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Barrier Zones in Red Maple: an Optical and Scanning Microscope Examination

J. Mulhern, W. Shortle, and A. Shigo

ABSTRACT. Barrier zones were studied in 10 wounded red maple trees using optical microscopy with reflected and transmitted light, scanning electron microscopy, and dye penetration. Vessels in the barrier zone were abnormal and fewer in number, and vessel segments were irregular in shape. Vertical transport of fluid in this region was markedly reduced, and opacity to transmitted light was increased, in comparison with normal secondary xylem. FOREST SCI. 25:311–316.

ADDITIONAL KEY WORDS. Wound, compartmentalization.

A MODEL SYSTEM called CODIT (Compartmentalization Of Decay In Trees) has been proposed to explain patterns of discoloration and decay in living trees (Shigo and Marx 1977). One of the key elements in the model is "wall 4" or the "barrier zone," which is formed by the cambium after wounding and separates wood formed before wounding from wood formed after wounding. The discoloration and decay processes associated with wounding stop at the barrier zone. Microorganisms do not spread into wood formed after wounding. Thus, wound-initiated defects are compartmentalized.

The purpose of our study was to clarify further the concept of a barrier zone and to determine some of its physical properties. This report describes some of the alterations that take place in wounded red maple trees (*Acer rubrum* L.).

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Concept.—A barrier zone type of concept was proposed by Hepting (1935) who postulated that marked differences exist between sapwood extant at the time of wounding and sapwood laid down after wounding to explain why decay was confined to wood extant at time of wounding. Gerry (1921) had previously described marked anatomical and chemical differences between extant wood of sweetgum and wood laid down after wounding, but she didn't relate these to decay. Shortle and Cowling (1976) recognized the connection between the work of Hepting (1935) and Gerry (1921). Later, Moore (1978) studied barrier zone formation in sweetgum. Shortle and Cowling (1976) noted that yellow-poplar had a barrier zone similar to that described by Sharon (1973) for sugar maple. But Sharon (1973) had called the tissue a "distinct tissue."

Sharon (1973) likened the "distinct tissue" of maple to the "protective zone" described by Hepting and Blaisdell (1936). Both were tissues filled with wound gum (dark deposits) and both appeared to have a protective function. These tissues are different. The protective zone arises from sapwood cells at and near the wound surface. The "distinct tissue" is the barrier zone which arises from the cambium after wounding.

Shain (1967) described yet another protective zone in trees as the "reaction zone," which formed in extant wood of pine in response to injury and infection. Similar tissues have since been described in spruce (Shain 1971), and red maple and hybrid poplar (Shortle 1977). The "reaction zone" corresponds to a combination of walls 1, 2, and 3 of the CODIT system and is a discrete zone having the properties of protection wood as proposed by Jorgensen (1962). The "reaction zone" surrounds the developing column of discolored and decayed wood.

The barrier zone was first called a barrier wall (Shigo and Hillis 1973, Shigo 1975). As the tissue was studied later in detail, the term "wall" was changed to "zone." This term was meant to characterize a real physical entity, which corresponds to a "wall" in the CODIT model (Shigo and Marx 1977). Properties of the barrier zone were reported by Sharon (1973), McGinnes and others (1977), and Moore (1978). All authors agree that there are anatomical and chemical changes in wood formed after wounding and that these changes reach a maximum proximal to the wound and decrease with increasing distance from the wound in all three planes.

Materials and Methods

Specimens were taken from 10 red maple trees containing barrier zones associated with various types of wounds. The wounds ranged in size from drill wounds 5 mm diameter by 2 cm deep to logging wounds involving half the basal circumference of the tree. The wood specimens contained wood extant at wounding and laid down thereafter. Specimens of healthy wood controls within the same tree or neighboring nonwounded trees were taken also.

Cross sections 1 to 3 mm thick were examined under a dissecting microscope at 10–40× using reflected and transmitted light. Vessel density and diameter and ray width were observed both inside and outside the barrier zone. Cross sections 1 cm thick and containing both barrier zone and normal tissues were placed so that one of the transverse faces was immersed in aster blue dye solution. The sections were then removed from the dye and machined to determine the depth of dye penetration.

Sequential, tangential sections, 0.5 mm thick were cut from the barrier zone, coated with carbon and examined under a scanning electron microscope. The sections were then scanned with an EDAX X-ray system to determine the mineral elements present in the barrier zone and the normal tissues.

Results

Barrier zones ranged from broad dark bands which contrast sharply with the adjacent prewound and postbarrier zone wood, to narrow regions which blended with the surrounding tissue so as to be virtually unnoticeable (Fig. 1).

When reviewed through a dissecting microscope at 25× using reflected light, a cross-sectional view of a section (≈0.3 mm thick) showed a barrier having a well-defined boundary on each side of the zone (Fig. 2). The number of vessels/unit area in the barrier zone was much decreased as compared to the prewound tissue. The magnitude of the decrease in any given specimen seemed to depend on the severity of the wound and the distance

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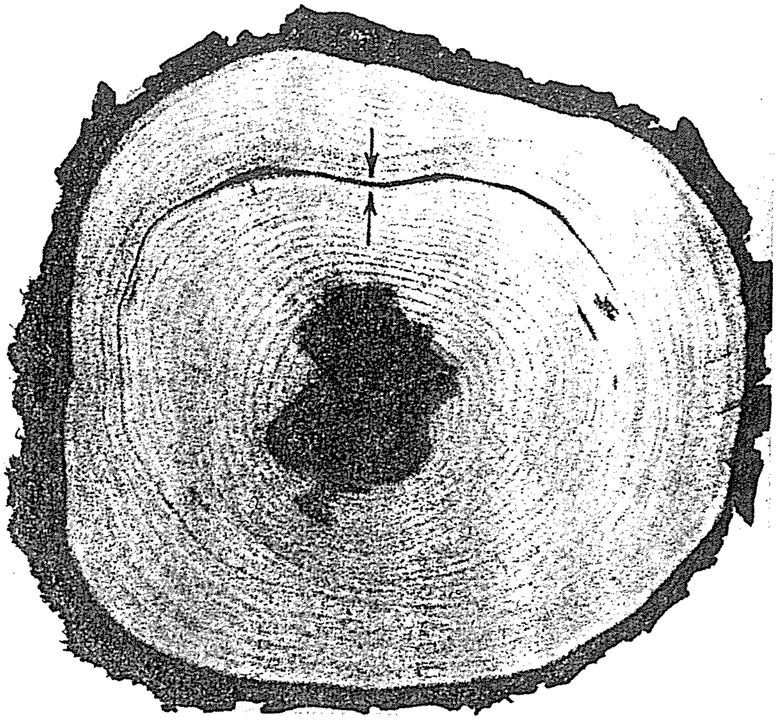


FIGURE 1. A cross-sectional view of the trunk of a red maple tree, 15 cm in diameter, which received a severe wound 20 cm below the surface shown. The barrier zone, indicated by arrows, stands out clearly as a dark streak following an annual ring contour and fading out circumferentially.

from the wound that the specimen was taken. Some specimens were observed in which several seasons of postwound wood were laid down before the vessel density returned to normal.

In tracing the rays outward from the center of the tree, they sometimes appeared increased in width at the inner boundary of the barrier zone. Each barrier zone appeared to begin and end within the same growing season.

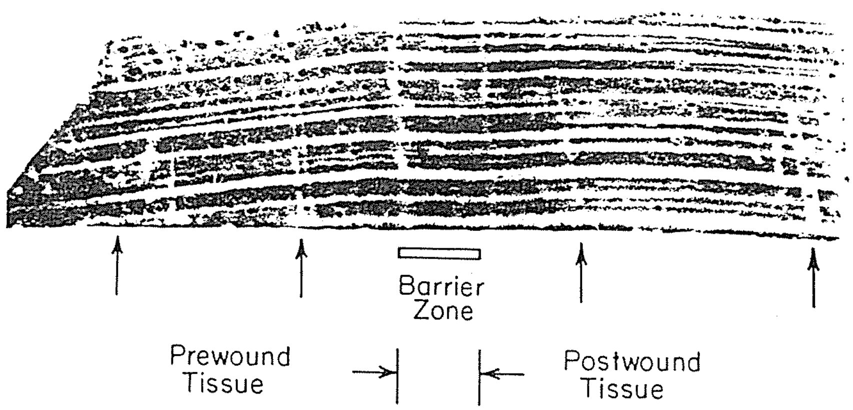


FIGURE 2. A 25× view of a cross section of red maple taken through a dissecting microscope using reflected light. Prewound, postwound, and barrier tissues are shown. The annual rings are indicated by vertical arrows.

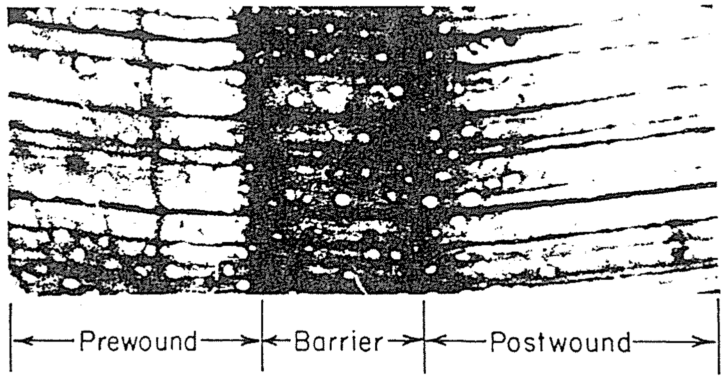


FIGURE 3. A 40× view of a 1.5-mm-thick cross section of red maple taken through a dissection microscope using transmitted light. The barrier zone is more opaque than either the prewound or postwound tissue.

The barrier zone had greater opacity than the surrounding tissue when transverse sections were viewed using transmitted light (Fig. 3). The striking difference in opacity between barrier zone and the surrounding tissue was observed even when the barrier zone was relatively inconspicuous as viewed in reflected light.

A comparison of tangential sections of normal sapwood (Fig. 4) with corresponding sections of barrier zone tissue (Fig. 5) showed that the barrier zone had fewer vessels, usually of smaller diameter, and more fiber than normal tissue. Some of the vessel segments in barrier zone tissue are incompletely differentiated, which was not observed in normal tissue (Fig. 5).

X-ray analysis of barrier zone and normal tissue indicated no differences in mineral elements between tissues. Elements observed were Na, K, Ca, Mg, Si, P, and S.

Cross sections 1 cm thick of barrier zone and normal tissues from five different trees were placed so that one face of the specimen was saturated with an aqueous solution of aster blue dye. The top surface was observed for dye penetration. The dye moved readily

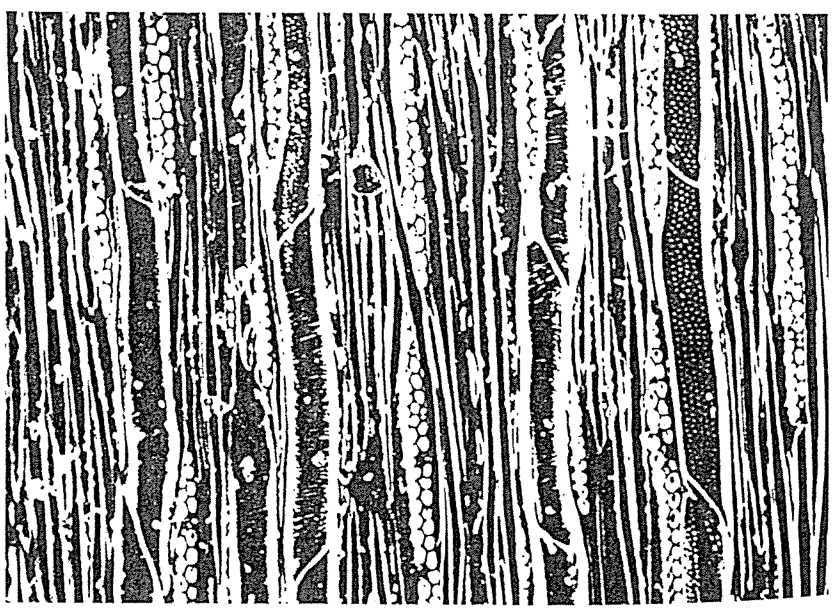
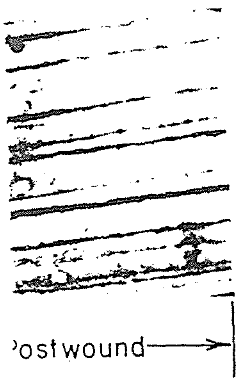


FIGURE 4. A 100× scanning microscope view of a tangential section of normal red maple sapwood



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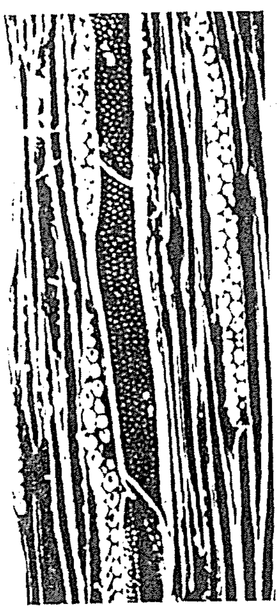

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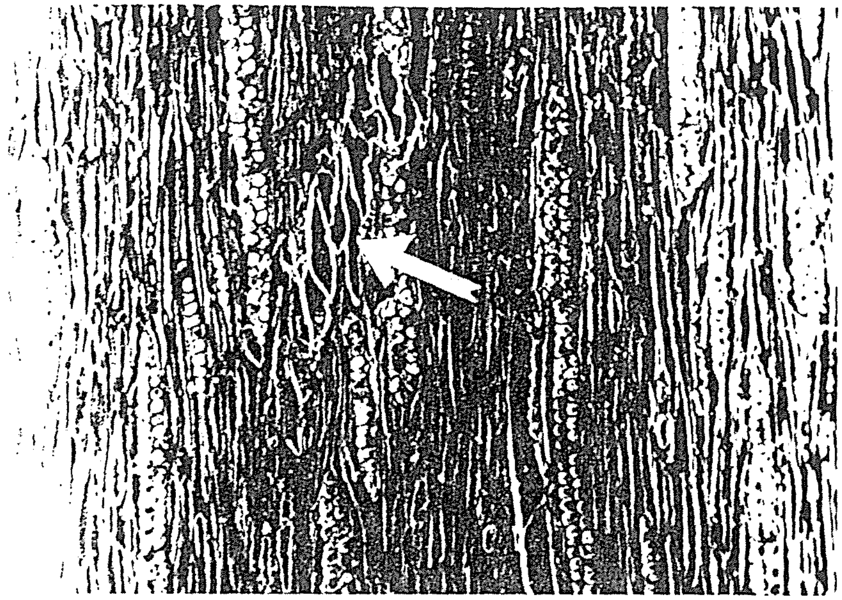

FIGURE 5. A 100× scanning microscope view of a tangential section of red maple which was cut through a barrier zone. There are fewer vessels than in normal sapwood, they are smaller in diameter, and some of them are incompletely differentiated (see arrow).

through the prewound sapwood, and the sapwood of the control specimens. However, the dye did not move readily through the vessels of the barrier zone. In some cases the dye solution did not penetrate through any of the barrier vessels, while in other cases, it did penetrate through some, or all of the vessels. In the latter cases it took longer for the dye to get through the barrier zone than through the wood formed before wounding. The dye often penetrated only slightly through many of the vessels of the postbarrier region. This varied considerably from one specimen to another. The dye did not penetrate sapwood, where vessel plugs are known to occur, contiguous to discolored wood.

DISCUSSION

The barrier zone which can usually be seen with the naked eye, often "disappears" when viewed through a dissecting microscope using reflected light. The zone becomes progressively less noticeable when viewed at increasing distances from the wound. Under such conditions, the enhanced opacity of the barrier zone is a useful characteristic. The barrier zone becomes readily apparent when a cross section approximately 2 mm thick is viewed in transmitted light; the zone's boundaries become distinct.

Fluid transport is markedly reduced in this zone of increased opacity. Vessels are fewer per unit area, vessels are often of smaller diameter, and abnormal vessel segments can often be seen. The abnormalities in vessel segments, as well as fibers, observed in SEM photos, were confirmed by maceration and light microscopy (Smith and Mulhern 1978). Thus it appears that abnormal differentiation of cambial derivatives produces a tissue of greater density which has lost all or part of its capacity to act as a transport system.

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