COMPARTMENTALIZATION OF DECAY IN TREES

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Watercolor illustrations by David M. Carroll, Warner, New Hampshire.

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COMPARTMENTALIZATION OF DECAY IN TREES

Alex L. Shigo
Plant Pathologist, U.S. Department of Agriculture,
Forest Service, Northeastern Forest Experiment Station,
Durham, New Hampshire
and
Harold G. Marx
Research Applications Staff Assistant, U.S. Department of Agriculture,
Forest Service, Washington, D.C.

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INTRODUCTION

The science of tree pathology emerged from studies on decay almost a century ago. Many of the concepts developed then have changed little over the years. But, in the last few decades some additional information on the decay process in trees has been developed. This new information has added to the basic story of decay without subtracting anything important from it. The new expanded concept of decay is simply more complete. And this new, more complete concept gives us a better opportunity to regulate and control decay.

Dr. George H. Hepting made the first sound observations on compartmentalization of decay in trees in 1935. His ideas acted as a trigger for the work that followed. The work presented here is an expansion of his ideas.

The information in this publication is based on 16 years of research by Dr. Shigo that involved complete dissections of approximately 10,000 trees—mostly deciduous hardwoods, at least 1,000 conifers, and 17 tropical species. Details of these studies have been published elsewhere.

The purpose of this publication is to show how most columns of discolored and decayed wood associated with trunk wounds in trees are compartmentalized. A great number of confusing terms are given to a wide variety of defects caused by discolorations and decays in trees. This book describes a system that makes it possible for forest managers to understand how most of these defects develop. To understand the system, the report must be studied very carefully. The system is called

CODIT

Compartmentalization **O**f **D**ecay **I**n **T**rees

When the system is learned, it will act as the code for understanding a wide variety of defects on most tree species.

The CODIT system is based on two major points. First, a tree is a highly compartmented plant. Second, after a tree is wounded, the resulting defects are compartmentalized.

To apply the CODIT system it is necessary to understand that the new expanded decay concept developed in the last few decades includes: 1) *Successions* of microorganisms associated with discoloration and decay, and 2) *Compartmentalization* of discolored and decayed wood associated with trunk wounds.

To begin with, decay of wood is a natural process caused by microorganisms, mainly fungi, that enter trees through wounds. Tree wounds are usually inflicted by fire, weather, insects, birds, small or large animals, or man and his activities. These wounds start the processes that can lead to decay, and decay is a major cause of damage to trees. While wood decay is most often caused by decay-causing fungi, these fungi are often intimately associated with bacteria and nondecay fungi in the process. Decay is the breakdown or decomposition of dead organic matter. It is also essential to new life.

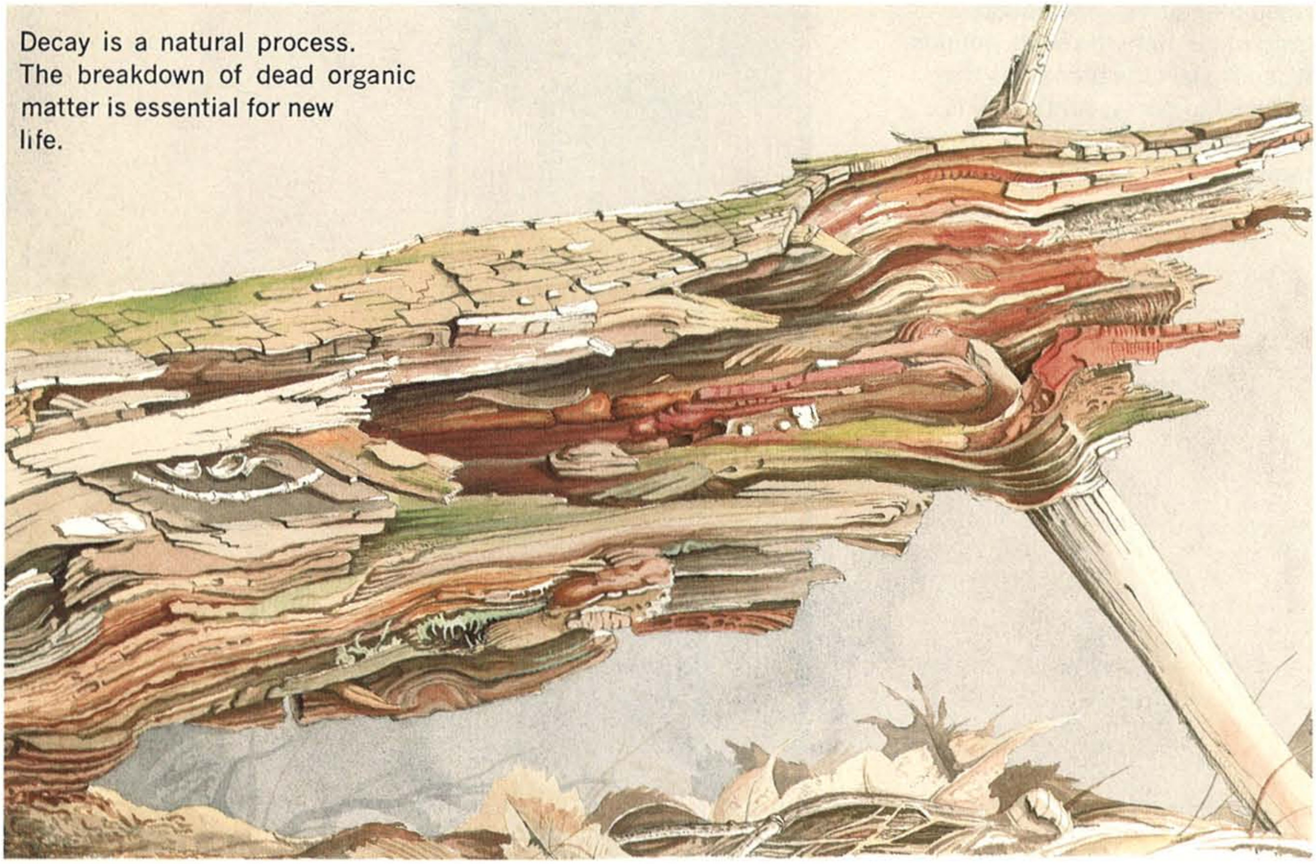
To understand how trees react to wounding and the associated defects by compartmentalizing the defects, it is necessary to reevaluate our concept of how a tree is constructed. A tree is considered here as a highly compartmented plant. In a sense, a tree is made up of many trees; each growth ring is a "tree." Each "tree" is divided into many compartments. A compartment can be thought of as a "room," with side walls made up of rays and front and back walls made up of cells that are the last to form in each growth ring. The top and bottom of the compartment is formed after wounding when the elements that transport liquids plug up. The compartment is the least common denominator of the tree. All the types of cells found in the woody stem of a tree will be found in each compartment.

When microorganisms invade tree stems through wounds, they do so in successions. Bacteria, nondecay fungi, and decay fungi are often intimately associated in this invasion process. When microorganisms invade, they first surmount the chemical protective barriers set up by the tree and then move into the tree from compartment to compartment.

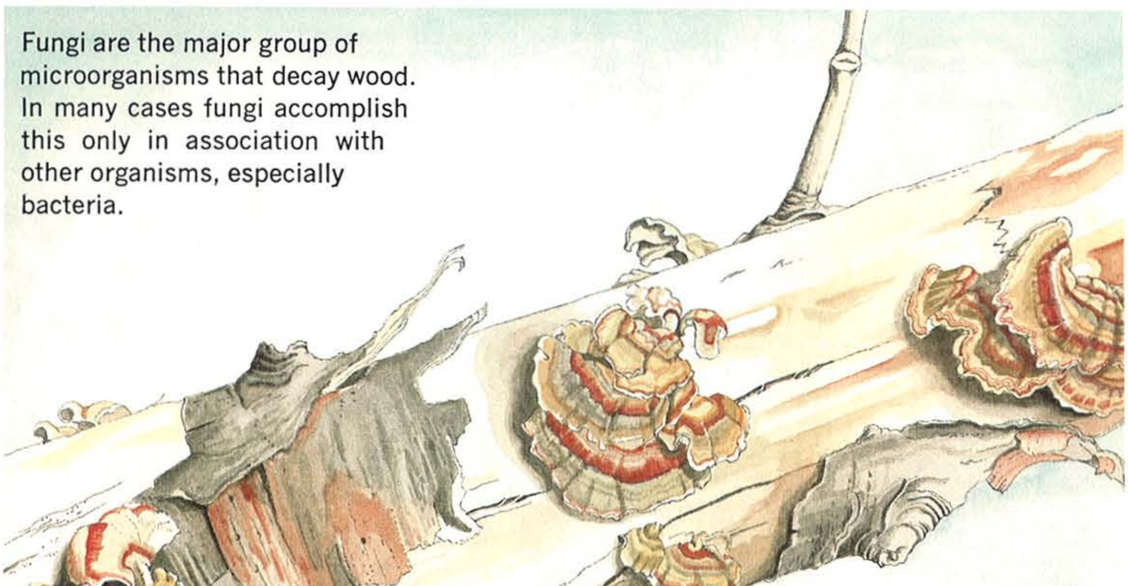
The weakest walls of a compartment are the tops and bottoms, and the inner walls. The side walls are fairly strong. When all these walls fall to the invading microorganisms, there is another wall that begins to form. The wall formed by the cambium after wounding is the barrier zone. This wall confines the invasion to the wood present at the time of wounding. The new "trees" or rings that continue to form are then protected from invasion unless new wounds are inflicted. When new wounds are inflicted at later times, multiple columns of defect develop.

An understanding of CODIT will help to clarify many misconceptions about decay.

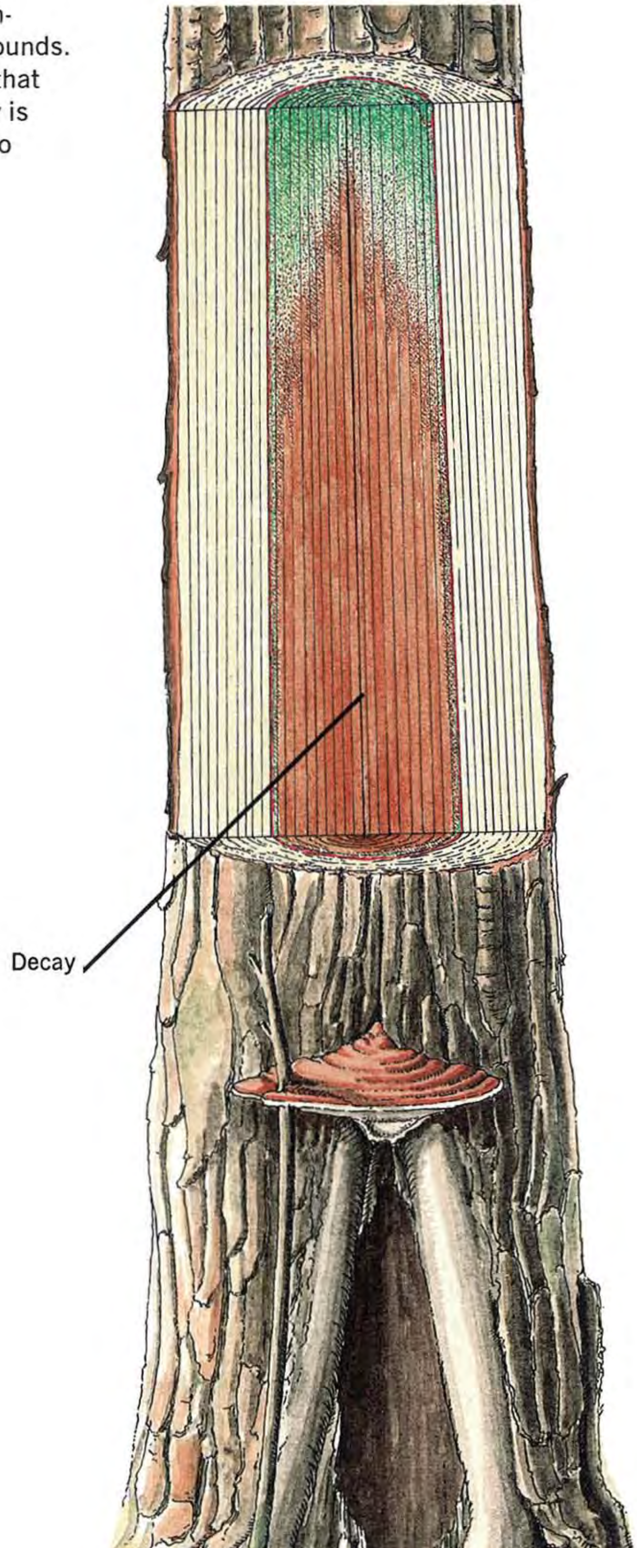
Decay is a natural process. The breakdown of dead organic matter is essential for new life.

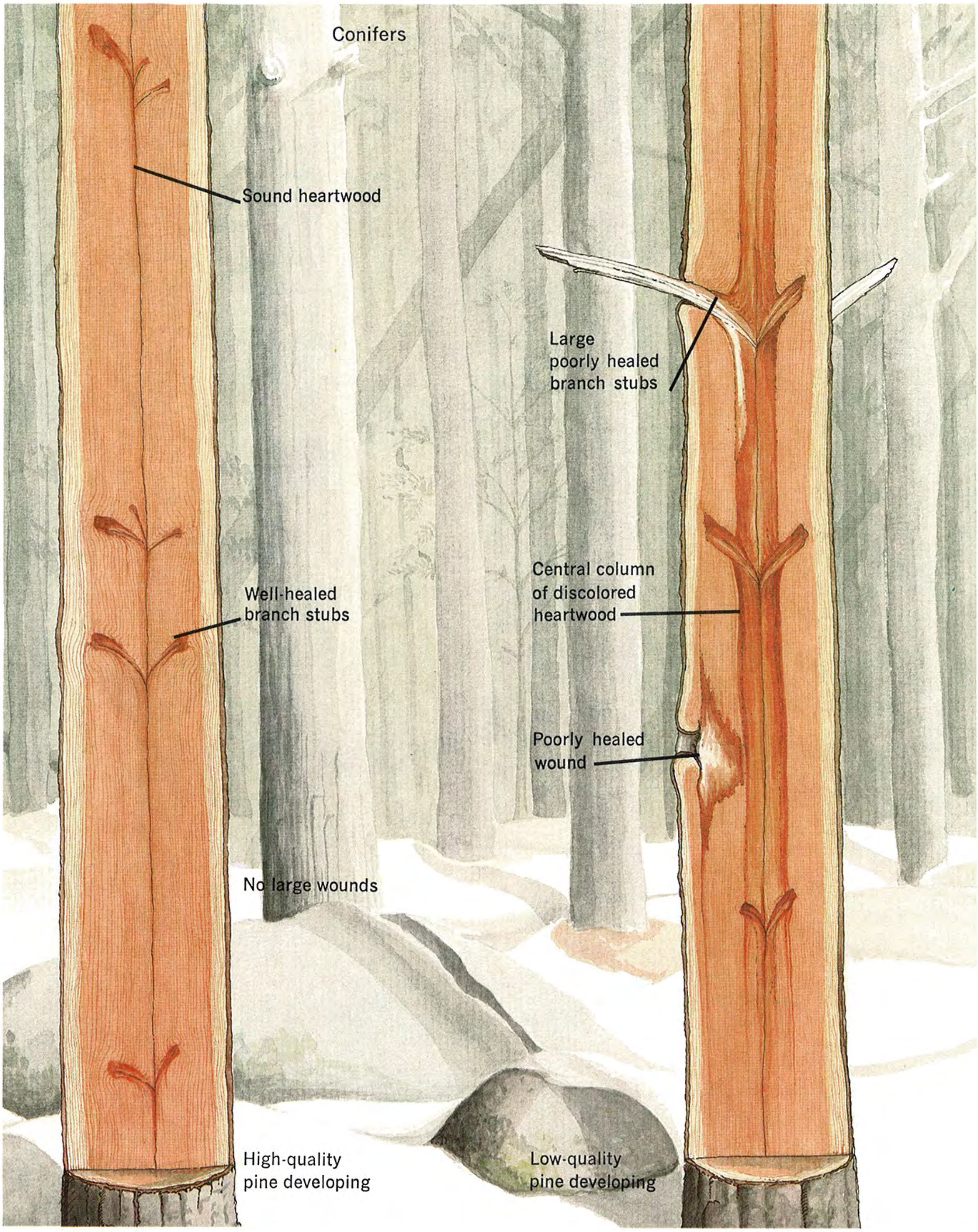


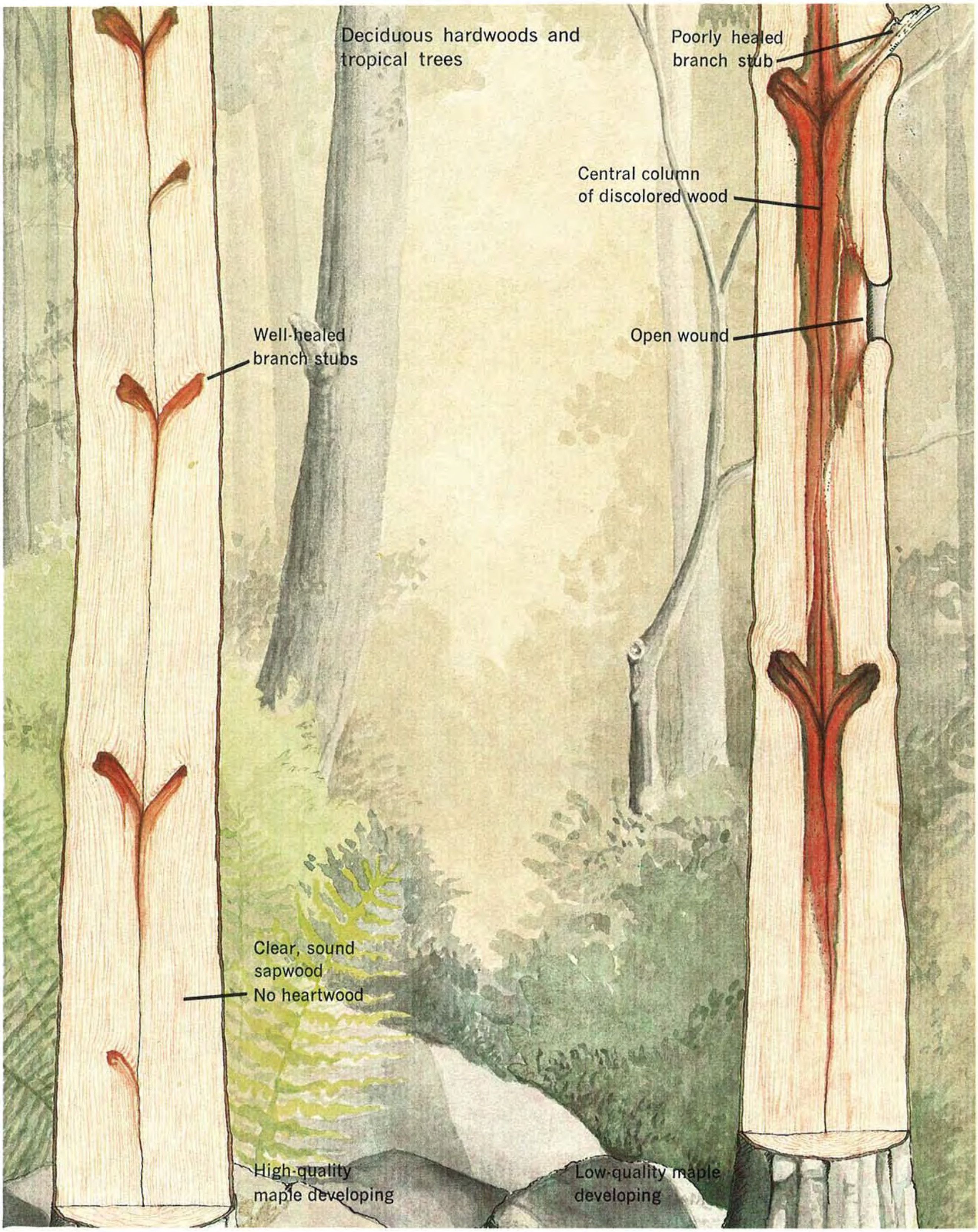
Fungi are the major group of microorganisms that decay wood. In many cases fungi accomplish this only in association with other organisms, especially bacteria.



Wood-inhabiting microorganisms enter trees through wounds. Wounds start the processes that can lead to decay. And decay is a major cause of damage to trees.




Conifers
Sound heartwood
Well-healed
branch stubs
No large wounds
High-quality
pine developing
Large
poorly healed
branch stubs
Central column
of discolored
heartwood
Poorly healed
wound
Low-quality
pine developing

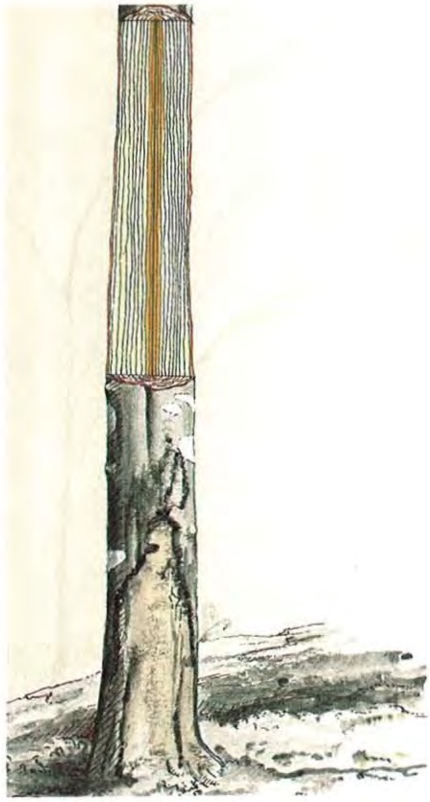

Deciduous hardwoods and tropical trees
Poorly healed branch stub
Central column of discolored wood
Well-healed branch stubs
Open wound
Clear, sound sapwood
No heartwood
High-quality maple developing
Low-quality maple developing

Some common wounding agents
are

Birds

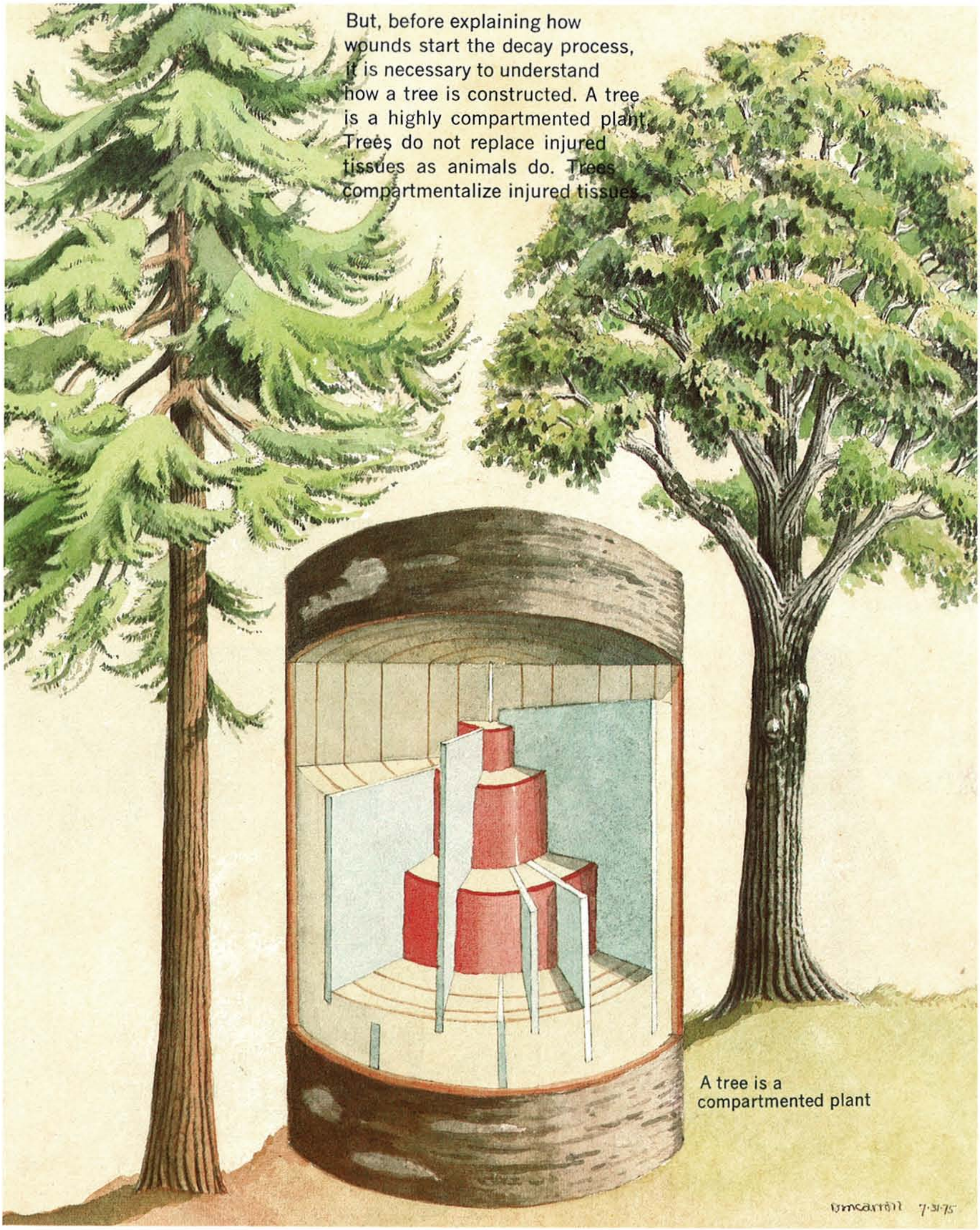
Small animals

Insects


Fire

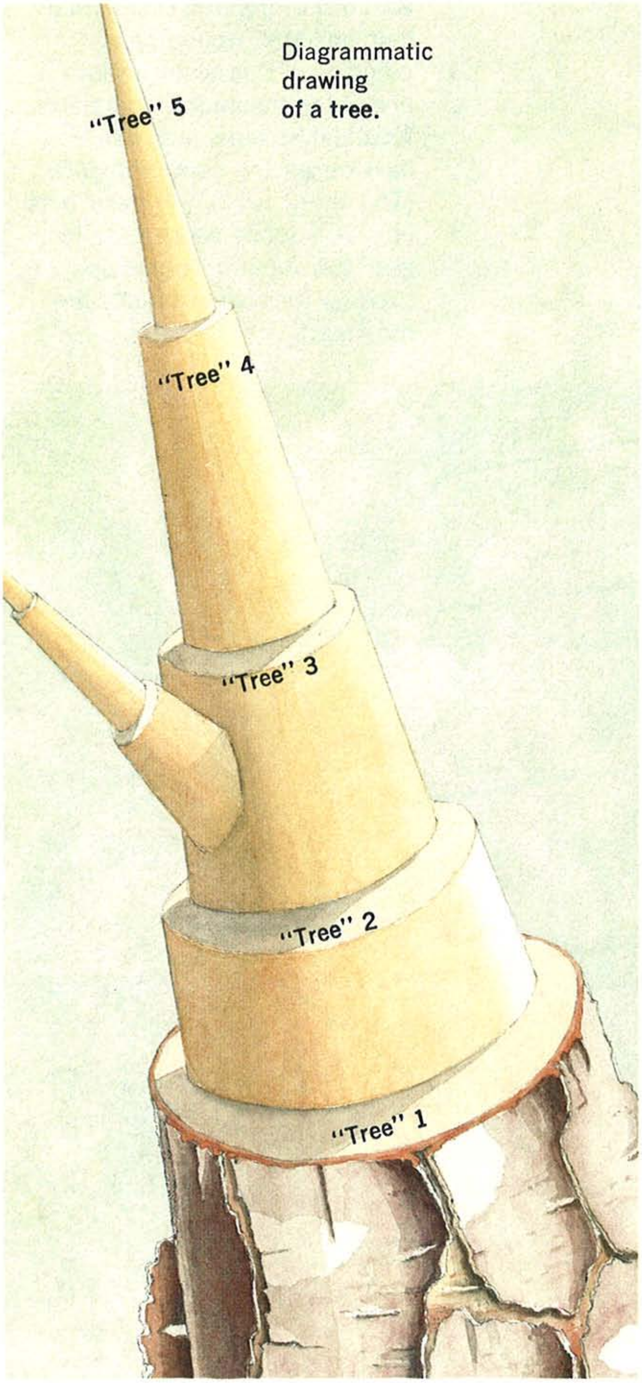
Large animals

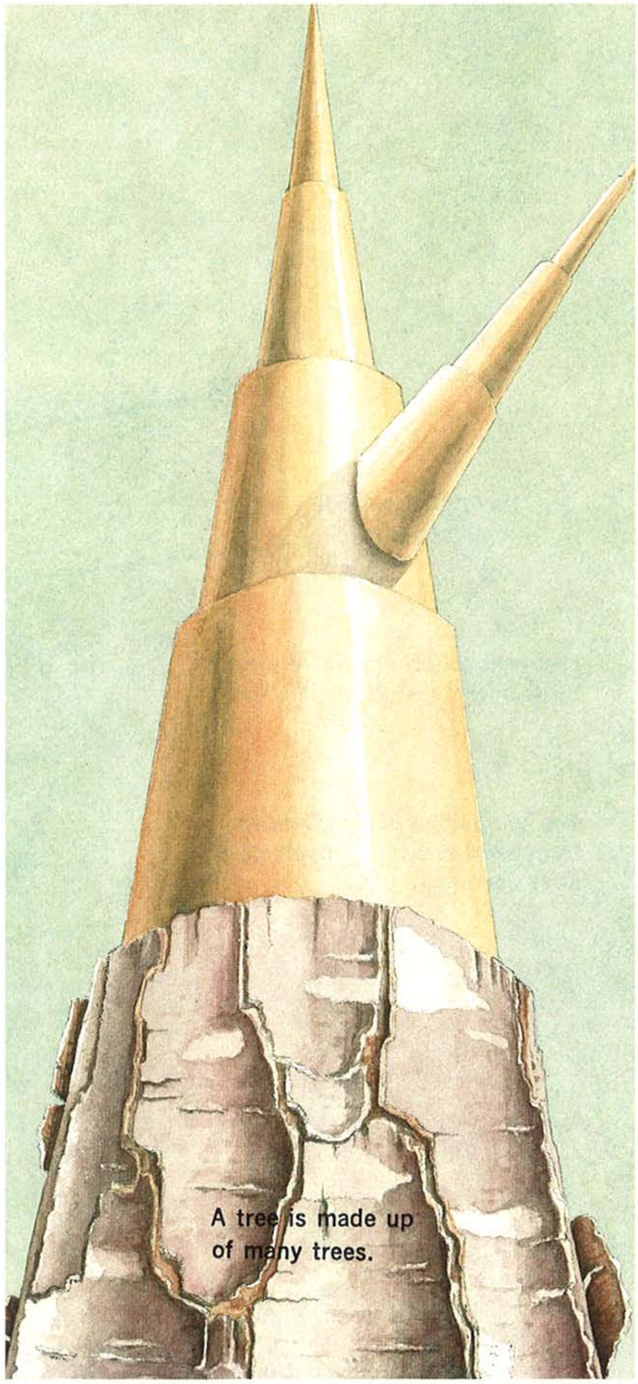
But, before explaining how wounds start the decay process, it is necessary to understand how a tree is constructed. A tree is a highly compartmented plant. Trees do not replace injured tissues as animals do. Trees compartmentalize injured tissues.



A tree is a compartmented plant

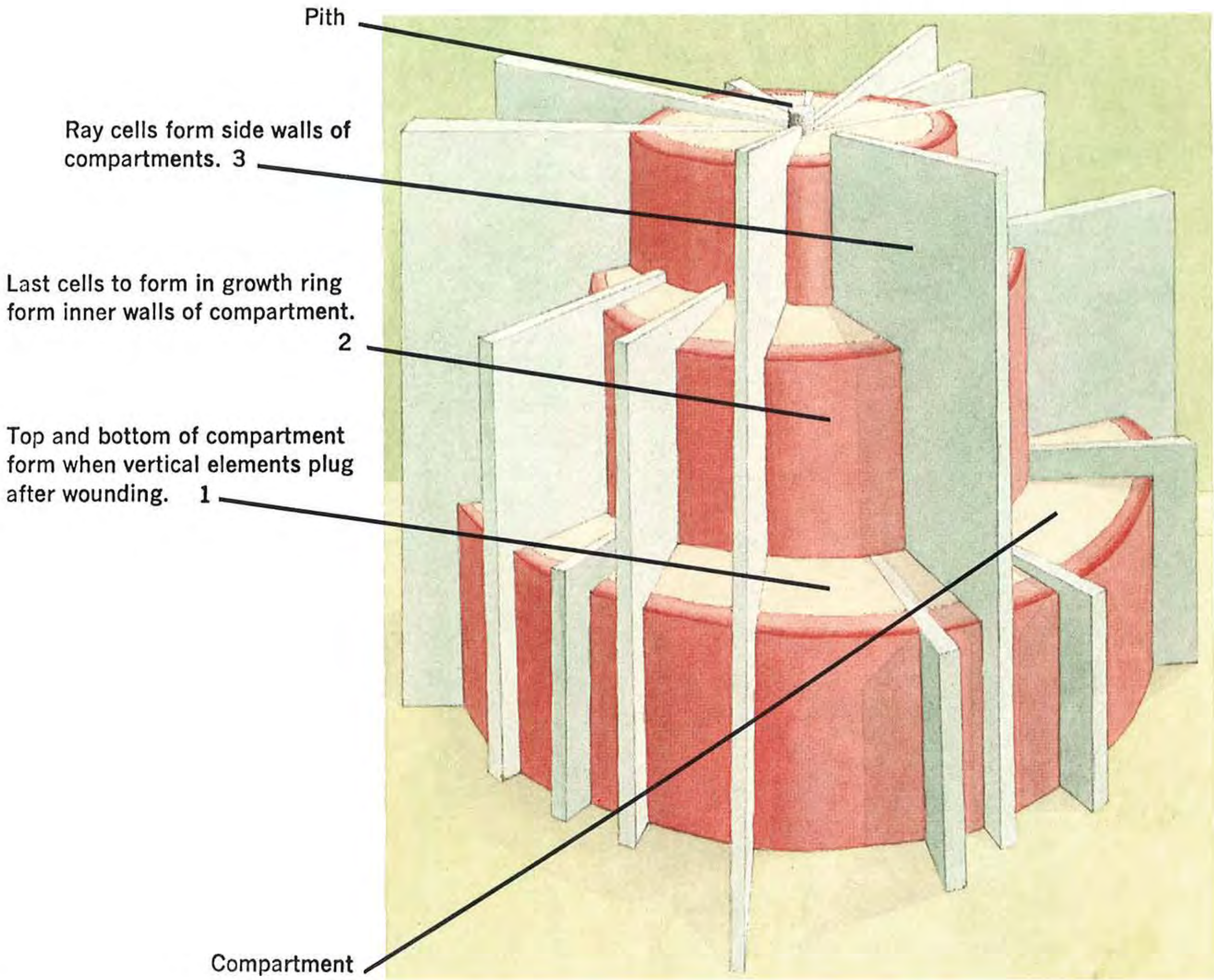
In a sense, a tree is made up of many trees. Each growth ring can be thought of as a separate tree.





In a diagrammatic way, here is how a tree is constructed. (The drawings are designed to give a general impression of compartments in trees and they are not intended as technical anatomical descriptions of cell types and arrangements.)

The rays define the side walls of the compartments. The last few series of cells in the growth ring define the inner walls. The compartment has holes in the top and bottom walls because the flow of materials is maintained in a vertical direction. But, one of the first events that happens after wounding is a plugging of this system above and below the injury. Complete tops and bottoms then begin to develop on the compartments. (The term "walls" is used here in a very loose sense only to give the mental impression of "rooms" or compartments in the tree.)



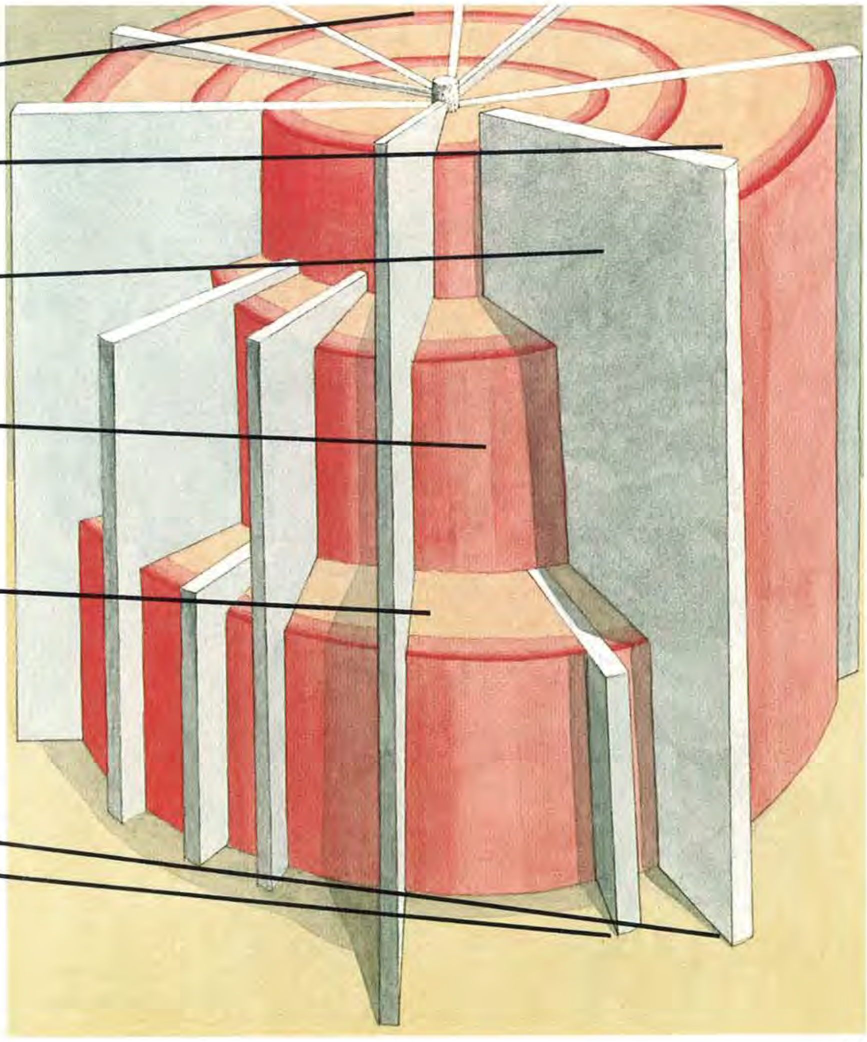
In wood present at the time of wounding, the tops and bottoms of the compartments are the weakest walls. These we will call Wall 1. The inner walls are the second in weakness—Wall 2. The side walls are fairly strong—Wall 3. The strongest wall is the one formed by the cambium after wounding—Wall 4.

Wall 1 is incomplete in living sapwood because the conducting elements—vessels, tracheids—conduct liquids in a vertical direction. But as heartwood forms, or after wounds are inflicted, pits close or the conducting elements are plugged. The rate and degree of pit closure and element plugging depend on many factors. Completion of Wall 1 is the result of a dynamic process. The plugging will then set the limits for the vertical extension of each compartment. When plugging occurs rapidly, short compartments form, but when plugging is slow, long compartments form.

Wall 2 is continuous around every growth ring, and from the top to bottom of the tree.

Wall 3 is discontinuous because sheets of ray cells are not continuous radially and longitudinally throughout the tree.

Wall 4 is a much stronger, more localized version of Wall 2. The area—longitudinal, tangential—covered by Wall 4 will depend on many factors: Wound size, type, position, severity, time of year when wounding occurs, and intrinsic genetic potential to respond to wounds.



Each growth ring is made up of many compartments.

Walls 2 are continuous around the rings and from top to bottom.

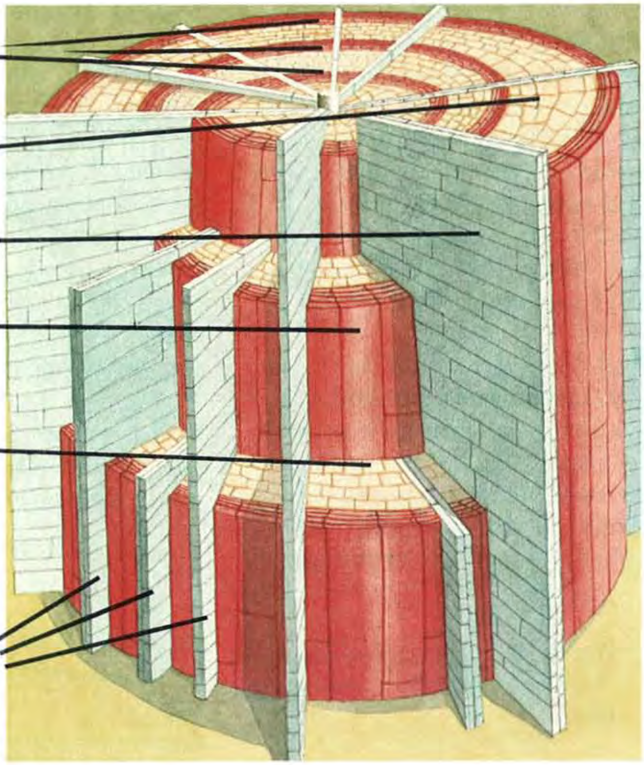
A compartment

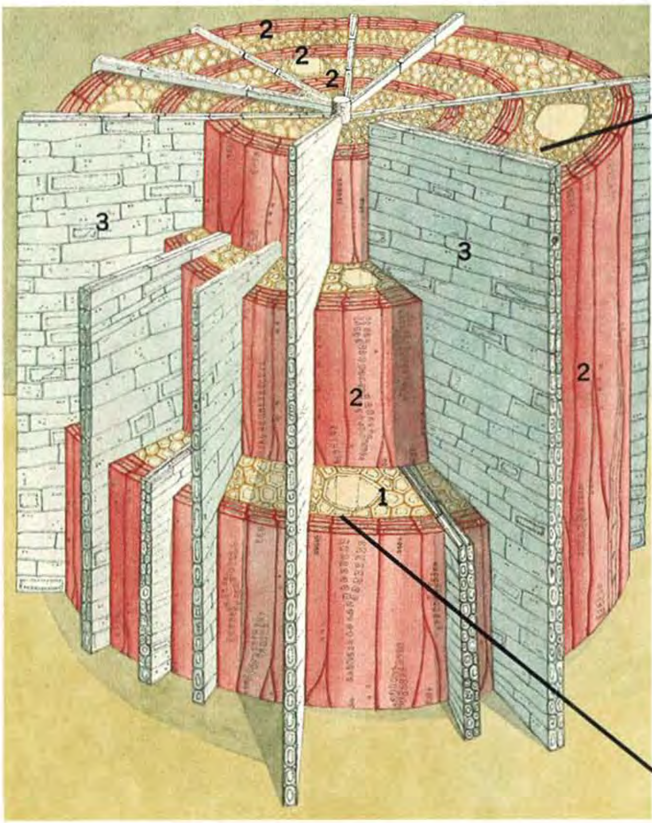
Wall 3

Wall 2

Wall 1 is incomplete until after wounding.

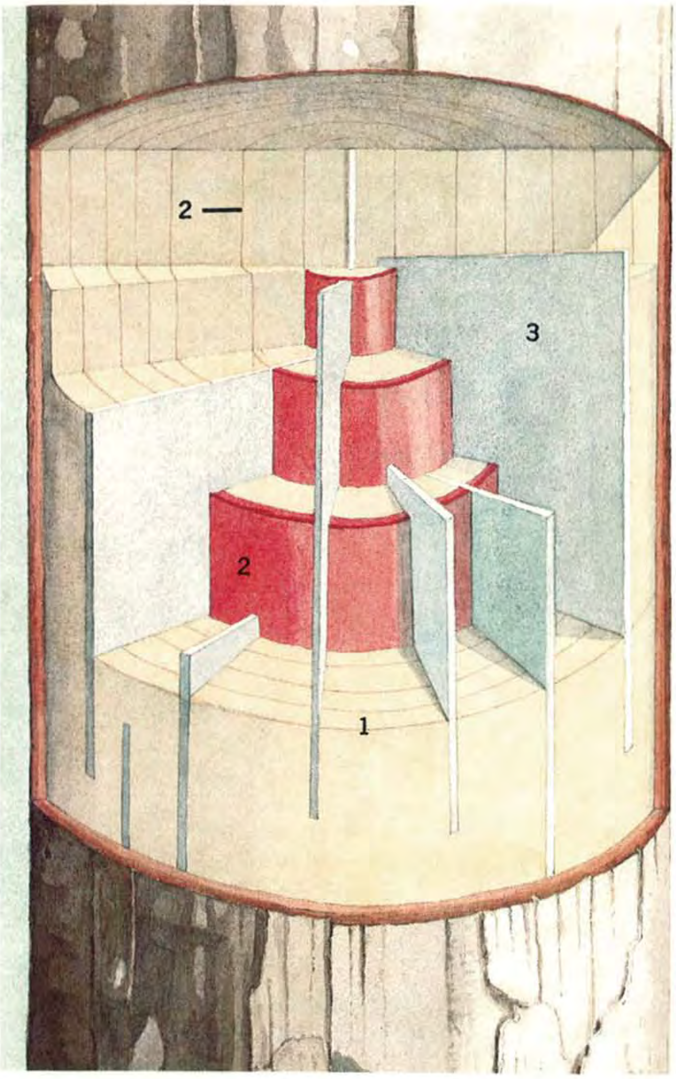
Walls 3 are discontinuous inward and up and down.





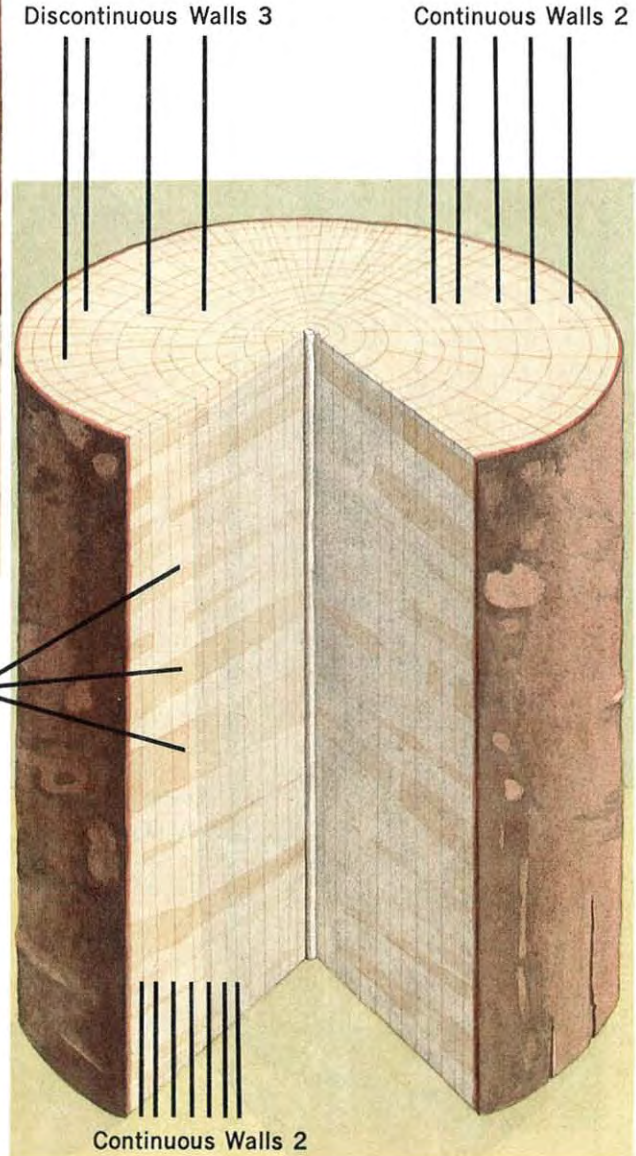
A compartment

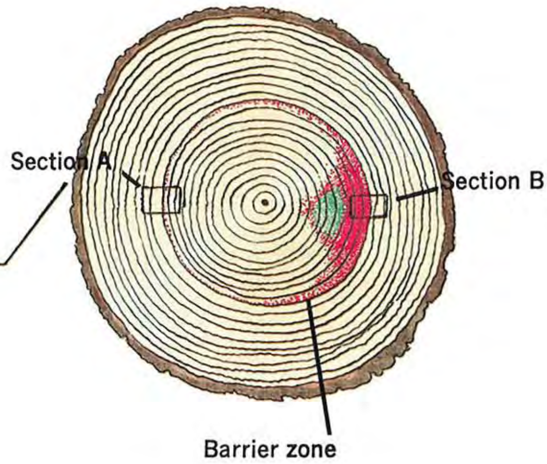
Vascular elements plug after wounding and complete Wall 1.

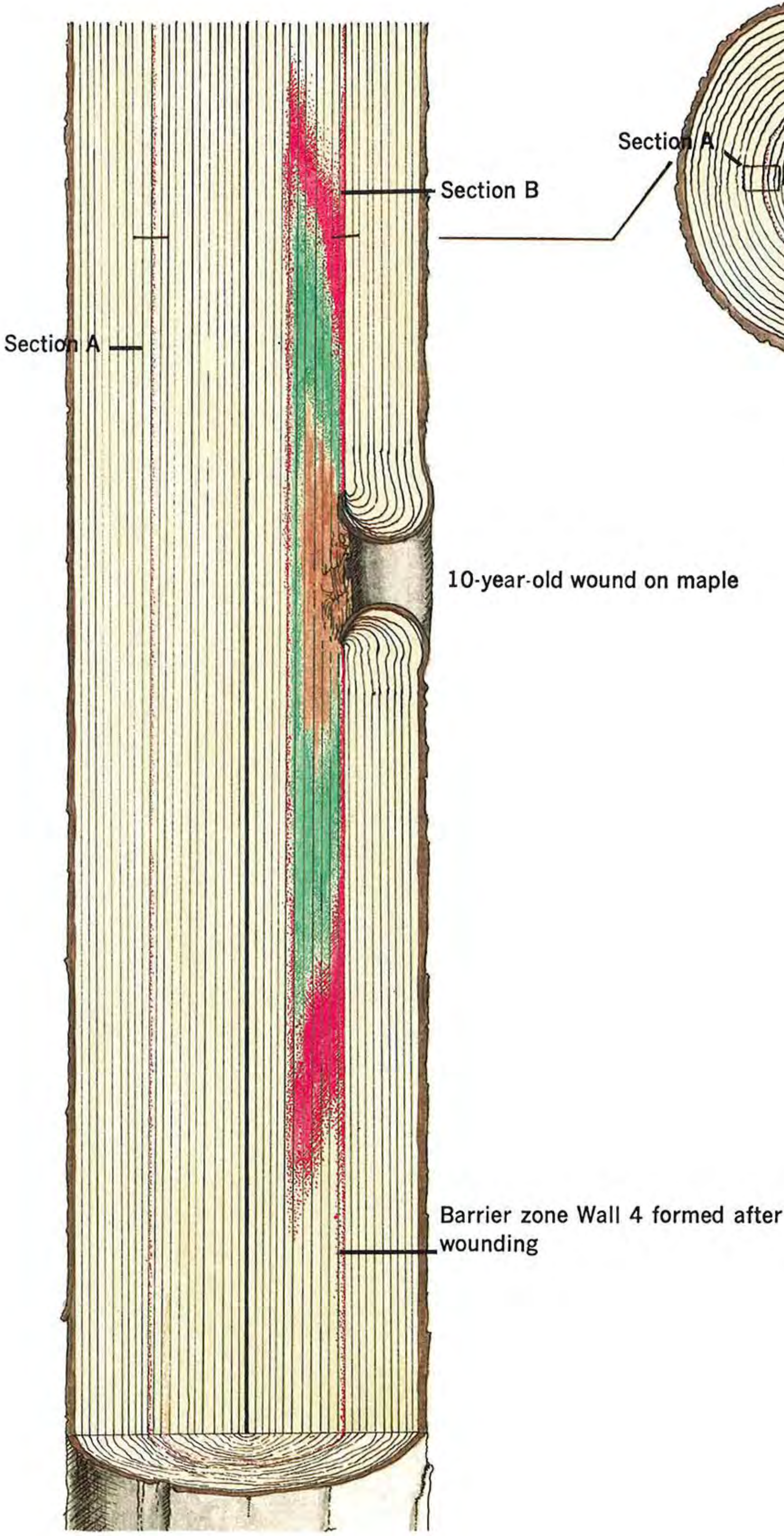


Each growth ring is made up of many compartments.

A tree is a highly compartmented plant.







After wounding, the cambium forms Wall 4. This wall is called a barrier zone. It separates wood formed before wounding from wood that forms after wounding.

Color key to all drawings

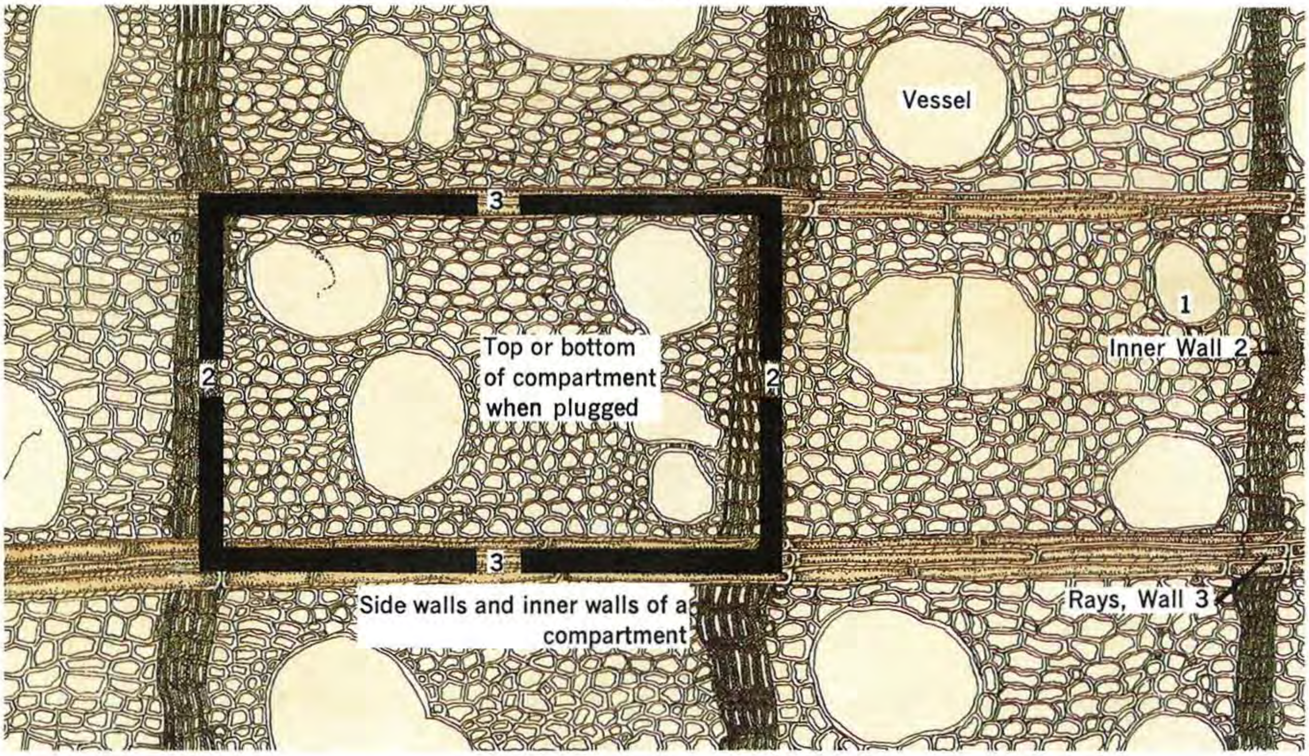
RED—Host response to wounding, chemical reactions to STOP invasion.

GREEN—Invasion processes by microorganisms GO through the barriers set up by the tree.

BLUE—Infection of dead and dying tissues on wound surface.

BROWN—Decay processes.

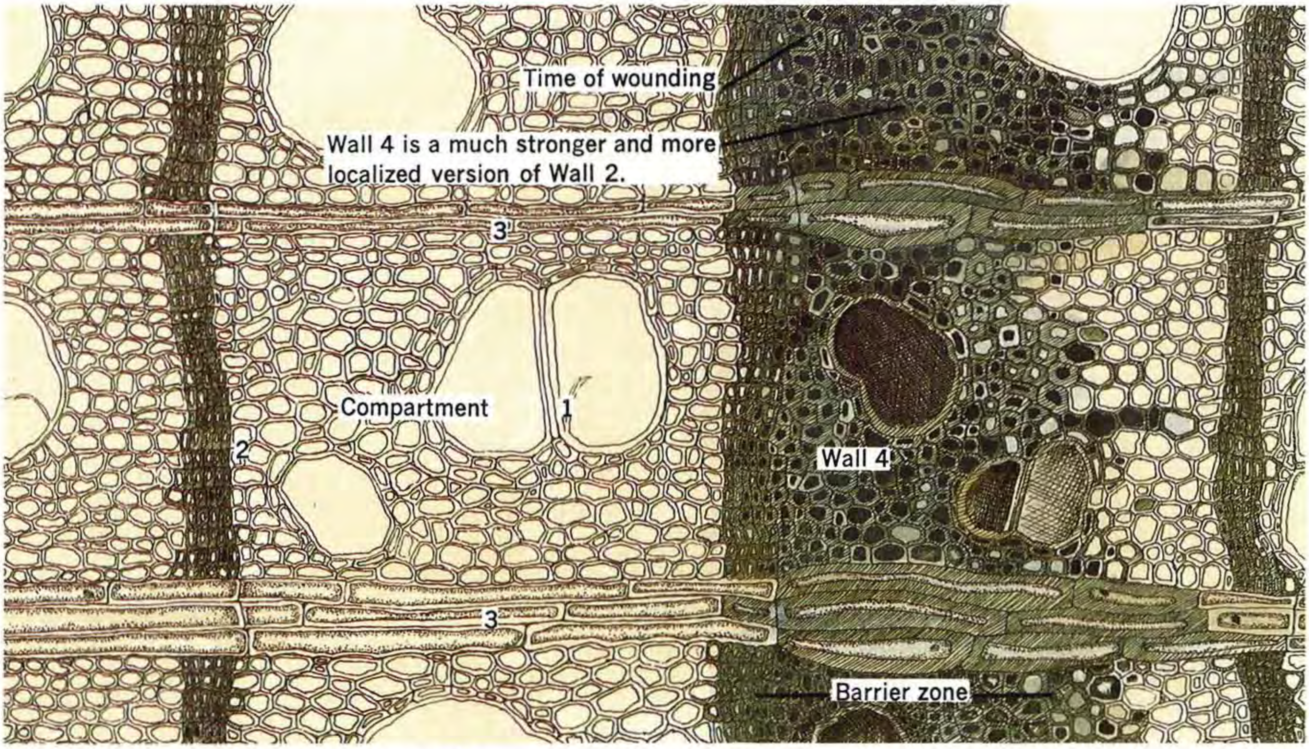
Section A



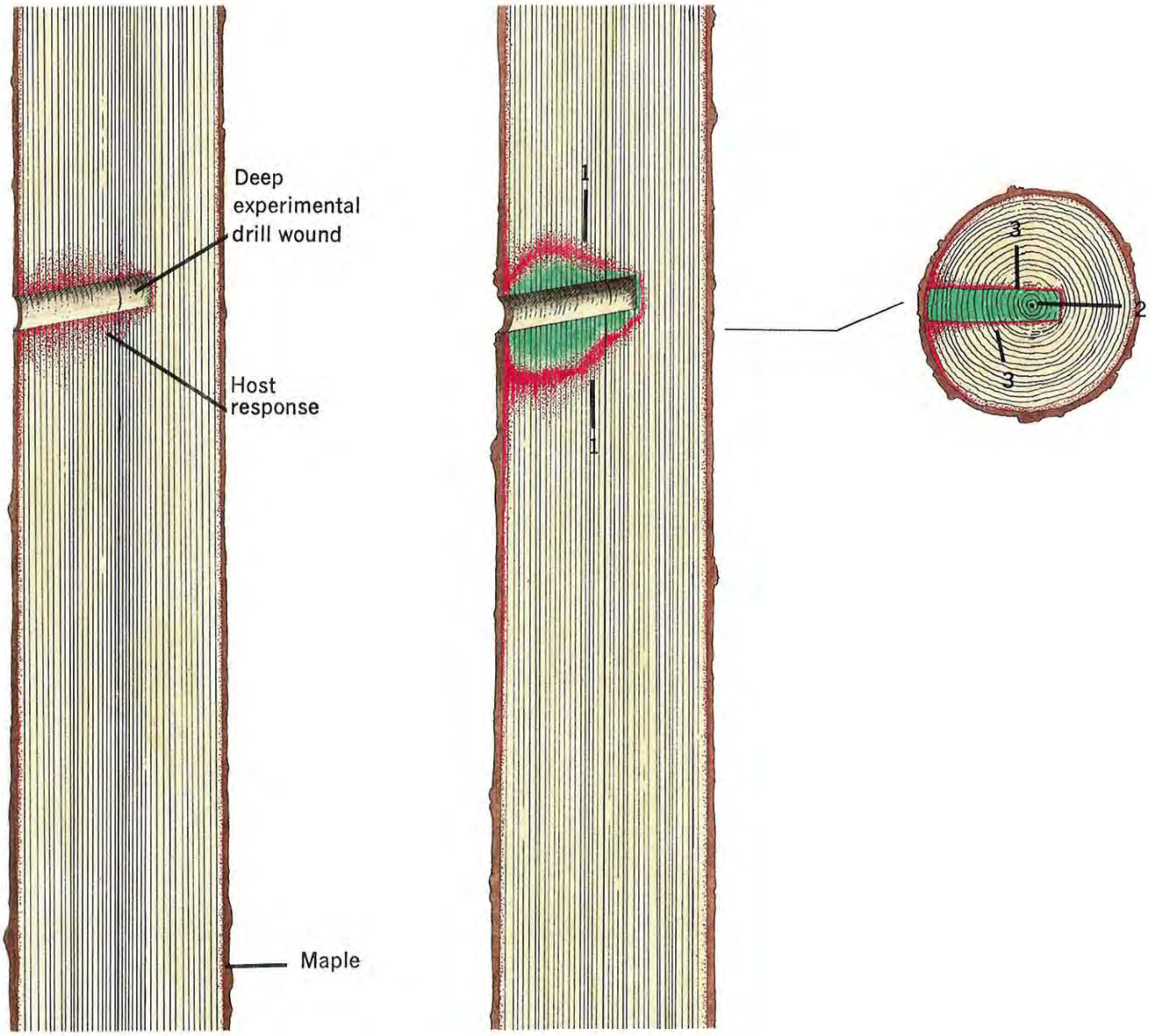
Bark

Section B

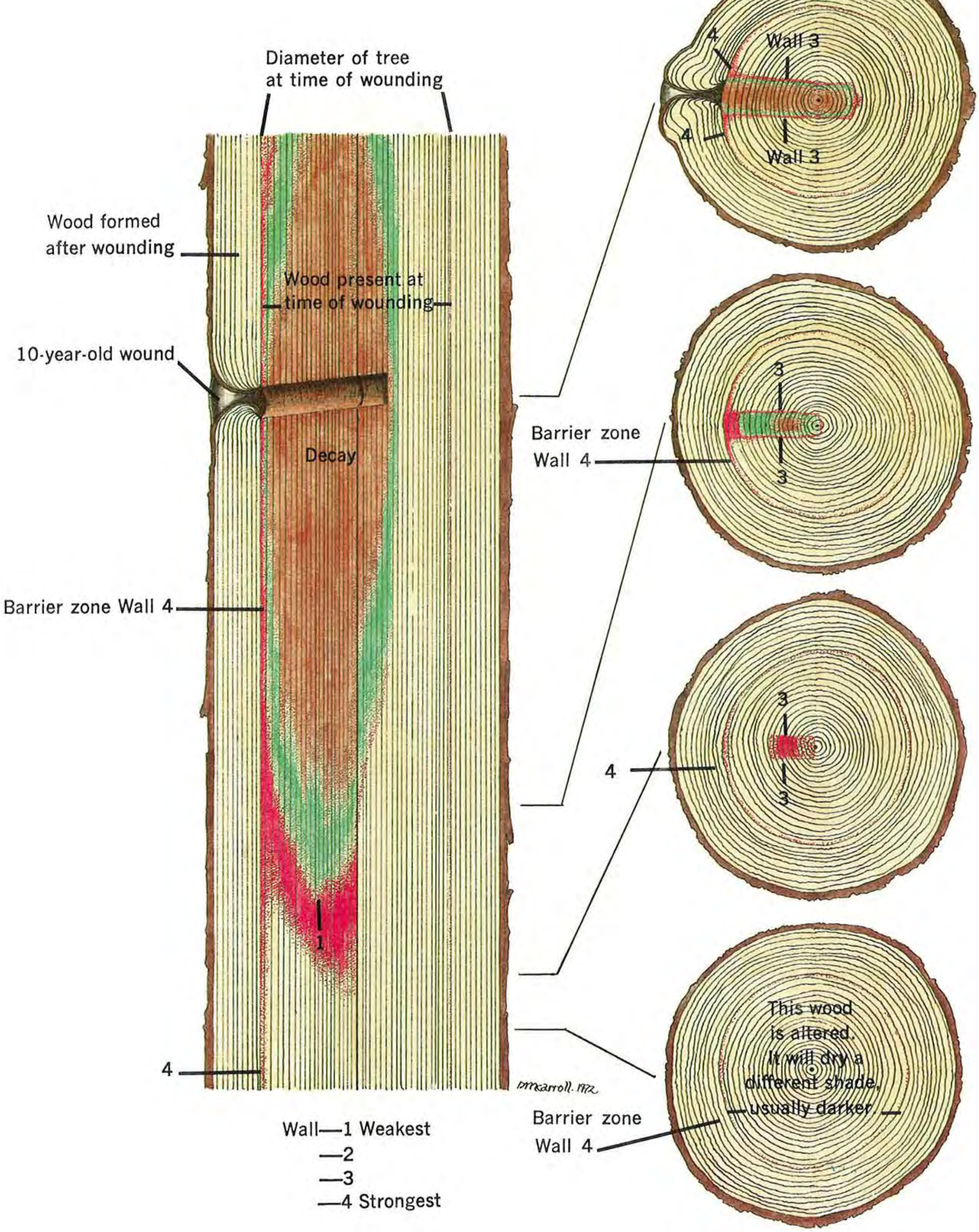
Bark



1—Top and bottom walls are weakest walls 2—Inner wall 3—Ray wall
4—Barrier zone equals strongest wall

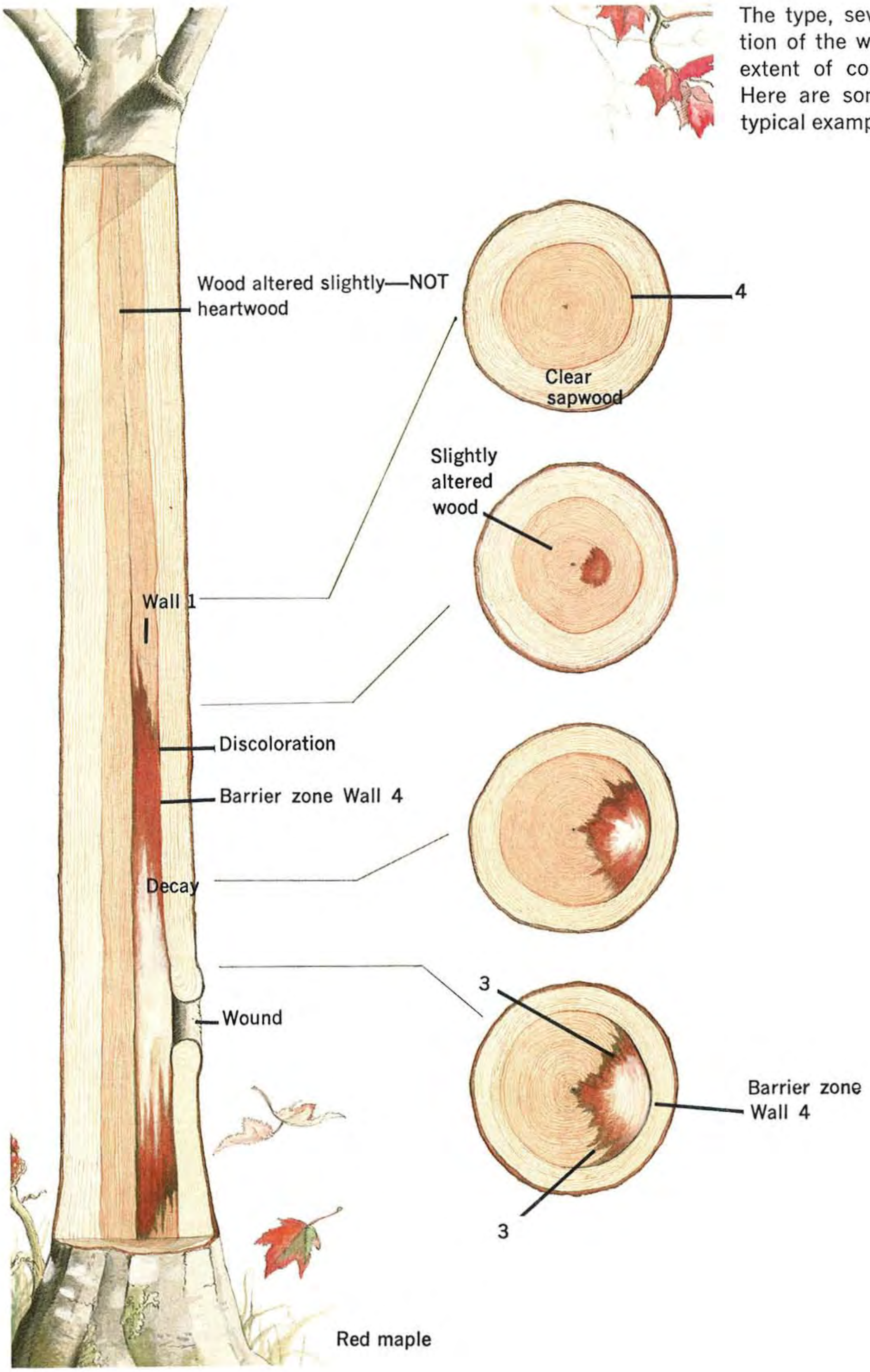


After wounding, the tree reacts. Chemical barriers develop around the injured tissues. Some wood-inhabiting microorganisms surmount these barriers and begin to interact with the tree. The tree exerts a living protective force to keep the invaders out, and the invaders exert a strong force to get into the tree through the wound. When microorganisms are able to get in, they move from compartment to compartment. And when the walls of the compartments begin to fall to the force of the invaders, the tops and bottoms (Wall 1) go first, then the inner walls (Wall 2), and then the side walls (Wall 3). But, most of the time the barrier zone (Wall 4) holds, and confines the invaders to the wood present at the time of wounding. The figures 1, 2, 3, and 4, in addition to naming the wall, also indicate the relative strength of each wall. It must be emphasized that the walls are not absolute in their compartmentalizing capacities and given enough time, even the barrier zone (Wall 4) will fall.

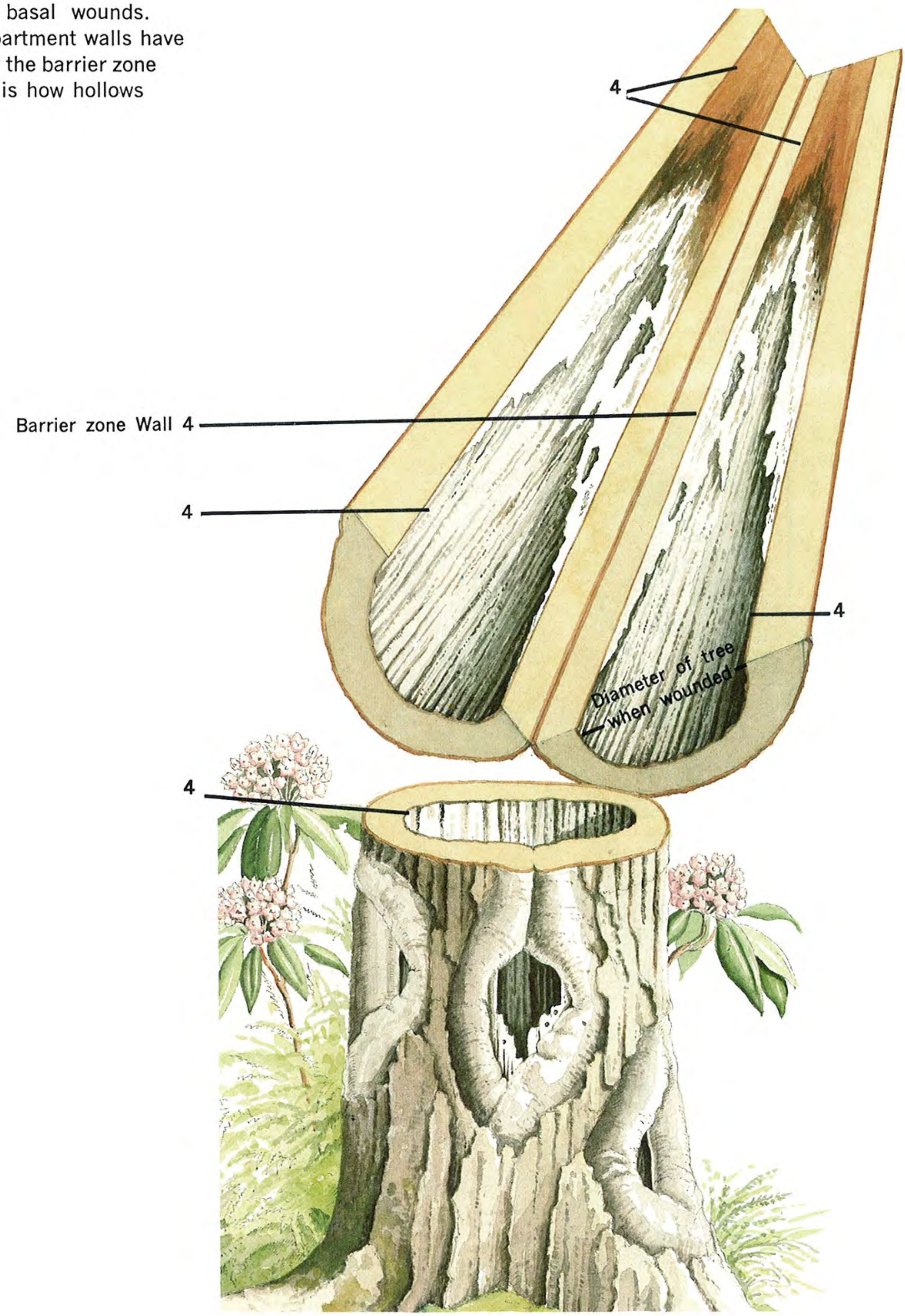


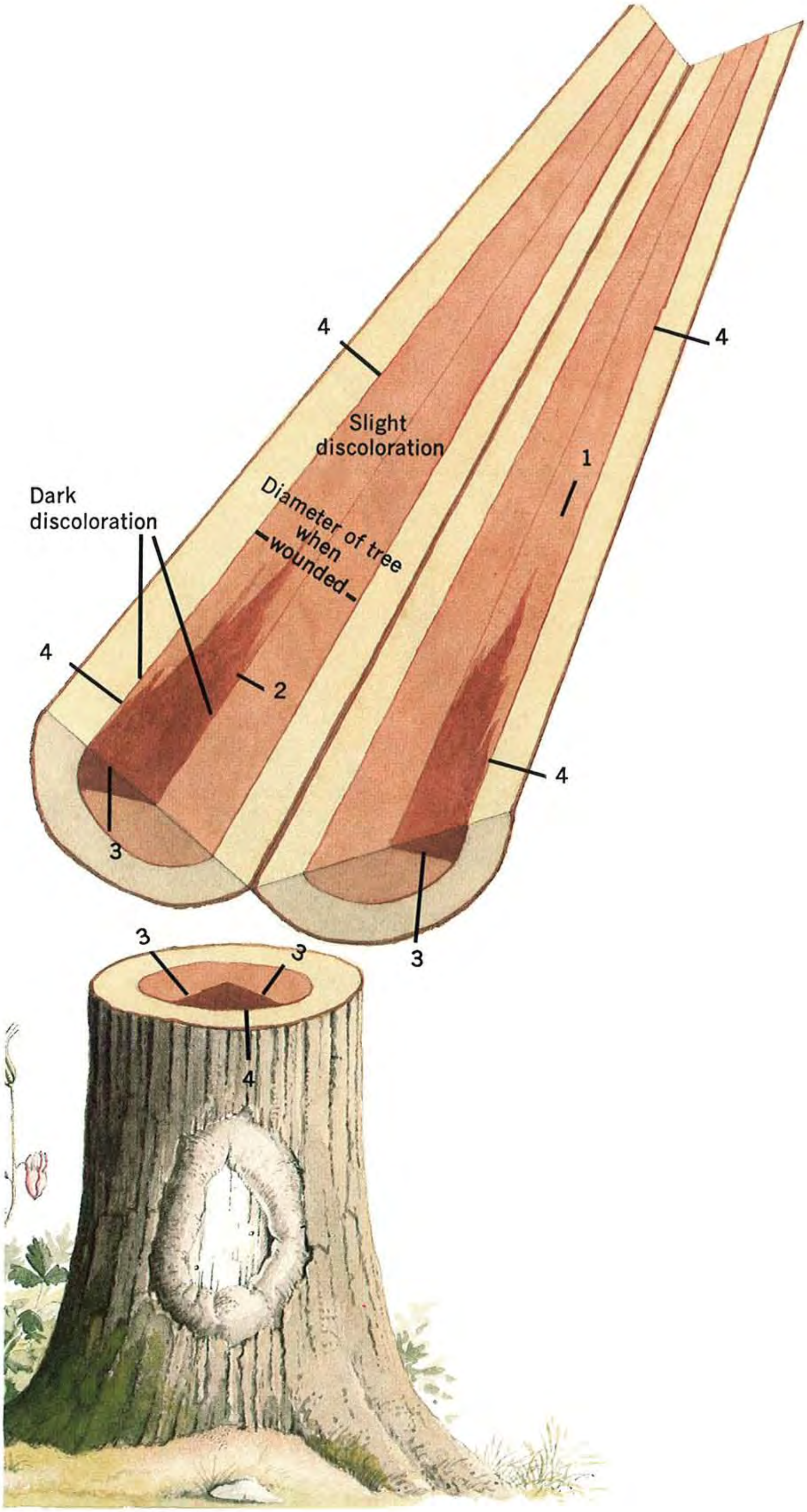
Diameter of tree
at time of wounding
Wood formed
after wounding
Wood present at
time of wounding
10-year-old wound
Decay
Barrier zone Wall 4
1
4
Wall—1 Weakest
—2
—3
—4 Strongest
4
Wall 3
4
Wall 3
3
3
Barrier zone
Wall 4
3
3
4
This wood
is altered.
It will dry a
different shade,
usually darker
Barrier zone
Wall 4

The type, severity, and position of the wound will affect the extent of compartmentalization. Here are some of the most typical examples.



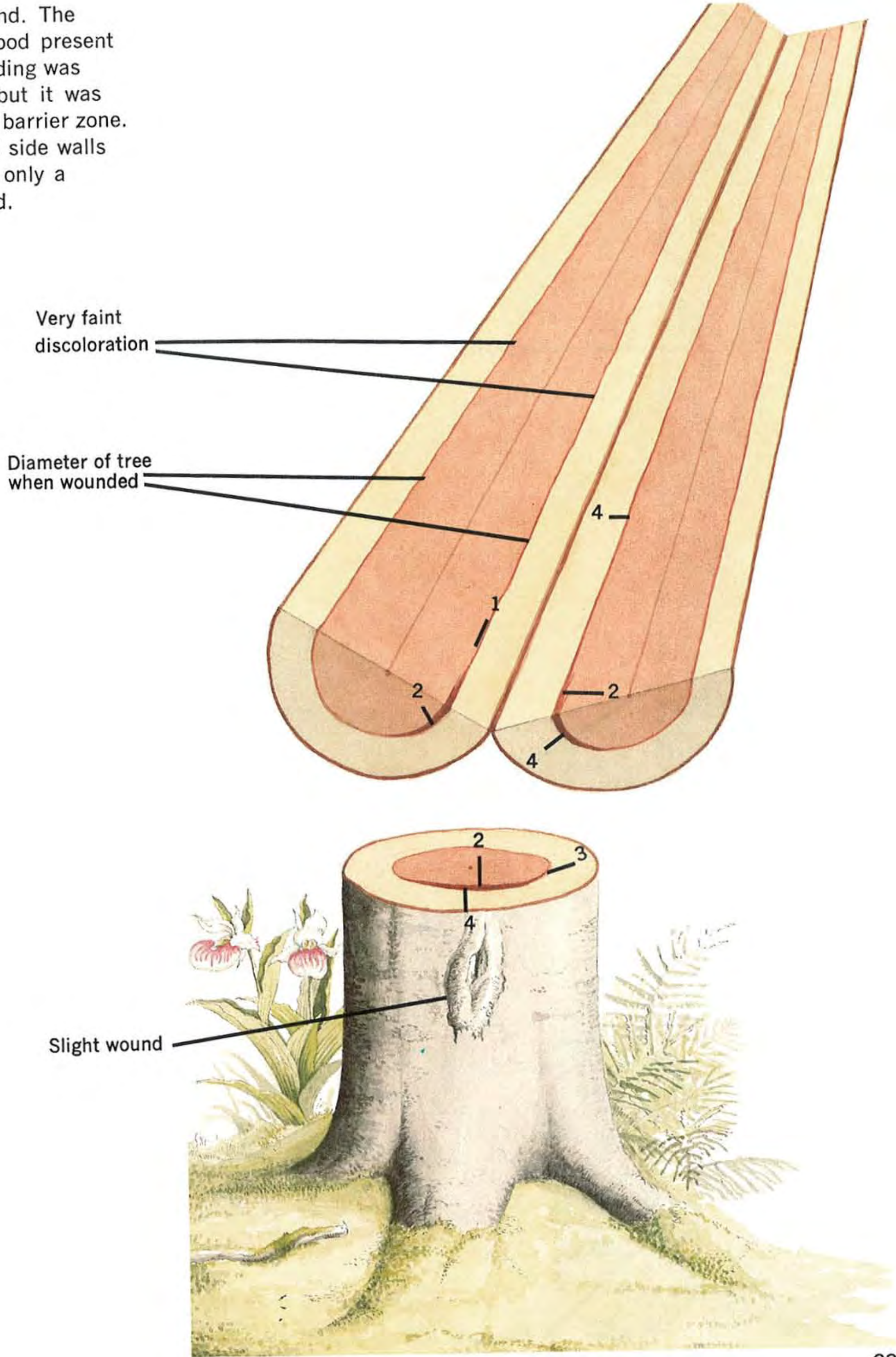
Three severe basal wounds. All inner compartment walls have fallen and only the barrier zone remains. This is how hollows develop.



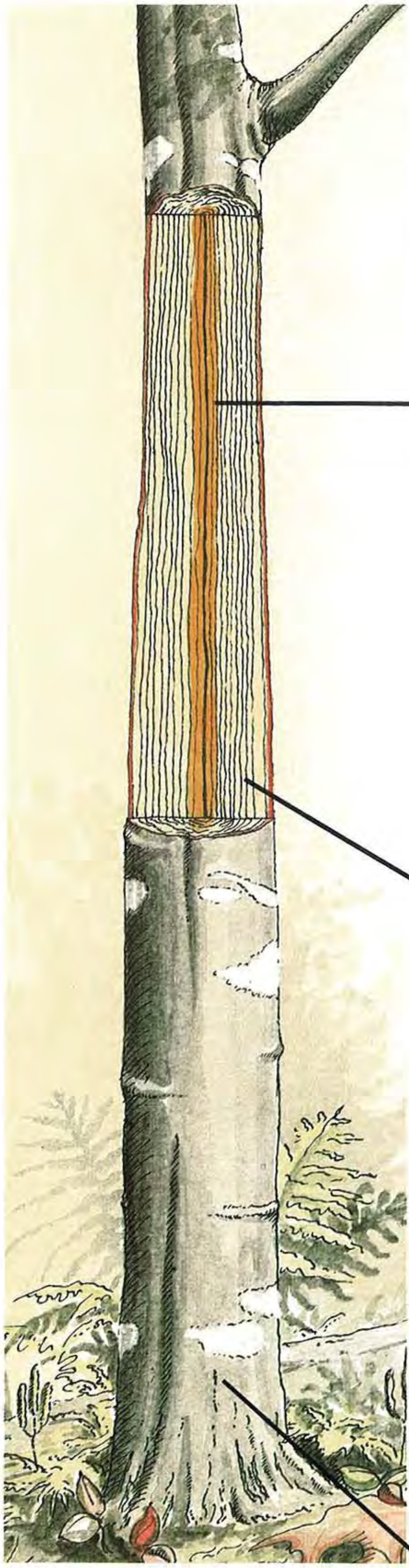


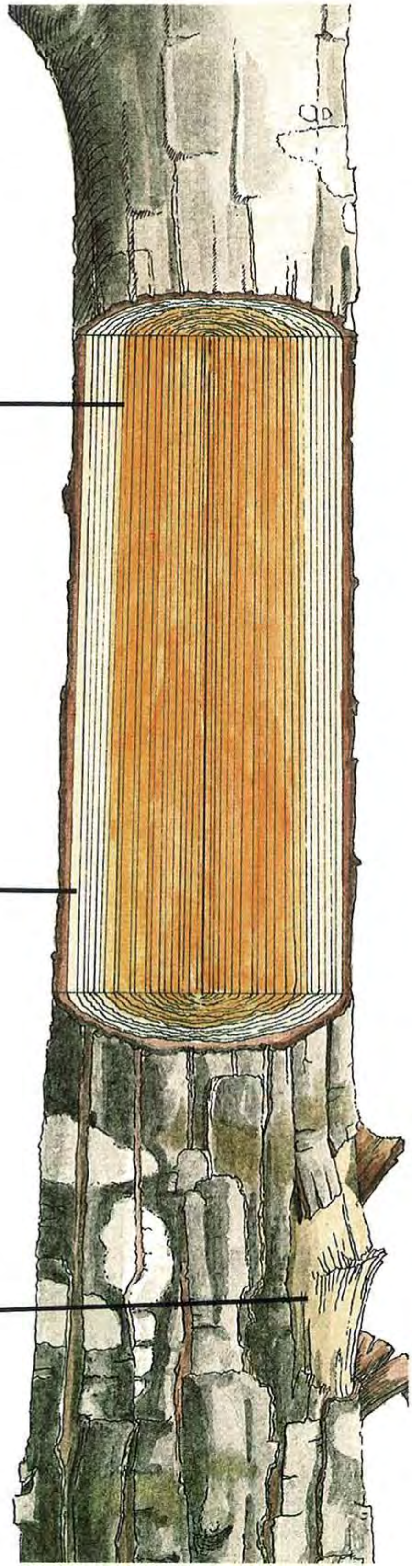
A basal wound of moderate severity. The entire "group of trees" present at the time of wounding was altered slightly, and were confined by the barrier zone. The side walls, or rays, held here and the column was wedge-shaped in cross-section. The jagged vertical edge was due to variation in confining ability of compartment tops and bottoms in different growth rings.

A slight basal wound. The entire column of wood present at the time of wounding was altered very little, but it was still confined by the barrier zone. The inner walls and side walls held firm here and only a "moon ring" formed.

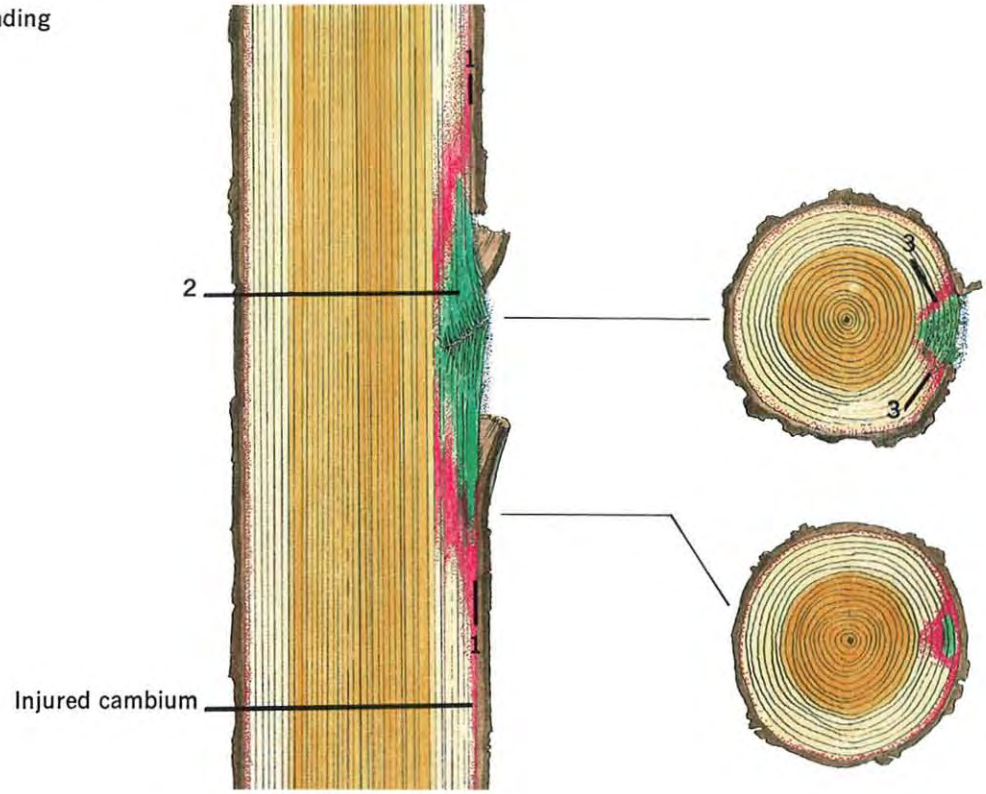


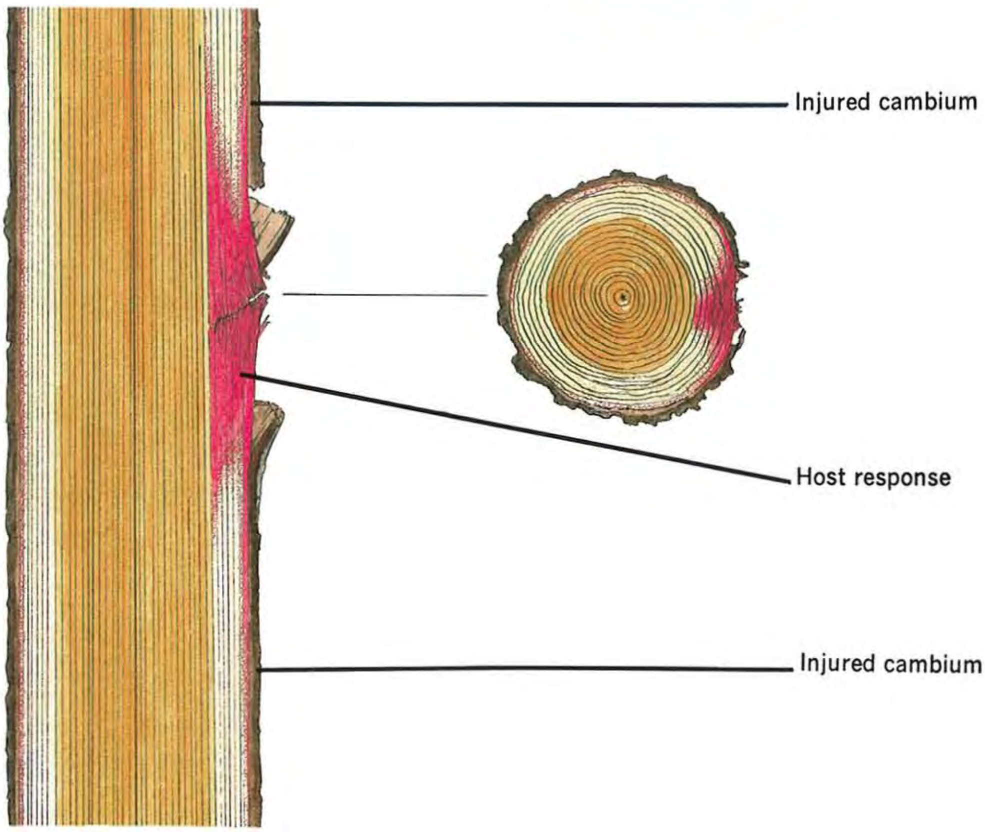
In general, the same types of columns occur in trees that have a heartwood core. Discolored and decayed wood is compartmentalized in heartwood. When a mechanical wound penetrates the sapwood to the heartwood, the column develops most rapidly along the sapwood-heartwood boundary.

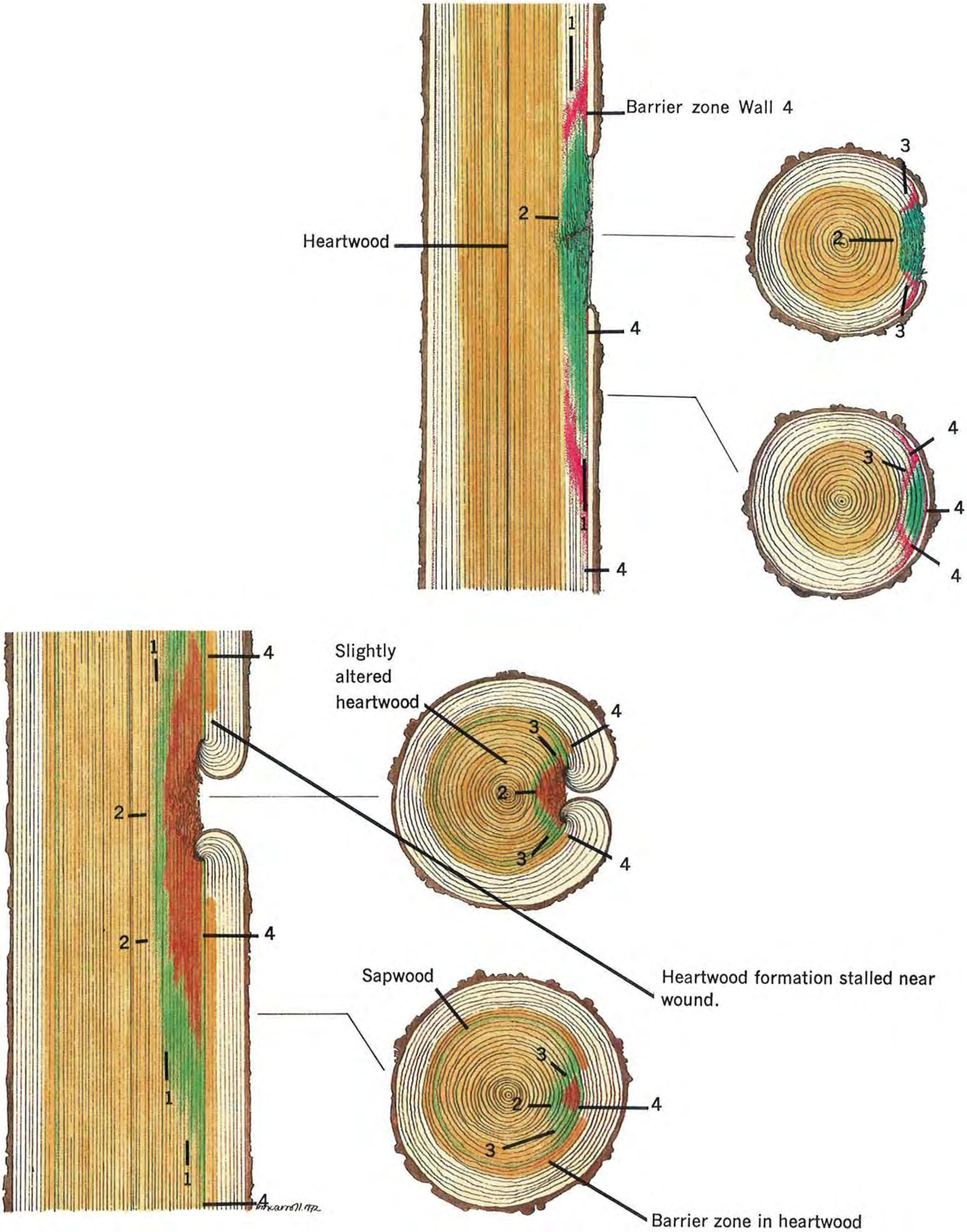




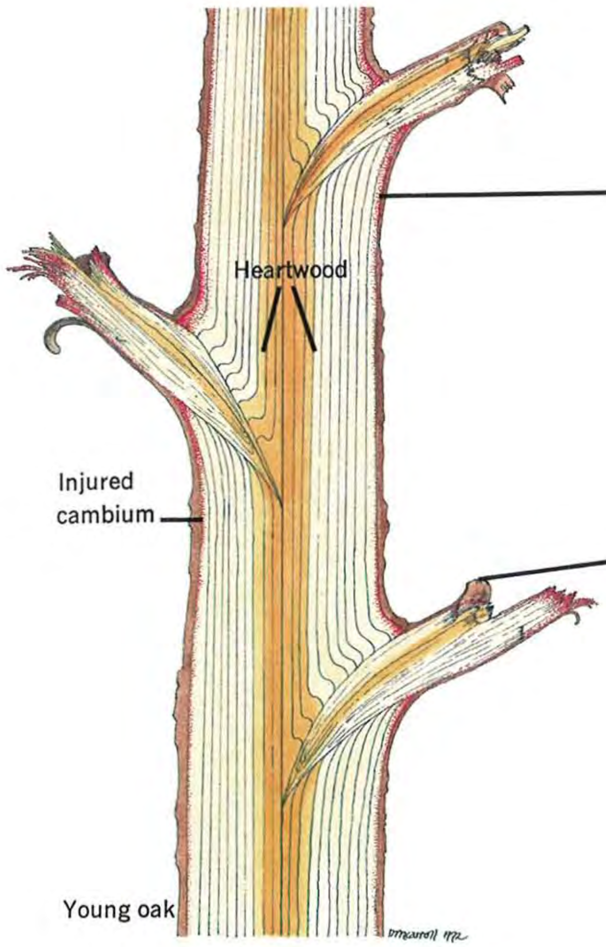
RED—Host response to wounding
BLUE—Surface infection
GREEN—Discoloration
BROWN—Decay
YELLOW—Heartwood

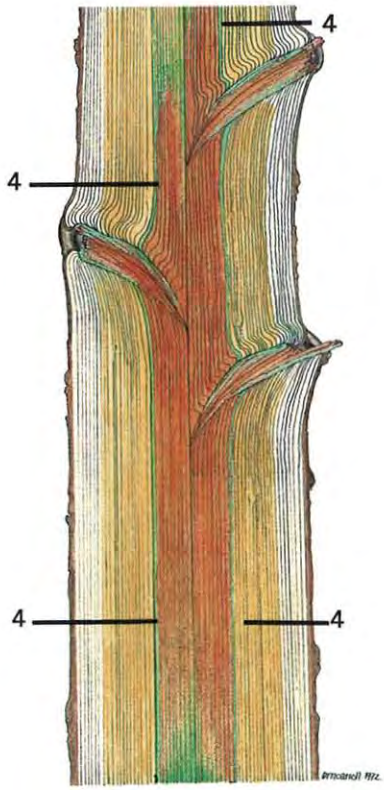


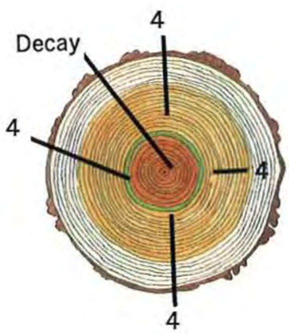



1
Barrier zone Wall 4
3
2
Heartwood
2
3
4
4
3
4
4
1
4
1
4
Slightly
altered
heartwood
4
3
2
2
4
3
2
4
Sapwood
Heartwood formation stalled near
wound.
3
2
4
3
1
1
4
Barrier zone in heartwood

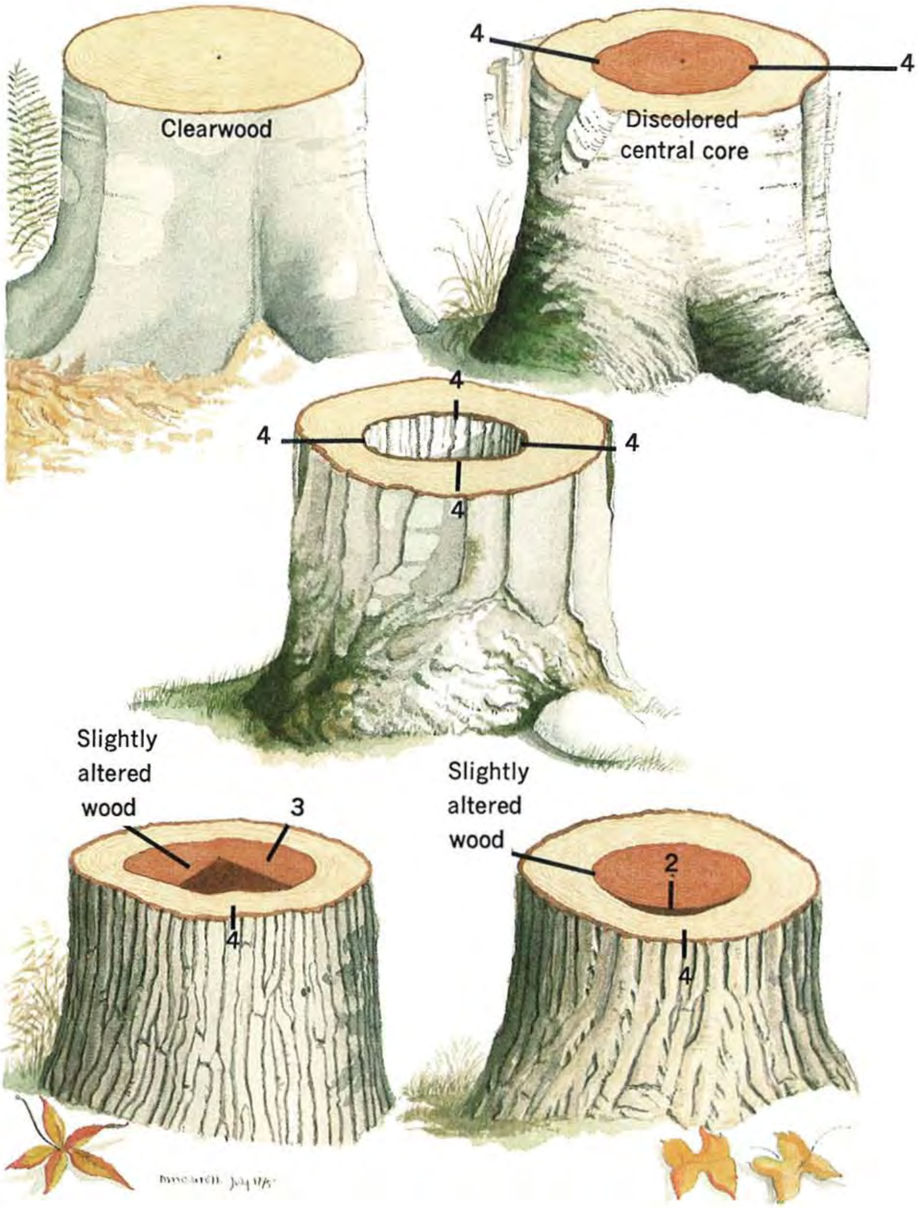
Discolored and decayed wood associated with poorly healed large branch stubs is compartmentalized in heartwood. Central columns of defect in heartwood-forming trees are often associated with poorly healed branch stubs.



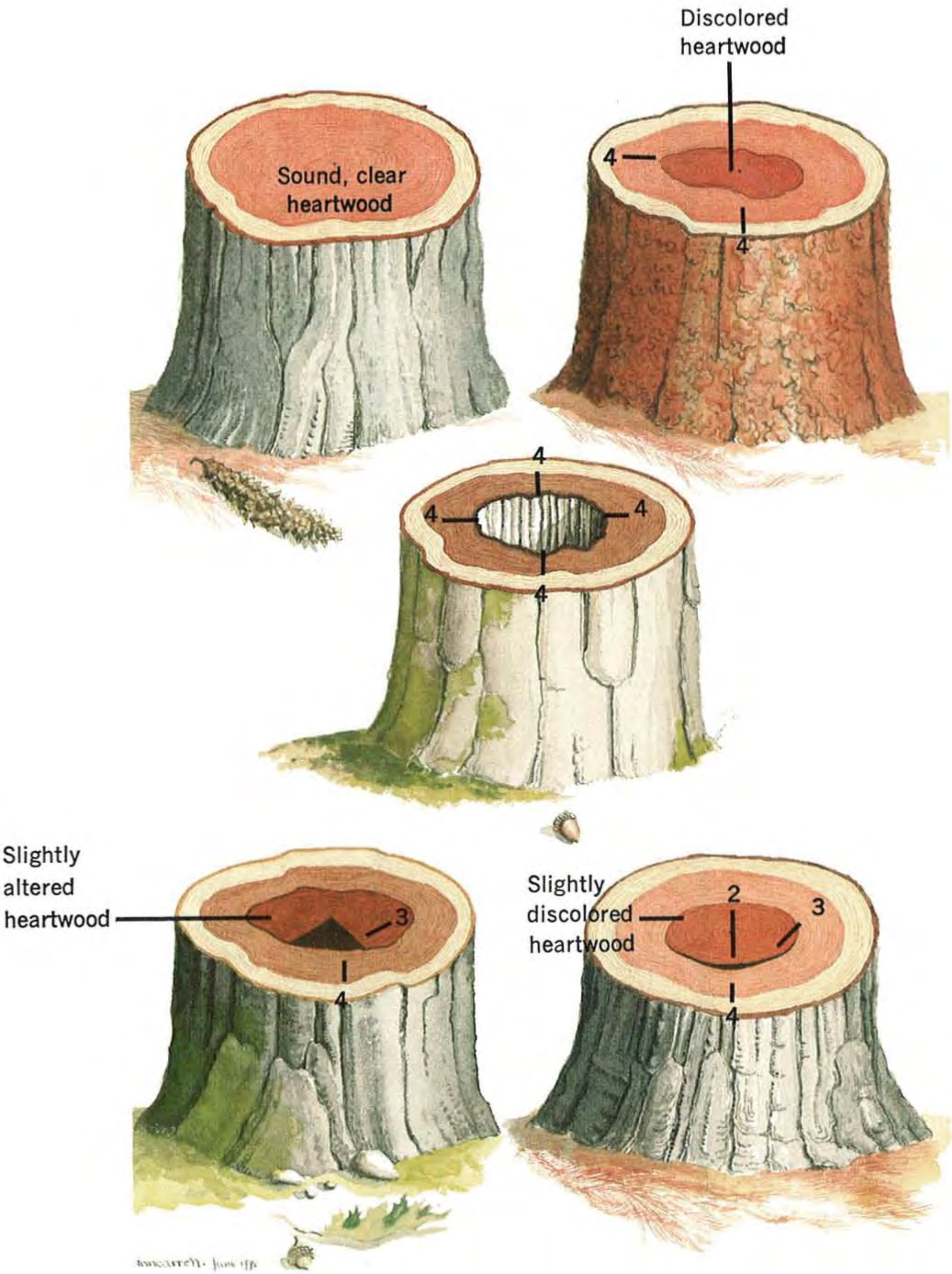


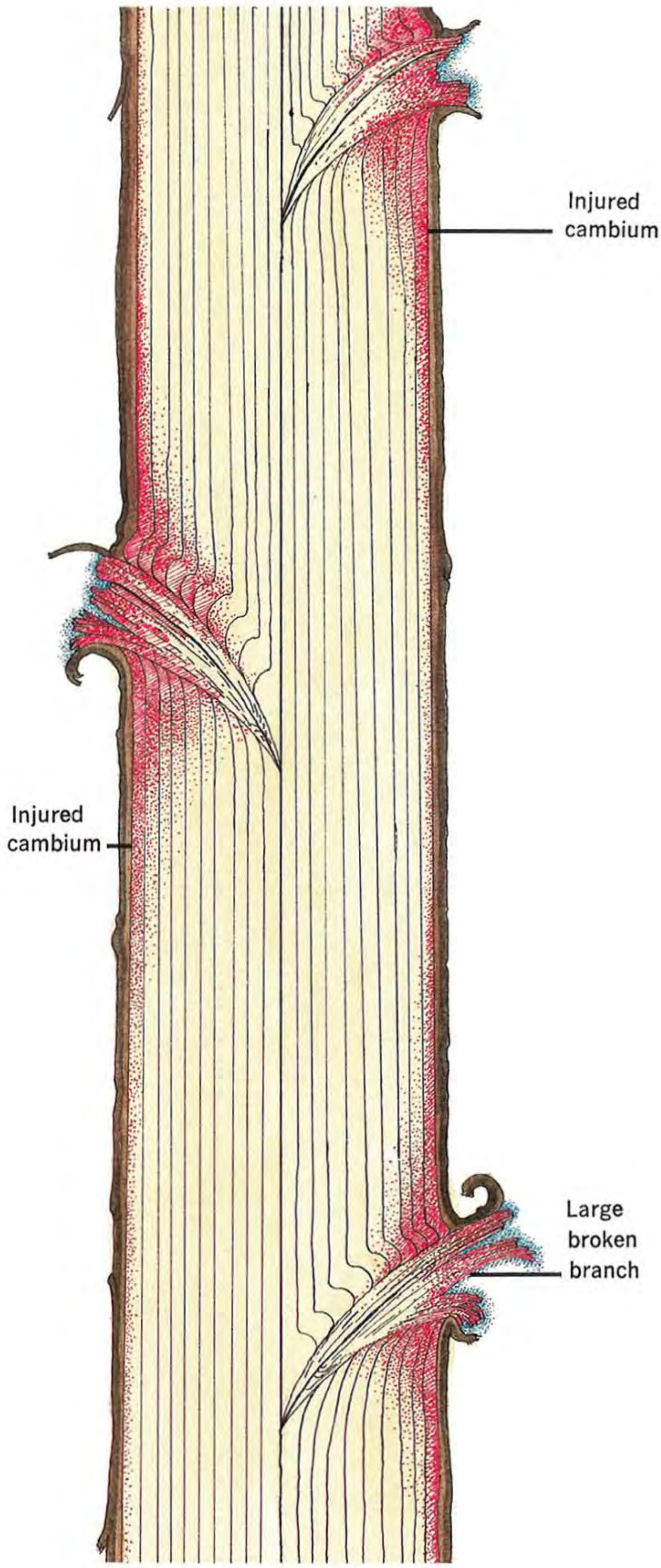


Here are the basic patterns of compartmentalized columns of discolored and decayed wood associated with a single wound and with several wounds at one time shown on cross section in nonheartwood-forming trees.

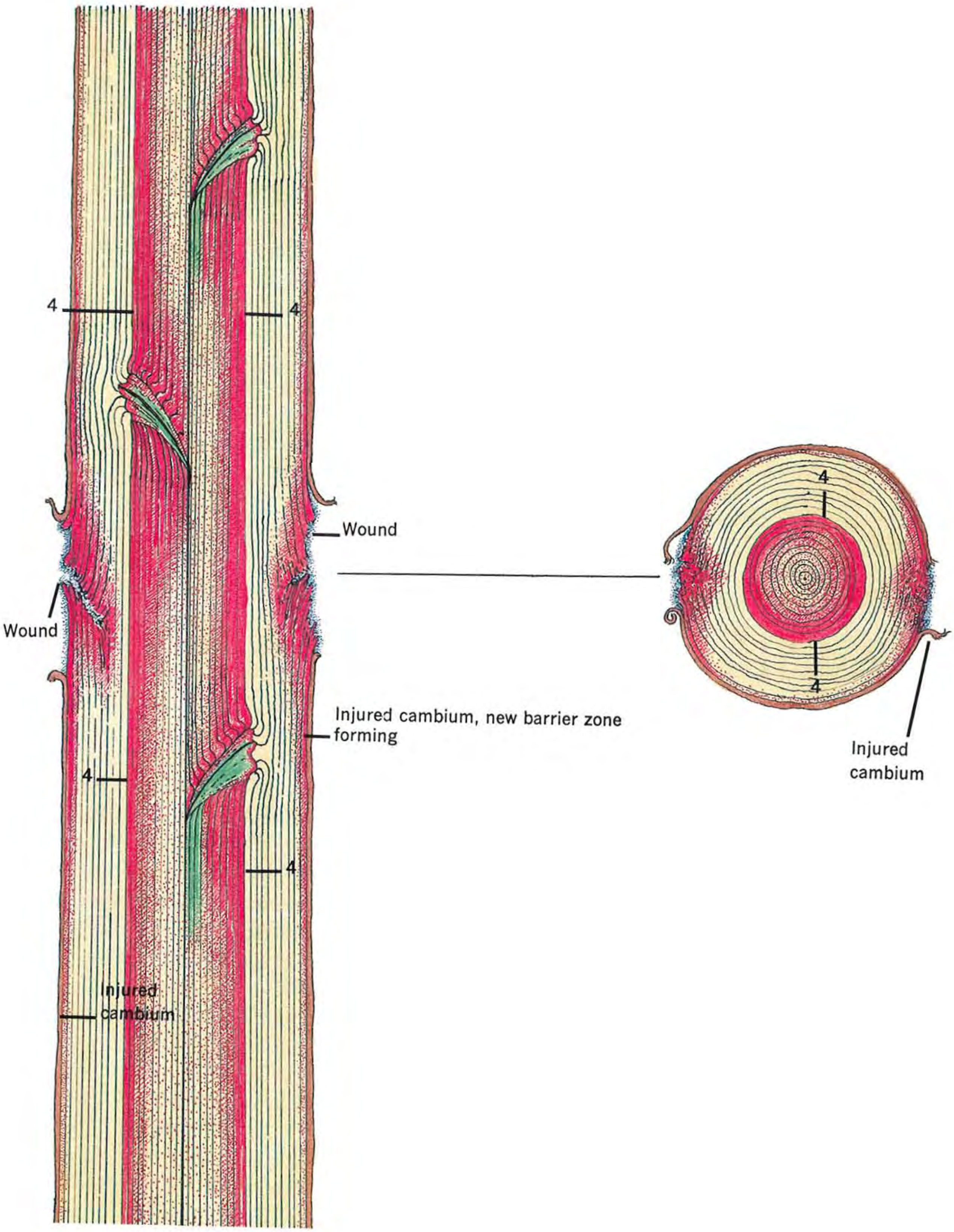


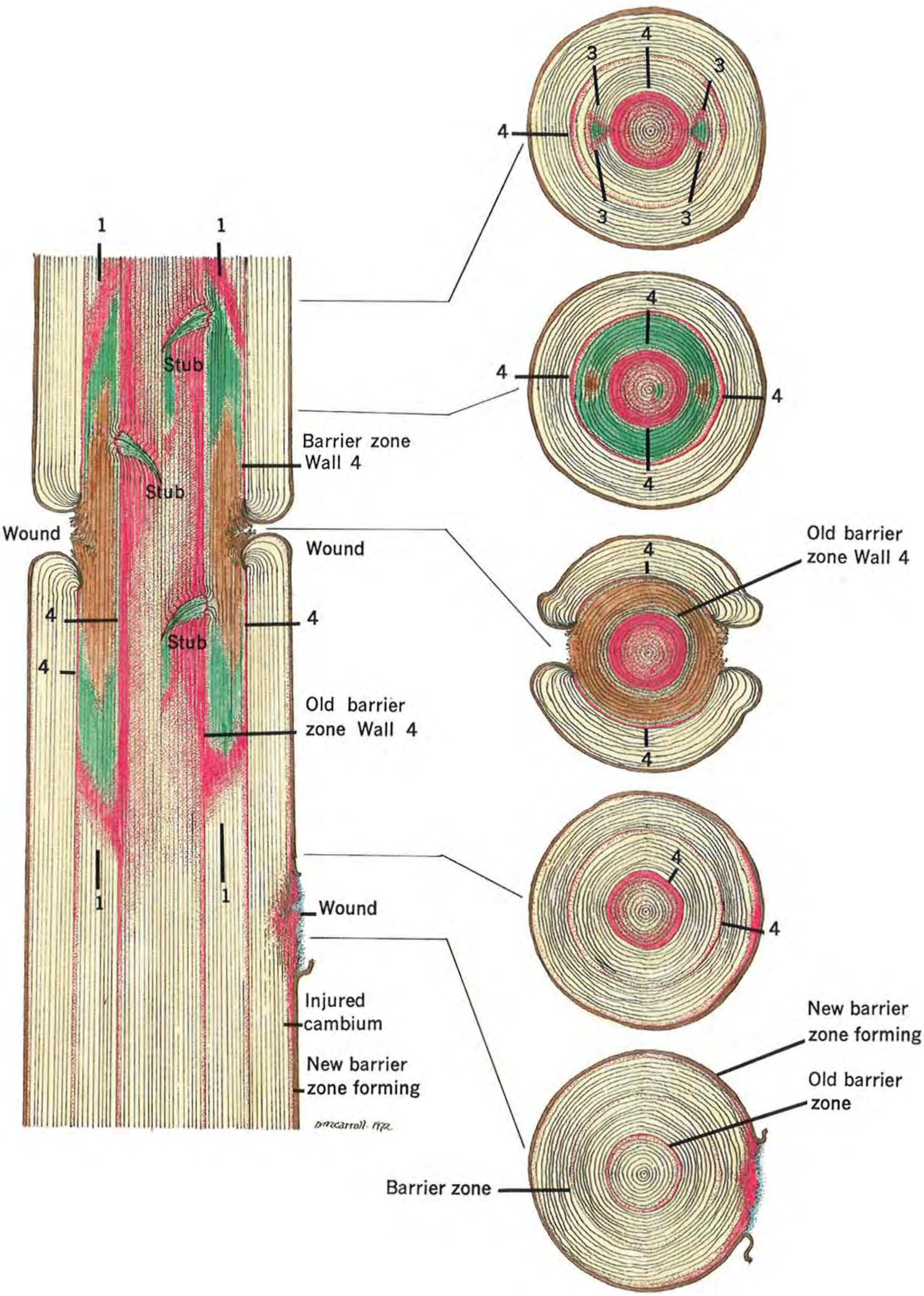
Here are some basic patterns for heartwood-forming trees.

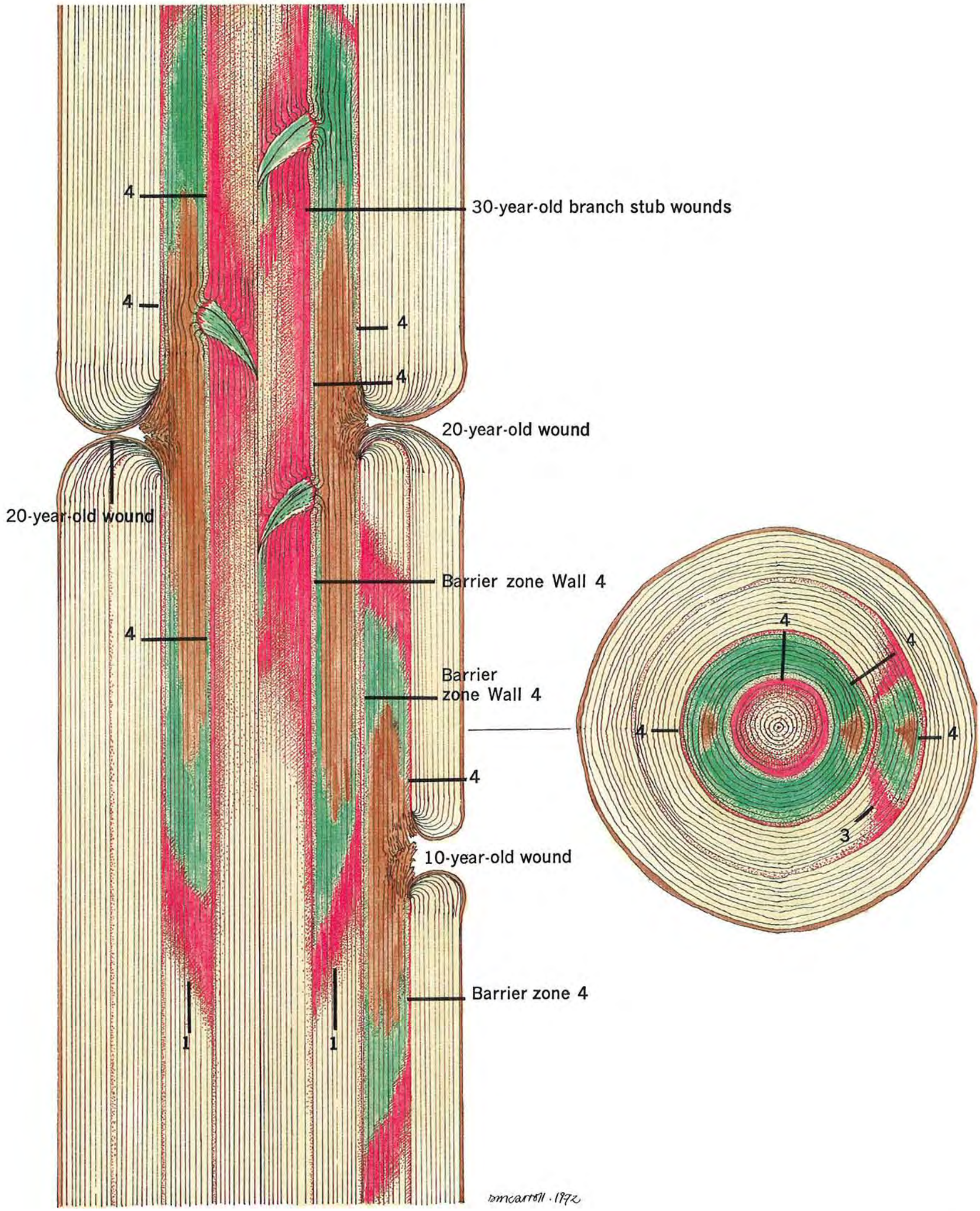




Most trees receive many wounds during their lives. Every tree has some branches that die. When the branches are small and the wounds close rapidly, very little internal defect follows. But, when large branches die and healing is slow, trouble starts for the tree. Add to this the injuries caused by other types of wounds at irregular time intervals and a pattern of multiple columns begins to develop. But again the tree compartmentalizes the injuries and each column is separated from the others.

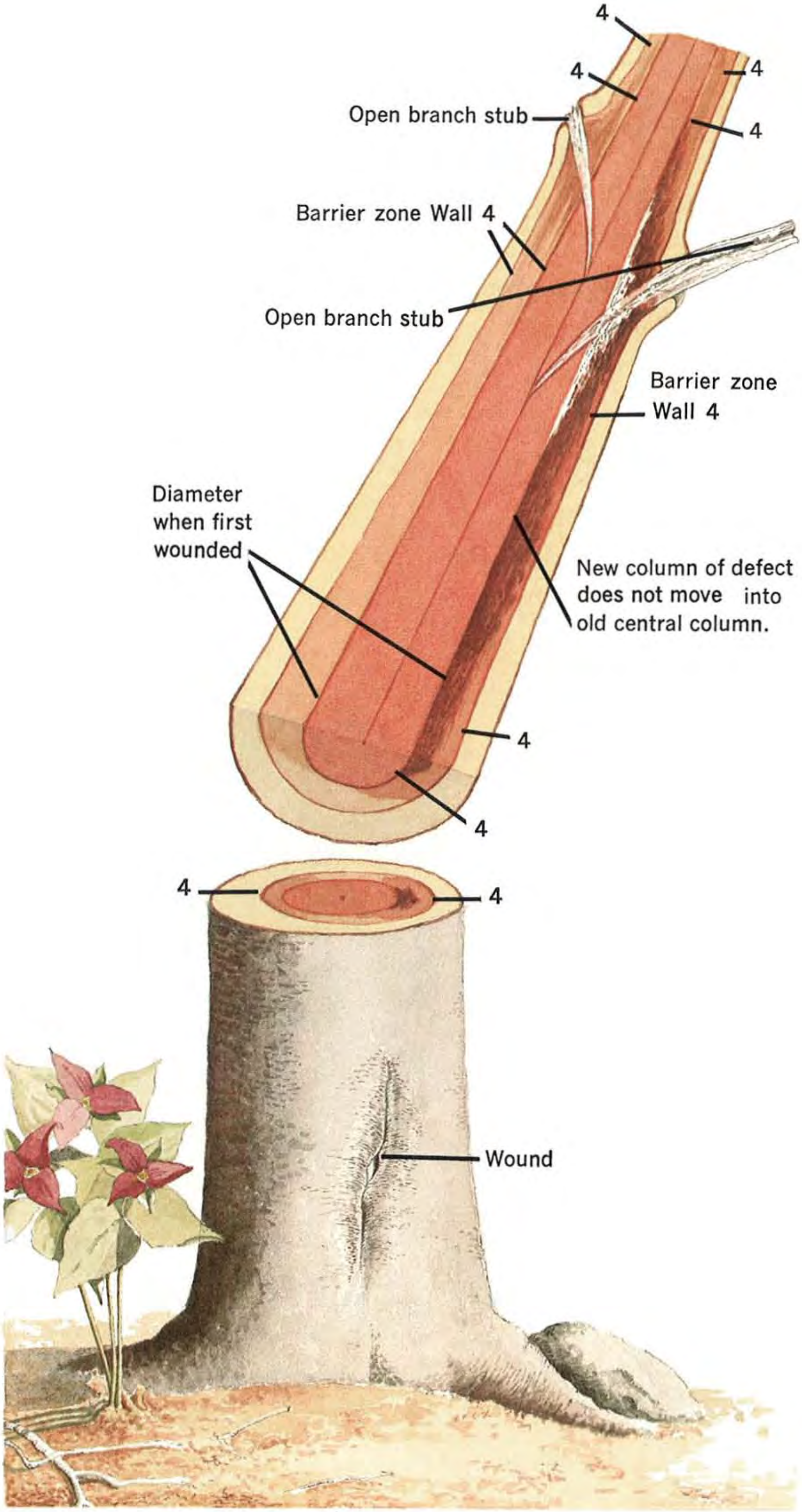

4
4
Wound
Wound
Injured cambium, new barrier zone forming
4
4
Injured cambium
4
4
Injured cambium


1
1
Stub
Stub
Stub
Barrier zone
Wall 4
Wound
Wound
4
4
4
Old barrier
zone Wall 4
1
1
Wound
Injured
cambium
New barrier
zone forming
3
4
3
4
3
3
4
4
4
4
4
4
4
Old barrier
zone Wall 4
4
4
4
New barrier
zone forming
Old barrier
zone
Barrier zone

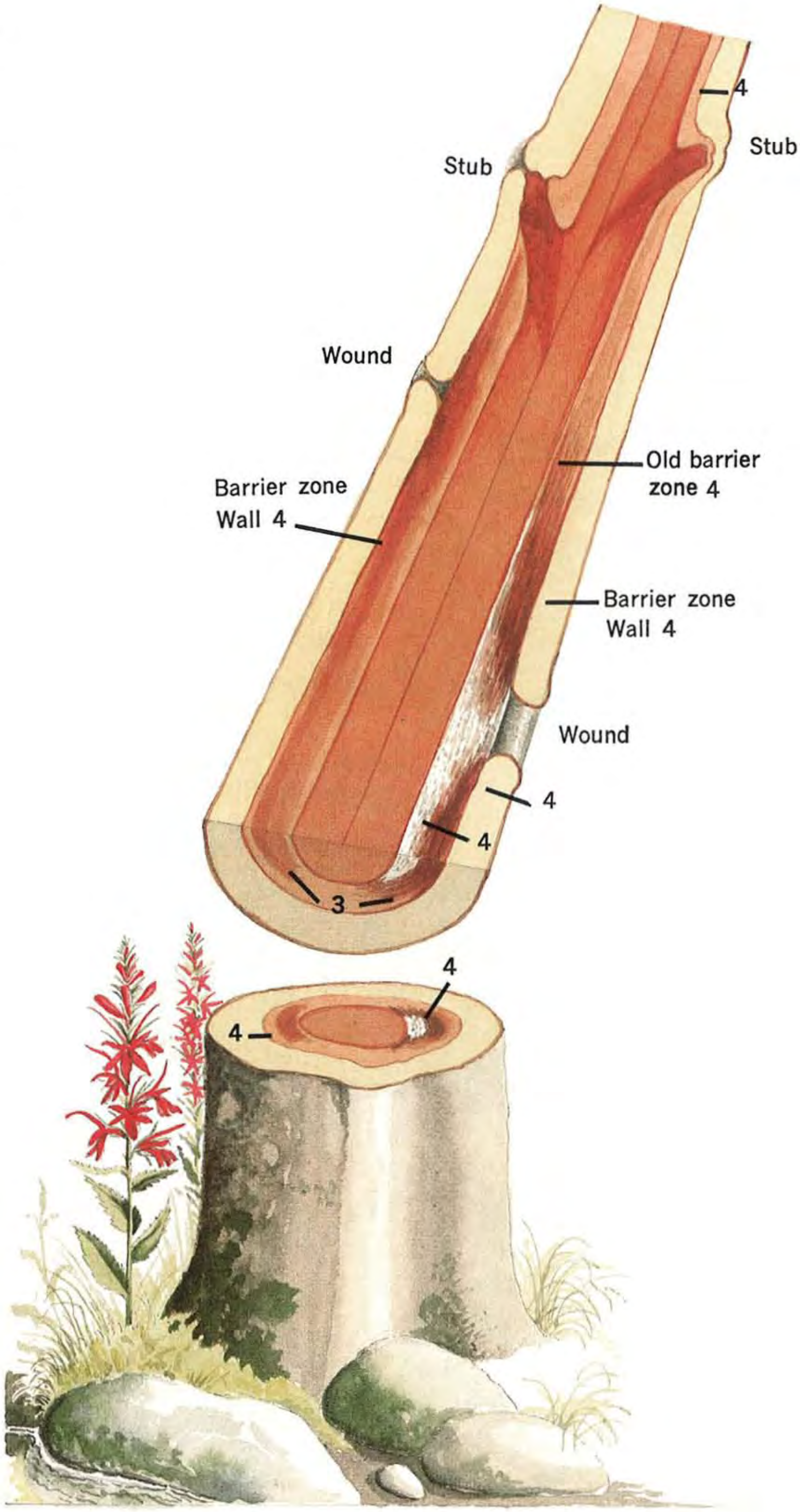


30-year-old branch stub wounds
4
4
4
4
20-year-old wound
20-year-old wound
Barrier zone Wall 4
4
Barrier
zone Wall 4
4
10-year-old wound
Barrier zone 4
1
1
4
4
4
4
3
dmcarroll · 1972

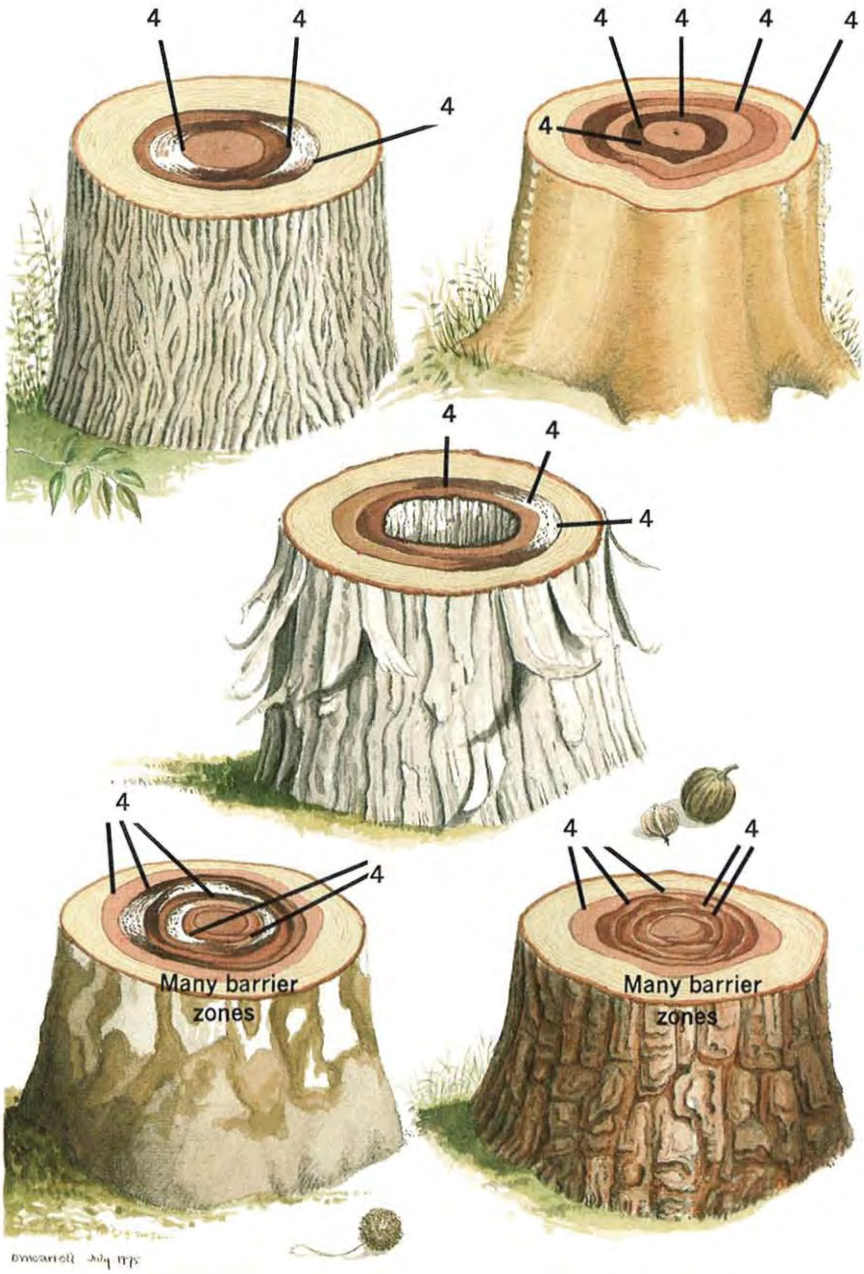
Multiple columns are common in trees. A minor wound may set up a central column of discolored wood and later large branches die and heal slowly. The decay associated with the branch stubs does not penetrate the inner column of compartmentalized discolored wood.



A central column of compartmentalized discolored wood may be associated with large branch stubs that healed slowly, but did close before decay set in. Additional columns of discolored and decayed wood could develop later, for example, from severe mechanical wounds on the trunk.



Here are some typical patterns of multiple columns found in nonheartwood-forming trees.

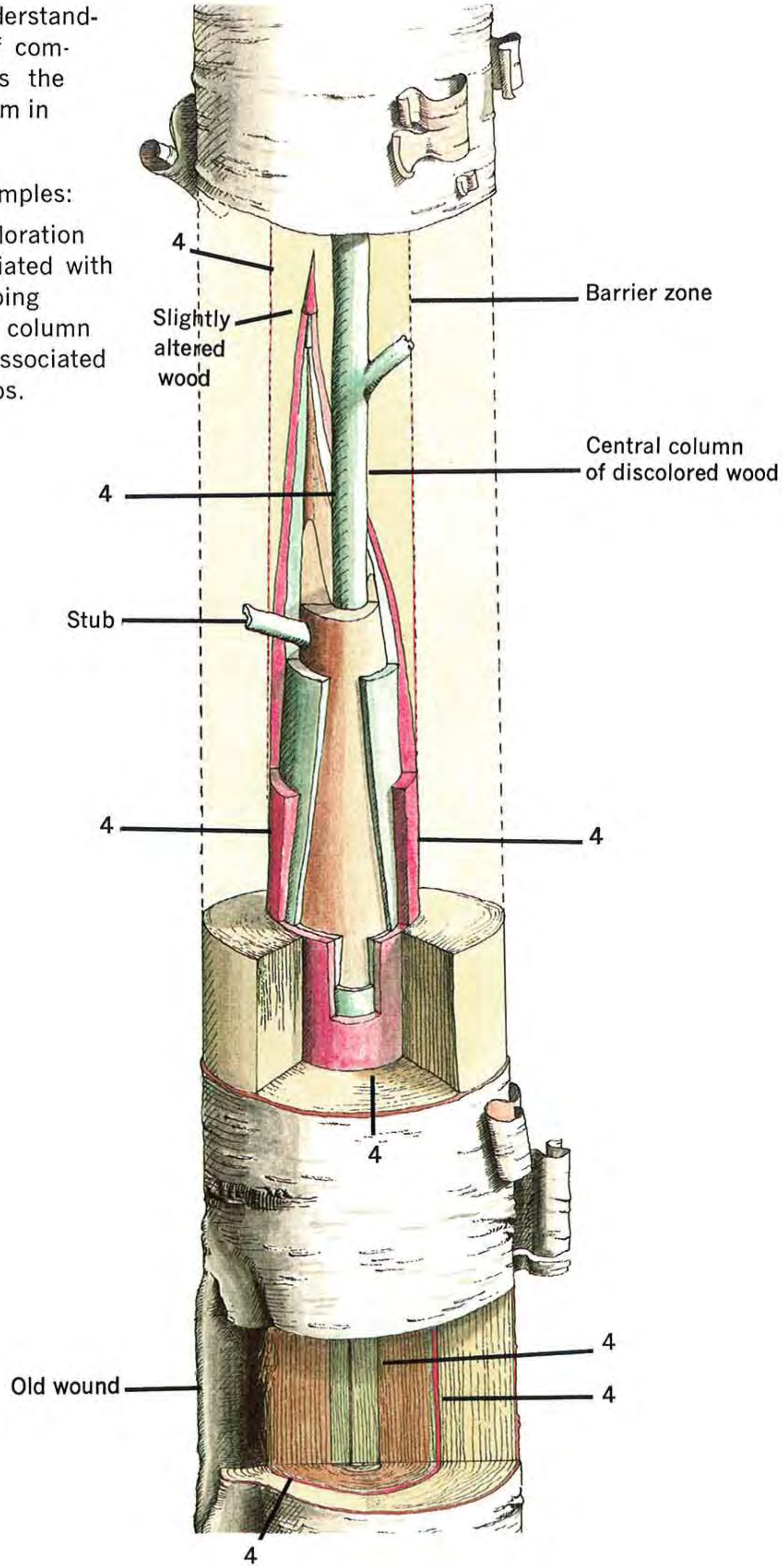


In heartwood-forming trees the patterns are the same, but they are sometimes difficult to see because they are often contained in heartwood that is already dark in color. Compartmentalization explains how columns of discolored and decayed wood can be found in ring patterns separated by sound wood.

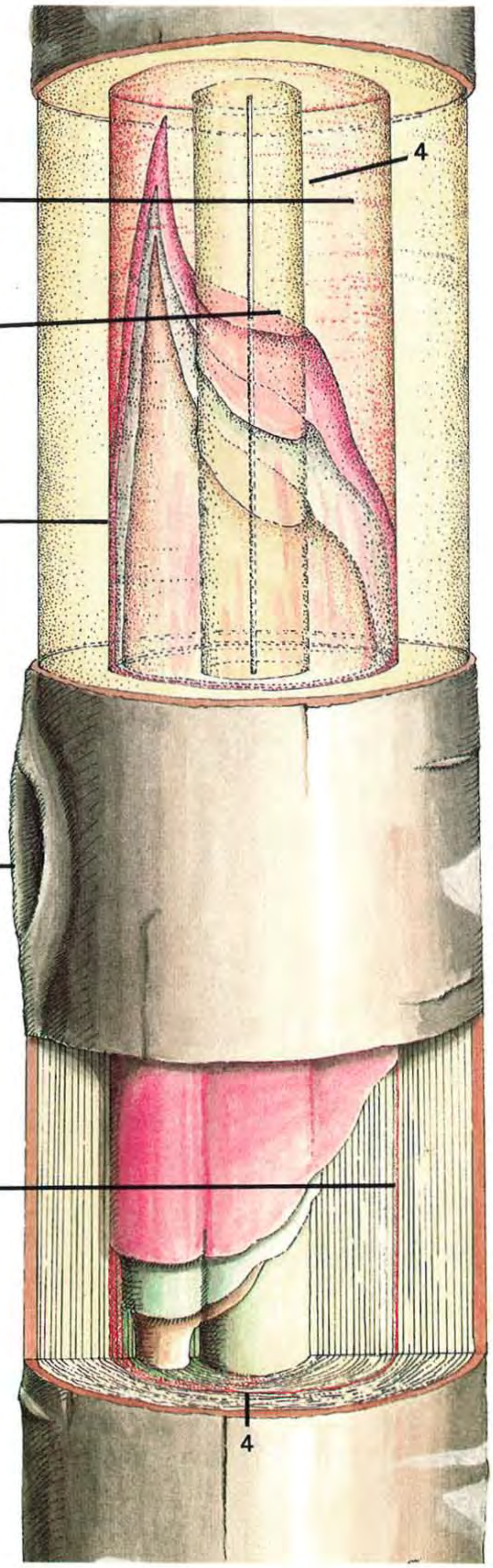
A major obstacle in understanding multiple columns of compartmentalized decay is the difficulty in "seeing" them in three dimensions.

Here are some examples:

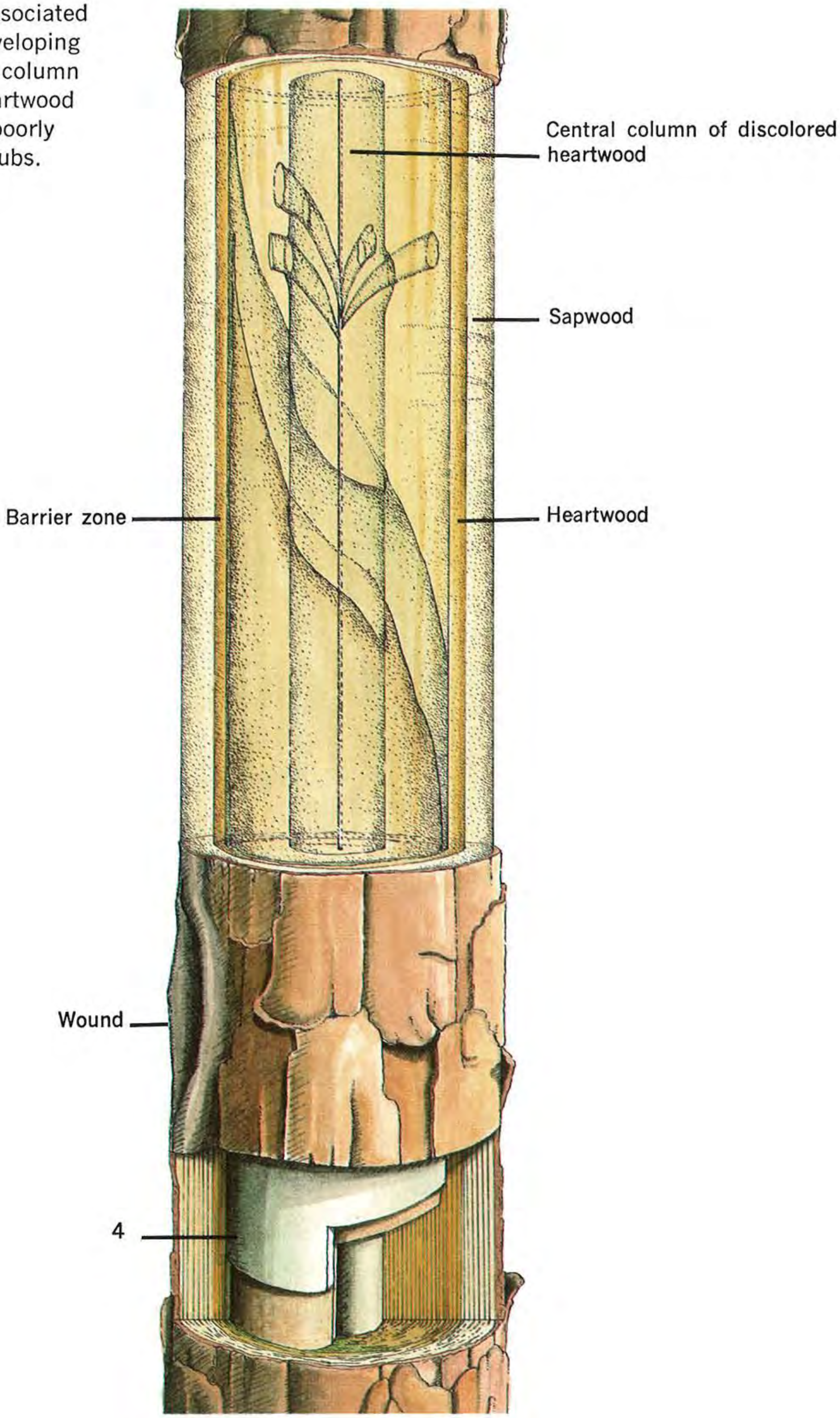
Birch—Column of discoloration and decay associated with a wound developing around a central column of discoloration associated with branch stubs.



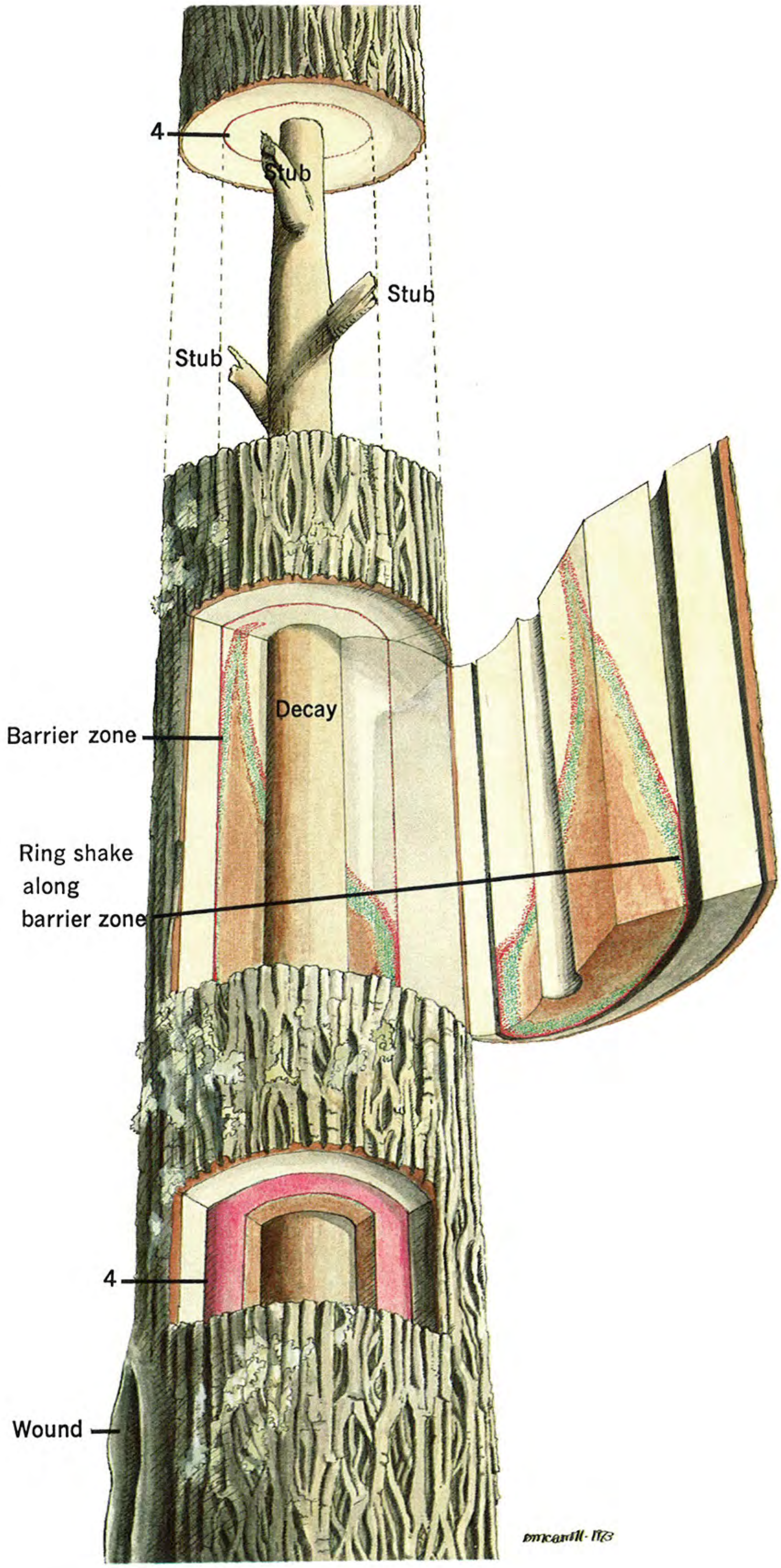
Maple—Column of discoloration and decay associated with a wound developing around a central column of discoloration. The entire column of wood present at the time of wounding has been altered slightly. When this wood is dried, it will be a different shade from the wood that formed after wounding.



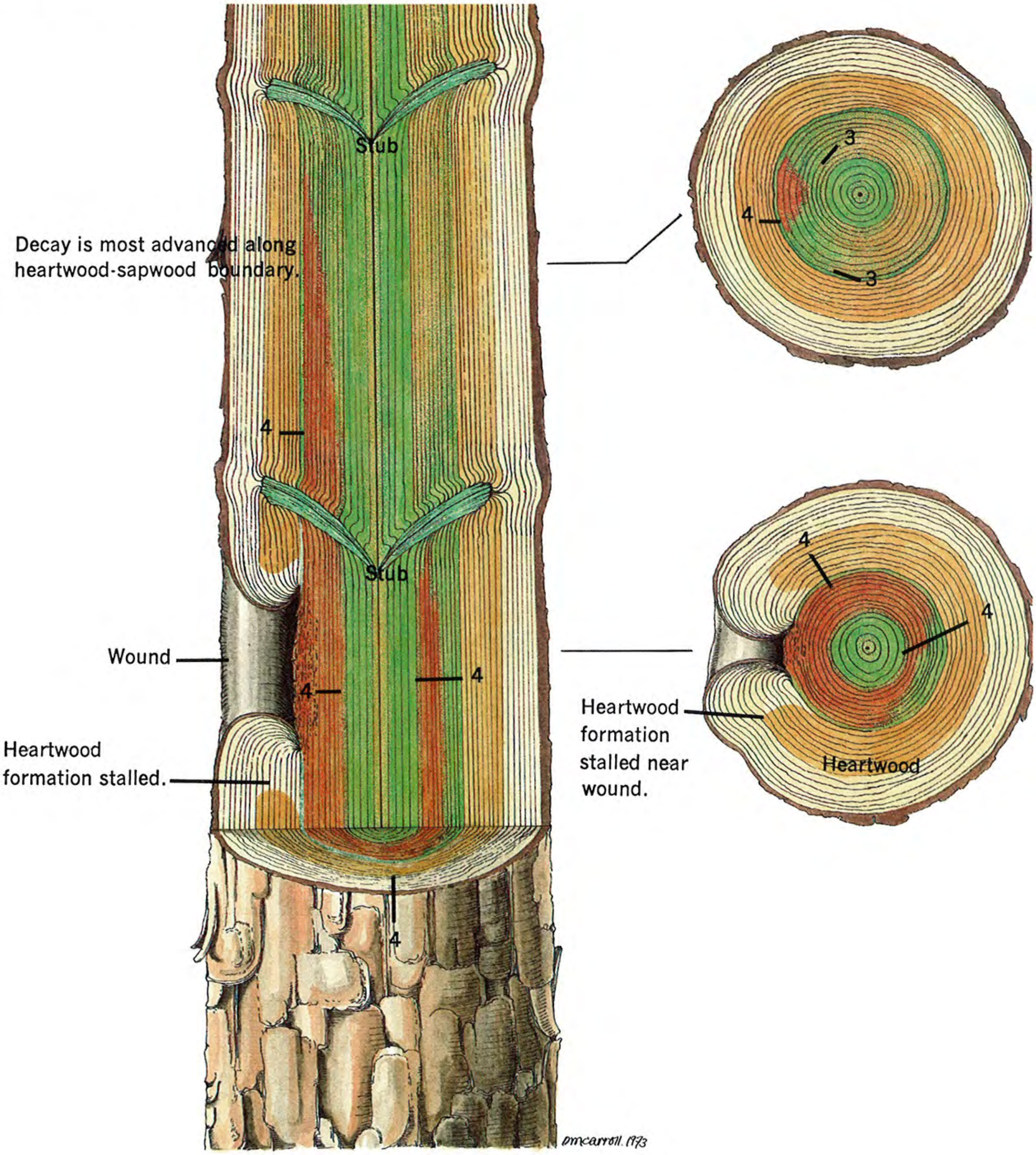
Pine—Column of discolored and decayed wood associated with a wound developing around a central column of discolored heartwood associated with poorly healed branch stubs.



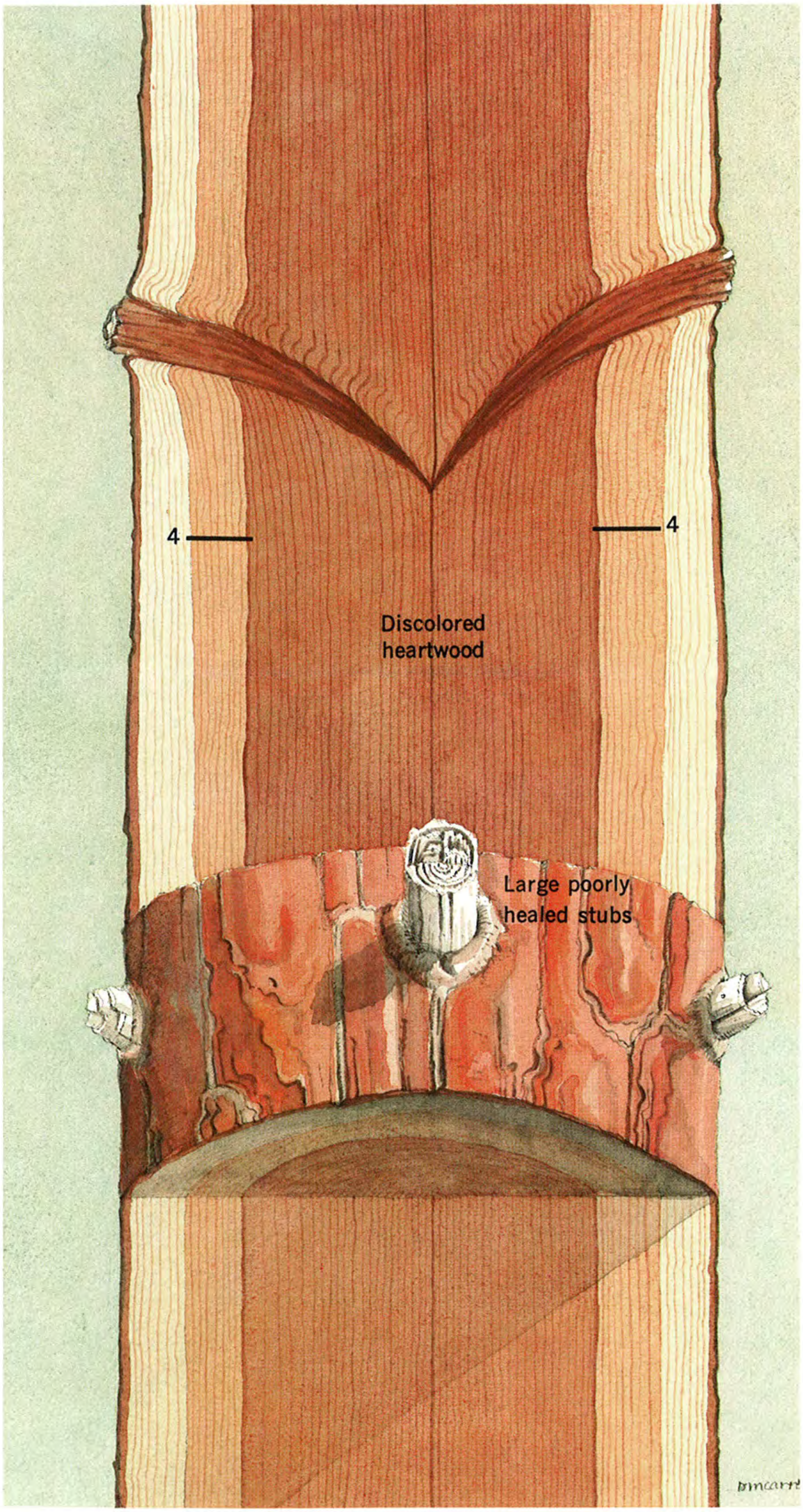
Ash—Column of discolored and decayed wood associated with a wound developing around a central column of decay associated with old, poorly healed branch stubs. The barrier zone is the ring shake boundary.

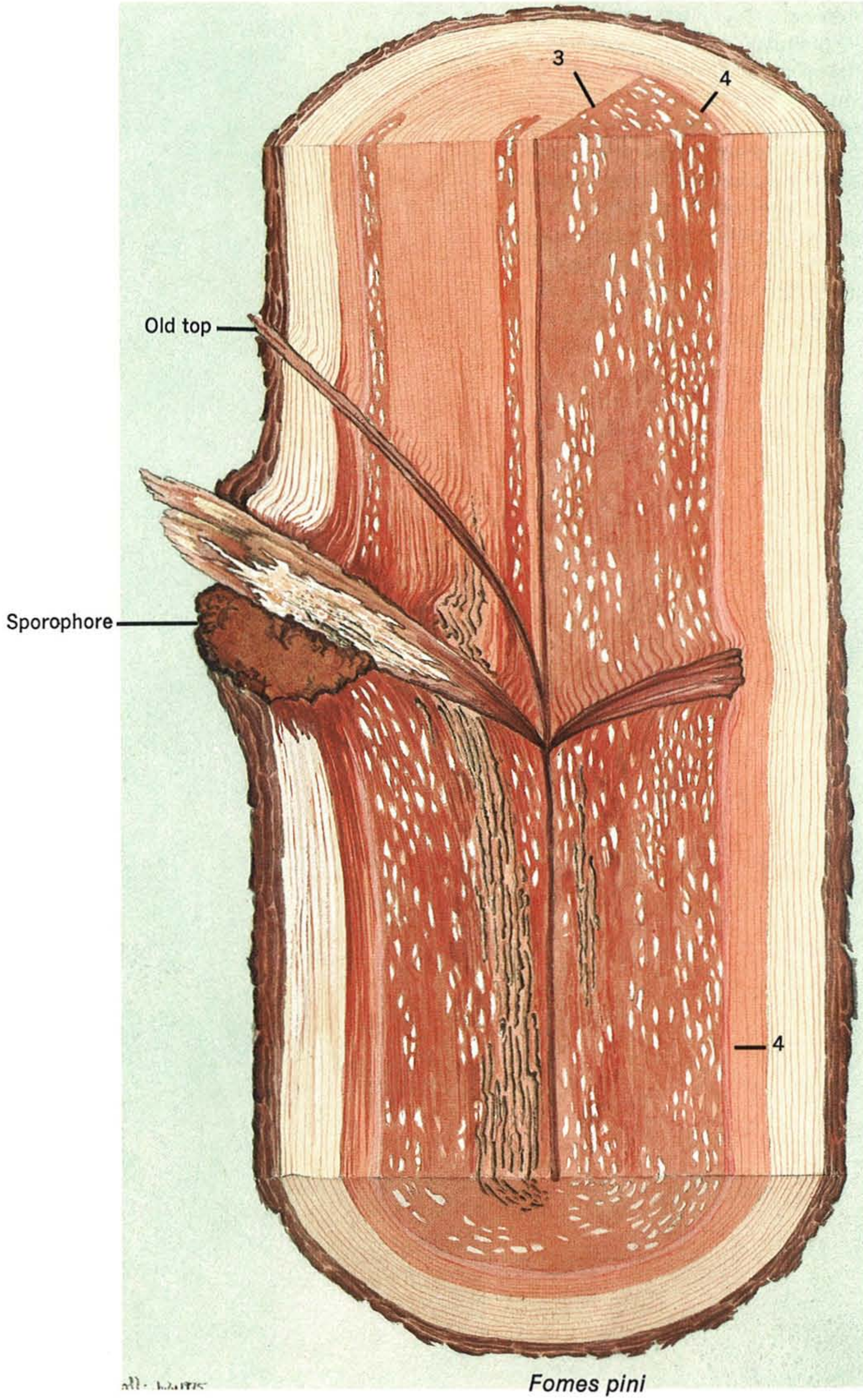


Slightly altered columns of compartmentalized wood associated with wounds in pines are sometimes difficult to see. Some ring patterns of defects in pine form when mechanical wounds are inflicted on trees that already have discolored heartwood.

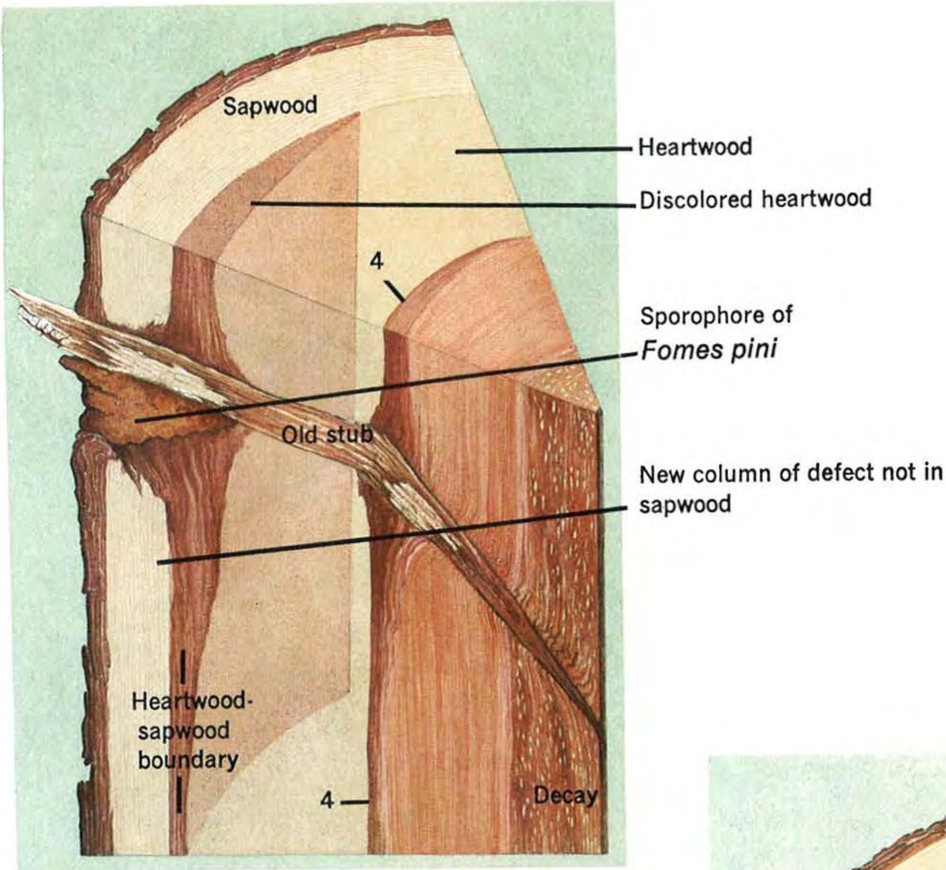


Another explanation for ring rots in pine and related genera is that some of the decay fungi, such as *Fomes pini*, first get established in the center of the trunk through branch infections. After establishment, new columns of decay form at the boundaries of the sapwood and heartwood. The new columns are compartmentalized and appear as rings.

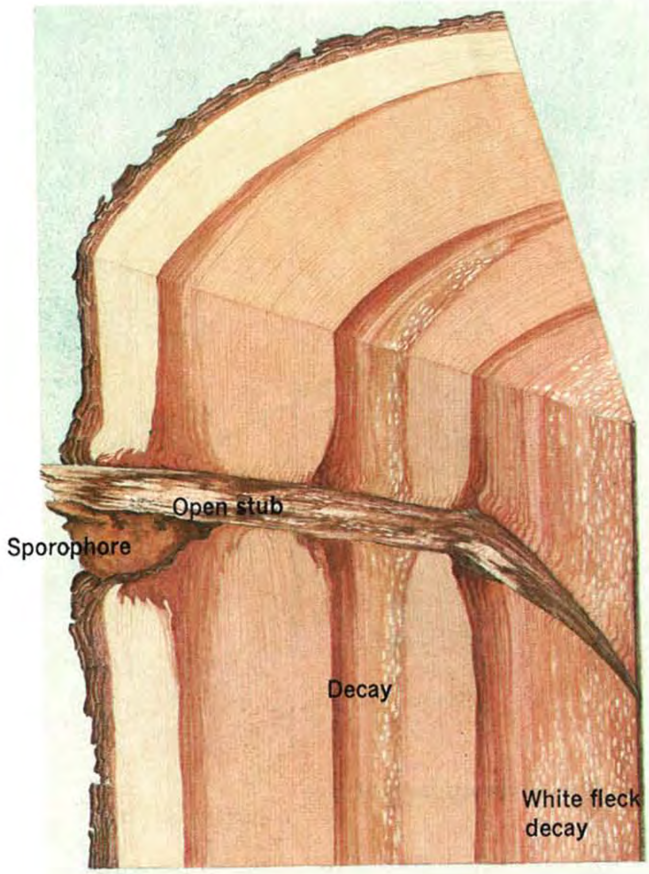




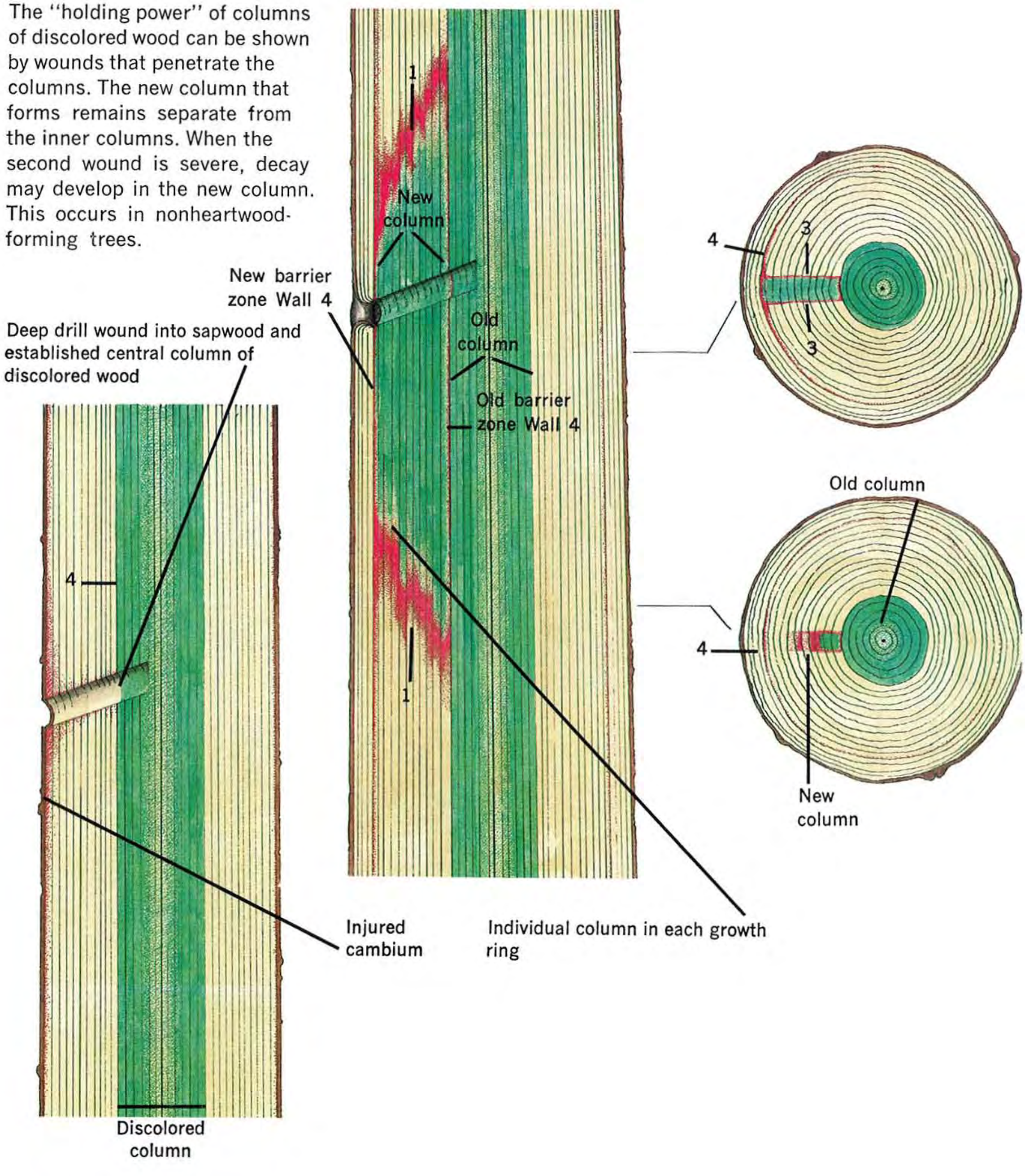
Fomes pini


Sapwood
Heartwood
Discolored heartwood
4
Sporophore of
Fomes pini
Old stub
New column of defect not in
sapwood
Heartwood-
sapwood
boundary
4
Decay

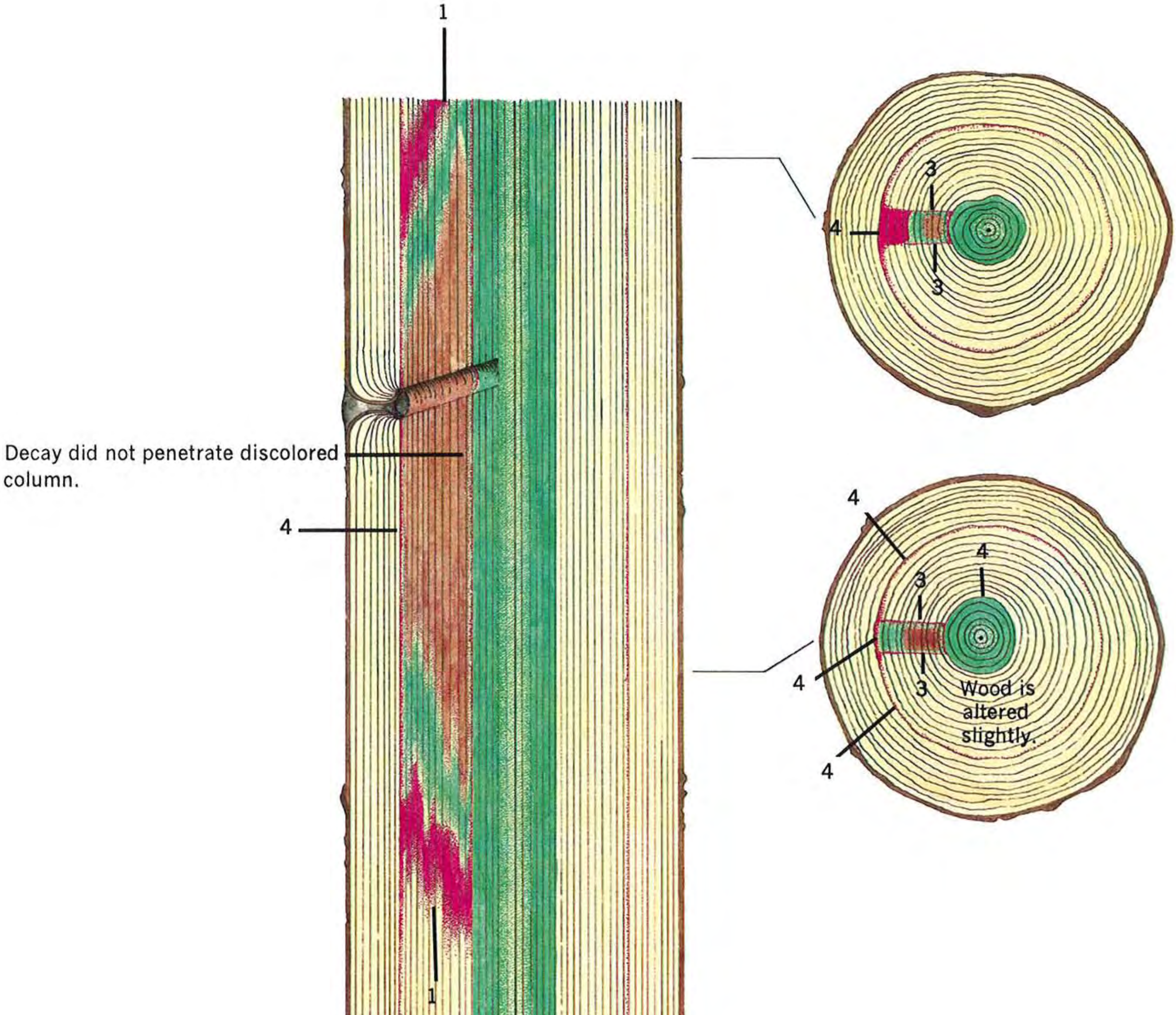
White
pine


Open stub
Sporophore
Decay
White fleck
decay

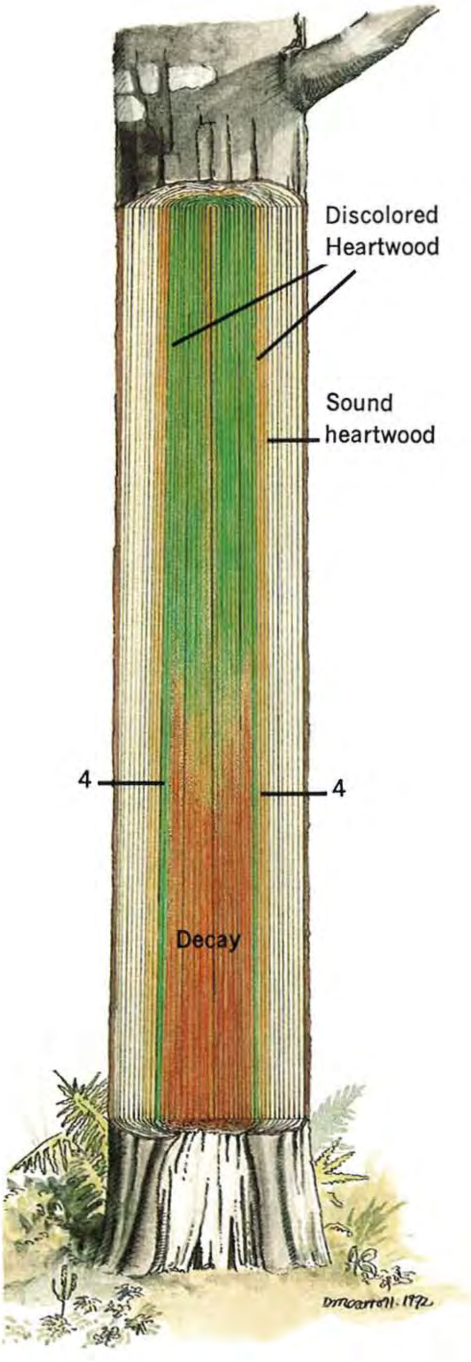
The "holding power" of columns of discolored wood can be shown by wounds that penetrate the columns. The new column that forms remains separate from the inner columns. When the second wound is severe, decay may develop in the new column. This occurs in nonheartwood-forming trees.

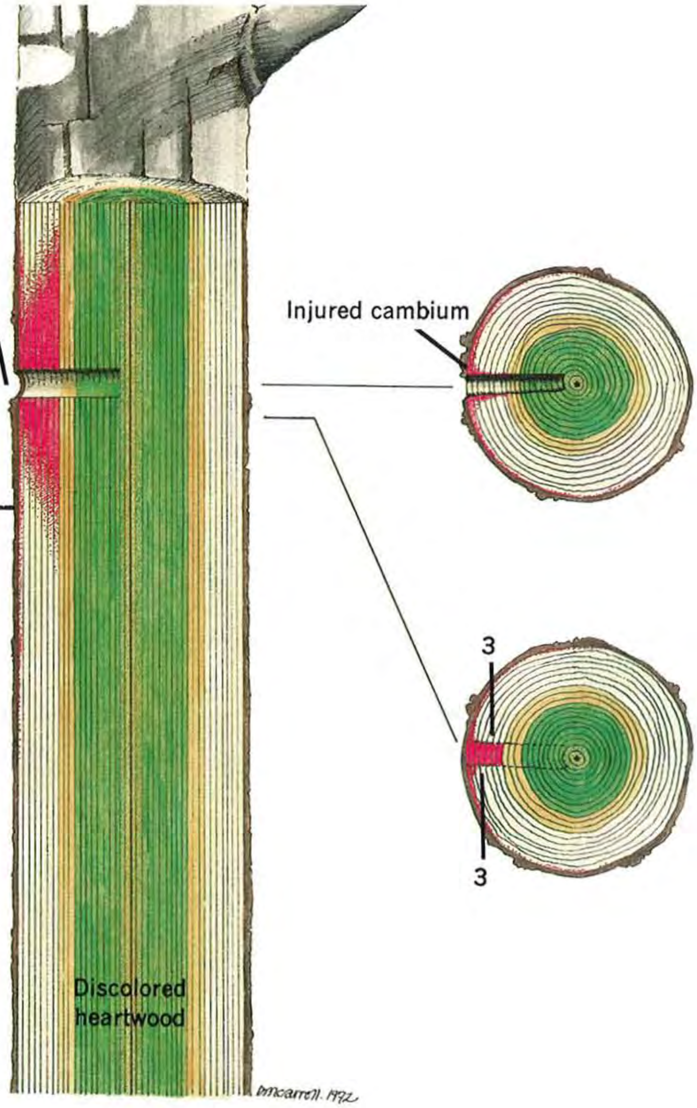


Nonheartwood-forming tree

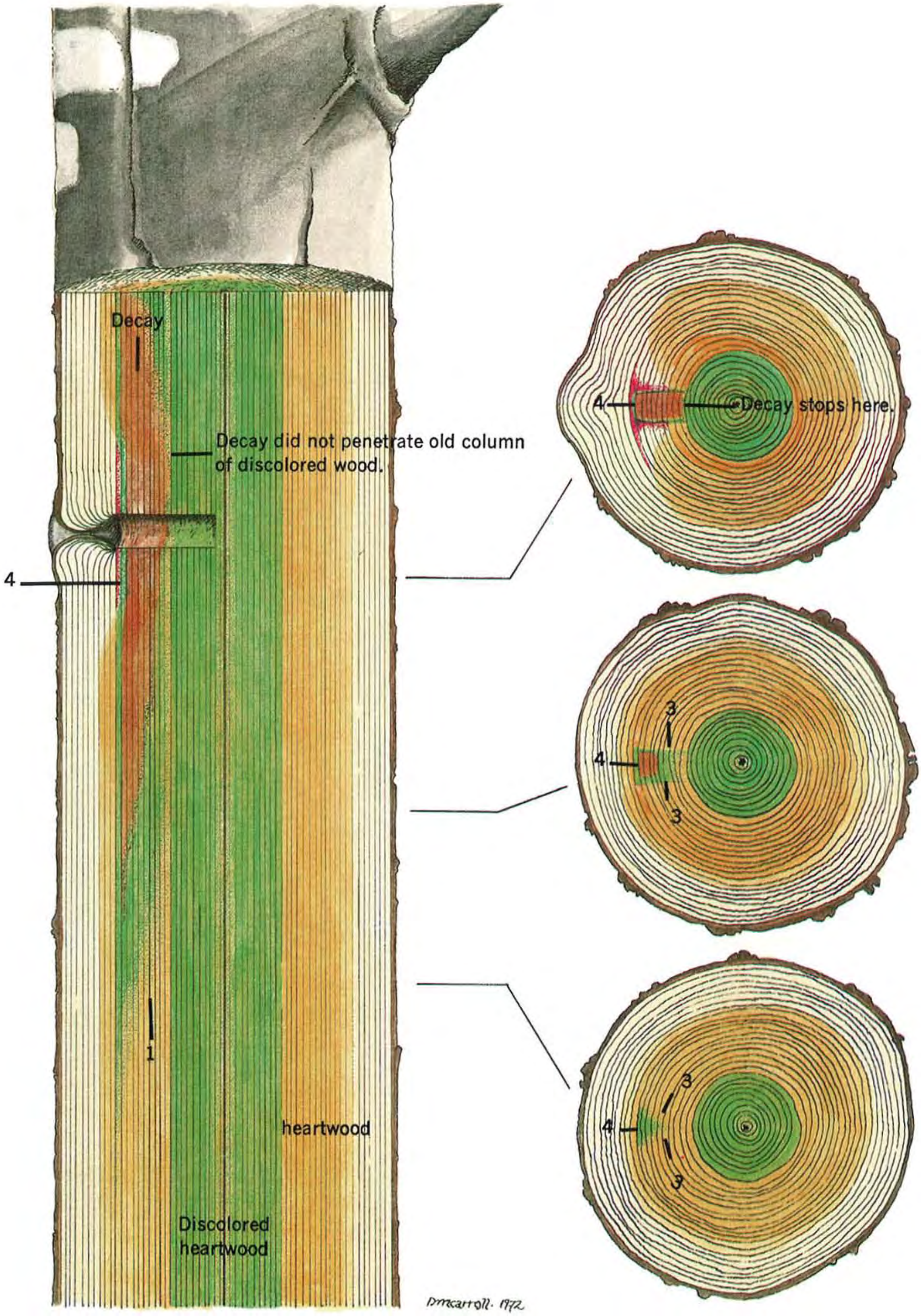

1
Decay did not penetrate discolored column.
4
1
3
4
3
4
4
3
4
3
Wood is altered slightly.
4
4

And in heartwood-forming trees.



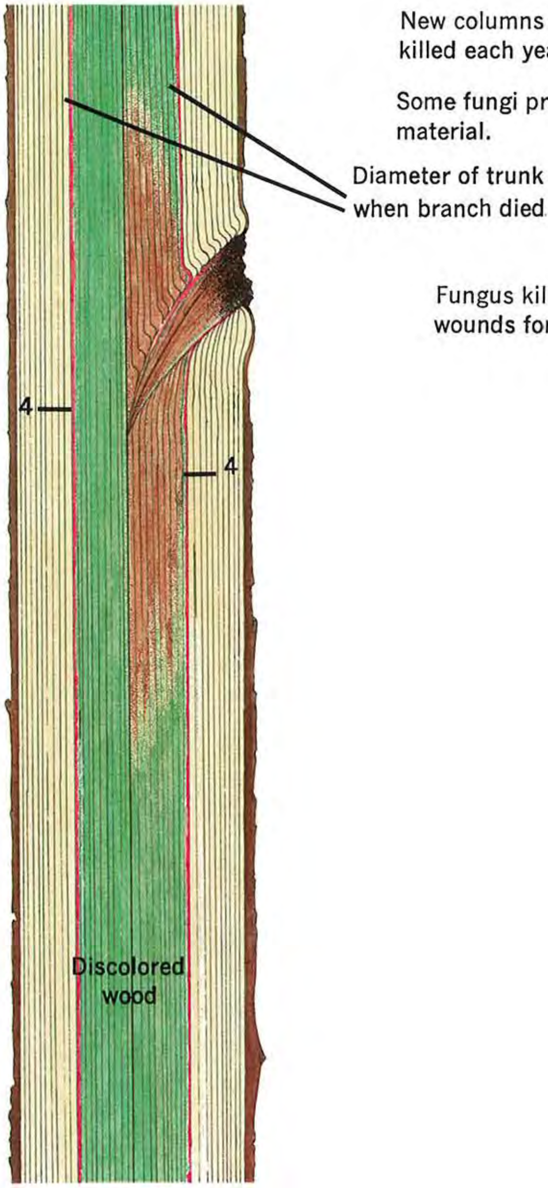


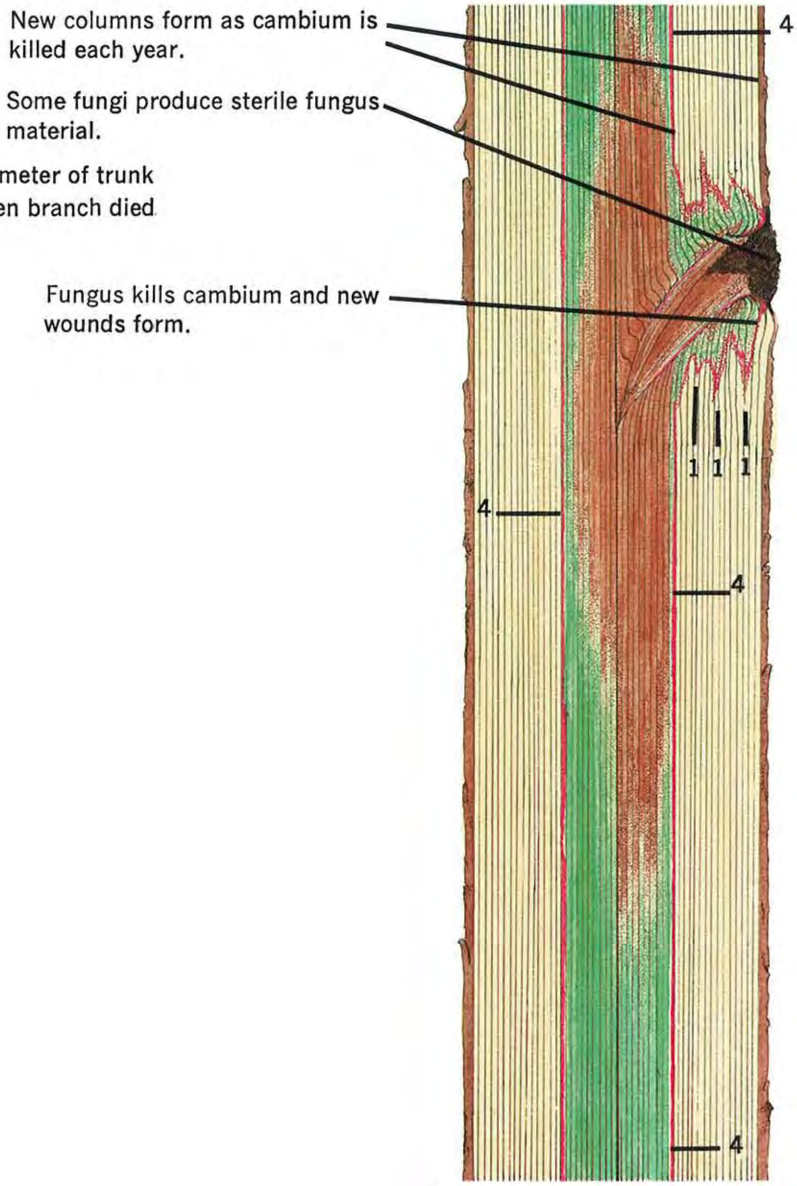
When new wounds penetrate old columns of decay, the decay process proceeds rapidly in the new column.

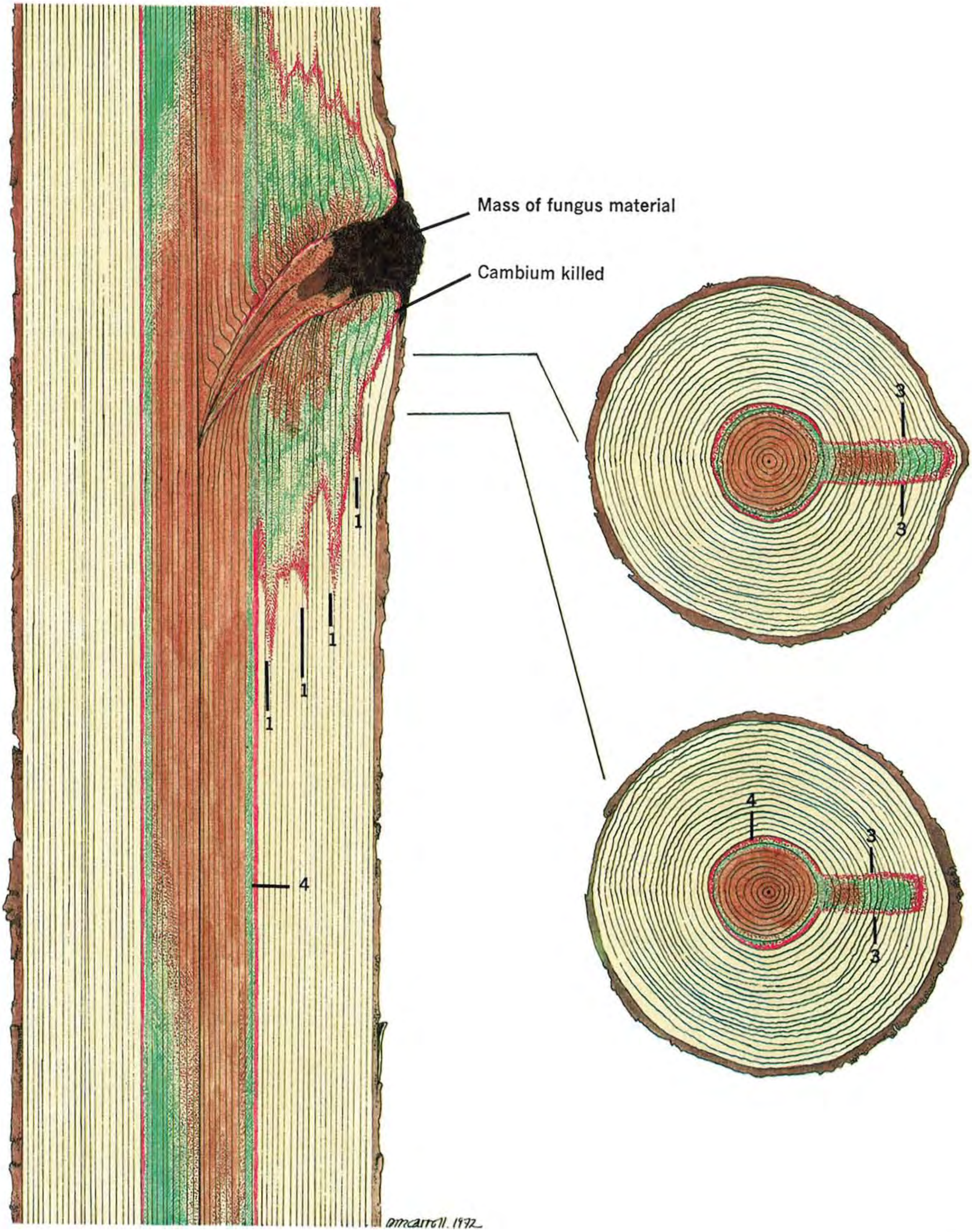


Decay
Decay did not penetrate old column of discolored wood.
4
1
heartwood
Discolored heartwood
4
Decay stops here.
3
4
3
3
4
3
DMcarroll. 1972

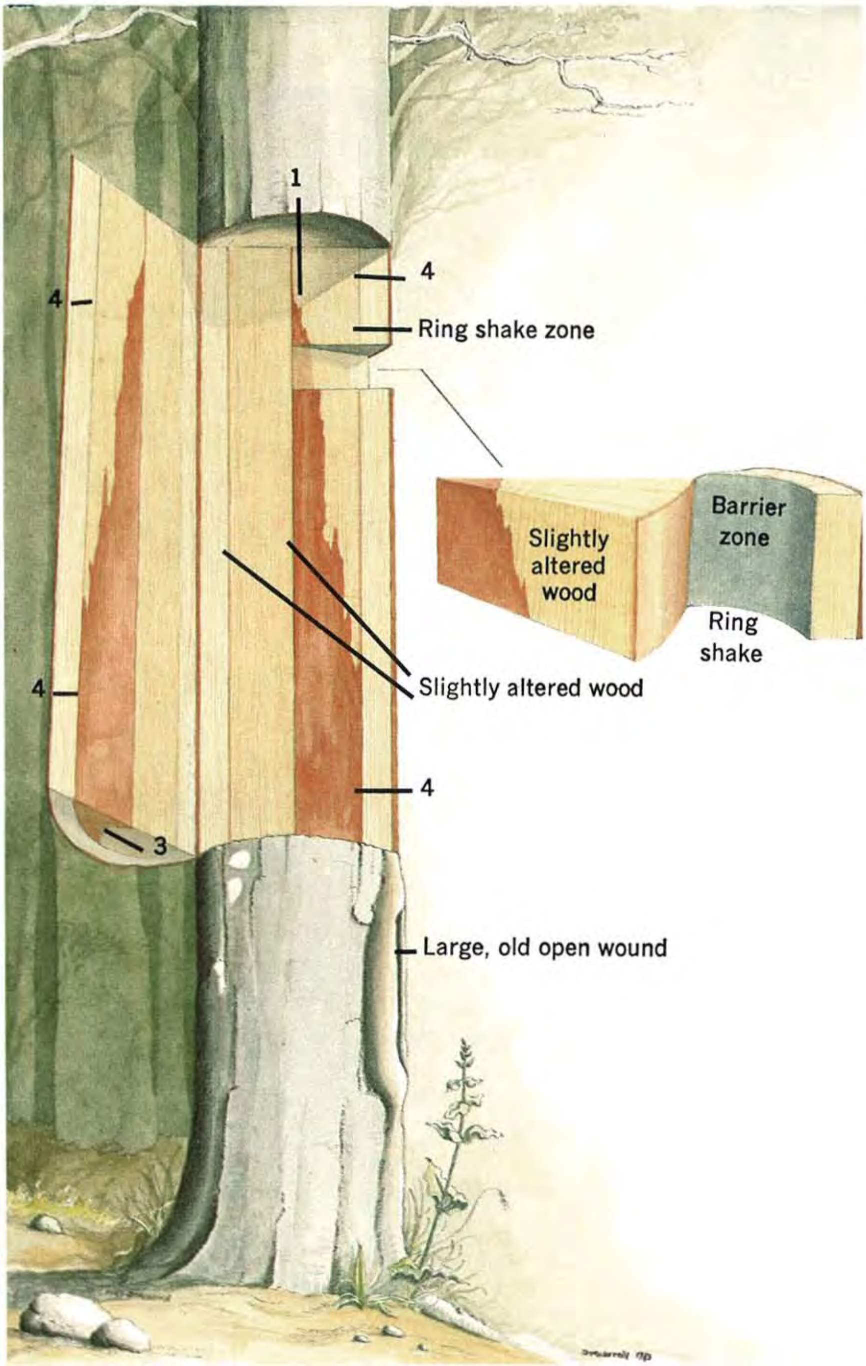
There are some patterns of defects that on first inspection do not appear to fit the concept of compartmentalization. However, they do. The most notable are the defects associated with canker rots. Canker rot fungi, once established in a tree, keep the wound open by slowly killing some living tissues around the wound. This process is the same as re-wounding. And, when the new wound is made, a new column begins to develop. An intricate pattern of multiple columns is associated with canker rot.



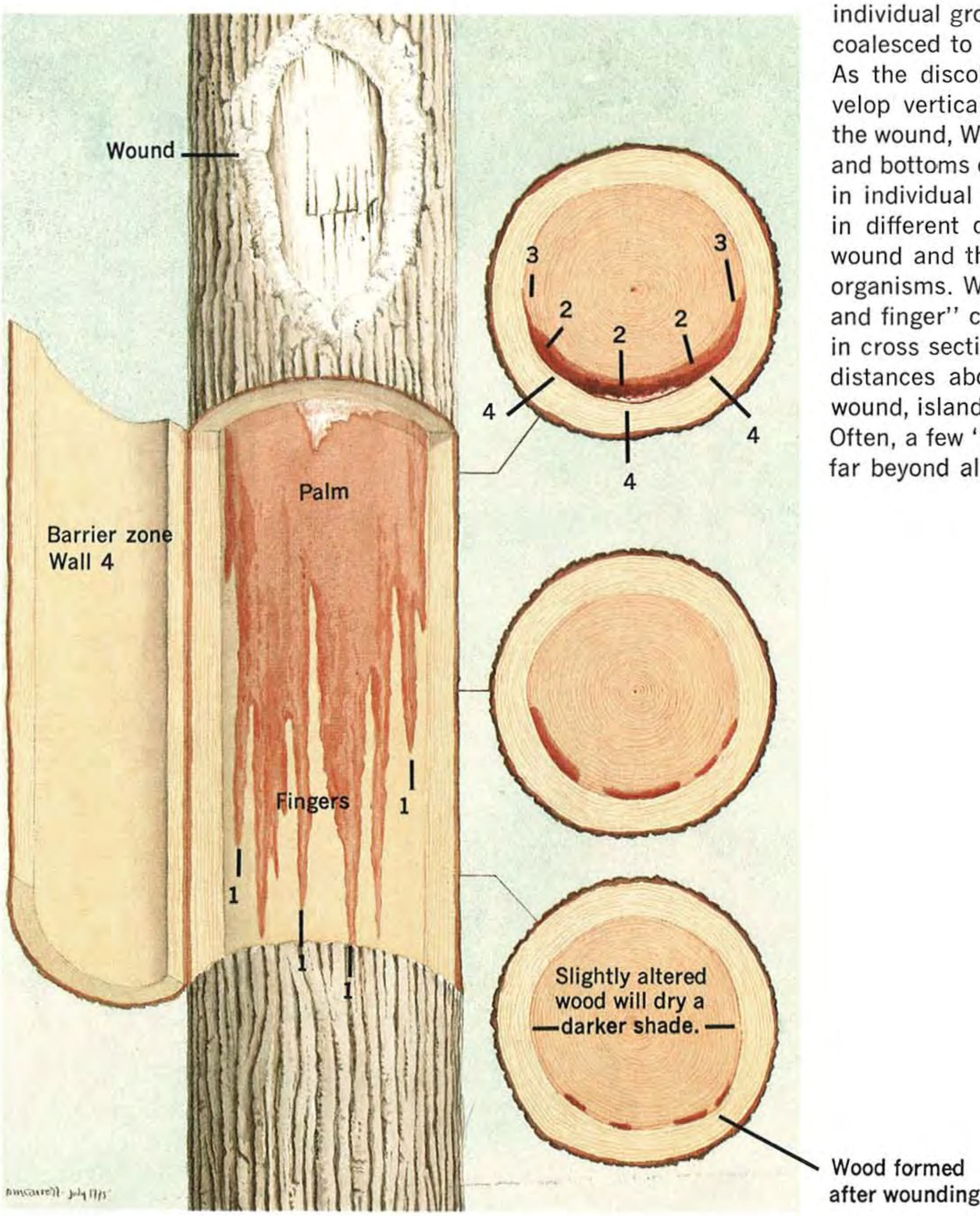



Mass of fungus material
Cambium killed
1
1
1
1
4
3
3
4
3
3
omcarroll. 1972

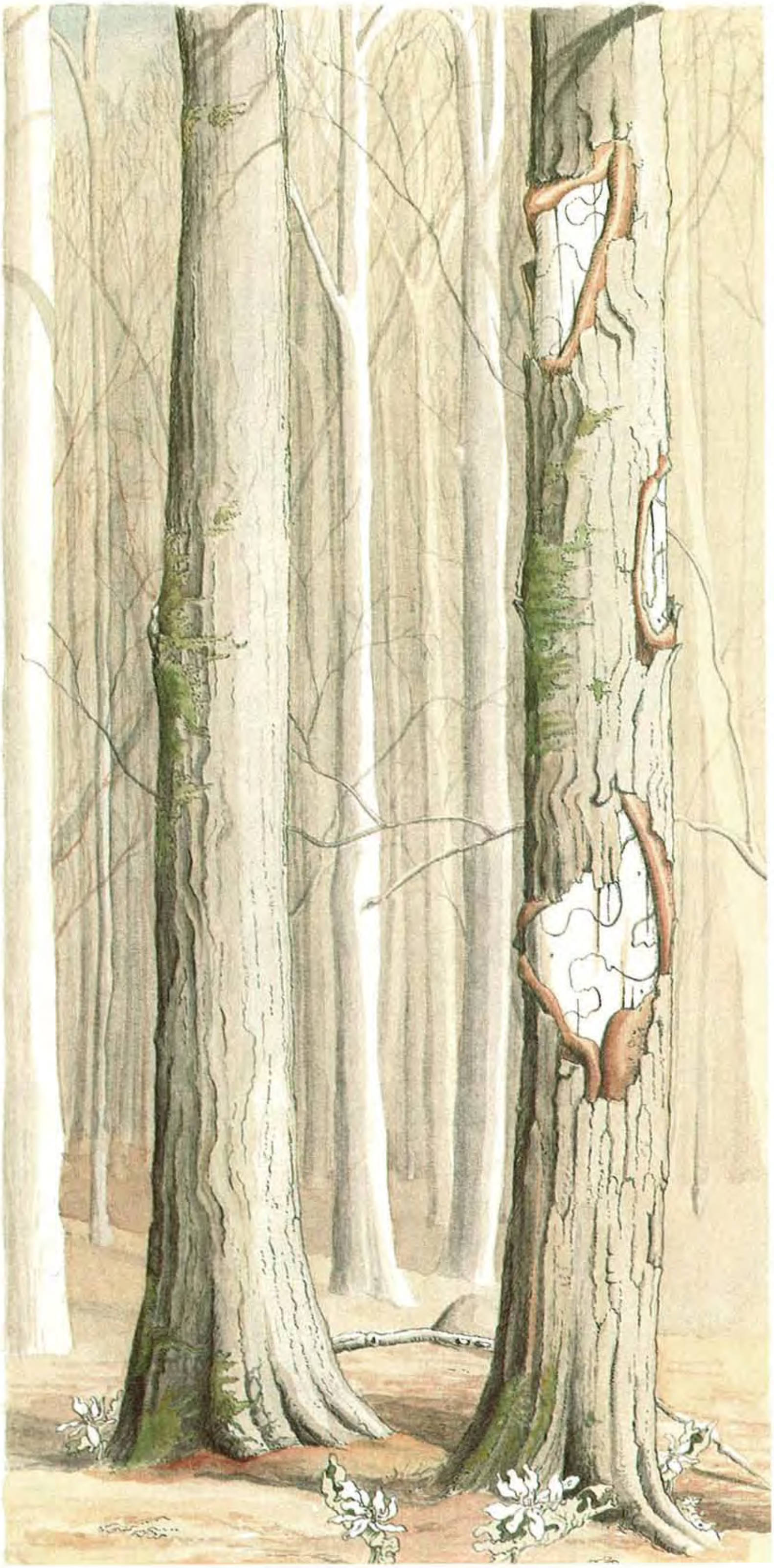
Another type of defect that does not appear to fit the concept are ring shakes—separation of the wood along the rings. The problem here is that the barrier zone associated with the wounds often forms far beyond the visible column of defect. The barrier zone acts as a partition between the wood present at the time of wounding and the new wood formed after. When growth stresses or other stresses are applied, the wood sometimes pulls apart along the barrier zone. Most shakes are associated with wounds, but not all wounds result in shakes.

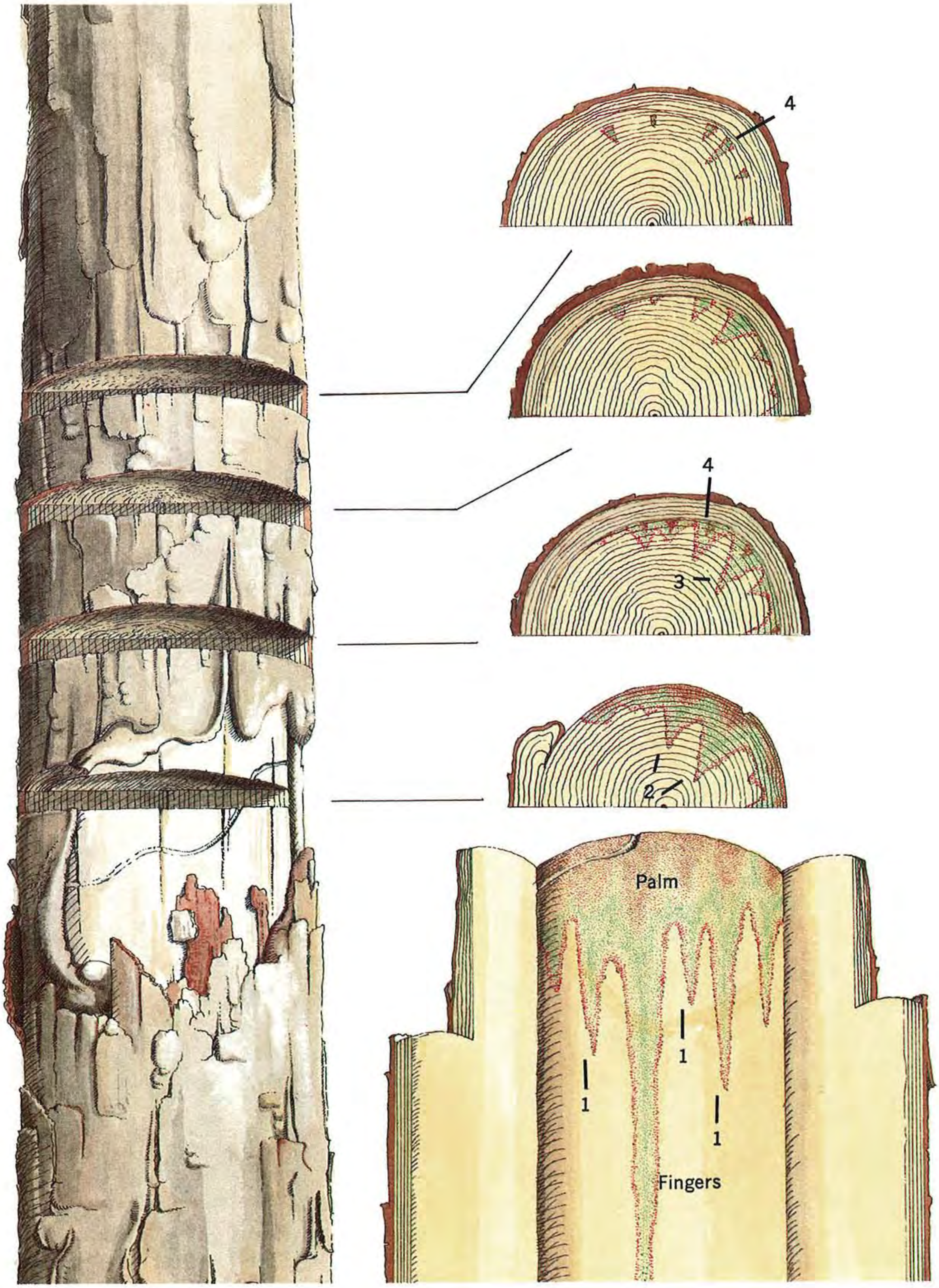


And, yet another type of defect pattern that appears not to fit the compartmentalization concept is the "island" pattern or streak pattern often spoken of as mineral streak. Wounds indeed start these processes. A pattern type that can be termed "palm and fingers" develops. Near the wound all the columns in the individual growth ring are coalesced to form the "palm." As the discolored columns develop vertically above and below the wound, Walls 1, or the tops and bottoms of the compartments in individual growth rings, react in different degrees to the wound and the invading microorganisms. When such a "palm and finger" column is viewed in cross section at increasing distances above and below the wound, islands of defect appear. Often, a few "fingers" will develop far beyond all the others.



In sugar maple, for example, the "palm and finger" pattern is the mineral streak pattern associated with sugar maple borer wounds. This insect is a major cause of mineral streak in sugar maple.

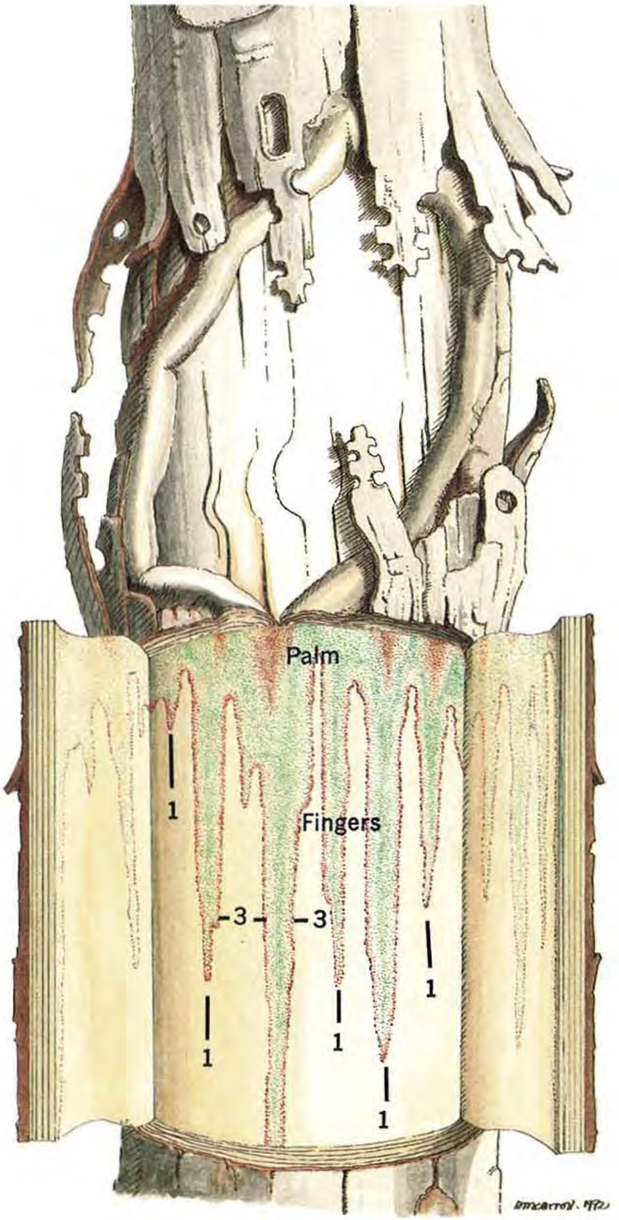


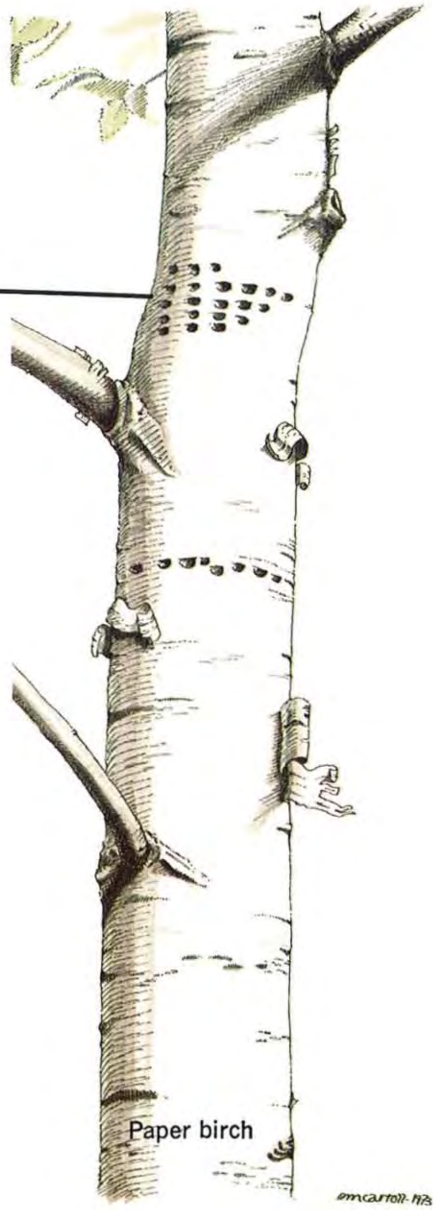


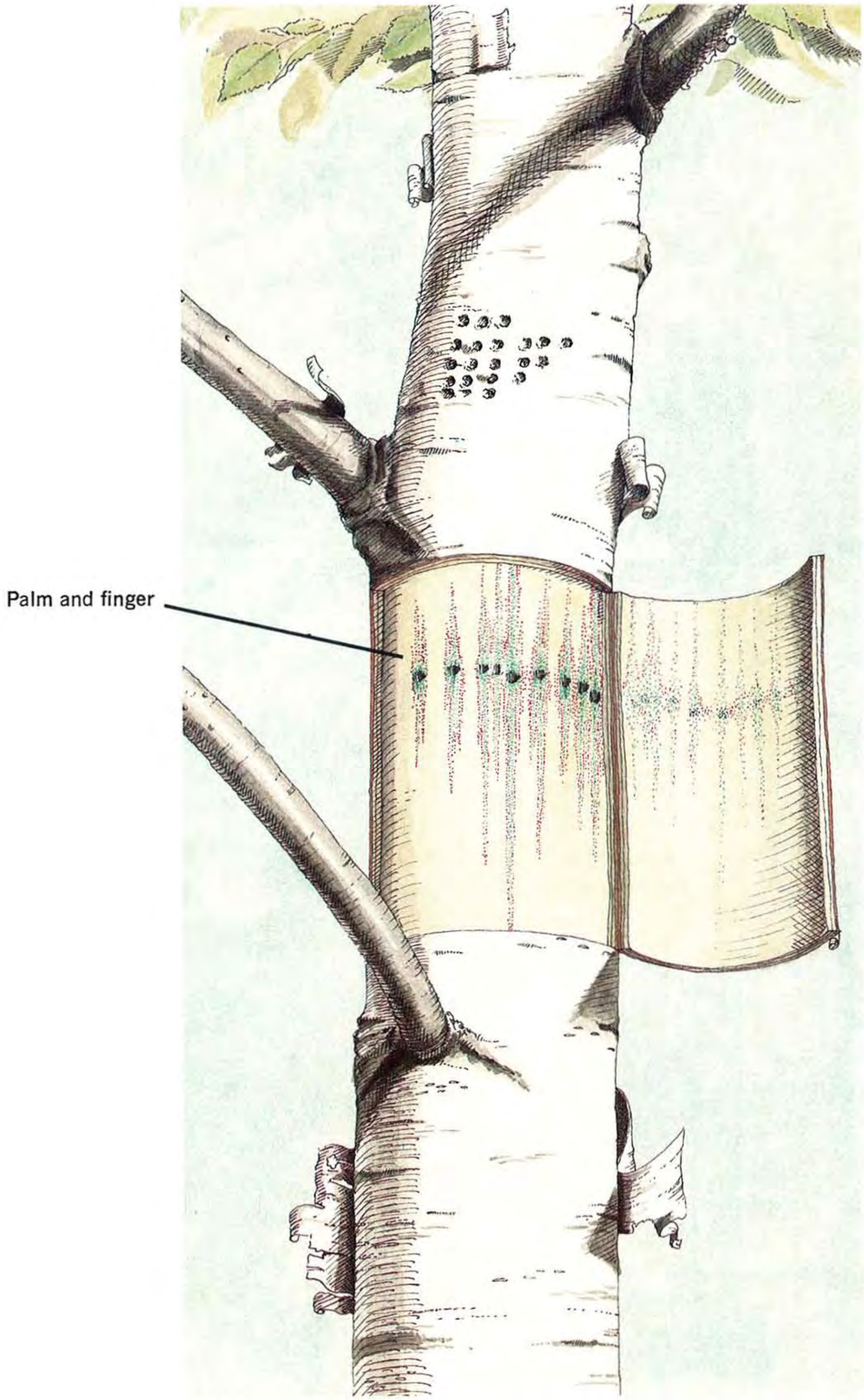
4
4
3
2
Palm
1
1
1
1
Fingers

The yellow-bellied sapsucker (see page 7) inflicts several types of wound patterns on many species of trees. In one type of wound pattern a large wound is the result, and the "palm and finger" defect pattern develops. Again, the "fingers" may extend great distances above and below the wound. And cross sections of trunks made through the "fingers" will show islands of defect, or mineral streaks.

The "palm and finger" defect pattern is also associated with some other wounding patterns made by the sapsuckers.

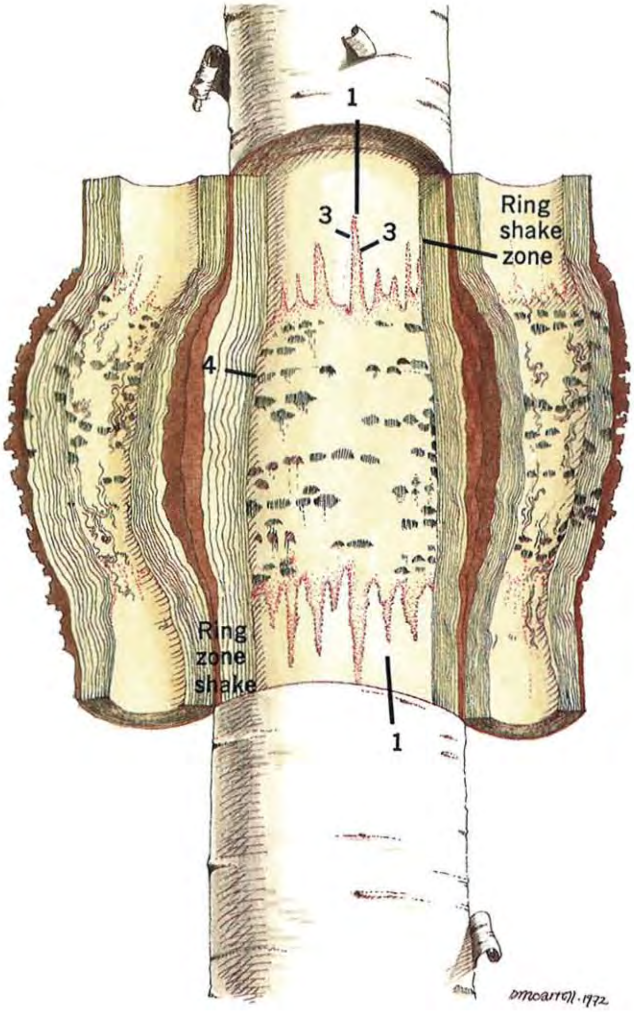





Palm and finger

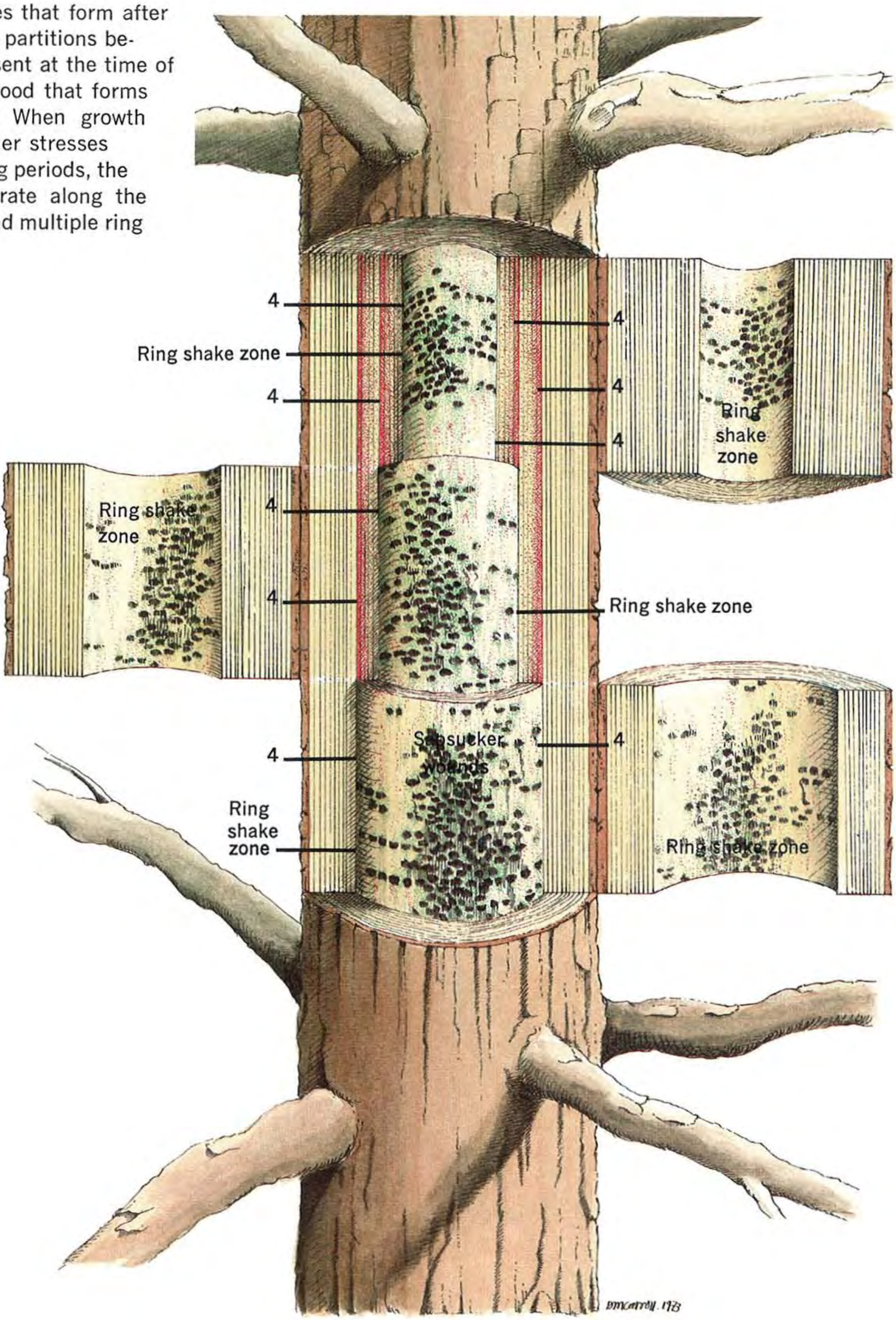
Sapsuckers will often wound one area on a trunk. On paper birch a swollen black band will form at these sites.

Not only will discolored streaks of the "palm and finger" pattern develop from such wounds, but the barrier zone that develops after wounding may pull apart from the inner rings to form a complete ring shake which is sometimes called cup shake or loose heart.

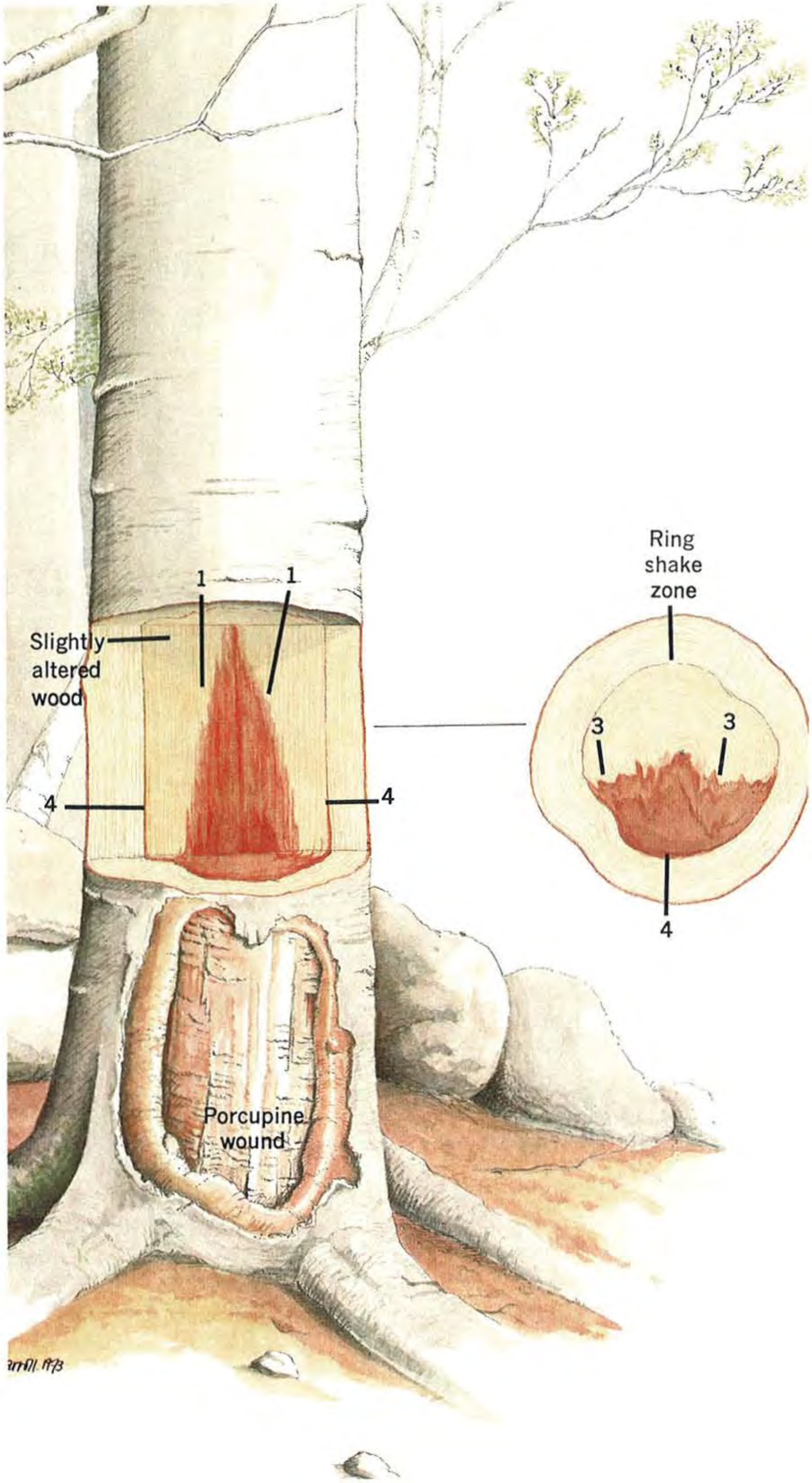


On some trees, such as eastern hemlock, the yellow-bellied sapsucker inflicts many wounds over large areas of the trunk.

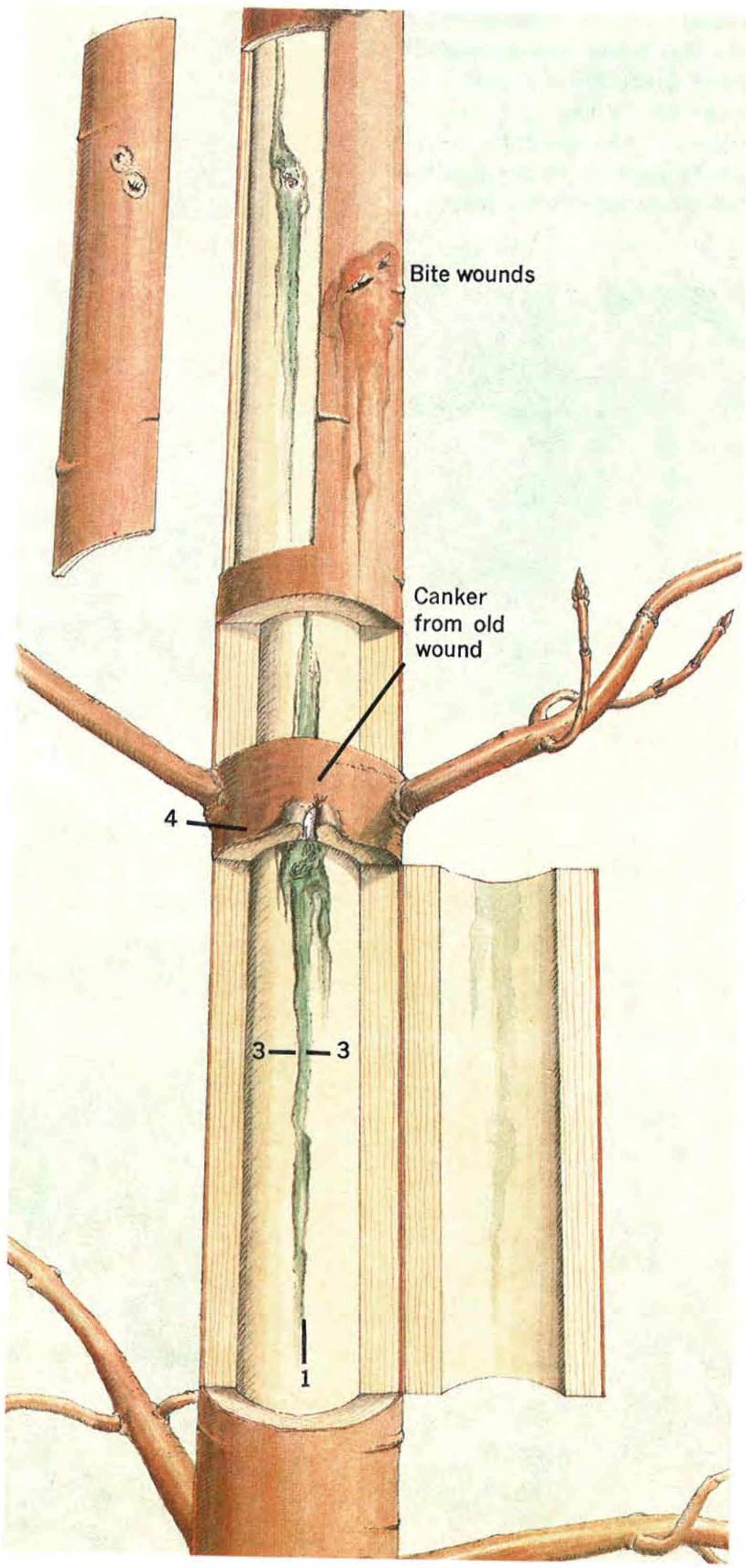
The barrier zones that form after wounding act as partitions between wood present at the time of wounding and wood that forms after wounding. When growth stresses and other stresses develop over long periods, the wood may separate along the barrier zones, and multiple ring shakes form.



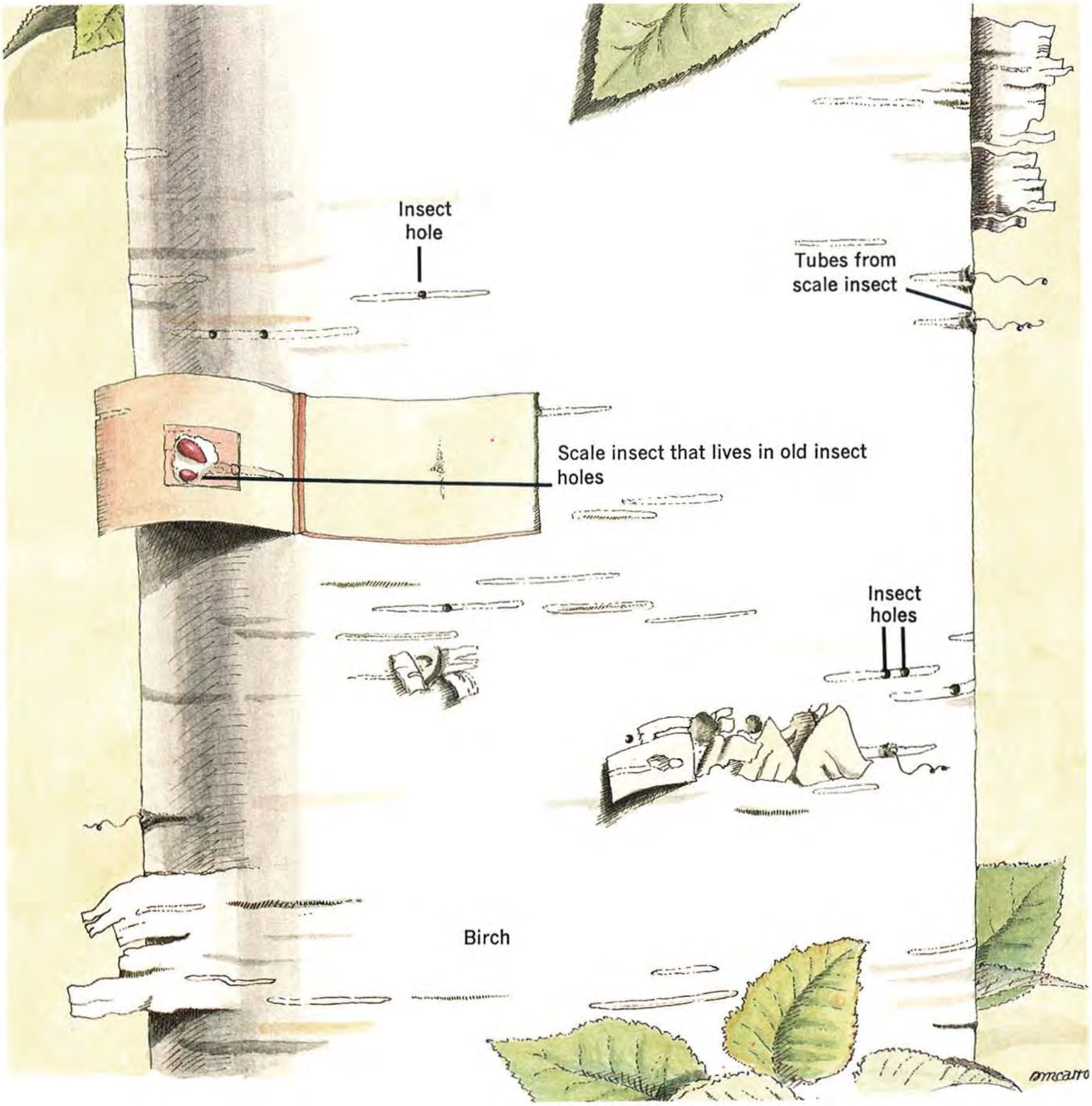
The "palm and finger" pattern of defect and barrier zones that form shake are commonly associated with wounds made by larger animals such as beavers and porcupines (see page 9). When wounds are severe, Walls 1 and 2 may fall to invading microorganisms.



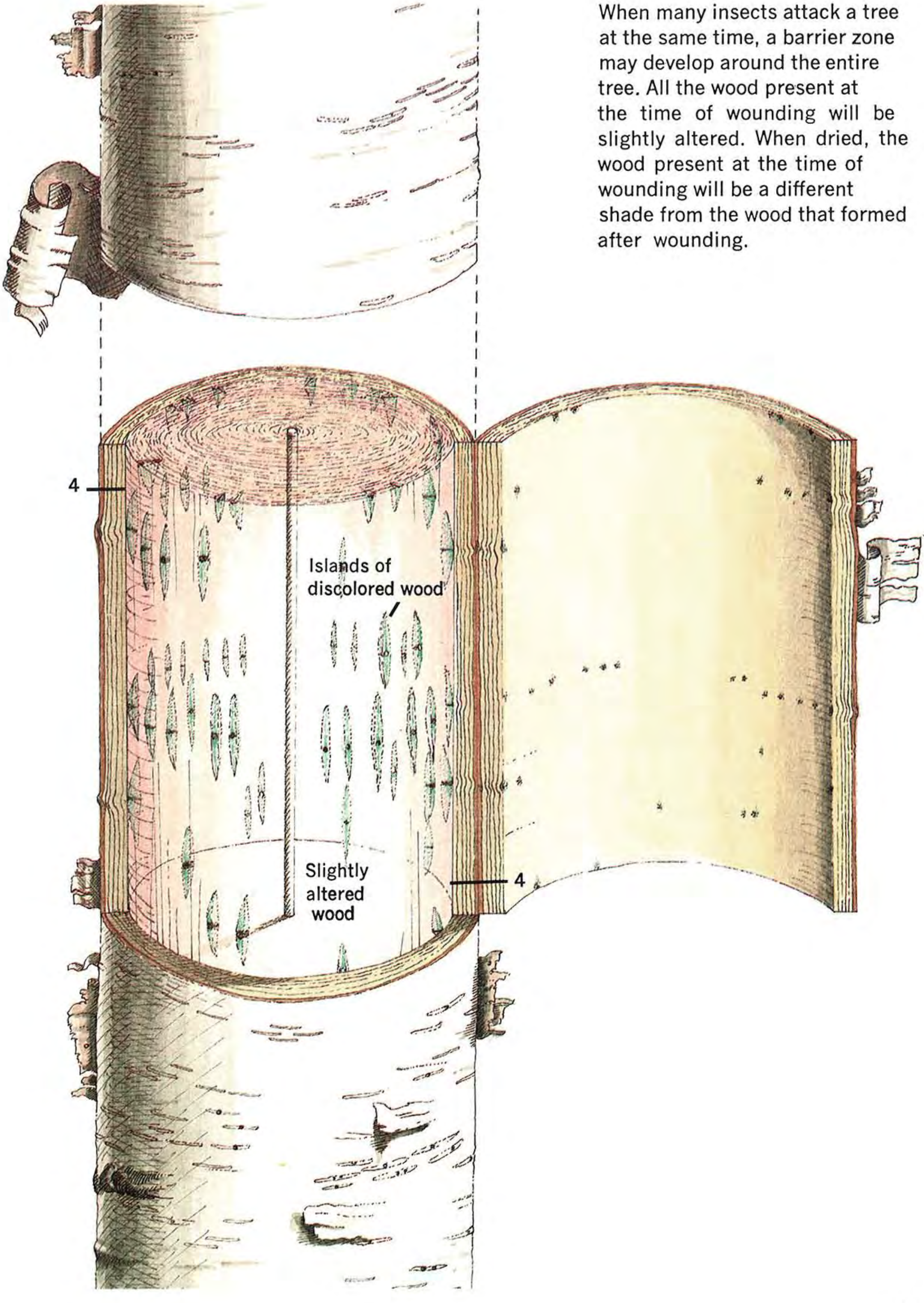
Squirrels wound young, smooth-barked trees in several genera (see page 8). The typical "palm and finger" defect pattern results. In some species these defects are called mineral streaks.



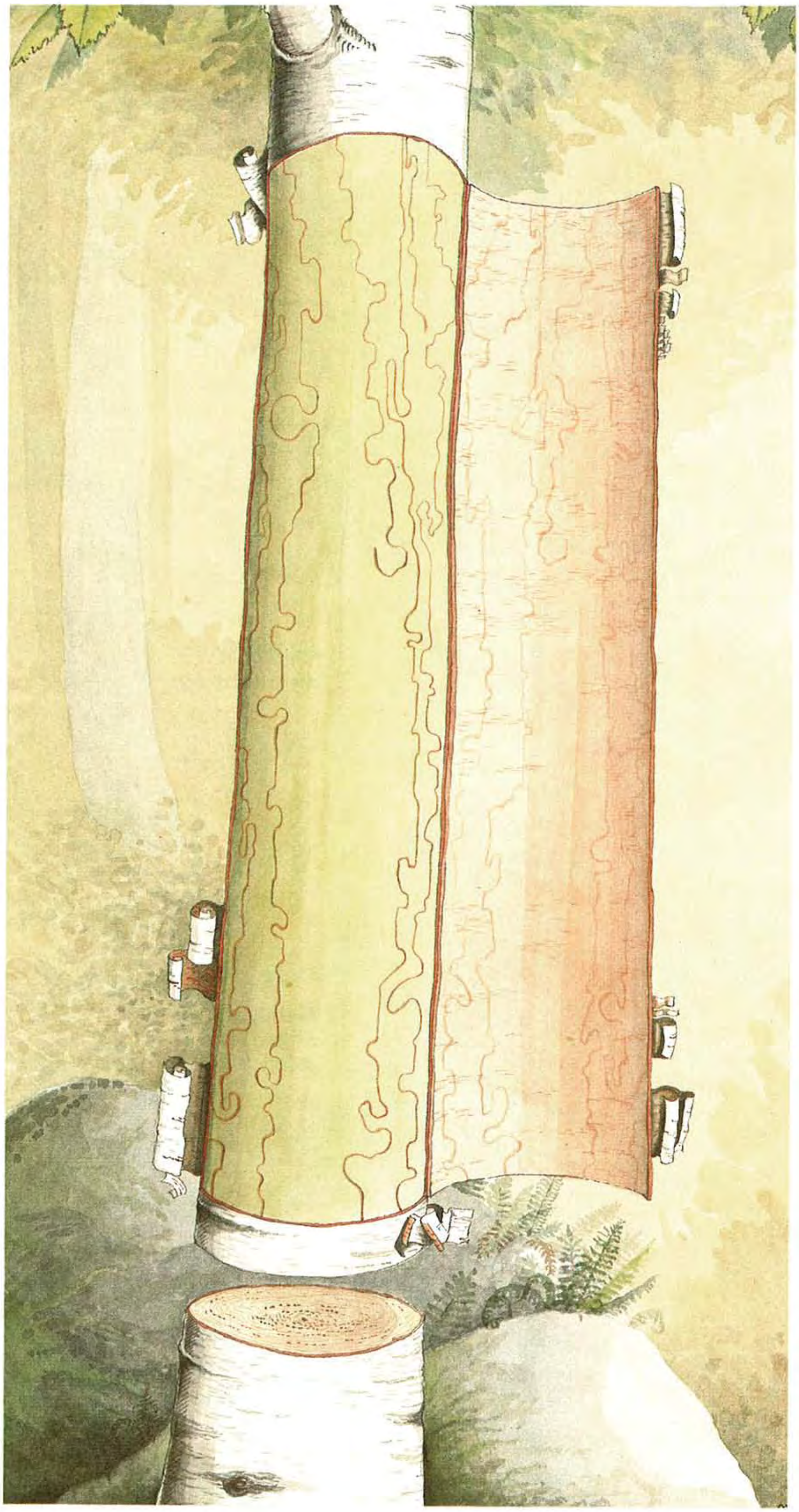
Insects wound trees (see page 8) and small islands of defects form. Each island of defect is a small "palm and finger" column. The columns usually penetrate only to the depth of the hole made by the insect.



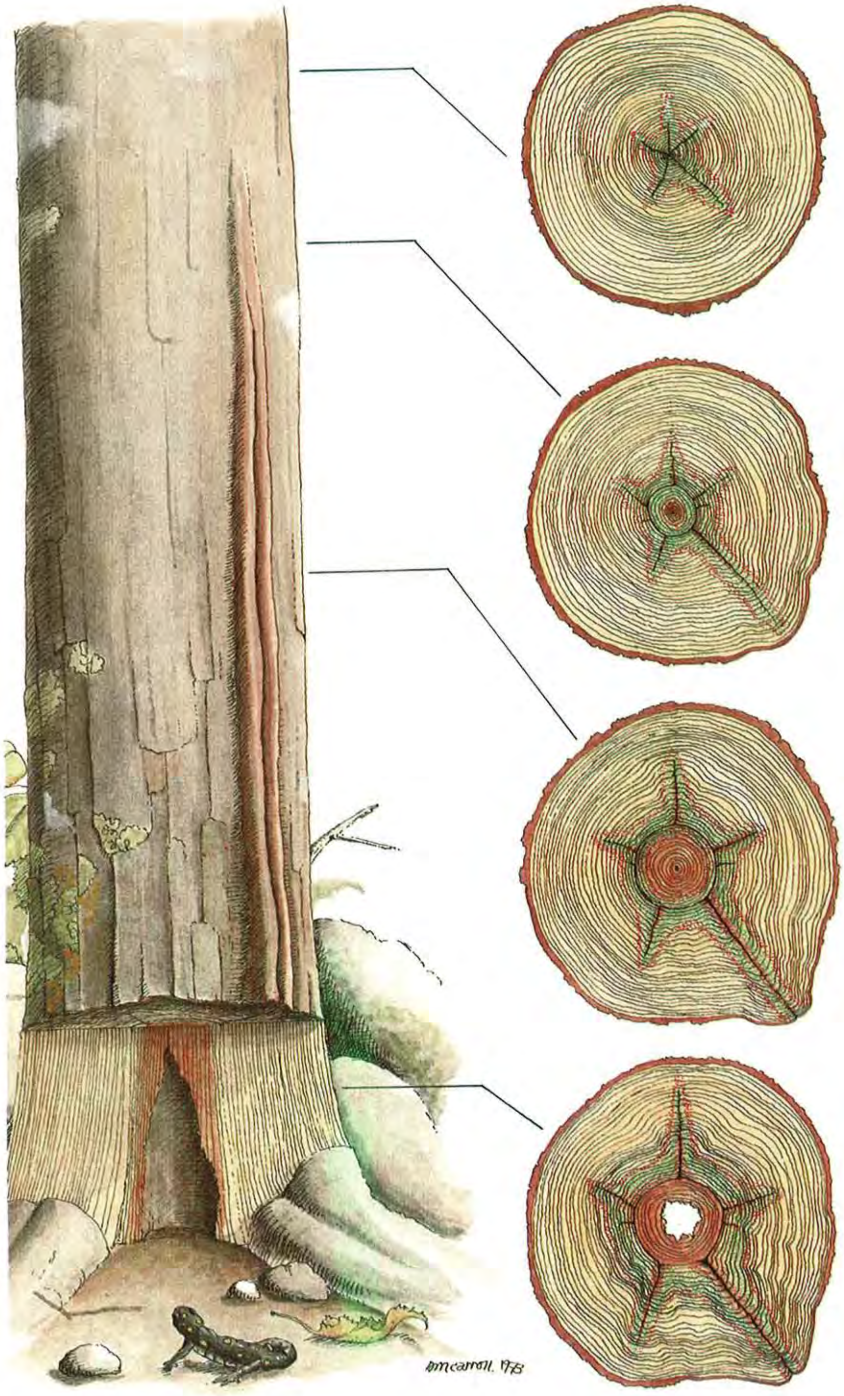
When many insects attack a tree at the same time, a barrier zone may develop around the entire tree. All the wood present at the time of wounding will be slightly altered. When dried, the wood present at the time of wounding will be a different shade from the wood that formed after wounding.



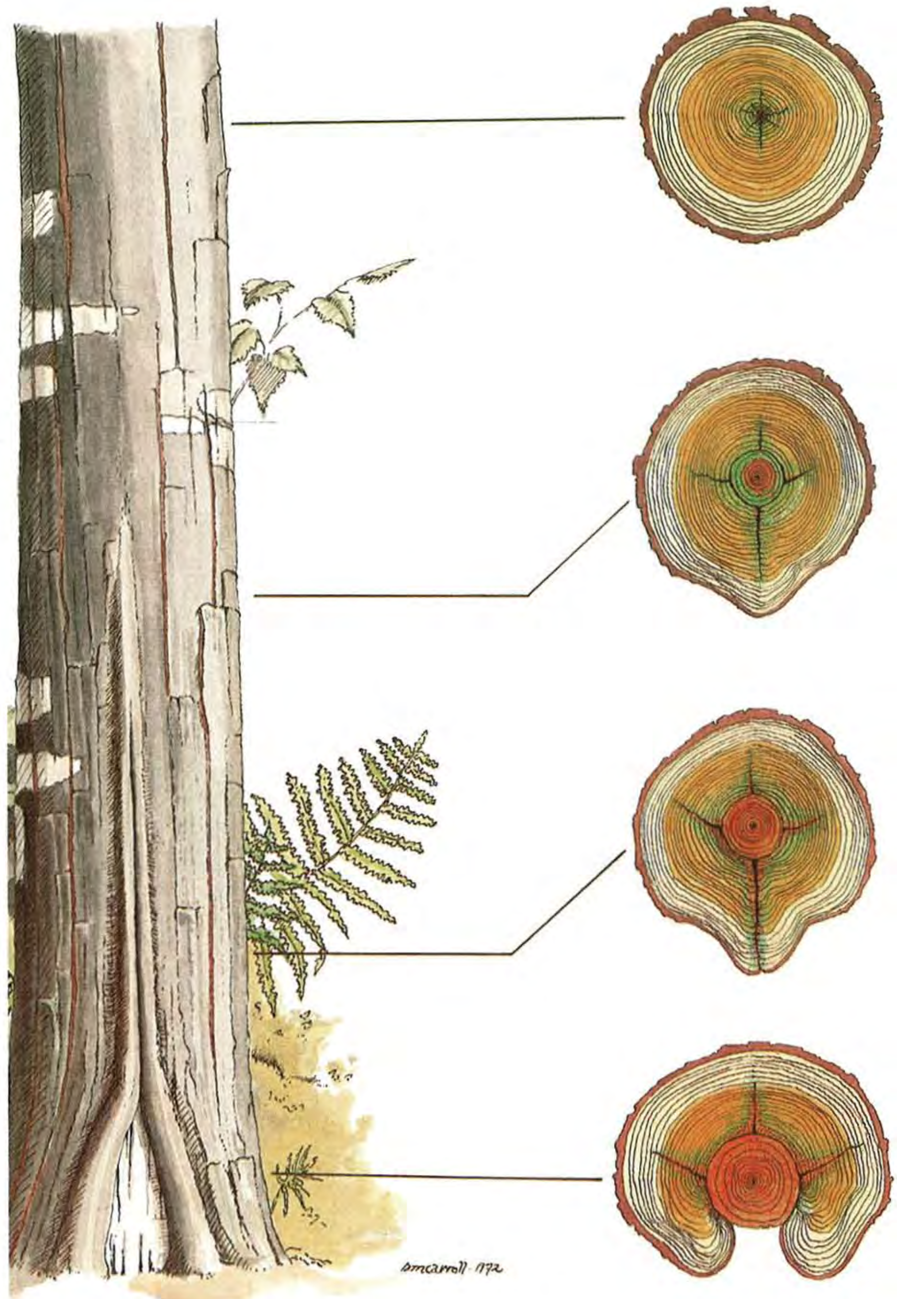
The cambium miner is a small larva of a type of fly that eats its way down the cambial region of some trees. The "tracks" of the larvae are compartmentalized as very long narrow streaks of discolored wood within growth rings.



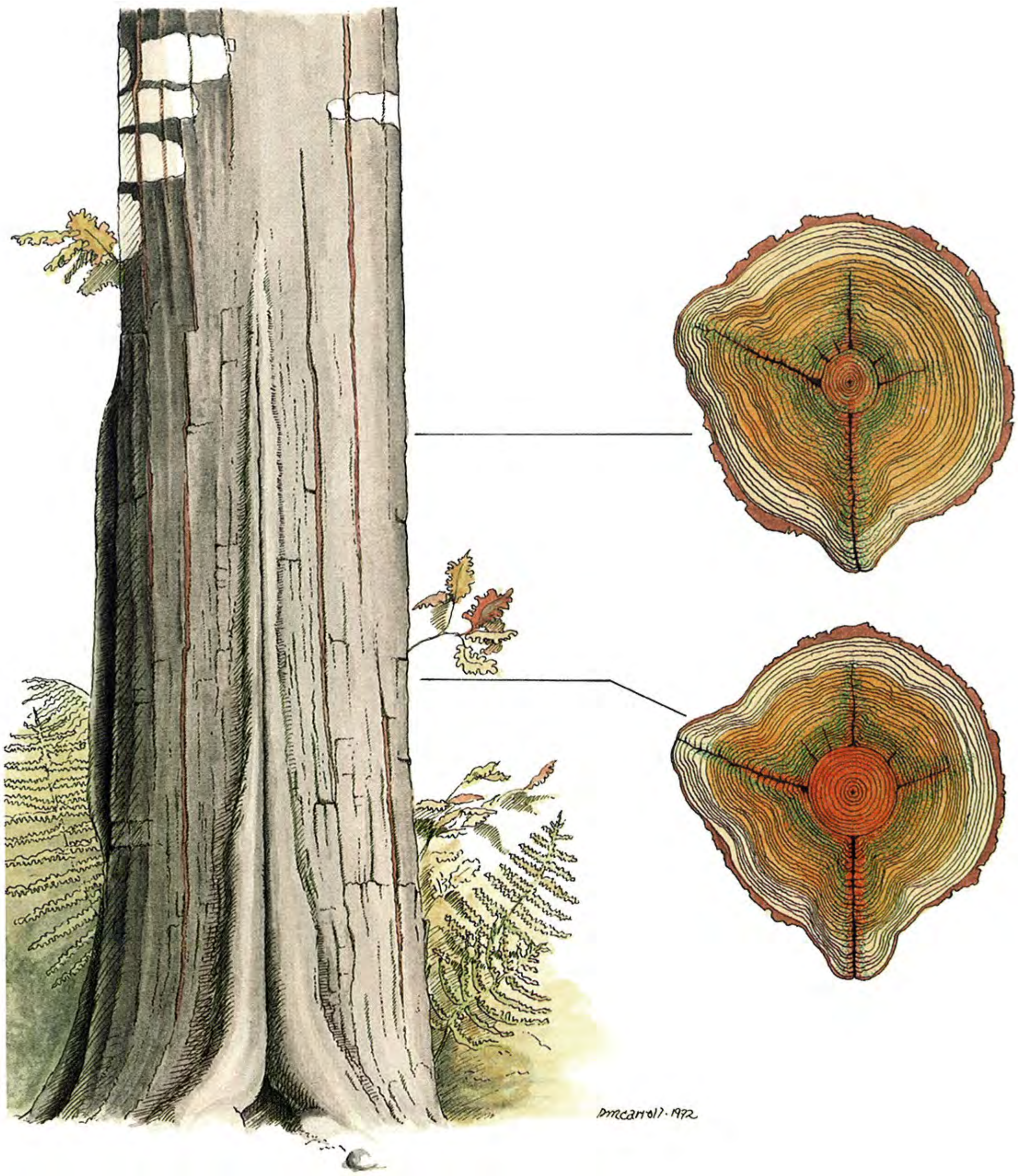
On some trees the wounds are not visible. This is common with small basal wounds, especially those caused by fire when the tree was very young and now the healed wound is hidden by forest litter. The barrier zone still forms around such wounds and often results in ring shake. Also, the inrolled callus serves as a weak spot on the tree that may continue to split vertically. Additional cracks may form from the barrier zone outward into the wood that forms after wounding. When the cross section of a trunk with such a pattern of internal defect is viewed above the base, a star-shaped pattern of cracks radiating out from the center will be seen.



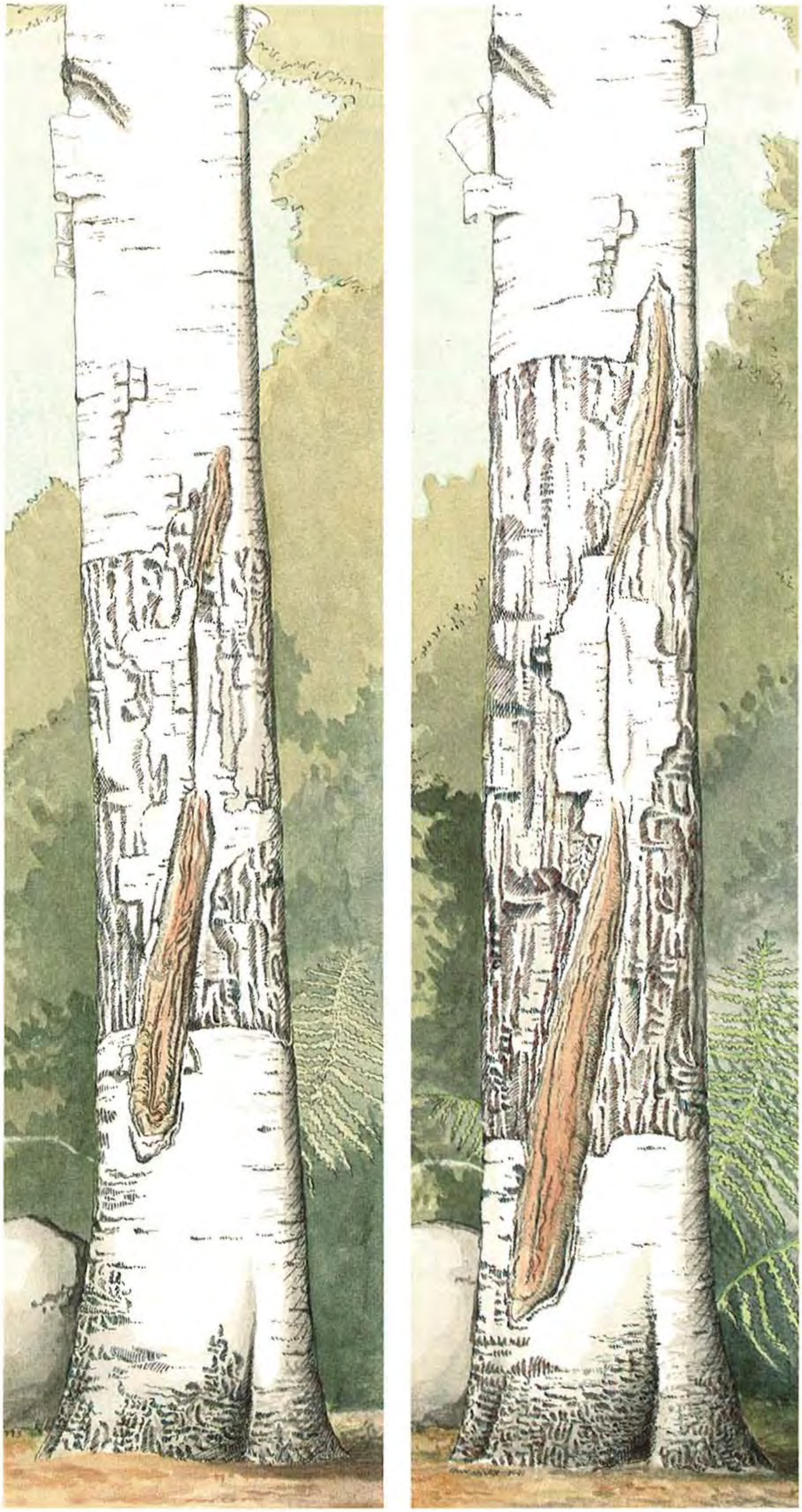
With some basal wounds, long internal cracks, called seams, form at right angles to the wounds at the points where the callus inrolls.



As these cracks continue to enlarge and get closer to the edge of the trunk, they may suddenly split out to the bark. These secondary seams will be at right angles to the main seam. Most large seams start from old wounds and move outward.



Seams will also form from mechanical wounds on trunks. Once a seam begins to form, it will usually continue to enlarge throughout the life of the tree.



In summary, the compartmentalization of defects in trees is a survival system that is effective most of the time—not all of the time! And after the tree dies, the powerful decay processes continue to decompose the wood. The decaying wood provides nourishment for a wide variety of organisms.

The decomposed wood provides
nourishment for new trees.

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