ADVANCED TREE BIOLOGY:

TREE ANATOMY I

by Dr. Kim D. Coder, Professor of Tree Biology & Health Care
Warnell School of Forestry & Natural Resources, University of Georgia

Abstract:

Professional tree health care providers and tree managers should always use the proper terms and definitions for tree components, parts, and growth patterns. Understanding proper scientific names for anatomical components is critical in identifying and describing tree parts and problems. This workshop is an advanced technical look at tree anatomy and morphology at the macroscopic levels (<15X) in above ground structures. Concentration will be on identifying and naming common tree growth forms, and visible tree tissues and their organization. Coverage includes twig, branch, stem, and periderm anatomy, along with identifying features visible with the naked eye or under low magnification. Can you tell one part from another? A certificate of completion will be provided.

Workshop Outline:

WORKSHOP MANUAL GUIDE

INTRODUCTION

morphology = study of external shape, form, and structure

seed bearing plants = angiosperms & gymnosperms (both part of Spermatophytes)
flowering plants = angiosperms
- angiosperms = flowering plants which have seeds enclosed in carpels (fruit)
  - eudicots = 75% of angiosperms – modern
  - dicots = 3% of angiosperms – ancient (Magnoliosida)
  - monocots = 22% of angiosperms

gymnosperms = seed plants with ovules not in an ovary but exposed to the environment (i.e. naked seeds)
- conifer = gymnosperm bearing cones (Coniferales)

phanerogamae = ancient term for Gymnosperms and Angiosperms (Spermatophyta)
phanerophyte = tree with resting buds exposed on branches and stem well above soil

megaphanerophyte = tree over 99 feet (30m) tall
mesophanerophyte = tree with height between 98feet (30m) and 26feet (8m)
microphanerophyte = tree with height between 25feet (8m) and 6.5feet (2m)

tree = a perennial woody plant with a stem, leaves, root, and tricombes
- dendron = a tree
- diplocaulescent = main axis with branches
- dendroid = plant with tall erect main axis and many branches
- arborescent = tree-like form
- phanerophyte = life form with its main axis and resting buds above

ground on stem and branches and open to the environment

tree master definition = large, tall, woody, perennial plant with a single, unbranched, erect, self-supporting stem holding an elevated and distinct crown of branches greater than 10 feet in height and greater than 3 inches in diameter.

definitions used for trees: (multiple sources, 155 descriptors, 45 definitions)

plant	20%	20%
woody	16%	36%
single stem	14%	50%
tall / height	13%	63%
branched	9%	72%
perennial	8%	80%
girth / diameter	7%	87%
elevated crown	4%	91%
distinct crown	3%	94%
self-supporting stem and branches	3%	97%
lower stem without branches	2%	99%
erect / upright stem	1%	100%

symplast = connected network of living cells
apoplast = portions within the boundary of a tree outside the living cell membranes (dead and non-living areas)
symplast / apoplast intermeshed & woven togther cells and tissues living (10%) and dead (90%)

GENERAL CROWN FORM

tree form = defined by size, shape, crown composition (number of branches and twigs and position)

leader = upper-most portion of the main axis of tree
- polycormic = several strong vertical trunks

crown = upper portion of primary stem bearing live branches and foliage
- acrotony = upper branches elongate most in tree
- mesotony = middle branches elongate most in tree
- basitony = lower branches elongate most in tree

long shoot = internode growth allowed to elongate
short shoot = internode growth constrained in elongation

orthotropic shoot = vertical growth habit
plagiotrophic shoot = approaches horizontal growth habit

tree forms above ground

abcurrent	= aerial terminal bud and leaves (palm-like)
adcurrent	= basal buds and leaves (ground yucca types)
bicurrent	= irregular, forked, thick green stems (catus like)
decurrent	= many dominant branches, spreading form – lateral branches grow at similar rate with terminal, or terminal continues to die with lateral branches rebranching continuously -- no one central axis but many spreading branches (same as deliquescent)
deliquescent	= many dominant branches, spreading form – lateral branches grow at similar rate with terminal, or terminal continues to die with lateral branches rebranching continuously -- no one central axis but many spreading branches (same as decurrent)
excurrent	= single dominant leader, conical form -- terminal elongates more annually than lateral branches – distinct main axis and many short secondary branches

branch order = branch, branchlet, and twig subunit numbering system from main stem

live crown ratio = vertical height of live branch area in tree divided by total tree height

crown branching forms

- pyramidal
- conical
- spindle / columnar
- fastigiate
- ellipsoidal
- ovoid
- globose / circular
- broad
- vase
- umbrella
- irregular
- weeping

crown side-view shapes (with relative side view size)

square / cylinder	1.0
rounded edge cylinder	0.9
elongated spheroid	0.8
spheroid	0.7
expanded paraboid	0.6
paraboloid	0.5
fat cone	0.4
cone	0.3
neiloid	0.2
thin neiloid	0.1

MERISTEMS:

accrescent = plant increasing in size as it ages

meristem = point, layer or area of cells capable of generating new cells and tissues
- primary meristems = elongation of shoot tips and root tips with primary tissues
- secondary meristems = radial expansion in diameter from vascular cambium and phellogen with secondarily formed tissues (lateral meristems)

growth locations in tree:
- primary root tip – elongation
- primary shoot tip – elongation
- vascular cambium – radial expansion
- phellogen -- maintaining protective covering

2 primary and 2 secondary meristems

apical meristems = root or shoot primary growing point allowing for elongation
- stem apical meristem = primary growing tip of shoot used for elongation and generating leaves with associated growing points
- root apical meristem = primary growing tip of root used for root cap production and root elongation

axillary meristems = primary stem meristems in confluence of leaf base and supporting axis

secondary meristems = vascular cambium or phellogen area allowing for girth expansion
- vascular cambium = a secondary (non-primary) layer or area generating xylem, rays, and phloem beyond previous tissues -- a thin lateral meristem zone which initiates and sheathes secondary growth
- phellogen = a secondary (non-primary) layer or area generating phelloderm and phellem -- phellogen is secondary meristem zones generating exterior protection

vascular cambium zone (from outside to inside)
- non-conducting phloem
- mature conducting phloem
- dividing phloem - radially expanding
- phloem mother cells
- vascular cambium initial
- xylem mother cell
- dividing xylem - radially expanding
- mature xylem
- dead, active transporting xylem

radial cells lines are generated to either side of cambium

BUD DEFINITIONS

meristmatic points = undifferentiated tissue with no protective coverings (growing points)

bud = primary meristem inside protective coverings (scales) with unexpanded or undeveloped leaves, flowers, and axillary growing points on compacted nodes and unelongated internodes (a resting / protective organ with differentiated tissues)

bud positions

- terminal bud(s) = primary meristem located at apical end of shoot generating nodes and internodes, and developing leaves with associated axillary growing points, and/or flower primordia, protected by embryonic leaves, trichomes, or bud scales
  - pseudoterminal bud = most apical axillary bud beside terminal branch scar generating next flush of elongation growth

- axillary bud(s) = primary meristem located at base of leaf (in leaf axil) containing unexpanded and undeveloped leaves with associated primordial axil growing points, and/or flower primordia, within a protective covering (suppressed bud = lateral bud = axillary bud)
  - suppressed bud = protected axillary growing point constrained from growth by apical buds (not a dormant bud)
    - sunken bud = suppressed axillary bud partially or completely hidden in twig
    - subpetiolate bud = suppressed axillary bud concealed by base of petiole
  - extra-axillary bud = bud formed anywhere but in leaf axil

- accessory buds = additional suppressed buds occurring around primary axillary bud in same node
  - superposed buds = suppressed buds occur above or below primary axillary bud
  - collateral buds = suppressed buds positioned to either side of primary axillary bud

naked bud = growing point without protective scales but covered with embryonic leaves or trichomes

dormant bud = active and inactive buds kept quiescent by dormancy factors between growth periods

BUD CONTENTS

vegetative bud = bud containing unexpanded or undeveloped leaves with axillary growing points
- prefoliation = packing of leaves within vegetative bud
- ptyxis = how embryonic leaves in a vegetative bud are folded

flower bud = bud containing embryonic flower parts
- albastrum = antiquated term for flower bud
- prolification = growing point development in axils of sepals and petals

ambiparous bud = bud containing mix of both embryonic leaves, axillary growing points, and embryonic flowers

bud scales = modified leaf, or immature bract, as protective cover over all or part of a suppressed growing point
- cataphyll = reduced form of leaf (bud scales)

- single (1 scale) = one scale covering
- two ranked = paired scales covering
- imbricate = overlapping scales
- valvate = scales meeting at edges and not overlapping
- striate (lined) = scales with distinct lines or ridges
- fringed = scale margins edged with trichomes
  - ciliate = fringed with short trichomes
  - ciliatulate = widely dispersed fringe
  - ciliolate = fringed with minute trichomes
  - fimbriate = fringed
- none = growing point without scales (naked bud)

bud shapes
- round end / pointed end
- long / short
- narrow (thin) / wide (fat)
- conical
- oval
- stalked base / sessile base

bud types
- active / suppressed – (growth charge in growing season)
- terminal, lateral, axillary -- (position on shoot)
- suppressed / adventitious -- (age of formation)
- vegetative, flowering, mixed -- (content)
- shed & dead

GROWING POINT FORMS

preventitious growing points = formed in axillary positions, grows a little each year but are suppressed – may be clustered together due to other growing points inside old bud

from differentiated tissues which did not grow in the first season formed.

remains suppressed slowly growing at distal radial end of bud trace from xylem

when released can generate epicormic shoots / water sprouts

not dormant, just slowly elongating under suppression

adventitious growing points = differentiates from secondary tissues like small groups of parenchyma in secondary cortex over dilated phloem rays or next to preventitious buds

from undifferentiated callus tissues which grows as soon as formed

arise outside axillary or terminal position with no historic bud trace

usually generated in injury / wound areas from callus tissue, from exposed cambial zone, or without any injury from secondary cortex

current year formation then grows on if not suppressed

growing point trace = visible vascular connections behind bud within xylem appearing similar to a large xylem ray

sphaeroblast = secondary tissue radial growth and cell wall thickening pushing growing points sideways off growing point trace end – bud survives generating round ball of tissue in secondary cortex

proliferation = abnormal growing point and bud development with non-elongating internodes, nodes generated on nodes, and buds on buds caused by pest or chemical problems (witch's broom)

epicormic growth = new shoot from adventitious or preventitious growing points on trunk or branch

coppice = new shoot from adventitious or preventitious growing points from stump

TWIG FORM

twig = current or most recent growth increment on apical end of shoots

tip of twigs terminated with primary growing point which increases in length and partially suppresses other growing points

twig size

slender	= twig diameter across last few apical internodes <2mm
moderately slender	= twig diameter across last few apical internodes 2-4mm
moderately stout	= twig diameter across last few apical internodes 4-5mm
stout	= twig diameter across last few apical internodes >5mm
robust	= twig diameter is thick, stiff, and large in diameter (stout)

branchlet = 2nd and 3rd year growth increments just behind twig

branch = 4th or greater in age growth increment just behind branchlet

spur shoot = short knobby slow growing shoot without significant internode elongation and can be tipped with a spine or suppressed bud

node = non-elongating region of shoot generating leaves, shoots, buds, flowers, stipules, thorns, spines

nodal torus = node tissue circling the twig and larger than the axillary bud, stipule scar (cicatrix), and leaf scar area which reaches slightly above and significantly below leaf scar and axillary bud

twig bud present

- exterior position
  - sunken / submerged
  - normal visible
  - pedestal
- scale coverage
  - none / naked bud
  - single scale
  - valvate scales (two scales which do not overlap)
  - imbricate scales (several scales overlapping)
- scale edges
  - entire
  - ciliate = fringed with fine marginal tricombes
  - ciliatulate = fringed with widely dispersed fine marginal tricombes
  - ciliolate = finged with very short fine marginal tricombes

flexuose = zig-zag twig and branchlet growth pattern
geniculate = zig-zag twig and branchlet growth pattern

pith = cylinder of primary cells in center of axis surrounded by vascular tissue

medullary sheath = cell layer surrounding pith

pith may thin and change forms (i.e. become solid) at growth increment transitions

pith has live cells with chlorophyll in first to second year of growth

longitudinal section along twig

- homogenous = no cavities or cross walls with consistent uniformly solid soft tissue
  - solid = no cavities or cross walls with consistent uniformly solid soft tissue
  - entire = no cavities or cross walls with consistent uniformly solid soft tissue
- diaphragmed = homogenous or solid pith with cross walls
  - septate = homogenous or solid pith with cross walls
- spongy = homogenous pith perforated with holes
- chambered = excavated pith with numerous cross walls
  - discoid = excavated pith with numerous cross walls
- excavated = hollow or empty

cross-section shape across twig

- angled = distinct sides and corners (not rounded)
- terete = round
- stellate = star shaped

twig armature

prickles
spines = modified leaf, stipule, petiole, peduncle, root emergence forming sharp point
- bicalcarate = two-spined

bristles = from epidermis or periderm

thorns = modified branch
- spiniferous = bearing thorns
- spinescent = short rigid branch resembling thorn

inermis = unarmed and thornless (innocuous)

twig lenticels = unsuberized low density area on epidermis or in periderm which began as a stoma

complimentary tissue = loose thin-walled unsuberized cells in lenticel

- none visible
- round, elongated longitudinally, elongated horizonatlly
- sunken, surface, raised
- periderm color or contrasting color

twig surface
- glabrous
- pubescent
- scurfy = massed peltate scales or tricombes
- bloom (glaucous) = light colored wax coating
- verrucose = many small projections or bumps
- lenticellate = many visible lenticels

cross-section shape of twigs
- round
- angled = distinct sides and corners (not rounded)
- lined / fluted / ridged = regular ridges and grooves along longitutinal axis surface

twig periderm
- smooth
  - even
  - striated
  - mottled = older periderm falls away revealing different colors beneath
- papery
- rough
  - warty = raised projections
  - scaly = stiff plates edges curling and peeling away from underlying periderm
  - furrowed = longitudinal grooves and ridges on surface
    - ridges = longitudinal
    - plates = flat-topped rectangles
    - blocky = short squares

winged twigs
- wings = long, continuous flat corky emergences
  - alate = winged
  - ancipital = two-edged winged
- pterocaul = short localized flat corky emergences
- pterate = short winged

drooping / declining twigs
- cernuous = drooping or hanging
- pendent = hanging down
- pendulous = almost fully hanging down or declining

TWIG CICATRICES

cicatrix / cicatrices = visible periderm disruption after abscission or removal of an organ (scar)

visible scars = periderm disruption area representing former positions of structures due to abscision of leaf, stipule, shoot, or fruit

general scar types on twigs
- leaf scar
- inflorescence scar
- stipule scar
- branchlet scar
- bud scar
- terminal bud scar

leaf scar = visible periderm disruption where leaf fell from twig
- exterior position
  - raised / protruding = visible periderm disruption of past leaf attachment elevated above twig surface
  - normal
  - sunken (crater-like)
- arrangement
  - alternate
  - opposite
  - whorled
- shape
  - thin cresent = falcate (sickle-shaped)
  - broad cresent
  - shield
  - half round

circular
oval
triangular
3-lobed
heart
V
U
horseshoe

bundle scars (traces) = visible periderm disruption within leaf scar showing broken ends of vascular tissue

stipule scars = visible periderm disruption where stipules, modified leaves at the base of petiole or rachis, fell (noticeable in mid-Summer)
slit-like
ring-like

bud / bud scale scars (scar location)
terminal (terminal bud scale scar) = visible periderm disruption showing last year location of terminal bud

false terminal / pseudoterminal = branch scar = visible periderm disruption opposite false terminal bud where terminal shoot died (terminal branch scar)

axillary (bud scar) in confluence area of leaf petiole and axis
single = solitary axillary bud
superposed = above or below axillary (accessory buds)
collateral buds = to the side of axillary (accessory buds)
catkin flower bud = elongated inflorescence axillary bud

branch scar = visible periderm disruption where the terminal shoot was shed opposite across the twig tip from a false terminal bud

TWIG / BRANCH / STEM

many words and definitions:

trunk = upright massive main stem or main vertical axis of tree
- polycormic = several strong vertical trunks

bole = portion of stem or trunk of tree of such size from which lumber can be cut

stem = supporting axis of tree bearing living crown composed of tapering overlapping columns of wood increments

bough = large division axis of stem

limb = primary division of a stem or bough bearing foliage

branch = large and small divisions of main axis equal to or greater than 4 years / growing seasons in age
- dedoublement = branching
- ramify = branch or subdivide an axis
- ramiform = branched
- ramose = many branches (ramulose)
- ramulus = very small branch
- macrocladous = long branches
- arthocladous = long straight branches
- brachycladous = short branches
- pachycladous = thick branches
- acanthocladous = spiny branches

spray = flattened unit of leaves twigs and branchlets usually in gymnosperms

branchlet = small division of branch equal to 2-3 years / growing seasons old

twig = current or most recent growing season's extension growth at apical end of shoots
- virgatus = twiggy

sprig = a portion of a twig

shoot (1) = a modular twig section comprised of one node with associated leaf(s) and axillary meristem(s), and an elongated internode section below, and an apical meristem above (if twig is in terminal position)

other shoot terms = modules = phytomers = metamers

shoots (2) = any above ground portion of tree bearing or supporting leaves, as contrasted with roots and branches (1 growing season = 1 growth unit)

different shoot types
- terminal leaders
- laterals

basal shoots
- coppice shoots = from suppressed buds at stem base
- root suckers = from adventitious buds newly formed

long shoots = twig and branchlets with normally elongated internodes
short shoots = twig and branchlets without normal internode elongation (either determinant or indeterminant)
- determinant short shoots = spur shoot with terminal bud
- indeterminant short shoot = spur shoot without terminal bud
- brachyblast = spur shoot bearing leaves and flowers

whorl = branches / branchlets growing from one nodal torus
- verticel = one whorl
- verticillate = whorled
- plytomous = several branches from same nodal torus
- geminate = paired branches from same node on same side of axis

STEM CROSS-SECTION

wood = lignified secondary xylem
lignin = complex CHO inserted into cellulose framework to form wood

cross-section list of tissues in stem from outside to inside:
- phellem
- phellogen — periderm — lenticels
- phelloderm
- secondary cortex
- non-conducting phloem
- dialated phloem rays
- conducting phloem
- cambial zone
- vessel segments form tubes
- conducting xylem (sapwood)
- xylem rays
- non-conducting xylem (sapwood)
- closed vessels with tyloses / gums
- sapwood / heartwood transition zone
- heartwood
- pith

stem cross-section component definitions

periderm = a multiple layer tissue responsible for tree protection and water conservation generated over the outside of a tree from shoot to root,
and produced by the phellogen (cork cambium)

secondary cortex = an assorted layer cake of living, dead, and crushed phloem cells, terminal ray remnants, and periderm cells just beneath to latest periderm

phloem rays = produced by cambium extending rays from xylem as far as just past the phellogen

phloem = actively transporting raw and processed resources primarily from the photosynthetically active regions to storage areas and respiration sinks

vascular cambium = a zone of cell generation through division and expansion which adds tissue volume to the circumference of a tree with xylem generation to the inside and phloem generation to the outside

sapwood xylem = an area of wood containing living cells and dead resource transport
tissues with active vertical (longitudinal) transport confined to the youngest growth increments

sapwood rays = radially oriented, living cells used for resource storage, for system
maintenance and defense, and for radial transport into and out of growth increments

heartwood = a central core of internally shed dead xylem and rays which can have their cell volumes or walls filled with defensive or waste materials

pith = a residual core of tissue generated in the shoot over which all other
cell layers were deposited (not found in roots)

growth increment = xylem tissues developed over one growth period and separated in time from more internal adjacent tissues by generation after a non-growing or dormant period (i.e. growth ring)

stem attributes = pith, high lignum, chl in secondary cortex
root attributes = no pith, medium lignum, no chl

ray distance apart remains constant from inside to outside with cambial initiates generating new rays in-between old rays

proportions of periderm, secondary cortext, and phloem vary by diameter of tree part
smaller parts have higher proportion of non-xylem components

STEM FORM

tree xylem growth increments = a three dimensional hollow conical shaped xylem layer
is generated over the immediately last, most exterior layer, of xylem

over many growth periods generates a “nested” or “stacked” set of growth cones

stacking / nesting a series of hollow cones on top of one-another allows the whole series to become taller and wider with each new conical layer deposited

a cross-section of these cone stacks will show a series of growing season increments

thickness of each increment dependent upon amount of resources used for its construction at that location in tree

radial growth rings are two dimensional forms representing a three dimensional growth increment, sheath, or cone

reaction wood / adaptive wood
compression wood = gymnosperms (bottom side with extra lignin)
tension wood = angiosperms (top side with extra cellulose)
tension wood cells (reaction wood in angiosperms) may contain concentrated cellulosic cell wall material called a gelatinous layer because it looked wet and shiny under a microscope

tyloses = balloon-like enlargement and expansion of non-conducting sapwood axial and radial parenchyma cell membranes surrounding vessel elements out into vessel elements causing blockage of vessel and providing a framework for other blockage materials to be deposited

spur branch (spine) = apical meristem shuts down and lignifies
may bear leaves with axillary buds, and/or flower and fruit
will show leaf and bud scars (cicatrices)

other stem types
rhizome = horizontal stem below soil surface
stolon = horizontal stem on soil surface or in surface litter
runner = horizontal stem above soil surface

stem / branch gall (burl) = abnormal wood development caused by tree reactions (both organized and unorganized) to insect, mite, thrips, nematodes, chemicals, and pathogens

witch’s broom = type of gall with a proliferation of buds and shoots in one spot caused by pest, mechanical, or chemical damage

shake = rupture / crack / check between cells forming and opening in xylem
shake types

ring (wind) = forms along annual increment boundary
radial (heart) = forms radially through xylem along rays (same as heart)
heart (rift) = forms radially through xylem along rays (same as radial)
star = multiple heart shakes radiating from pith

knots = conical shaped branch protection zones / stem flange area where stem tissue parted to allow branch tissue expansion

encased (loose knot) = dead branch base tissues grown over by stem flange
intergrown (tight knot) = live branch base tissues grown around and interlaced with stem flange

interlocked grain = dominant angle of fiber grain reverses every few years
spiral grain = dominant angle of fiber grain remains angled away from the longitudinal axis

SHOOT GROWTH PATTERNS

determinant shoots (fixed or monopodial) = terminal shoot elongates followed by period of inactivity until new bud forms, is released from dormancy controls and expands (all parts set one year and expand the next)

apical meristem terminates growth periodically
one per growing season = single flush
several per growing season = multiflush
multiple growth waves or flushes keep forming a fixed bud then immediately grows without dormancy period

indeterminant shoots (free or sympodial) = shoots do not expand from terminal bud but from axillary buds behind terminal through either an aborted / dead terminal, or a flowering terminal (continuous new production of nodes and internodes)

(***Betula, Carpinus, Catalpa, Corylus, persimmon, Gleditsia, Platanus, Robinia, Salix, Tilia, Ulmus***)

apical meristem continues to grow (elongate) until environment ends cycle
two sets of leaves may or may not appear different
early leaves which are preformed in over-wintering bud
late leaves which are newly formed and expand from subsequent growing points

dichopodium = sympodial branching system in dichotomous branching t5rees where one branch is shed and the other grows on then divides

abnormal shoots = later in growing season expansion of buds
lammas shoots (Lammas Day = Aug. 1) from terminal buds
proleptic shoots (summer shoots) from lateral buds close to terminal
sylleptic shoots from axillary buds from branch before terminal is set (spring shoots)

juvinile shoots are more free growing than mature shoots in same species

SECONDARY XYLEM & PHLOEM

secondary tissues in tree interlaced axial and radial cells
interwoven basket of live and dead cells with ~98% cells dead

cells live only a few years then are shed

pectin = combination of four CHO which form a water soluable gell between cells (part of middle lamella)

lumen = central empty space enclosed by cell wall

xylem within growth increment composed of axial (longitudinal) and radial components

axial elements include:
transport and structural cells (tracheids / vessels)
structural cells generically called fibers
storage and defensive cells classified as axial parenchyma

radial elements include:
storage and defensive cells classified as ray parenchyma

parenchyma cells (both axial and radial)
starch granules = stored food (iodine staining) only available to tree when in living parenchyma cells

as parenchyma cells decline and die farther inside column of tree, they may concentrate or generate materials which provide a passive defense for internally shed growth increments (heartwood)

cambial zone not a single layer

three wood surfaces
radial (from pith to exterior)
transverse (cross-section)
tangentional (face of cylinder)

GYMNOSPERMS

gymnosperm xylem =

axial = all components are tracheids (~90%) (fiber tracheids in latewood), a few axial parenchyma, and epithelial cells

epithelial cells = parenchyma around cavity secreting resin / gum

earlywood tracheids thinner walls / latewood tracheids thicker walls

axial parenchyma (more in older species forms)

thin-walled axial parenchyma in podocarps, *Cupressaceae* (Thuja, Cupressus, Chamaecyparis, Juniper), and *Taxodiaceae* (Sequoia, Taxodium)

little or no axial parenchyma is found in araucaria, *Pinaceae* (Larix, Picea, Pseudotsuga, Tsuga, Abies), and *Taxaceae* (Taxus, Torreya)

no axial parenchyma in pines (Pinus)

radial = horizontal ray traceids, ray parenchyma and/or epithelial cells
narrow uniserate or biserrate rays and may have wide resin ducts

rays can be thin (1-2 cells wide) with occasional ray tracheids along sides
uniseriate ray = ray one cell wide

resin ducts or canals are long intercellular spaces between cells in both axial and radial directions branching in many directions surrounded by epithelial cells which secrete resin into gaps

resin = acidic insoluble phenolic derivative or oxidized terpenes secreted into tissue cavities
resin cyst = cavity blister filled with resin
schizogenous = cavity in tissue formed by cell separations

resin ducts can be normal features or can be initiated by injury

Pinus (pines), Larix (larch) and Pseudotsuga (Douglas-fir)
normal resin ducts

Picea (spruce) less abundant resin canals

Abies (fir), Sequoia, and Taxodium (baldcypress) generate
resin canals only upon injury

pitch pockets = eliptical openings / cavities in xylem usually at end of annual increment containing soil or liquid resin (in conifers)

ANGIOSPERMS

angiosperm xylem =

axial = vessel elements, tracheids, axial parenchyma, and fibers which comprise most of xylem

apotracheal parenchyma bands independent of pores across / around increment
paratracheal parenchyma bands associated with pores

radial = rays can be narrow, wide, or aggregate (multiple narrow rays closely spaced together)
multiseriate ray = a ray many cells wide

phloem = composed of sieve tubes which collapse quickly as surrounding parenchyma continues to enlarge

expansion of surrounding cells destroys clear phloem annual increment boundaries and any associated early / late phloem growth increment changes

conducting phloem = <1mm wide with companion cells
companion cell = live cell next to and associated with a seive tube cell

non-conducting phloem = sclerification, crystal deposition, collapse, dilation of phloem rays

bast fibers = strong fiber portions in non-conducting phloem, secondary cortex, and phelloderm

latiferous duct = cavity into which latex is secreted
latex = milky liquid containing sugars, proteins, alkaloids, oils and other materials secreted into ducts
lactiferous = producing latex

druse = spiked calcium oxalate crystal ball found in cells of secondary cortex, pith and phloem
raphide = needle shaped crystals of calcium oxalate occurring as singles or clumps within cells
sphaerraphide = round spike mass of calcium oxalate crystals in cells

XYLEM INCREMENT TYPES

growing season = intermittent periods of growth among rest periods, caused by rain/dry, warm/cold, and/or internal dormant/active cycles, which sustains coordinated longitudinal and radial expansion of woody tissues

annual xylem growth increments where initial growth is composed of large diameter vessels quickly changing to small vessel diameters produce distinct beginnings and ends are ring porous

ring porus term is reserved for Angiosperms although some Gymnosperms with determinant growth may generate distinct earlywood and latewood xylem increments

Examples: Castanea, Catalpa, Celtis. Fraxinus, Gleditsia, Morus, Quercus, Robinia, and Ulmus.

annual xylem growth increments where little or no differential in vessel cell diameter size occurs throughout the growing season are diffuse porous

Examples: Acer, Betula, Carpinus, Fagus, Liriodendron, Platanus, Populus, and Pyrus.

two intermediate forms of annual xylem growth increment earlywood / latewood transition

semi-ring porous = few large earlywood vessels gradually declining in diameter into latewood (Juglans, Sassafras, Diospyros).

semi-diffuse porous = many small diameter earlywood vessels which decline gradually in diameter into even smaller diameter vessels into the latewood (Populus, Salix).

annual xylem growth increments in gymnosperms are called non-porous

gymnosperms considered to have no vessels (or pores) in cross-section and so, considered non-porous regardless of xylem cross-section appearance

distinct increment = sharp visual change within annual increments
non-distinct increment = no visual change within annual increments

growing season / shoot expansion changes over one growth season

earlywood = first produced xylem increment at beginning of growth season
latewood = later produced xylem increment generated after ealywood to end of season

earlywood / latewood is proper term
not lightwood / densewood
not springwood / summerwood

earlywood / latewood transitions

sharp boundary	=	ring porus angiosperms
sharp intermediate	=	semi-ring porous angiosperms
gradual intermediate	=	semi-diffuse porous angiosperms
no boundary	=	diffuse porus angiosperms
gradual transition boundary	=	non-porus gymnosperms
abrupt transition boundary	=	non-porus gymnosperms

growth season increment in xylem can be bounded by marginal or terminal parenchyma and fibers (normal or compressed)

growth increment thickness

with identical annual tree productivity, increment widths in cross-section would decline each year

a given amount of xylem tissue spread over the circumference of a three-inch diameter tree will generate a much larger growth increment than the same amount of xylem tissue spread around the circumference of a 30-inch diameter tree

determining the end of one increment and beginning of next

depends upon porosity of each growth increment and uniqueness of each terminal boundary between growth increments

boundary differences

line of squashed elliptical-shaped (radially flattened) cells

line of cells with thicker than normal walls

high concentrations of axial parenchyma or thick-walled fibers

marginal apotracheal parenchyma band

paratracheal parenchyma = cells at the edges of annual increment around vessels

false annual increment = appearance of second growth increment within one growing season of xylem (usually in upper crown wood)

multiple shoot growth period and associated multiple cambial growth period generating multiple xylem increments

false ringing most prevalent in branch-wood and base of living crown, and rarely in stem

growth increment counts can be highly inaccurate because of false-rings

discontinuous annual increment = when the increment shealth is incomplet and does not cover the entire surface of the last sheath

caused by lop-sided crowns, severe stress, defoliation, suppressed trees

mini-rings = poor growth conditions generate a truncated growth increment or no growth increment in marginal branches, rapidly declining trees, cambial damage areas, or growth regulation disruption / destruction zones

truncated growth rings = when only first set of cells divide and expand

juvinile wood = cone of wood inside tree representing short rapidly growing cells of the first growth increments before full hormonal control and flowering occurred

SAPWOOD / HEARTWOOD

alburnum = antiquated term for sapwood
duramen = antiquated term for heartwood

sapwood (only ~10% of cells in sapwood alive)
- young sapwood transports water and materials from roots (dead when functional)
- young sapwood rays (radial parenchyma) and axial parenchyma (alive when functional)

heartwood transition
- programmed death of parenchyma (axial & radial), decrease in metabolic rate,
  - starch depletion, accumulation of extractives, final tyloses set,
  - may change moisture content
- irregular and does not follow one growth increment boundary
  - or stay in the same relative position from tree top to bottom
    - distinct / sharp / abrupt transition
    - semi-gradual
    - gradual (thin transition zone <½")
- deposition of extractives
  - gradual precussor buildup
  - rapid accumulation / conversion at boundary

heartwood / protection wood (all tree cells dead)
- heartwood = age-altered wood & can transition into wetwood or discolored wood
- false heartwood = wood altered by tissue shedding
- discolored wood (pathological heartwood) = altered by wounds, injury, infection, and sudden tissue death (woundwood)
- wetwood = altered by microbes (increase pH, water content and lower O2)

heartwood begins 1-3 meters high in stem and tapers down and up along stem center
- found in roots usually only near stem base

begins ranging from 5 years old (eucs) to >100 years old (beech)
depending upon species
only actual heartwood expands with age if no other injury or infection
maybe darker in color especially upon oxidation
extractives = polyphenols, fats, waxes in heartwood
xylochrome = mixture of substances giving color ro heartwood including tannins, gums, and resins (extractives)
cerasin = insoluable components of gums which swell with water

radial growth of sapwood / heartwood (based on area, not diameter inches or circumference)
sapwood remains constant area = steady growth
heartwood acceleration / sapwood area decline = tree / site stress
heartwood deceleration / sapwood area acceleration = expansive growth

wounds / injuries
deep wound (of any depth) exposes heartwood
shallow wound (of any depth) is 100% sapwood exposure

callus = undifferentiated meristatic tissue from cambium zone or rays
woundwood = differentiated tissues generated from callus

BRANCH ATTACHMENT

node = a zone perpendicular to the long axis of a stem or twig where vascular connections are diverted to support axillary buds, leaves, and elongating shoots / twigs (a vascular confluence zone)

internode = a elongated stem segment between nodes

branch = shoot tissue separated from stem 4 years old and older

codominant branch = secondary branch from primary branch or main stem large enough (>2/3 diameter of originating branch or stem) to have a diminished defensive zone and associated wound reactions

fork = conjoined stems or branches of roughly the same size where the confluence is stem-like or equal on both sides, the defensive zone is compromised, and no stem flange is present

divaricate = widely spreading fork
divergent = spreading fork

periderm (bark) unions = external periderm disruption at top of stem-branch confluence
periderm chine (bark chine) = ridge of periderm pushed up in confluence
periderm rimple (bark rimple) = periderm caught internally in confluence generating a crack or wrinkle

periderm (bark) union expansion = periderm unions grow from upper / topmost point in confluence as secondary growth of both stem and branch expand against each other and continually slough off the periderm union to each side

stem-branch confluence area (stem flange) = defensive zone and mechanical support zone at base of branch where branch tissue is diverted downward (basipetally) toward roots, and stem tissues intermingle with branch tissues and flow around the conical branch base

defensive zone = nested cones of each year's confluence tissues comprise the stem flange area

branch collar = stem flange
(no connection between stem xylem and branch xylem above branch)

stem flange = area at confluence of stem and branch providing vascular connection and mechanical support to branch, and defensive potential to stem

stem flange much larger on bottom than top to resist gravity downward and wind upward

stem flange outward extent limit = (considered two identifiable targets for pruning)
branch top = zone at confluence of branch and stem just outside point on branch top just before periderm union begins

branch bottom = just outside point where any alteration in branch diameter occurs as it approaches stem

stem flange inward extent limit = area on branch side ending at periderm union and includes all annual cones of intermixed stem and branch tissues in confluence area

conical shape volume dwindling down until it nears the pith (or until the annual increment year when the branch first developed

PRUNING ANATOMY

proper pruning cut lines = 3 cuts made to remove branch made in order to minimize residual damage, defend defensive zones, facilitate wound closure, and conserve remaining live branch / stem tissue

first two cuts made to assure final cut can be targeted properly

final cut is made clearly outside stem flange area on branch

reduction pruning = properly pruning back the extent and reach of a branch or stem

nexus line = imaginary line placed at top of branch / branch or branch / stem confluence perpendicular to periderm union line (periderm chine or periderm rimple) if making a reduction cut on a fork, or perpendicular to the main stem or primary branch longitudinal axis when reducing to a proper sized secondary branch

lift line = imaginary line established at least 3 saw kerfs or ideally 1/9 of removal branch / stem diameter above (more distal from) the nexus line along one side of a fork chosen for removal, or above a nexus line on a stem or primary branch when reducing to a proper sized secondary branch

reduction cut lines = 3 cuts made in reduction of a branch made to minimize residual damage, defend defensive zones, facilitate wound closure, and conserve remaining live branch / stem tissue

final cut is a 30^{o} down angle from lift line on inside of fork or on inside of branch for removal.

PERIDERM DEFINITIONS

periderm = most external of tissues providing protection, water conservation, insulation, and environmental sensing

a protective tissue generated over and beyond live conducting and non-conducting cells of the food transport system (phloem).

tannins, gums, resins, latex, and crystals (i.e. calcium oxalate or silicates) can all be deposited into periderm cells and cell walls

over time multiple periderms may be generated and stacked beneath each other

new shoots and twigs are covered with a primary epidermis overlaying a primary cortex of simple cells

once secondary growth (expansion in circumference or girth) begins, epidermis may keep pace with expansion.

periderm is a secondary tissue of stems, branches, and roots generated in a tree as the primary epidermis and cortex are crushed and pulled apart by secondary growth

rhytidome = dead layers of old periderms to the outside of current periderm

secondary cortex = area of interlaced cells (phloem and phelloderm) derived from two different lateral meristems by formation and reformation of new phellogens closer to the vascular cambium and can be photosynthetic

lenticel = loosely packed, less suberized cells in a localized area allowing for gas exchange in periderm

bark! = non-technical jargon term for any tissue outside vascular cambium and surrounding a tree stem, branch and root (should never be used!)

in generic terms, bark includes: secondary phloem, periderm, and dead tissues outside the periderm (including the remains of the primary epidermis and primary cortex) (composed of many tissues and defines none!).

in some cases, bark is divided into outer dead bark with no living tissue present, and inner bark with living tissue throughout (no clear visible dividing line!)

in the past many names and concepts have been used for periderm, secondary cortext, and phloem (little recognition of tissue genesis and function!)

PERIDERM FORM

periderm components

phellem = a corky dead tissue surrounding stems and roots

phellem has tightly packed dead cells with few intercellular spaces, except under lenticels.

phellem cells usually suberized and contain a variety of wax, oil, resin, and tannin

many phellem cells are first lignified (phenolic supported)
before they are suberized (polyester packed).

in many trees, phellem is called “cork”

cork = thick phellem / rhytidome layer with low density and heavy suberization (outer periderm)

suberin = complex polyester and product of fatty acids used for defense and water proofing

phellogen = a lateral secondary meristem generating phellem to the outside and phelloderm to the inside

phellogen generates phelloderm to the inside and phellem to the outside

phellogen, and one to two cells beyond are most exterior living tissue in a tree (i.e. outermost edge of the symplast)

phelloderm = a tissue with many live cells providing support for phellogen function and serves as a portion of the secondary cortex

phelloderm cells in stems and twigs may contain chloroplasts, process light, and fix carbon, especially in warm sunny periods of the dormant season.

phelloderm cells store starch and can be stimulated to generate a new phellogen.

phelloderm helps form, along with nonconducting (inactive) phloem, a secondary cortex

periderm is initiated just below lenticels, splits, or breaks in the epidermis, or are formed below the epidermis all the way around a stem, branch or root.

periderm can also be generated along the interior of shallow wounds occurring outside of the xylem core.

periderm forms

arc / scale

arc or scale periderms are generated in small, localized areas cutting off overlapping volumes of tissues

arc or scale periderms generate a scaly or flaky external appearance

ring / circular

ring or circular ring periderms are generated concentrically around an entire stem, branch, or root

concentric ring periderms tend to peel away in strings, strips, or rings, like in species of the genera *Cryptomeria, Thuja,* and *Juniperus*

intermediate
intermediate form of periderm has very large scales and plates like *Platanus*

flaky periderms have many sclereids which cause periderms to pull away in scales or flakes such as in genera *Picea, Ostrya, Larix, Quercus*, and *Acer*.

scaly periderms derived from multiple periderm arcs have many different layers composed of periderm and phloem, as in genera *Pinus, Carya*, and *Acer*.

blocky = furrowed periderm with thinck square or short retangular plates

platy = periderm pieces raised, flat-topped and edged by horizontal and longitudinal furrows

exfoliating = periderm peeling off in thin layers

obliteration = crushing a closing of older cells by development and expansion of new cells

pyrophyte = a tree which has thick periderm protecting it from fire

SELECTED LITERATURE

Barthelemy, D. & Y. Caraglio. 2007. Plant architecture: A dynamic, multilevel and comprehensive approach to plant form, structure and ontogeny. Annals of Botany 99:375-407.

Beck, C.B. 2010. **An Introduction To Plant Structure & Development** (2nd edition). Cambridge University Press, Cambridge, UK.

Bell, A.D. 2008. **Plant Form: An Illustrated Guide to Flowering Plant Morphology**. Timber Press, Portland, Oregon. Pp.431.

Coder, Kim D. 2008. Arboriculture: Foundations of Classic Design Pruning. University of Georgia Warnell School of Forestry & Natural Resources Outreach Monograph WSFNR08-13 (v. 7.1). Pp.82.

Coder, Kim D. 2009. Tree periderm: Bark, rhytidome, & protection. University of Georgia Warnell School of Forestry & Natural Resources Outreach Publication WSFNR09-10. Pp.32.

Coder, Kim D. 2010. Tree periderm: Less than bark deep. Arborist News 19(2):39-42.

Coder, Kim D. 2011. Secondary tree growth increments: Ring development and forms. University of Georgia Warnell School of Forestry & Natural Resources Outreach Publication WSFNR11-07. Pp.18.

Coder, Kim D. 2014. Advanced Twig Anatomy (Part I): Starting Little To Get Big. Arborist News 23(1):12-18.

Coder, Kim D. 2014. Advanced Twig Anatomy (Part II): Everyone Needs Buds. Arborist News 23(2):12-19.

Coder, Kim D. 2014. Tree Anchorage & Root Strength. University of Georgia Warnell School of Forestry & Natural Resources Outreach Monograph WSFNR14-9. Pp.67.

Evert, R.F. 2006. **Esau's Plant Anatomy** (3rd edition). John Wiley & Sons, Hoboken, NJ.

Fink, S. 1983. The occurrence of adventitious and preventitious buds within the bark of some temperate and tropical trees. American Journal of Botany 70(4):533-542.

Harris, J.G. & M.W. Harris. 2006. **Plant Identification Terminology: An Illustrated Glossary** (2nd edition). Spring Lake Publishing, Payson, Utah.

Iqbal, M. 1994. **Growth Pattern in Vascular Plants**. Dioscorides Press, Portland, Oregon.

Lance, R. 2004. **Woody Plants of the Southeastern United States: A Winter Guide**. University of Georgia Press, Athens, GA.

MacAdam, J.W. 2009. **Structure & Function of Plants**. Wiley-Blackwell, Ames, IA.

McSteen, P. & O. Leyser. 2005. Shoot branching. Annual Review of Plant Biology 56:353-374.

Metcalfe, C.R. & L. Chalk. 1979. **Anatomy of the Dicotyledons** (2nd edition) – Volume 1. Oxford University Press, New York. Pp.288.

Pallardy, S.G. 2008. **Physiology of Woody Plants** (3rd edition). Academic Press, Burlington, MA.

Preston, R.J. & V.G. Wright. 1985. **Identification of Southeastern Trees in Winter** (reprint). #AG-42. North Carolina Agricultural Extension Service, Raleigh, NC

Rudall, P. 2007. **Anatomy of Flowering Plants** (3rd edition). Cambridge University Press, New York.

Schweingruber, F., A. Borner, & E.D. Schulze. 2008. **Atlas of Woody Plant Stems**. Springer-Verlag, Berlin, Germany.

Schweingruber, F., A. Borner, & E.D. Schulze. 2011. **Atlas of Stem Anatomy in Herbs, Shrubs & Trees** (Volume 1). Springer-Verlag, Berlin, Germany.

Shigo, A.L. 1994. **Tree Anatomy**. Shigo & Trees, Associates, Durham, NH.

Shmulsky, R. & P.D. Jones. 2011. **Forest Products & Wood Science** (6th edition). Wiley-Blackwell, West Sussex, UK.

Wilson, K. & White, D.J.B. 1986. **The Anatomy of Wood**. Stobart & Sons, London, UK.