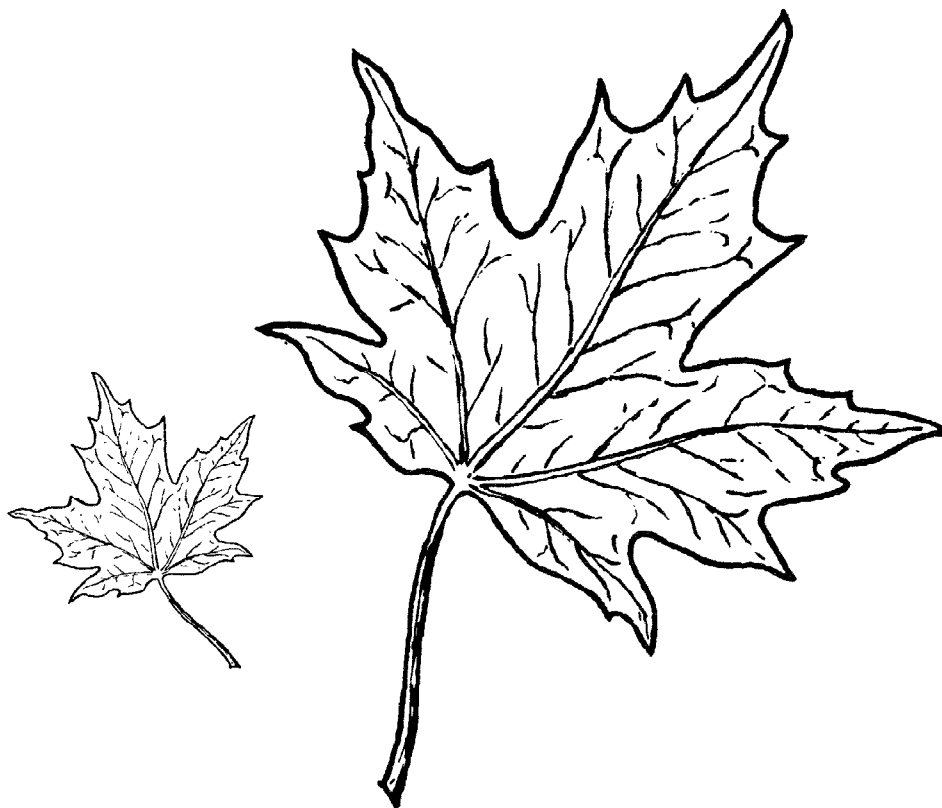


by **Russell S. Walters and Alex L. Shigo**

TAPHOLES IN SUGAR MAPLES: WHAT HAPPENS IN THE TREE



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Abstract

Maple syrup production starts by drilling a taphole in the tree. This process injures the wood, which may become discolored or decayed as a result. If trees are to be tapped, every effort must be made to minimize injury while obtaining the desired amount of sap. Information about tapholes is given here for the benefit of the producer. Some important points discussed are: how trees compartmentalize discolored and decayed wood associated with tapholes, how some tapping procedures lead to cambial dieback around the hole, the problem of overtapping related to increased use of mechanical tappers, and new information on the use of paraformaldehyde pills, which can lead to more decay in trees.

INTRODUCTION

TO OBTAIN SAP from sugar maples for syrup production, tapholes must first be drilled in the trees. Essentially, a taphole is a wound. The vessels in the wood are severed by drilling, and the sap flows out. The resulting wound injures the wood and exposes it to microorganisms, but most sugar maple trees are tough, and they can react ef-

fectively so that some wounding does not cause internal problems. However, tapholes are frequently the source of internal problems that lead to extreme decay—even death—of trees. We need to learn how to drill tapholes without causing serious internal injury. If we can do this, trees can be tapped for many years and remain healthy. This paper gives information about tapholes that will help the operator to minimize injury to the trees, and maximize production of sap (Fig. 1).

Figure 1.—Decayed and discolored wood associated with paraformaldehyde-treated tapholes on the left, and only discolored wood associated with a nontreated taphole from the same tree on the right. The decayed wood is surrounded by discolored wood (B). The arrows indicate the barrier zone between tissues formed before and after wounding. Unless other wounds are inflicted, the discolored and decayed wood will remain on the inside of the arrows. The decayed wood in this sample is typical of the type associated with the fungus *Coriolus versicolor*. This decay-causing fungus was the one most frequently isolated from the pill-treated tapholes.



WHAT HAPPENS WHEN A TAPHOLE IS MADE?

Why maple sap flows

Maple sap will flow from a taphole in dormant sugar maples when the internal pressure of the tree is greater than the atmospheric pressure (Jones and others 1903, Marvin 1958). This occurs when certain daily changes in air temperature cause internal pressure changes—usually in the early spring, and sometimes in the fall. Cold temperatures induce a negative pressure within a tree, and moisture is absorbed through the roots. Warm temperatures induce a positive internal pressure, which forces sap from the tapholes. The volume of sap is not related to the temperature rise on the day of the flow, but rather to the length of the preceding cooling period (Marvin 1958).

Sauter (1974) suggests that sap flow is in part due to gas (CO₂) expansion, contraction, and solubility in response to temperature. As a result of respiration, living xylem cells generate CO₂, which accumulates in a gas-filled fibrous tissue surrounding the vessels and quickly dissolves in the water of the fiber walls. Larger amounts are dissolved at lower temperatures. Higher temperatures warm the tree, which drives CO₂ out of solution. Warming also causes the gas to expand, which compresses the vessels and creates positive internal pressure and sap flow from severed vessels (taphole). When cooled, the CO₂ contracts and redissolves, which creates negative pressure (relaxation of the vessels), and sap is reabsorbed.

A tree reacts to wounds

When a taphole is drilled, the tree reacts. The living cells in the injured wood begin to change their internal processes. Substances used normally for the maintenance of the tree are shunted to materials that have protective functions (Shortle and others 1971, Tatter and Rich 1973).

As a result of a tree's chemical protective response to wounding, the wood surrounding the wound begins to discolor. In discolored wood the contents of living cells are altered. There is little or no loss of strength. The discolored wood indicates chemical changes. These include the oxidation and polymerization of phenols (Shortle and others 1971, Tatter and Rich 1973). The discoloration

process intensifies as microorganisms infect the wound.

After wounding, vessel plugs begin to form (Rier and Shigo 1972) which cause the flow of sap to decrease and finally stop. The plugs are not tyloses but an aggregation of granular or gumlike amber globules that form from materials secreted from neighboring living cells (Rier and Shigo 1972, Sharon 1973). Many factors affect the rate and intensity of plugging, which differ from tree to tree. Studies with other species suggest that the processes may be under genetic control.

Soon after a wound is inflicted, it is infected by the many ever-present microorganisms. Bacteria, nondecay fungi, and decay-causing fungi all have an equal opportunity to infect fresh wounds. But the protective chemicals produced by the tree often inhibit infection by some microorganisms, especially the decay-causing fungi. Some species of bacteria and nondecay fungi digest or alter the protective chemicals. These organisms are the first to interact with the tree. They are the pioneers. Once they infect, they inhibit other organisms from growing into the wound. When decay-causing microorganisms do infect, they grow through the discolored tissues that were first inhabited by the pioneers. Decayed wood is wood in which the cell walls have been digested by the invading organisms. There is a great loss of strength. However, decayed wood does not develop from all wounds.

Compartmentalization

When a tree is wounded, the injured and infected tissues are never replaced, repaired, or restored to their previous healthy state. In this sense, tree wounds do not heal. Instead, trees wall off, confine, or compartmentalize the injured and infected tissues. A tree is a highly compartmented plant. Each growth ring is divided into many compartments. The tangential walls of the compartments are made up of the last cells that formed in each growth ring. (The term "wall" is used here is a diagrammatic sense in the model system, not as an anatomical feature.) The radial side walls are formed by the rays. After injury, the vessel plugs form and these complete the top and bottom, or horizontal, walls to the compartments (Fig. 1). The injury also triggers protective mechanisms in the cambium, and the new cells that form after wounding are altered. This newly-formed protec-

tive tissue acts as a barrier zone that separates the wood that forms after the injury from the wood present at the time of wounding. This barrier zone is very effective in excluding the invading microorganisms from the new wood tissues. Details on compartmentalization have been published (Shigo and Hillis 1973, Shigo 1976, Shigo and Marx 1977).

The compartmenting process may be genetically controlled. Information from other tree species strongly suggests that some individuals within a species are more effective compartmentalizers than others. When several clones of hybrid poplar (*Populus deltoides* X *P. trichocarpa*) were wounded with drill holes, compartmentation ranged from excellent, where the discoloration columns were only as wide as the original wounds, to poor, where large columns of discolored wood formed. There were gradations between these extremes, but individuals of each clone reacted similarly (Garrett and others 1976, Shigo and others 1977). If this is true for sugar maple, it will be possible to select trees that are good compartmentalizers for use in maple syrup production. Such trees would withstand repeated taphole drilling, and because they would have small central columns of discolored wood, they would also be high sap producers. Small compartments of discolored or decayed wood mean more living wood is available for productive tapholes. Most sugar maples are strong compartmentalizers, but even they can develop decay problems from overlapping.

USE OF PARAFORMALDEHYDE IN TAPHOLES

The studies

Paraformaldehyde has been used in tapholes to increase and prolong the yield of sap. Shigo and Laing (1970) suggested that paraformaldehyde caused considerable internal injury, and the long-term effects were questioned. Two studies (Walters and Shigo 1978) were done subsequently to determine these effects. One study, started in 1970, used sugar maple trees in six different areas in Vermont. The second study, started in 1973, used sugar maple trees in Vermont, New York, Michigan, Maine, and Pennsylvania. The experimental design was similar in both studies: two tap-

holes were drilled in each tree. One taphole was treated with a 250-mg paraformaldehyde pill, the other was an untreated control. After treatment, the trees were dissected after selected intervals ranging from 2 months to 5 years. The vertical length of discolored and decayed wood associated with each taphole was recorded (Fig. 1), and the microorganisms associated with the discolored and decayed wood from selected tapholes were determined.

The results

Statistical analysis indicated that there was more decay (higher incidence and greater total length of column) associated with pill-treated than with the controls (Fig. 2). This was evident 20 months after treatment. It was true for trees in Vermont and the other states. The fungus *Coriolus (Polyporus) versicolor* (L. ex Fr.) Quel was the decay-causing fungus most frequently isolated from the pill-treated tapholes.

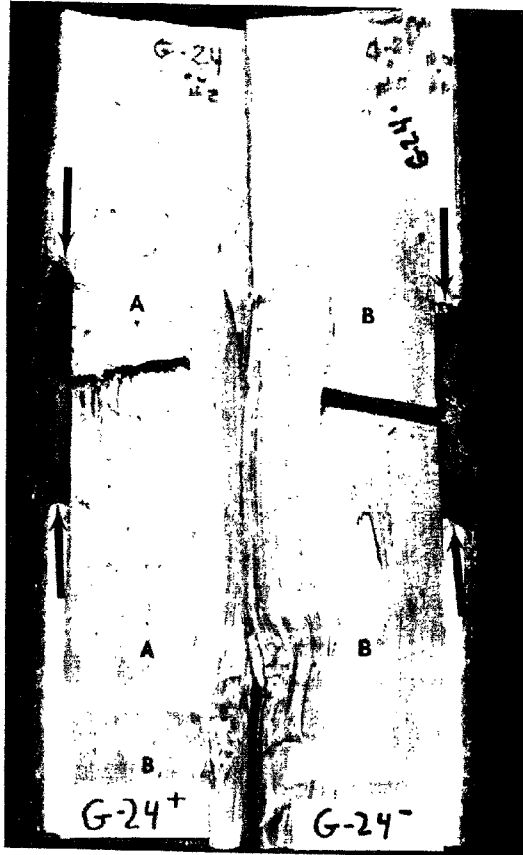
Paraformaldehyde apparently alters the tree's vascular and ray systems that play an important role in vessel plugging. When vessel plugging is delayed, the formation of the top and bottom walls of the compartments is retarded, which facilitates invasion by wood-decaying fungi. Paraformaldehyde may interfere with the usual groups of wound-infecting pioneer microorganisms. Because paraformaldehyde kills xylem cells so quickly, the normal chemicals that are antagonistic to wood-decaying fungi may not form. Thus when paraformaldehyde is used, the normal defense response, and the normal successional patterns of microorganisms, appear to be altered. In effect, the paraformaldehyde makes the hole inside the tree larger by swiftly killing many extra wood cells adjacent to the taphole.

To use or not to use the pill

In general, we do not recommend the use of paraformaldehyde pills in sugar maple tapholes. Their use can seriously harm the tree, but whether to use them is a management decision. The short-range benefits of greater sap yield must be weighed against the long-range damage to the trees, and an eventual great decrease in sap yields.

On the other hand, the pill can be used when selected trees are designated to be cut within a few

Figure 2.—The arrows indicate the large dieback areas associated with the two tapholes in this tree. Although both wounds had equal dieback areas, the paraformaldehyde wound had a large pocket of advanced decay (A) surrounded by discolored wood (B). Only discolored wood (B) was associated with the control tapholes.



years. A maple syrup producer could then use the pill to increase the sap yield from those trees before they are cut.

TO TAP A MAPLE TREE

Drilling tapholes

Tapholes should be drilled as close to the beginning of the spring sap-flow season as possible. This is difficult to judge, because early warm weather does not always begin every year on the same date, nor at the same time in all parts of the maple

region. If tapped too late, early sap flows may be missed; if tapped too early, the taphole may dry out before the season ends, or the trees may be frozen and seriously damaged by splitting the bark while driving in the spout (Walters 1978) (Fig. 3).

Figure 3.—A seriously damaged taphole. The bark split above and below the taphole. The dead cambium can be seen through the taphole and the split in the bark.



Tapholes are drilled in the lower portion of the tree trunk either by hand with a carpenter's brace, or by portable power (gasoline or electric) equipment. For sap collection with buckets, the hole should be about 2 or 3 feet aboveground or snow level. For sap collection with a plastic pipeline, the taphole may be placed higher, or lower, to match the pipeline configuration. Tapholes should be drilled at a slight upward pitch of about 10 degrees to facilitate sap drainage. If the holes are pitched downward, ice crystals may form in the hole which loosen the spout.

Only very sharp drills should be used to bore tapholes. A sharp drill will cut a clean-edged hole through the bark, reducing the probability of cambial dieback. A sharp drill also cleanly slices the vessels intersected by the taphole, which facilitates sap flow (Fig. 4). A dull drill makes a ragged hole; the vessels are crushed and torn. Ragged tapholes might also impede sap flow as well as make infection by microorganisms easier (Fig. 5).

Figure 4.—This taphole was drilled with a sharp bit. Notice that the fibers at the upper and lower edges of the taphole are cleanly severed. Compare this with Figure 5.

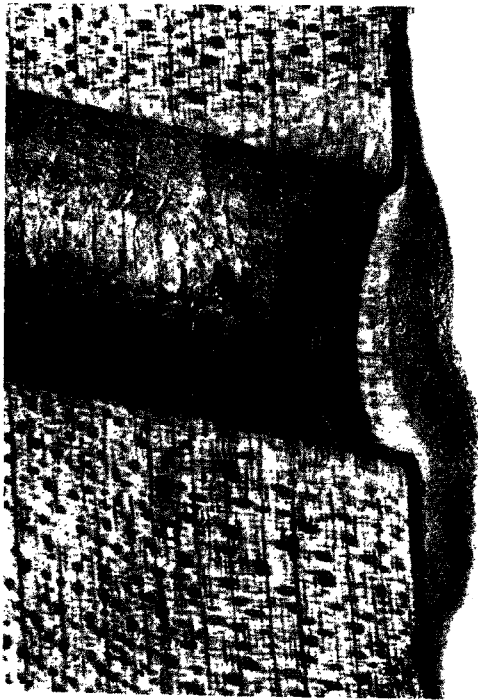
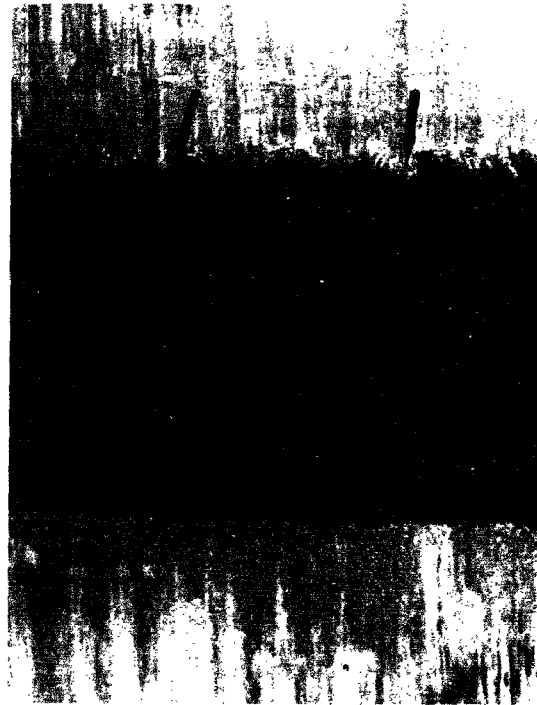


Figure 5.—This taphole was drilled with a dull bit. The arrow indicates where the vessels were crushed and torn, leaving a tangle of fibrous materials.

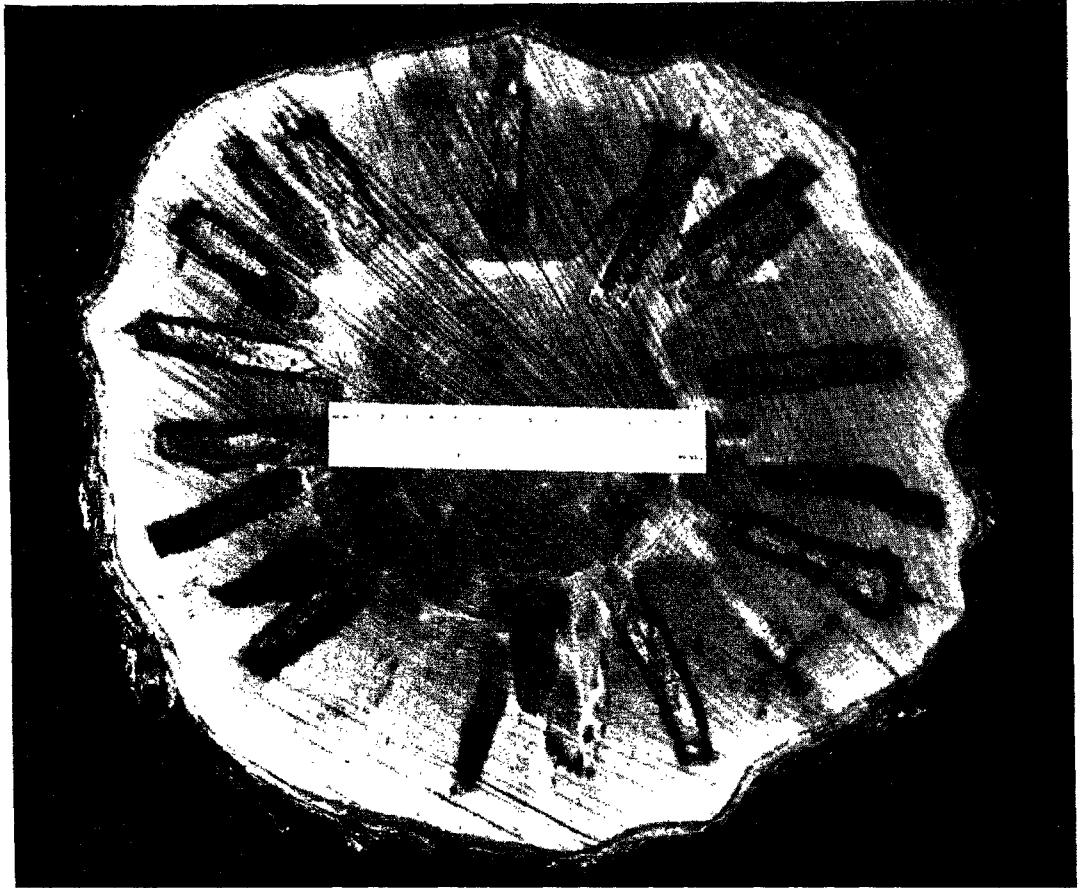


Taphole size

In the past, drills of many difference sizes were used to make tapholes. Today, the industry uses a standard 7/16-inch-diameter drill, and spouts are designed for this size hole.

Taphole depth is not so standardized, however, and it should not be. A commonly recommended depth is 3 inches (Willits 1958). This is thought to be the optimum depth for maximizing quantity and sweetness of sap. Deeper tapholes will not yield much additional sap, and sap from deeper in the tree may have a lower sugar content (Gibbs 1969). A maximum depth of 2-1/2 inches is even better. But even 2-1/2 to 3 inches is too deep for many trees that have been heavily tapped or damaged in other ways (Fig. 6). New tapholes should not be so deep as to break into compartmented, discolored, or decayed wood. If dark wood shavings come out of the hole, it is too deep. Experience in tapping will help establish the best

Figure 6.—This sugar maple was tapped heavily, and wood decay has developed adjacent to many of the tapholes. Although the decayed wood is compartmented, the decayed zones in one area of the tree can greatly weaken the stem. These trees are likely to fall during storms, or when heavily laden with snow.



depth. When in doubt, drill a shallower, rather than a deeper, hole.

The exact width of sound wood in a tree can now be determined by using an electric meter called a Shigometer[®].¹ Details of how to use this

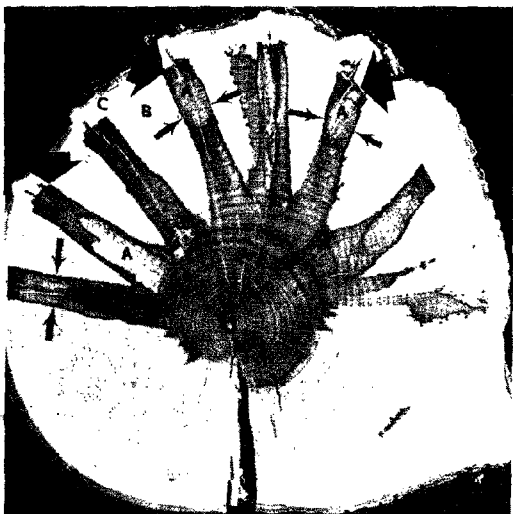
¹ The Shigometer[®] is a registered trademark for a pulsed-current meter manufactured by Northeast Electronics Corporation at Concord, New Hampshire. The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute endorsement or approval by the U. S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

meter have been published (Shigo and Shigo 1974).

Tapping pattern

Trees may be tapped every year for many years, if the tapping is done correctly (Fig. 7). A safe tapping pattern is to drill holes no closer than 6 inches (measured around the circumference of the tree) to an old taphole until after it has closed. After new tree growth has closed over a taphole, it is safe to drill closer than 6 inches. New and old tapholes should be in a staggered pattern up and down the tree; they should not be on the same horizontal or vertical plane (Fig. 8).

Figure 7.—When callus growth quickly closes over a taphole, the internal damage to the tree is minimized. The tree remains healthy and vigorous, and can be tapped each year for many years.



A sugar maple tree less than 10 inches in diameter or 31 inches in circumference at the tapping zone should not be tapped. The number of taps per tree may normally be determined as follows, based on tree diameter (Willits 1958). For convenience, we have added tree sizes by circumference:

<i>Tree diameter in inches</i>	<i>Tree circumference in inches</i>	<i>Number of tapholes</i>
less than 10	less than 31	0
10 to 14	31 to 44	1
15 to 19	45 to 60	2
20 or more	61 or more	3

If trees are not healthy and vigorous, or old tapholes did not close rapidly, or a tree is damaged, the number of tapholes should be reduced.

Overtapping

Overtapping seems to be more of a problem today than in former years (Figs. 9, 6). This may be due to the use of mechanical tapping equipment, because it is easy to make many holes in a short time. Overtapping does not necessarily remove too much sap, but rather, cause more injury. Too many holes means there will be too little undisturbed area for new tapholes, especially if there is cambial dieback around the tapholes. When tapholes are too close together, the resulting discolored columns coalesce inside the tree. If decay begins and quickly spreads through the discolored wood, the tree will be dangerously weakened. Even without decay, the large areas of discolored wood leave very little sap-producing wood for future tapholes.

Figure 8.—This sugar maple was tapped excessively on one side. Decayed wood (A) was associated with some of the tapholes. Slightly discolored wood (B) formed between the tapholes. The arrows indicate the radial compartmentalization of the tapholes. The large arrows indicate the barrier zone. The clear wood (C) continued to develop after the trees were tapped. The boundaries of tapholes are often bright green in sugar maple.

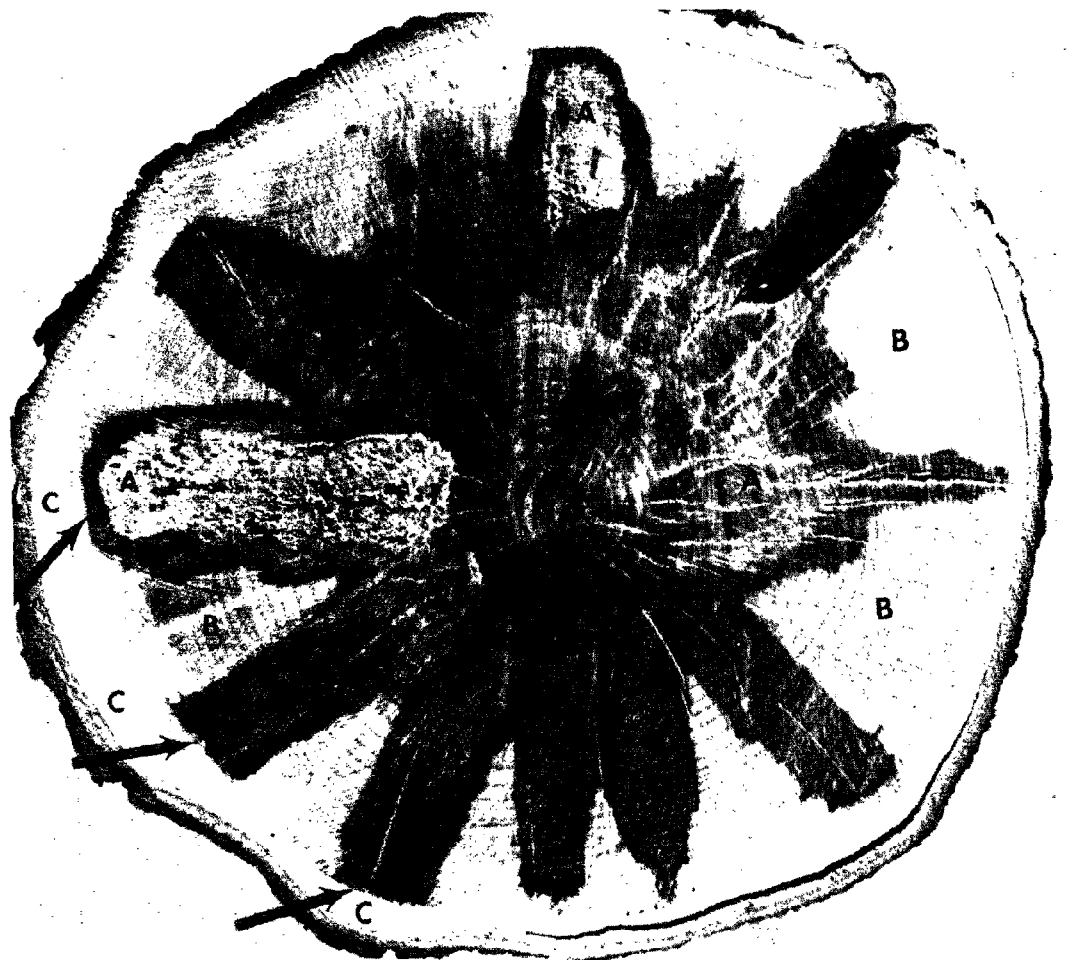


Figure 9.—This small maple was tapped excessively. Decayed wood (A) is associated with many of the tapholes. Discolored wood was associated with all tapholes. Slightly discolored wood (B) formed between the tapholes. Some of the cells in this wood have died. Arrows indicate the barrier zone that separates the wood present at the time of wounding from the tissues that formed subsequently. Healthy tissues (C) are bright white in this sample, whereas the slightly discolored tissues (B) have a pink tone. When young trees are tapped heavily, decay can set in rapidly. Decay develops in young trees just as rapidly as it does in old trees. Heavy tapping also reduces the area where new taps can be made.

Placing spouts

Sap collection spouts have a tapered end that is driven into the taphole. The spout must be driven in firmly enough to be seated, and secure enough to support collection buckets if they are used. The spout forms a seal that prevents sap loss, and if a plastic pipeline system is used, it prevents air leaks and vacuum loss. The spout must not be driven in so hard that it splits the bark and xylem tissue above and below the taphole. If there are splits, sap may be lost and vacuum may be difficult to maintain. The split also means that the cambial tissue around the taphole will die.

Cambial dieback around tapholes

The cambial tissue surrounding the taphole often dies, which results in elliptical wounds (Fig. 10) much larger than the original taphole. These enlarged wounds take longer to close, and are therefore susceptible to invasion by decay-causing fungi for a longer time. In addition, the wider the wound, the greater the column width of nonproductive, dead, and discolored wood inside the tree. Another possible cause of cambial dieback is driving spouts into the tapholes when the trees are frozen.

Figure 10.—A section of bark and wood removed from a sugar maple tree to reveal the dieback of cambial tissue as a result of tapping. Left, the bark side; right, the underside.



Decay begets decay

Before drilling a taphole, it is important to consider the condition of the wood. When a taphole penetrates sound wood, the injured and infected tissues will be compartmentalized. At worst, a column of rot only slightly wider than the diameter of the taphole will develop. When discolored wood is penetrated, no new column of discoloration will develop in the already discolored wood, but the clear wood surrounding the drill hole will become discolored. When a taphole penetrates decayed wood, the decay will develop rapidly outward into the newly injured tissues (Fig. 9). This means that great care should be taken when tapping trees that have obvious columns of decayed wood. If tapholes are drilled in such trees, the holes should be shallow and not enter the barrier zone surrounding the compartment of decayed wood. It is also useless to tap discolored, dead, and decayed wood. Such wood does not produce sap and may even yield water from the discolored and decayed area that will give an unwanted flavor to the syrup produced.

Hope for injured trees

In a sense, every year a new tree, one that is unaffected by old injuries, envelops all of the other trees (growth rings) that were affected by injuries. This should be kept in mind, especially with young trees. Of course, never forget that sugar maple trees, like all other organisms, grow old and die. There is a time when little can be done to help some trees.

A tree with serious injuries may need a rest. Fewer and shallower tapholes may be good enough. But it can also mean that no tapholes should be drilled for several years. This is a small price to pay to save a tree.

A tree with a large central column of discolored and decayed wood surrounded by a narrow band of healthy whitewood can be tapped; but if the band is only 2 or 3 annual rings wide, it should not be tapped. It never hurts a tree not to drill it (Fig. 6).

Trouble indicators

Sugar maple is one of the northern hardwoods that is most resistant to discoloration and decay. Yet there are many defective sugar maples.

Besides tapholes, there are a number of other causes of injury, discoloration, and decay. These include sugar maple borers, squirrels, porcupines, sapsuckers, human activity, and natural causes. Some of the more important decay-causing fungi in sugar maples are *Oxyporus populinus* (Schum. ex Fr.) Donk, *Phellinus igniarius* (L. ex Fr.) Quél., and *Inonotus glomeratus* (Pk.) Murr. There are many external signs that indicate when a sugar maple is in trouble. Lack of a healthy, vigorous appearance; small, sparse, yellowish leaves; reduced twig elongation; and dead twigs are some of the signs. Trees with many large basal wounds, badly trampled roots, large dead branch stubs, and broken limbs will usually have a large column of discolored wood. This is not true heartwood. Normally, sugar maple does not have a dark central core of wood. Other obvious signs of trouble are fungus fruit bodies, sugar maple borer scars, and sapsucker damage.

Wounds

Large basal wounds caused by scraping the bark from the tree and injuring the wood remain open for a long time, and often result in central discoloration and decay. These wounds often are inflicted by skidding logs and tractors. In the sugarbush they may also be caused by sap-gathering vehicles; around homes, by lawn mowers. Cattle often cause similar serious problems by trampling the tree roots and scraping the bark away from exposed roots and root collars.

Some wounds, such as branch stubs, cannot be prevented unless trees are pruned. When branches die from shading (natural pruning) and from wind and ice damage, stubs form. Falling trees and limbs may damage neighboring trees. Generally, such wounds are not serious unless they are numerous.

Sugar maple borer

The sugar maple borer (*Glycobius speciosus*) eats through the bark of sugar maple and lives first in the cambial area and later deep in the tree. Normally, it lives in the tree for 2 years and chews a deep gallery several feet long. After the adult emerges, the bark falls away, exposing the gallery and a large wound. Decay-causing fungi often invade the wound, and many borer-damaged trees

break off in high winds. Sugar maple borers attack both healthy and low-vigor trees (Shigo and Larson 1969).

Sapsucker wounds

The yellow-bellied sapsucker (*Sphyrapicus varius*) drills holes in sugar maple trees and other northern hardwoods. Although the small wounds cause many small streaks of discoloration, the health of the tree is not seriously impaired. But a concentrated patch of wounds is similar to one large wound, and will kill sections of the stem or the top of a tree. When such wounds encircle the tree, the entire tree will die. The discolored streaks associated with sapsucker and sugar maple borer wounds are often called mineral streaks (Shigo and Larson 1969).

Decay-causing fungi

Any wound may be a point of infection by decay-causing fungi. The longer the wound stays open, the greater the chance of infection. An ooze flowing from a wound indicates wetwood (a type of discolored wood associated with bacteria and fungi), decay, or both. Many fungi produce conks or fruiting bodies on or near the wounds. Some of the more important fungi to look for are:

Inonotus glomeratus (Pk.) Murr. (*Polyporus glomeratus*). Advanced decay is indicated by small masses of sterile black fungus material in swollen knots and spindle-shaped cankers. A cut into the knot or canker will reveal the fungus as a black, cinderlike material flecked with brown areas. The decayed wood has a strong medicinal odor. Because this fungus usually infects through branch stubs, it normally is not a serious problem in the tapping zone of the tree. However, its presence in the upper part of the tree can seriously affect tree vigor and eventual sap production.

Phellinus igniarius (L. ex Fr.) Quél. (*Fomes igniarius*). This fungus commonly infects all northern hardwood species and causes a light-colored rot, usually with dark zone lines. The frequently seen fruit body, which is black with white flecks inside, can be found on both branch stubs and other wounds. Because this fungus infects wounds in all parts of the tree, it can cause serious problems in the tapping zone of the tree bole, as well as in the upper crown.

Oxyporus populinus (Schm. ex Fr.) Donk

(*Fomes connatus*). The spongy white fruit body of this fungus is often found growing from a taphole. Its presence indicates advanced decay, but the decay does not extend a great distance above and below the wound unless other wounds are present. This fungus should be of special concern to the maple sugar producer because it usually infects wounds below 8 feet on the stem, i.e., in the tapping zone. Decay by this fungus can weaken trees to the extent that they are often blown over.

For additional details on defects in sugar maple trees, see Shigo and Larson (1969).

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