, heartwood area accelerates at a greater rate. Figure 13.

If sapwood volume accumulation (not diameter inches or circumference) remains constant over several growing seasons, this equates to steady growth rate and tree productivity. If heartwood volume accumulation is accelerating and sapwood volume is declining, the tree has a declining growth rate and decreasing productivity. If heartwood volume accumulation is decelerating and sapwood volume is accelerating, the tree has an expansive growth rate and increasing productivity.

Heartwood Exposure

Shallow injury and damage to sapwood is usually sealed off quickly and effectively. Shallow wounds are defined by being within a 100% sapwood area. Wound depth is not critical as long as the wound is surrounded by 100% sapwood. These types of shallow wounds stimulate the strongest compartmentalization and defense process because of the presence of living cells and stored carbohydrate (i.e. fuel for compartmentalization.) Figure 14.

A deep wound (regardless of the actual depth of damage into xylem tissue) is any wound penetrating into heartwood. A small branchlet or huge stem could both have heartwood, and cutting into the heartwood area of xylem tissue in either represents a deep wound. A deep wound is more difficult to defend against because all the innermost cells are dead and can not respond, and the chemical residue positioned in heartwood has a limited defensive capability. Figure 15 provides a heartwood exposure assessment for branch wounds or pruning cuts.

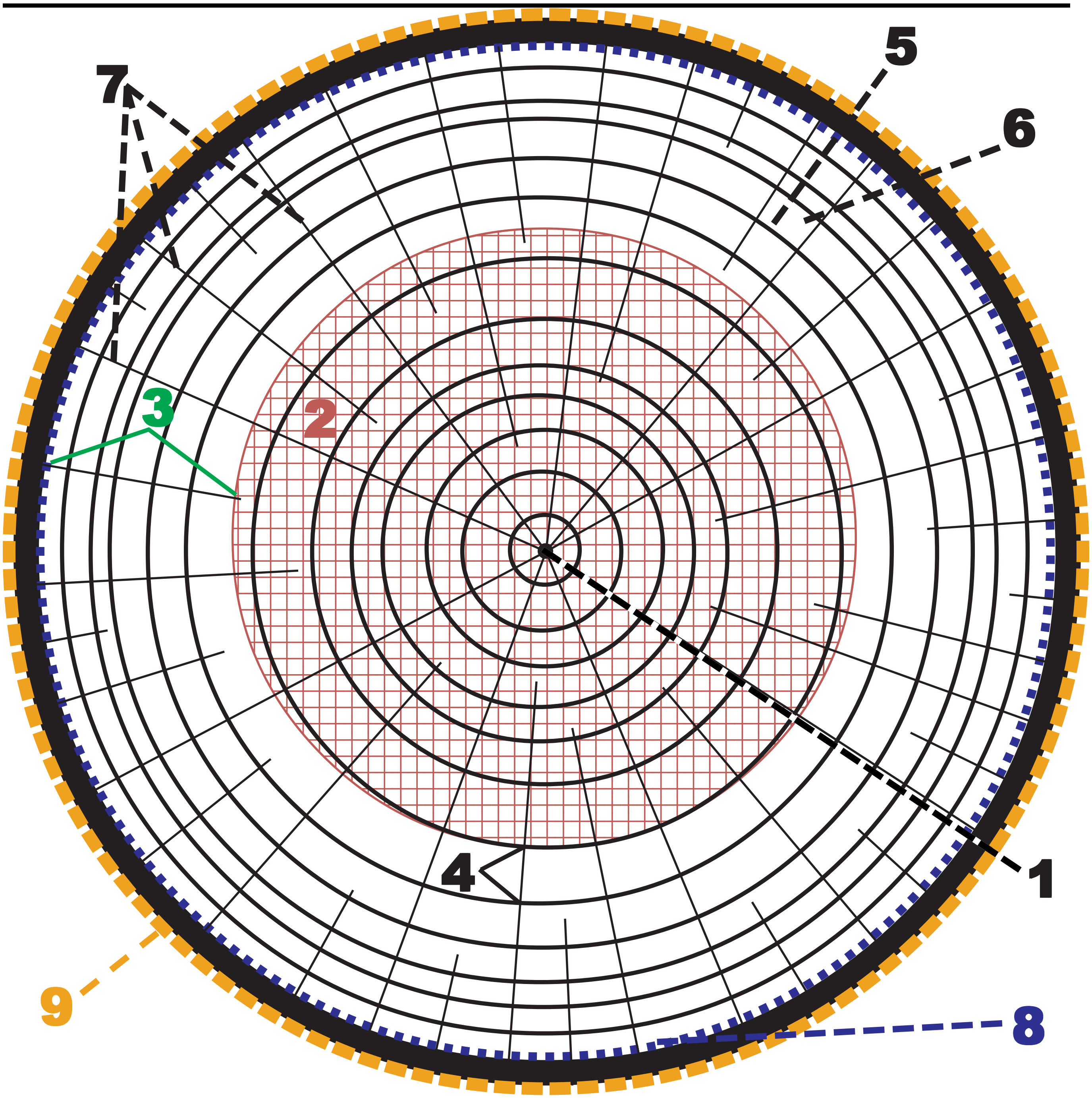


Figure 1: An idealized radial tree cross-section with more than 13 growing season increments represented.

Key componets include: 1) pith (in stems only); 2) heartwood; 3) sapwood; 4) a growth increment (one growth ring); 5) early-wood (within one growth increment); 6) late-wood (within one growth increment); 7) rays; 8) cambium with xylem generated to the inside and phloem generated to the outside; 9) periderm.

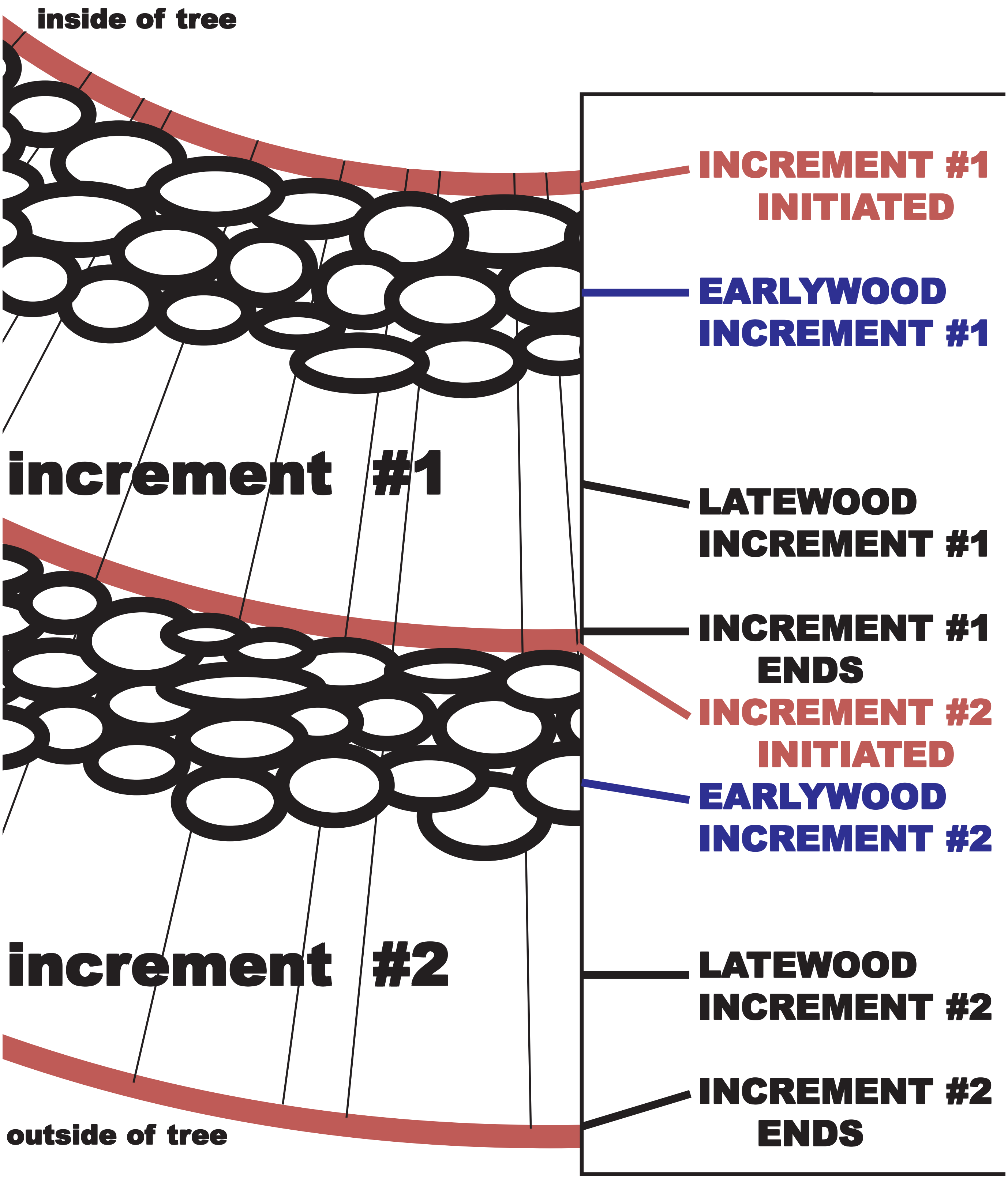


Figure 2: A graphical example of two growth increments in a tree with ring-porous xylem.

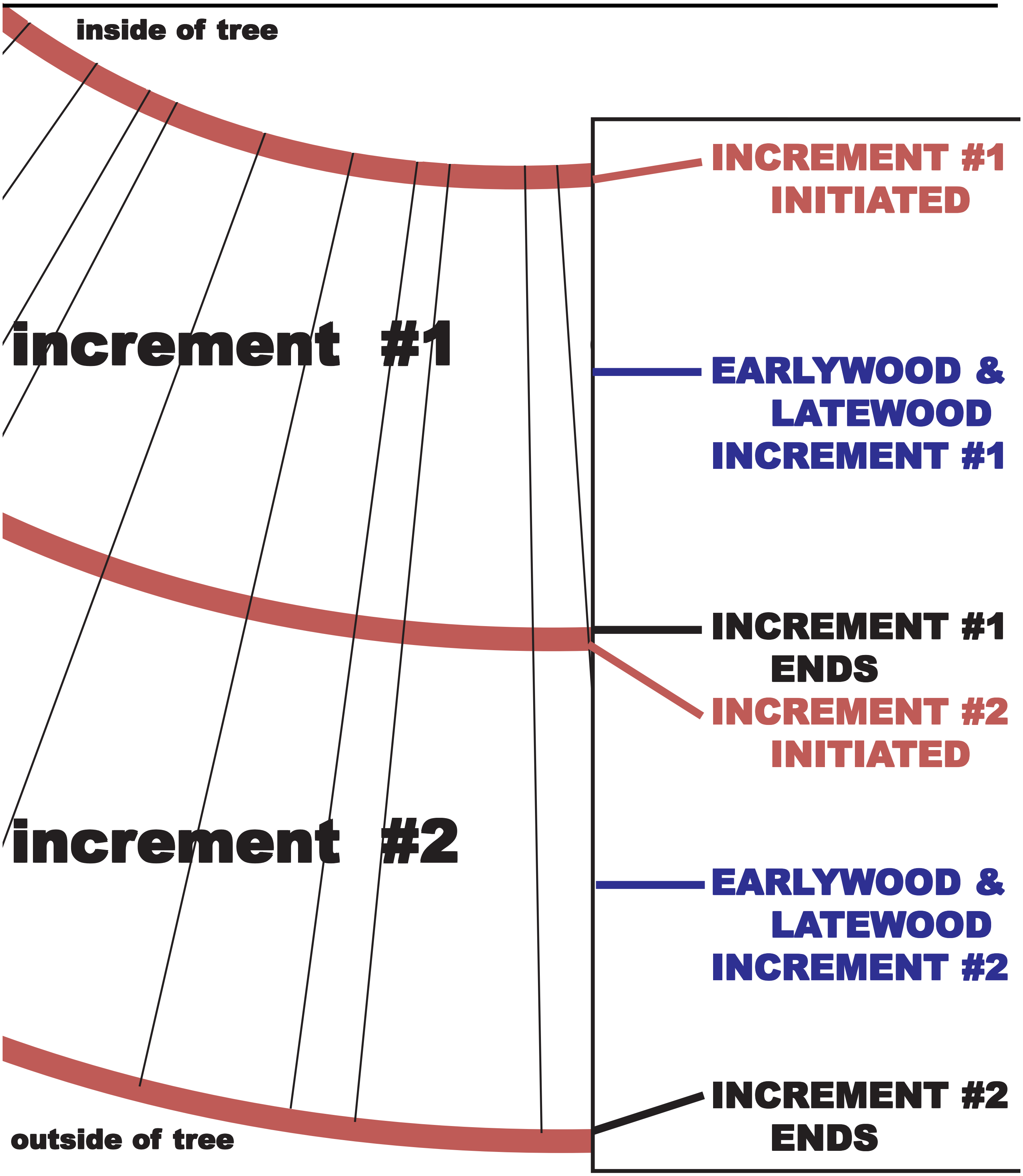


Figure 3: A graphical example of two growth increments in a tree with diffuse-porous xylem. Note the terms latewood and earlywood have little visual meaning.

Ring Porous Trees

(Many large vessels quickly declining to small vessels)

<u>Ailanthus</u>	(tree-of-heaven)
<u>Carya</u> spp.	(hickory)
<u>Castanea</u> spp.	(chestnut)
<u>Castanopsis</u> spp.	(chinkapin)
<u>Celtis</u> spp.	(hackberry)
<u>Fraxinus</u> spp.	(ash)
<u>Gleditsia</u> spp.	(honeylocust)
<u>Gymnocladus</u>	(coffeetree)
<u>Malclura</u>	(osage-orange)
<u>Morus</u> spp.	(mulberry)
<u>Quercus</u> spp.	(red / white oak groups)
<u>Robinia</u> spp.	(locust)
<u>Tectona</u> spp.	(teak)*
<u>Ulmus</u> spp.	(elm)

Figure 4: Ring porous tree increment form in selected *Angiosperms.*

Diffuse Porous Trees

(Many small vessels across growth increment)

Acer spp.	**(hard / soft maple)**
Aesculus spp.	**(buckeye)**
Afzelia spp.	**(lingue)***
Alnus spp.	**(alder)**
Antiaria spp.	**(ako)***
Arbutus spp.	**(madrone)**
Aucoumea spp.	**(okoume')***
Betula spp.	**(birch)**
Canarium spp.	**(aiele')***
Carpinus spp.	**(hornbeam)**
Ceratonia spp.	**(carobtree)**
Chlorophora spp.	**(odoum / iroko)***
Cornus spp.	**(dogwood)**
Corylus spp.	**(hazel)**
Dalbergia spp.	**(rosewood)***
Dumoria spp.	**(makore')***
Fagus spp.	**(beech)**
Gonystylus spp.	**(ramin)***
Guibourtia spp.	**(amazakoue')***
Ilex spp.	**(holly)**
Khaya spp.	**(acajou)***
Liquidambar spp.	**(sweetgum)**
Liriodendron	**(yellow-poplar)**
Lithocarpus	**(tanoak)**
Lovoa spp.	**(dibetou)***
Magnolia spp.	**(magnolia)**

Figure 5: Diffuse porous tree increment form in selected *Angiosperms.* (continued)

Diffuse Porous Trees (continued)

(Many small vessels across growth increment)

Mansonia spp.	**(bete')***
Microberlinia spp.	**(zebrano / zingana)***
Morus spp.	**(tropical mulberry)***
Nauclea spp.	**(opepe)***
Nyssa spp.	**(gum / tupelo)**
Ochroma spp.	**(balsa)***
Olea spp.	**(olive-tree)**
Ostrya spp.	**(hophornbeam)**
Oxydendrum	**(sourwood)**
Parashorea spp.	**(white lauan)***
Platanus spp.	**(sycamore)**
Populus spp.	**(poplar / aspen / cottonwood)**
Pterocarpus spp.	**(padauk)***
Rhamnus spp.	**(buckthorn)**
Salix spp.	**(willow)**
Shorea spp.	**(red lauan)***
Sorbus spp.	**(mountain ash)**
Swietenia spp.	**(mahogany)***
Tarrietia spp.	**(niangon)***
Terminalia spp.	**(afara / idigbo)***
Tilia spp.	**(basswood / linden)**
Triplochiton spp.	**(obeche)***
Umbellularia spp.	**(laurel)**

Figure 5: Diffuse porous tree increment form in selected *Angiosperms.* (continued)

Semi-Ring Porous Trees
(Few large vessels declining to small vessels)

Carya spp.	(hickory)
Catalpa spp.	(catalpa)
Cladrastis	(yellowwood)
Diospyros	(persimmon)
Juglans spp.	(walnut)
Morus spp.	(mulberry)
Prunus spp.	(cherry)
Quercus spp.	(live oak group)
Sassafras	(sassafras)
Ulmus spp.	(elm)

Figure 6: Semi-ring porous tree increment form in selected *Angiosperms.*

Semi-Diffuse

(Many small vessels declining slightly to smaller vessels)

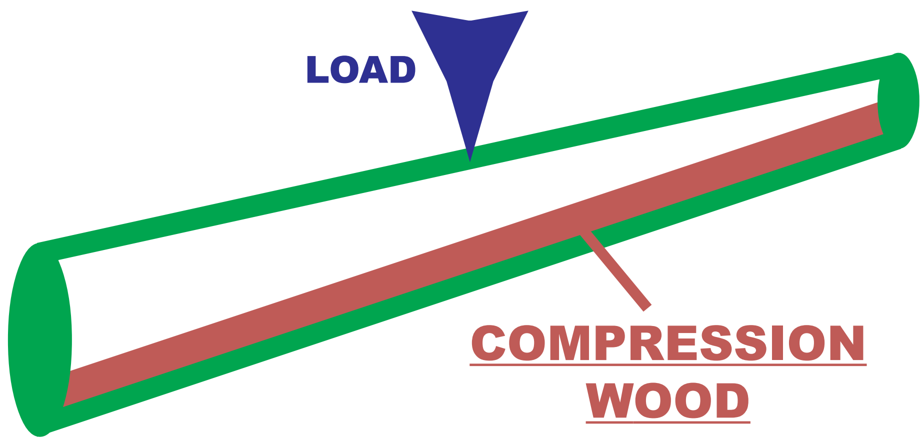
Lithocarpus	**(tanoak)**
Populus spp.	**(poplar / aspen / cottonwood)**
Quercus spp.	**(evergreen oak group)**
Salix spp.	**(willow)**

Figure 7: Semi-diffuse porous tree increment form in selected *Angiosperms.*

Gymnosperm trees

dominately compression wood

on underside of branches & stem leans
lignin-rich cells resist compression deformation
(like epoxy resin)



Angiosperm trees

dominately tension wood

on top / upper side of branches & stem leans
cellulose-rich cells resist tension deformation
(like carbon fibers)

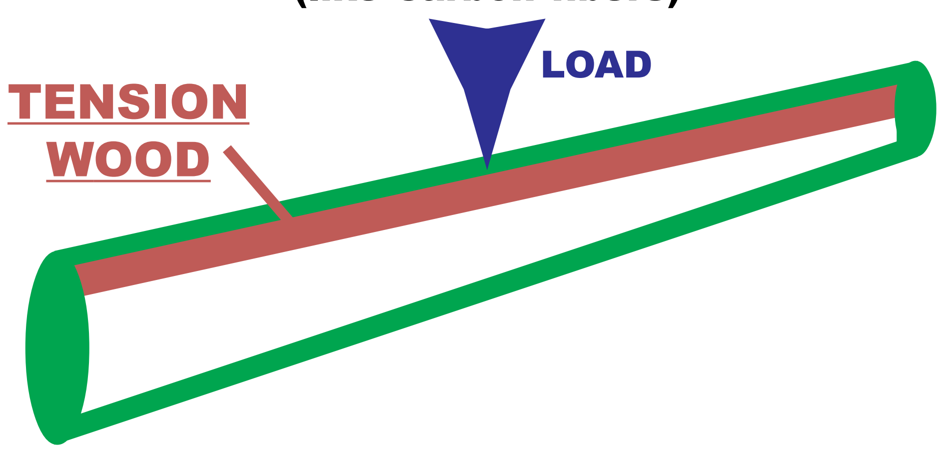
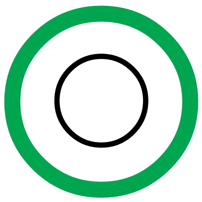
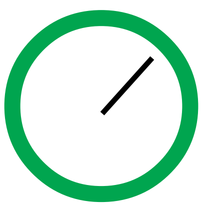


Figure 8: Primary forms of reaction wood, or mechanically adaptive wood, generated in response to gravity and wind loads.

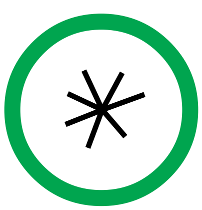
XYLEM CRACKS
(SHAKES, RUPTURES, CHECKS)



RING SHAKE
(cup or round shake)
wind or impact derived formed along annual increment boundary



RADIAL SHAKE
(heart or rift shake)
formed along ray paths



STAR SHAKE
(multiple heart shakes from center)
formed along ray paths radiating from pith

Figure 9: Major types of cracks or shakes within tree stems, usually formed along old compartmentalization walls.

most potential damage								least potential damage	
10	9	8	7	6	5	4	3	2	1

Twig	Root	Branch	Stem
Initial Periderm	Subsequent Periderms		Many Periderms
Thin / Smooth		Thick / Deeply Furrowed	
Peeling / Soft Periderm		Solid / Hard Periderm	
Spring (Leaf Expansion)	Summer (Wood Formation)	Fall	Dormant
Hot	Warm	Weather Cool	Cold
Continually Wet	Periodically Wet	Normal Moisture	

Predisposing Conditions Present:

1. Area Already With Periderm Damage.
2. Area Around Hardware Anchors / Attachments.
3. Area in Contact with Heat Source (light / lantern).
4. Area Continually Abraded / Eroded / Injured.
5. Area in Drainage Path of Cavity / Infection.
6. Area Damaged / Charred by Fire.

Figure 10: Potential damage assessment (Coder Periderm Damage Assessment System) for tree periderm / rhytidome caused by rope and other agents. Each line lists potential damage from greatest potential to least. If enough force is applied for a greater duration, periderm will be damaged regardless of conditions.

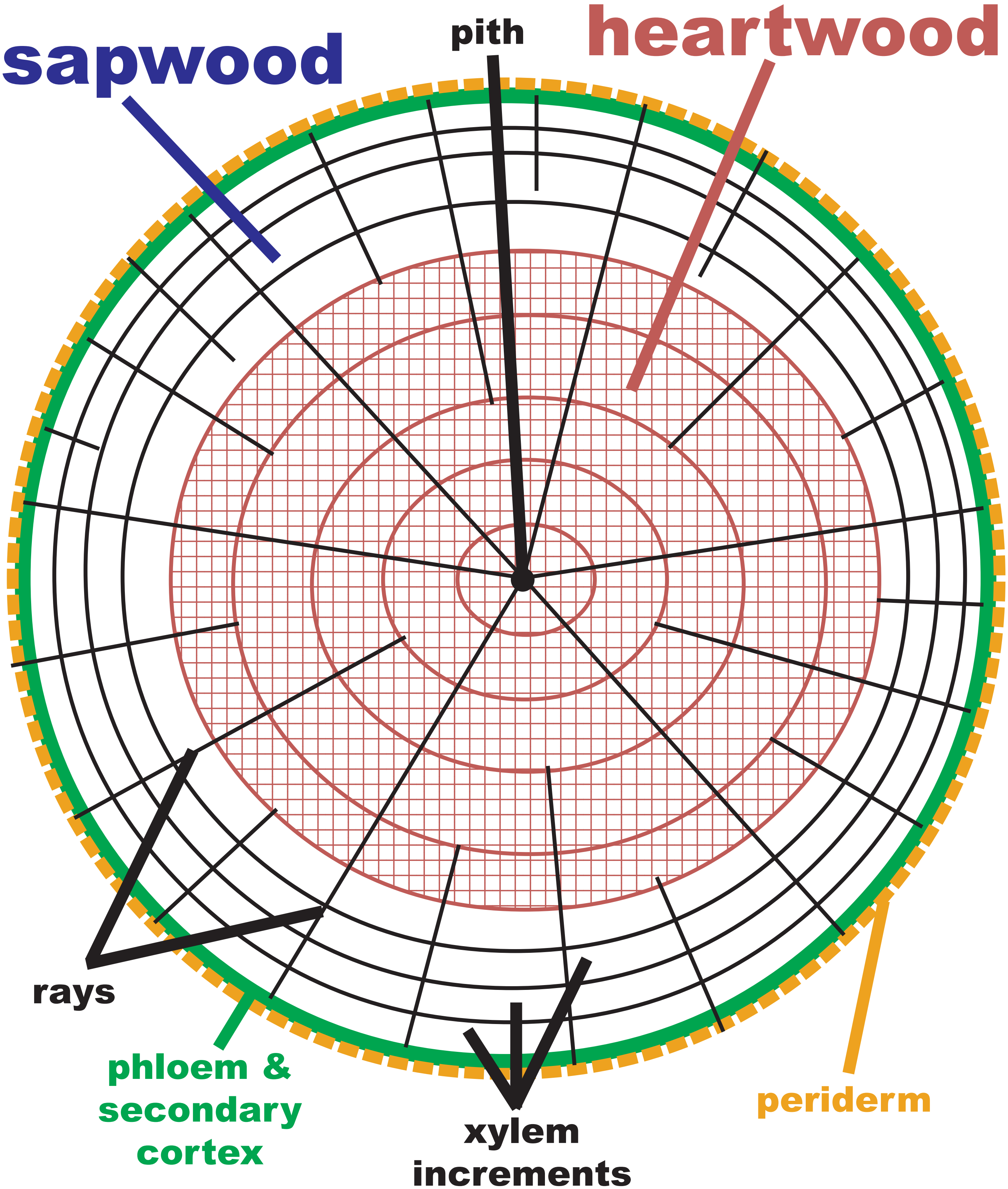


Figure 11: Diagram of stem cross-section highlighting sapwood and heartwood.

HEARTWOOD / HEARTWOOD-LIKE TISSUE

True Heartwood

age-altered xylem

(can be transformed into wetwood or discolored wood)

False Heartwood

xylem altered by shedding & compartment development process

Discolored Wood / Pathological Heartwood

sapwood killed / altered through wounds, injury, infection, & sudden death

Wetwood

xylem altered by microbes

(primarily bacteria & yeast -- increase pH & water content -- lower oxygen (O2) content)

Figure 12: Primary types of heartwood-like or protection wood visible in a tree cross-section. Xylem alteration may appear to be true heartwood, but may be associated with injury, compartmentalization, & tissue infection.

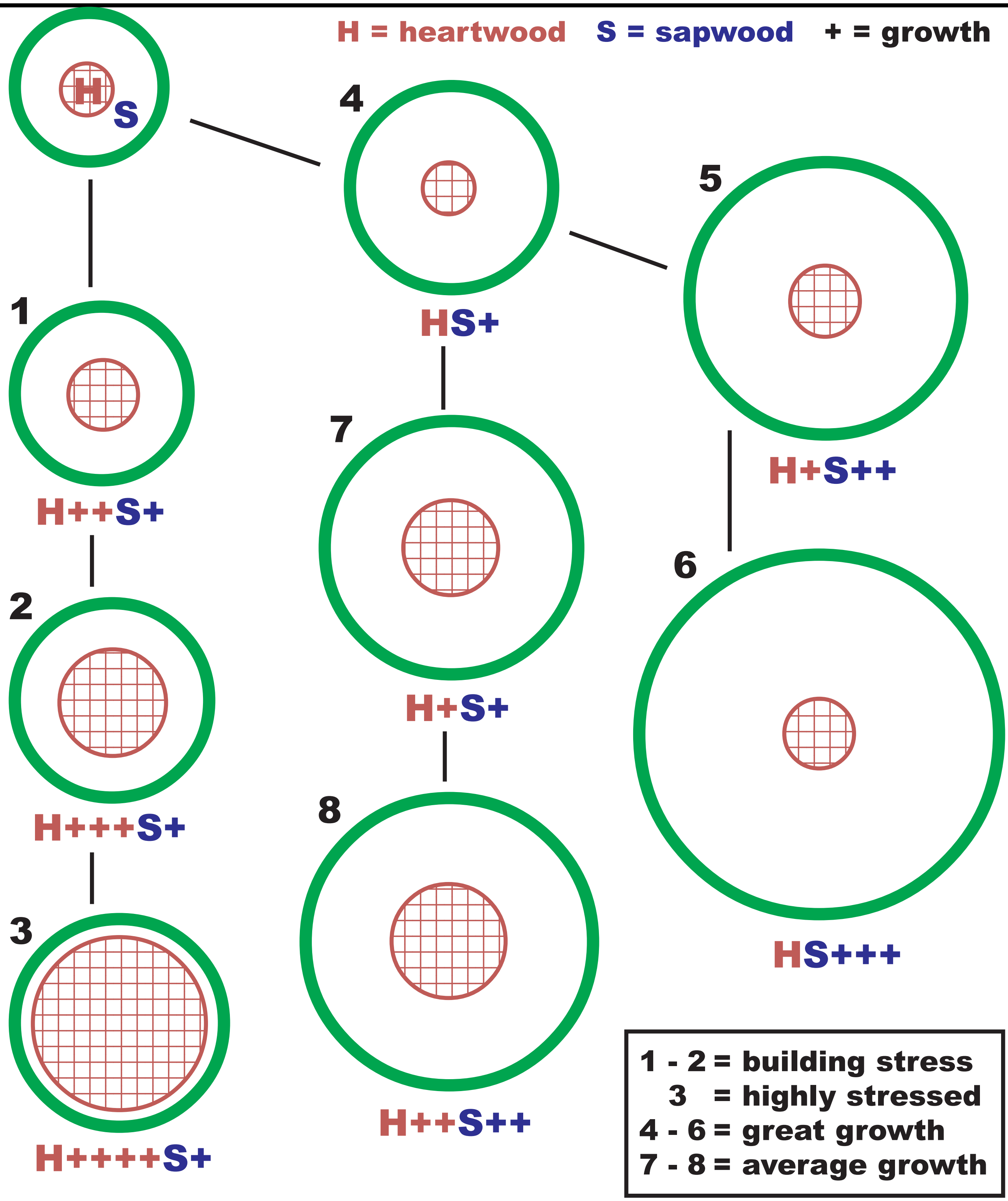


Figure 13: Diagram showing various cross-sectional sapwood / heartwood expansion and growth combinations representing different environmental constraints on trees.

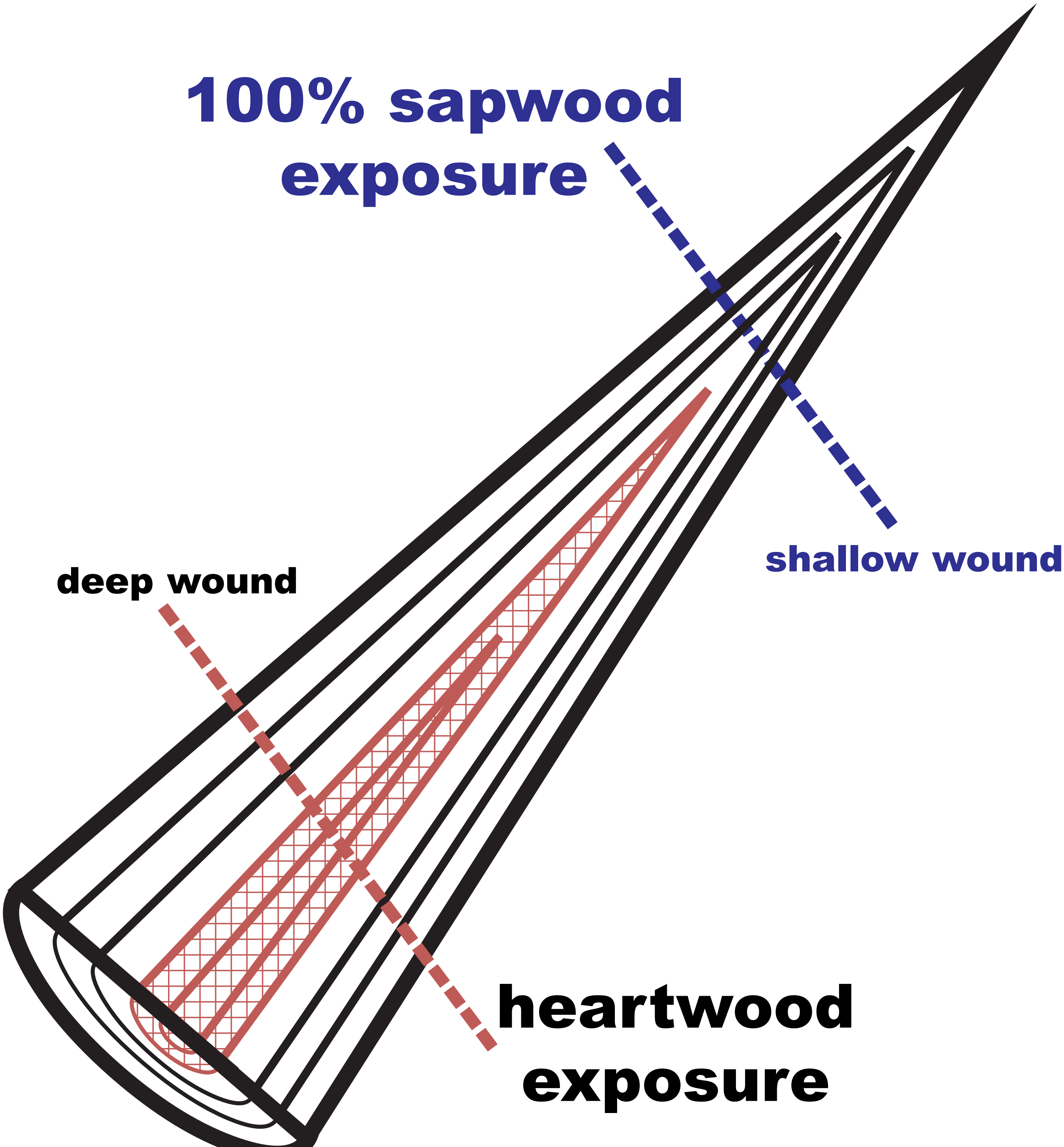


Figure 14: Diagram of a deep cut and a shallow cut using heartwood exposure to gauge relative wound depth.

CODER HEARTWOOD EXPOSURE WOUND ASSESSMENT

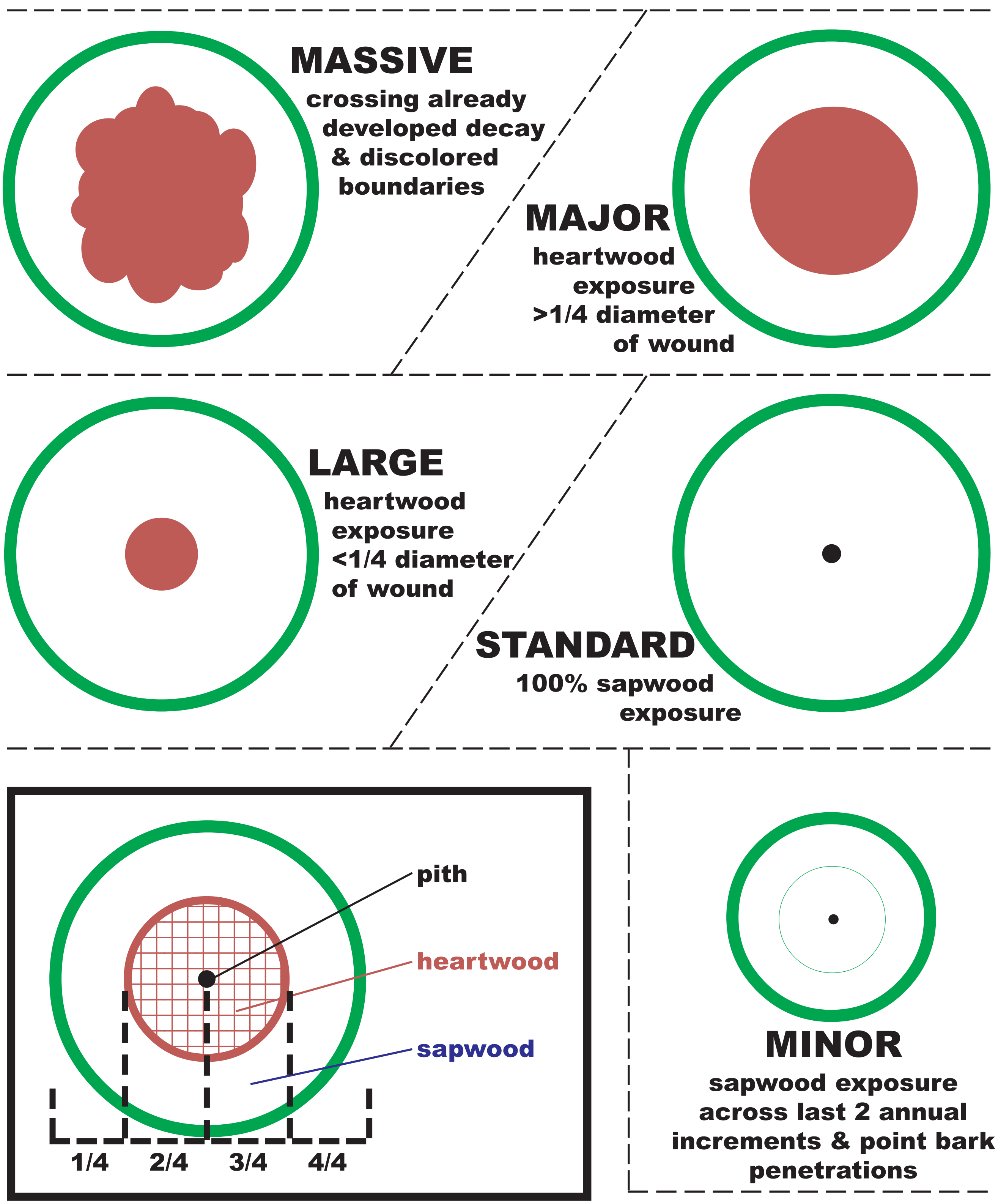


Figure 15: Diagrams describing five types of branch wounds using heartwood exposures on wound face.

Citation:

Coder, Kim D. 2022. Tree Anatomy: Xylem Increments. Warnell School of Forestry & Natural Resources, University of Georgia, Outreach Publication WSFNR-22-82C. Pp.24.