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WOOD ANATOMY AFTER TREE INJURY —A PICTORIAL STUDY

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WOOD ANATOMY AFTER TREE INJURY —A PICTORIAL STUDY

E. A. McGinnes, Jr., J. E. Phelps, P. S. Szopa, and A. L. Shigo

Introduction

Wood formation after tree injury has been described in forestry literature well into the last century. Most studies dealt with descriptions of callus formation at the injury site and an illucidation of wound closure by this type of tissue (or related growth). Recently the concept of "compartmentalization" has been applied to aid in a better understanding of the way a tree responds to environmental mishap. Under this concept the tree's response to injury is more involved than just callus formation—an effective "barrier" zone is formed by the tree after injury. This zone forms primarily in the tangential plane and contains tissue of both different anatomical and chemical makeup from normal wood. This tissue acts as a protective sheath isolating the new wood from that present at time of injury. The barrier zone may extend only a few centimeters in either the longitudinal, tangential planes up to a tangential band extending completely around the tree and running several meters vertically above and/or below the wound (injury) site.

A thorough understanding of the compartmentalization concept requires knowledge of several disciplines in addition to wood anatomy: pathology, physiology, and microbiology. The subject is complex. This bulletin was formulated with but one message—the anatomical structure of wood after injury.

A selected bibliography on additional aspects of the compartmentalization concept is added at the end for the reader who has a further interest in this subject.

Data are presented as a pictorial documentation of wood formation after injury for the three general classes of xylem structure typical of North American forest trees: a coniferous species, a ring porous hardwood, and a diffuse porous hardwood. In each instance, the reader is taken from a macroscopic view of the injury to microscopic views of selected aspects of the cellular structure of the xylem.

Materials and Methods

White pine (*Pinus strobus* L.), northern red oak (*Quercus rubra* L.), and red maple (*Acer rubrum* L.) trees with a known injury history were selected for study.

The trees were mature, and were grown in Maine. They were felled in the fall of 1976 and bolts averaging one meter in length, including the injury area, were removed for macroscopic and microscopic analyses of tissue formation after wounding.

Each tree was treated in the same manner. The bolt was photographed prior to dissection for study. A one-cm disk was cut directly through the center of the wound. This disk was sanded and photographed with areas marked where microscopic analyses were to be made. Both light microscopy and Scanning Electron Microscopy (SEM) techniques were used. Results of this investigation led to a second study. Microscopic examinations above and below the injury site were done as shown diagrammatically in Figure 1 for this second study. Disks removed were also 1 cm in thickness as for the original study. Again light and SEM analyses were undertaken.

For light microscopy, samples were stained with Safranin O, then counter-stained for 30 seconds in Fast Green (FCF), dehydrated and permanently mounted. For SEM investigations, samples were microtomed on the appropriate (cross, radial, or tangential) face, ovendried over P_2O_5, and then coated with a 0.2-.3 um of gold for examination. The instrument used was a JEOL JSM-S1. Tilt angles of either 20° or 45° and an accelerating voltage of 10 kV were utilized.

The format used for this bulletin relies on pictorial documentation to illustrate various facets of wood formation after some environmental mishap.

Discussion

Each tree is discussed separately.

Red Oak

The tree had a total ring count of 36 as determined on the cross-sectional view through the center of the injury (Figure 3). The injury was intentionally made by burning with a torch and then scribing the area in the form of an ellipse with long axis longitudinally oriented, on opposite sides of the tree four years prior to felling. Figures 2 - 10 show specific details of xylem abnormalities associated with wounding. Samples taken directly above and below the injury site (see Figure 1) usually displayed significant departure from normal xylem structure. Tyloses were most prevalent in the year following injury for the samples 5-cm below and 5-cm above the injury site. Gelatinous fibers, earlywood vessel wall infolding and abnormal earlywood perforation plate formations were most pronounced at these two locations also.

White Pine

This tree had a total ring count of 58 through the center of the injury zone; the injury was a fire wound that occurred 29 years prior to felling. This was not an intentional, man-made wound. The general contour is similar to that for the red

oak and red maple samples. Details are shown in Figures 11-18. This sample showed a significant increase in frequency of longitudinal resin ducts in the first five years after injury. Through the center of the injured area (Figure 16), and both above (Figure 18) and below the injury, the most significant anatomical abnormality was the development of tylosoid resin ducts.

The anatomical structure of coniferous species is simpler than that of deciduous species. Therefore, it is not surprising to note fewer types of anatomical deviations for the softwoods.

Red Maple

This tree had a ring count, through the center of the injured area, of 26 prior to an intentional man-made wound similar to that of the red oak. Ring count after wounding was four. Discoloration was more pronounced than for oak or pine. Some vessel plugging was found in this sample but no tyloses developments or infolding of vessel walls were encountered. Inclusions in both ray and longitudinal parenchyma cells were frequent. Lack of apparent vessel modifications (as tyloses development or alteration of perforation plate structure) is a contributing factor to more rapid and pronounced spread of discoloration of this species as compared to either oak or pine.

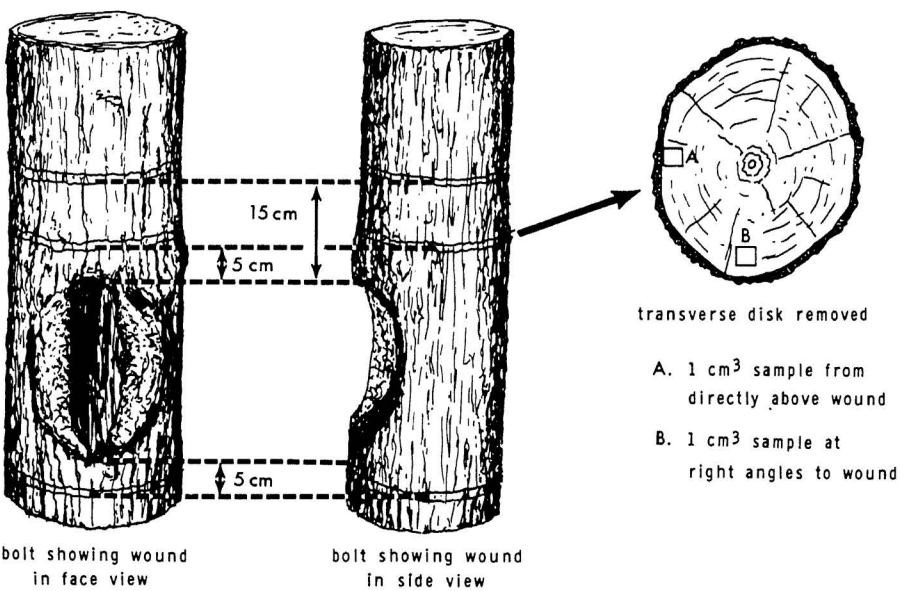


Figure 1. Details of sample orientation for examination of wood formation, after injury, above and below the injury area. Preliminary studies were done through the middle of the injury area. (See Figure 3, 12, and 20 for views of the cross-section right through the center of the injury areas.)

Figure 2. External view of red oak sample showing partial covering of wounded area by the tree over a period of four years. There is a similar wound 180 degrees around the tree. The scale is in cm.

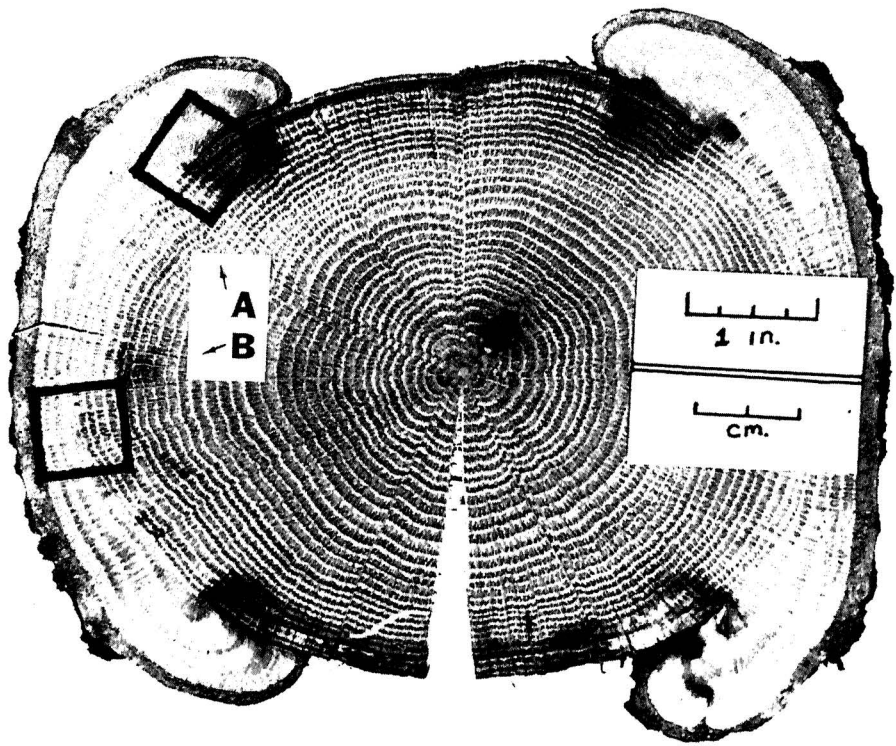


Figure 3. Surface view of cross-sectional disk, taken through the center of the injury, of red oak. Scale in inches and cm as shown. Radial split into center of disk is due to seasoning. No injury prior to intentional ones (top and bottom side of figure) is discernable. Note that wood present on original exposed tangential faces at time of injury shows slight discoloration in the outer four—five increments only. Growth after injury has "closed" the wound face approximately 2 cm (tangentially from each of the sides). At the site of wounding, growth has been rapid each year since the injury occurred. "Squares" ("A" and "B") are zones where microscopic analyses were undertaken.

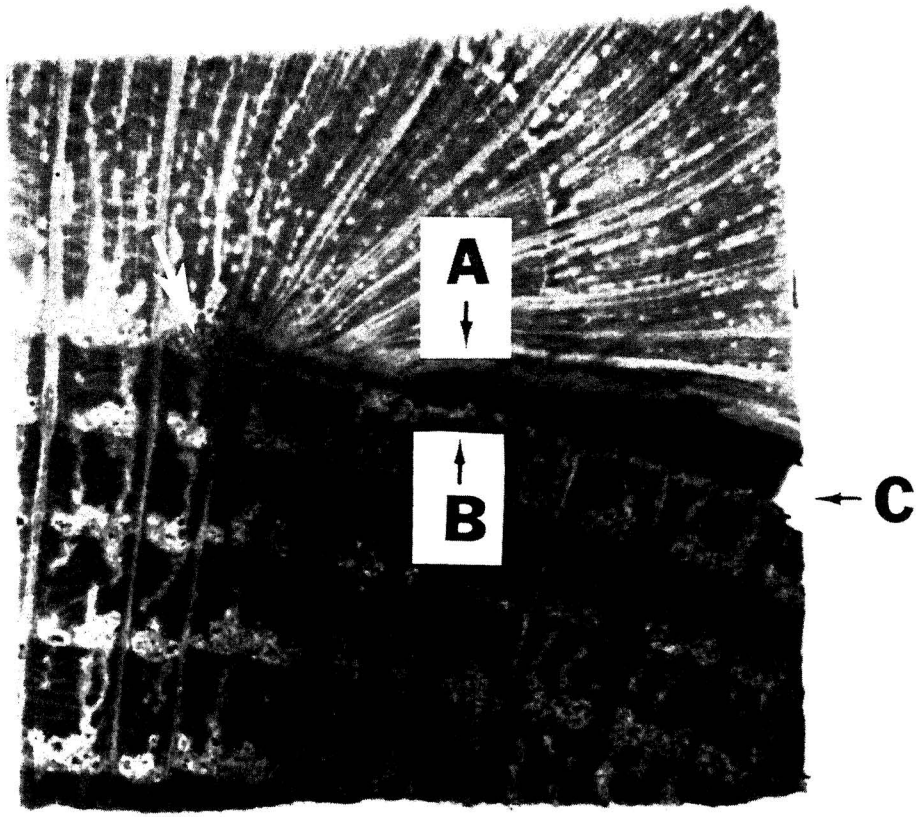
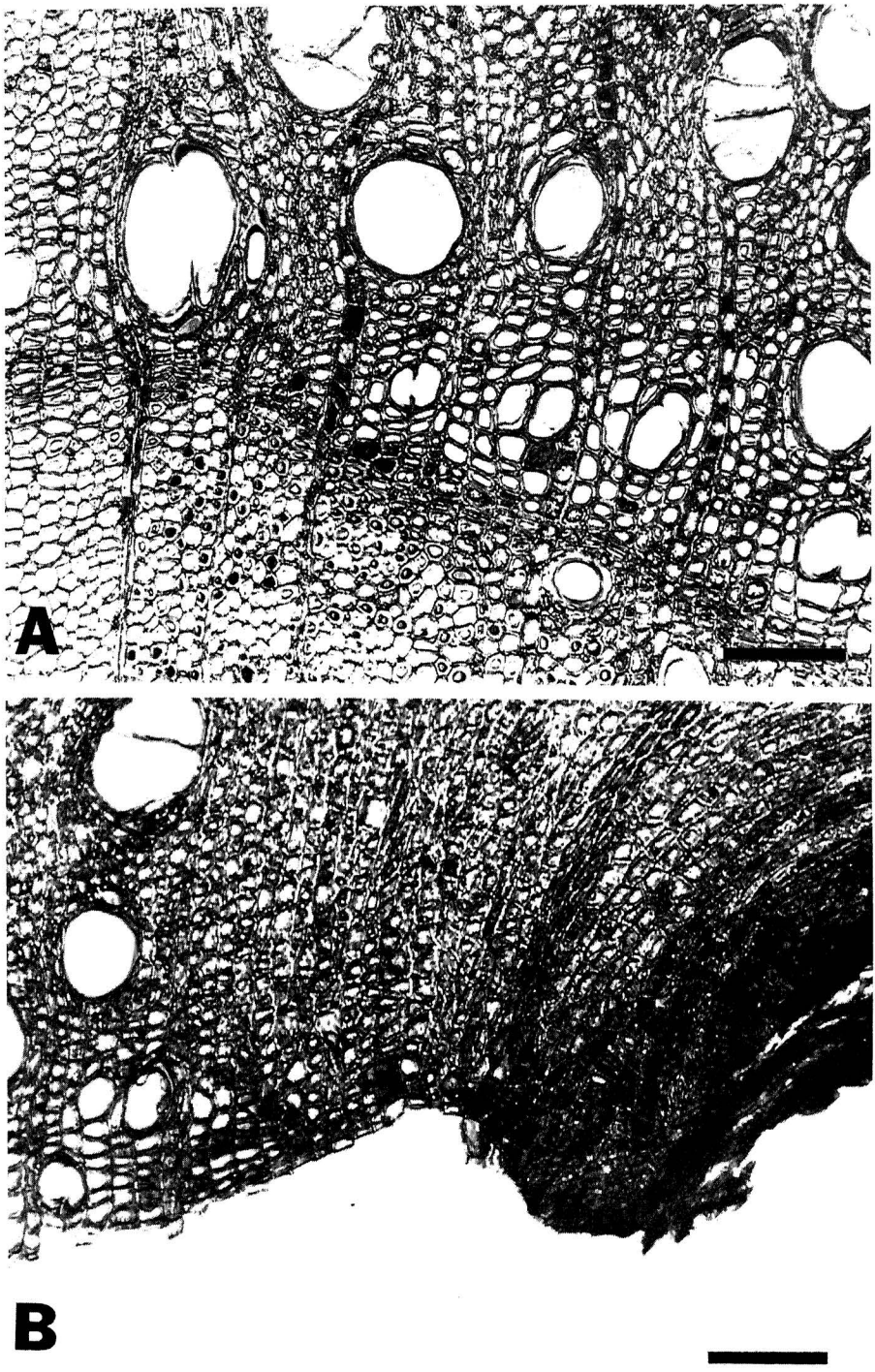


Figure 4. The red oak cube cut from the zone which contains the wood-new wood interface shown in "A" of Figure 3. "A" represents new wood formed after injury. Note the greater number of wide ray structures in this zone. "B" represents old wood present at time of injury. "C" is the separation zone between the old wood and the new wood. The arrow points to the region of wood formation shown in Figure 5 "A".

Right

Figure 5. Cross-sectional views of wood formation subsequent to injury. "A" (vicinity of larger arrow in Figure 4) shows the earlywood (upper half of Figure) formed after injury and latewood of preceding year (in lower half of Figure). The vessels formed in the earlywood zone following injury are disoriented slightly off their longitudinal axis. "B" shows wood formed after injury and is in the region immediately to the right of the larger arrow described above—in the region where the separation occurred. Note extensive cell occlusions in this zone and how the cells become progressively more disorientated going from left to right; magnification bars = 100 micrometers.


A
B

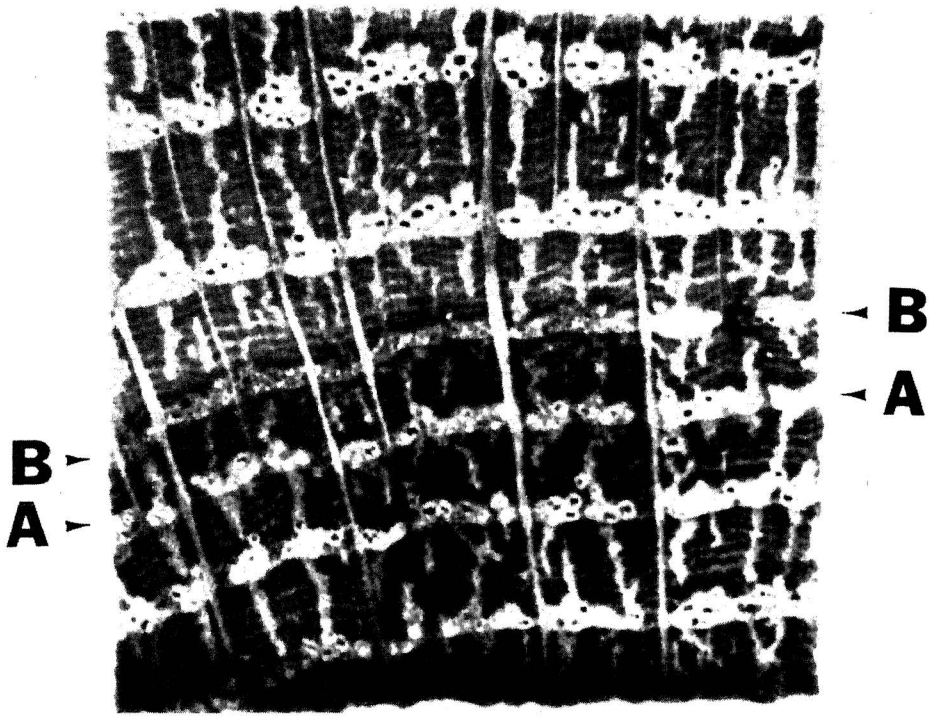
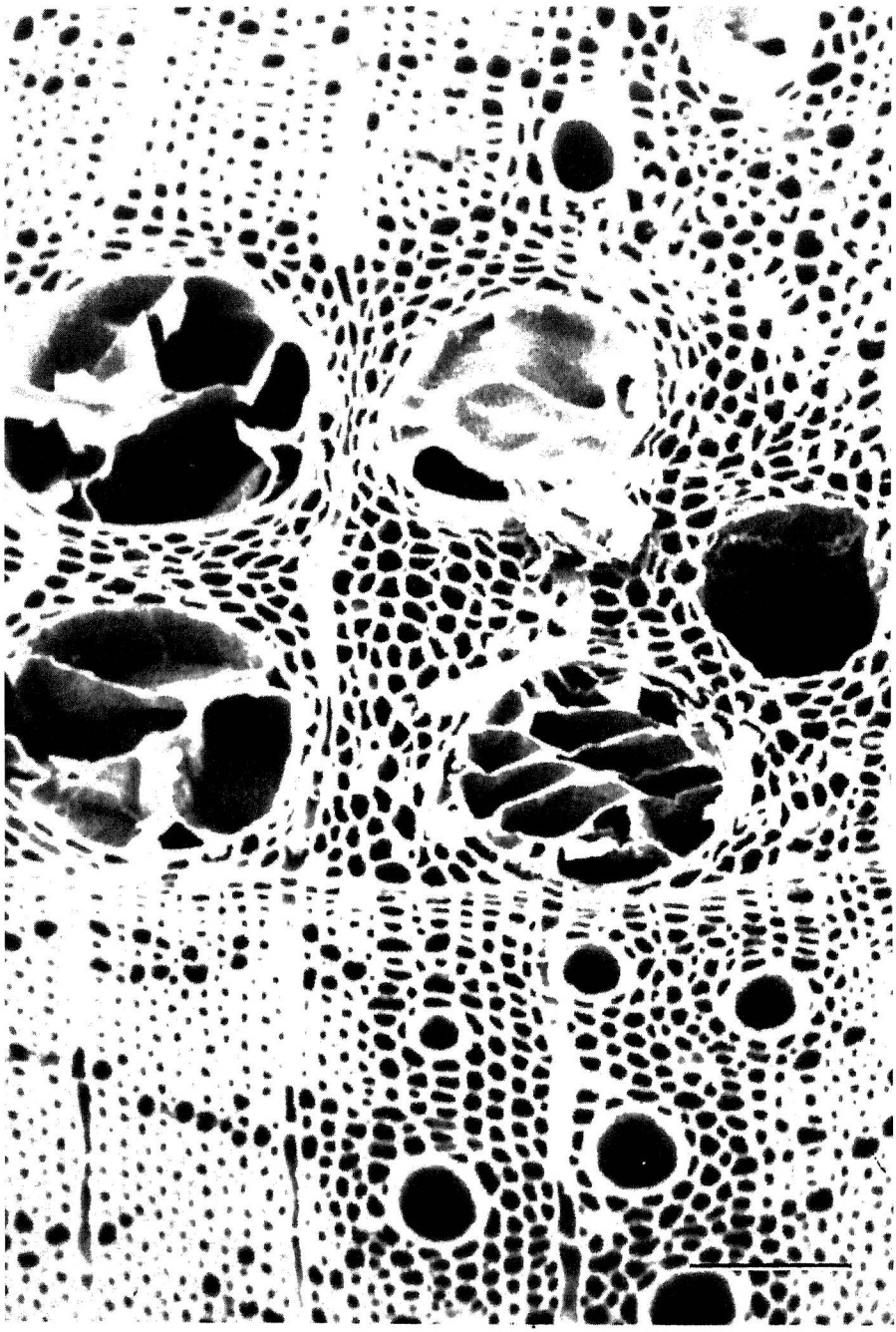


Figure 6. Sample area somewhat (about 90°) removed from injury area. Refer to zone "B" in Figure 3. "A" represents the injury year; "B" represents the first year after injury. Note that growth rate of the tree prior to and after injury is about the same. Also note smaller and fewer vessels in growth ring that formed after injury.

Right:

Figure 7. Cross-sectional view of growth ring one year after injury at sample location "B" in Figure 6. Tyloses formation was restricted to this year at this location. Tyloses shape and size is typical of those associated with wounding in both red and white oaks. The magnification bar is equal to 100 micrometers.



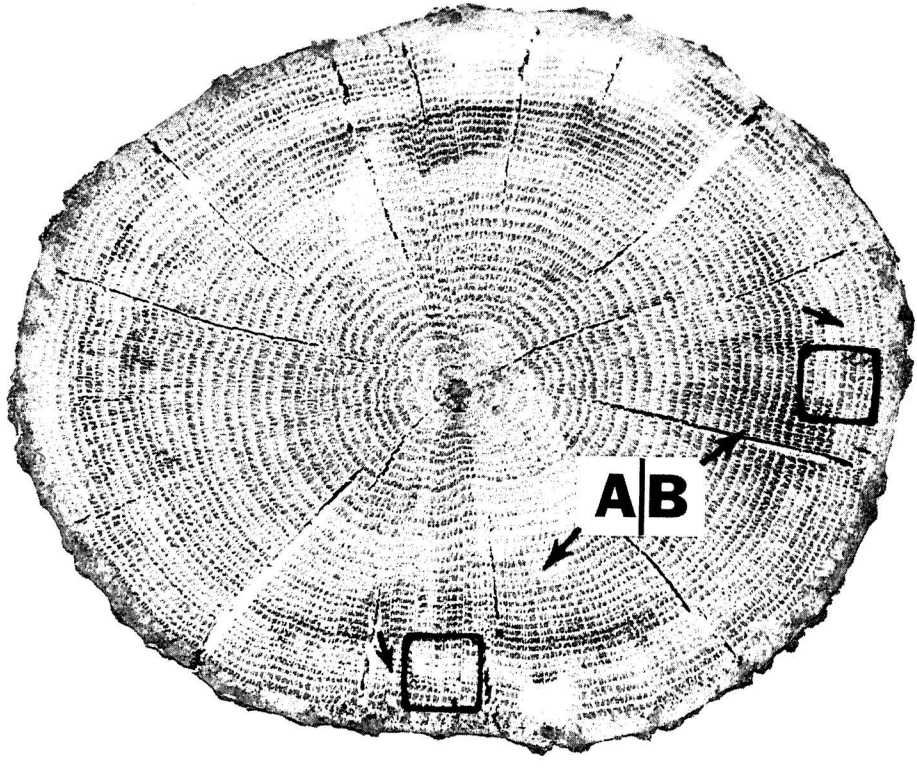


Figure 8. Sample disk removed 5 cm below wound (see Figure 1 for details of sample location). Disks removed above wound showed similar characteristics. Boxed portions show sample area "A" (directly above wound) and "B" (right angles to wound) where microscopic analyses were undertaken. Note that growth rate prior to and after injury is reasonably constant as was the case on the sample taken through center of injured area (Figure 3).

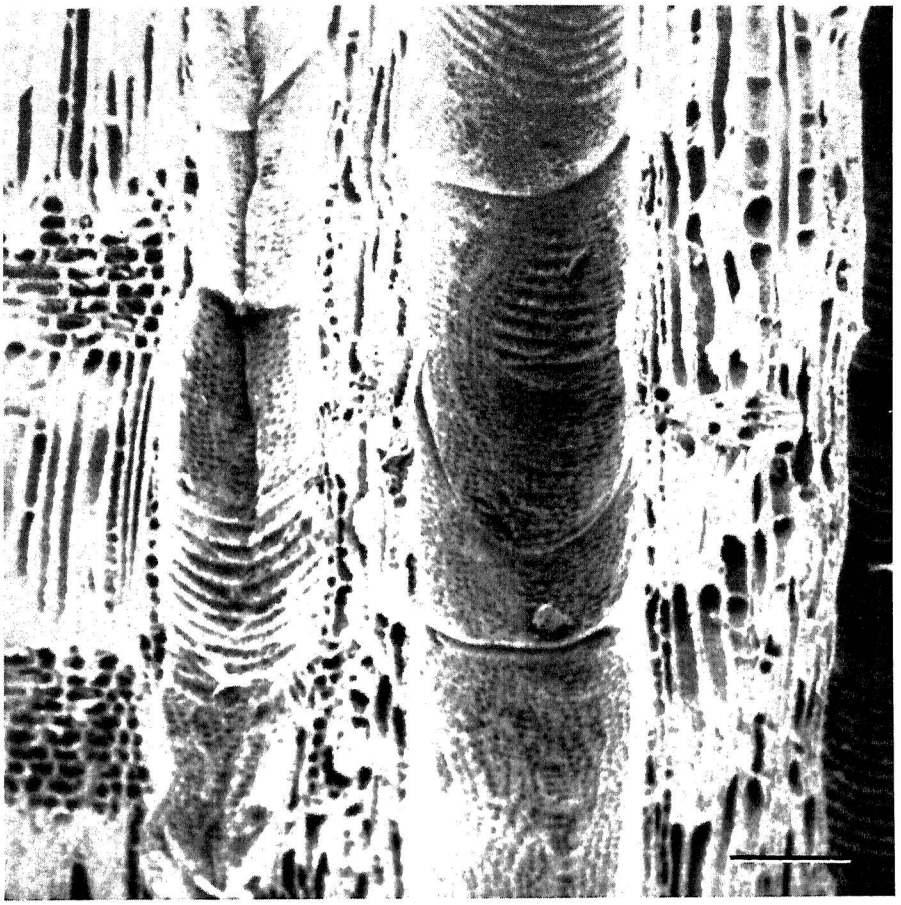


Figure 9. Early wood vessels immediately below wound area ("A" in Figure 8). Note infolding of vessel walls and oblique angle of perforation plates. These are abnormalities present in the year after injury. Magnification bar equals 100 micrometers.

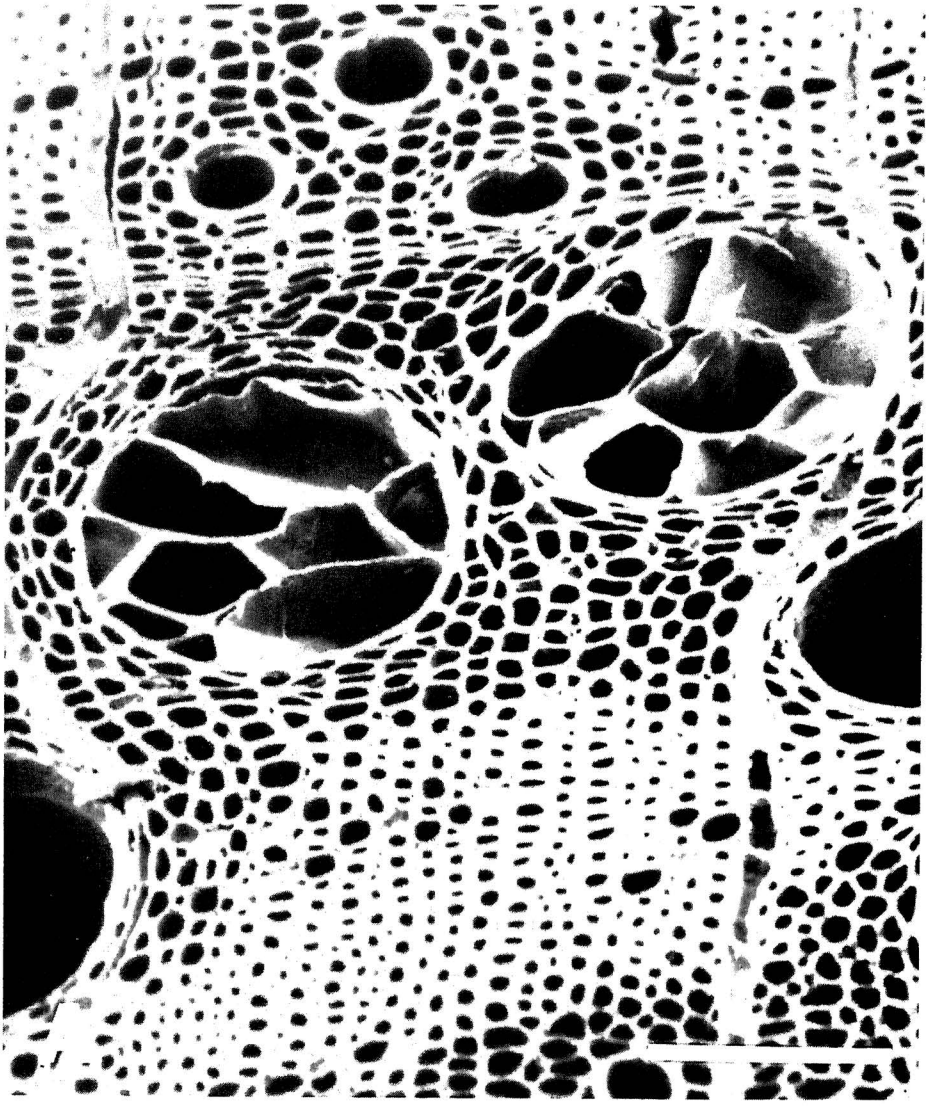


Figure 10. Abnormalities present in year after injury in sample shown in Figure 8.

A. Tyloses in earlywood portion of increment. Magnification bar equals 100 micrometers.

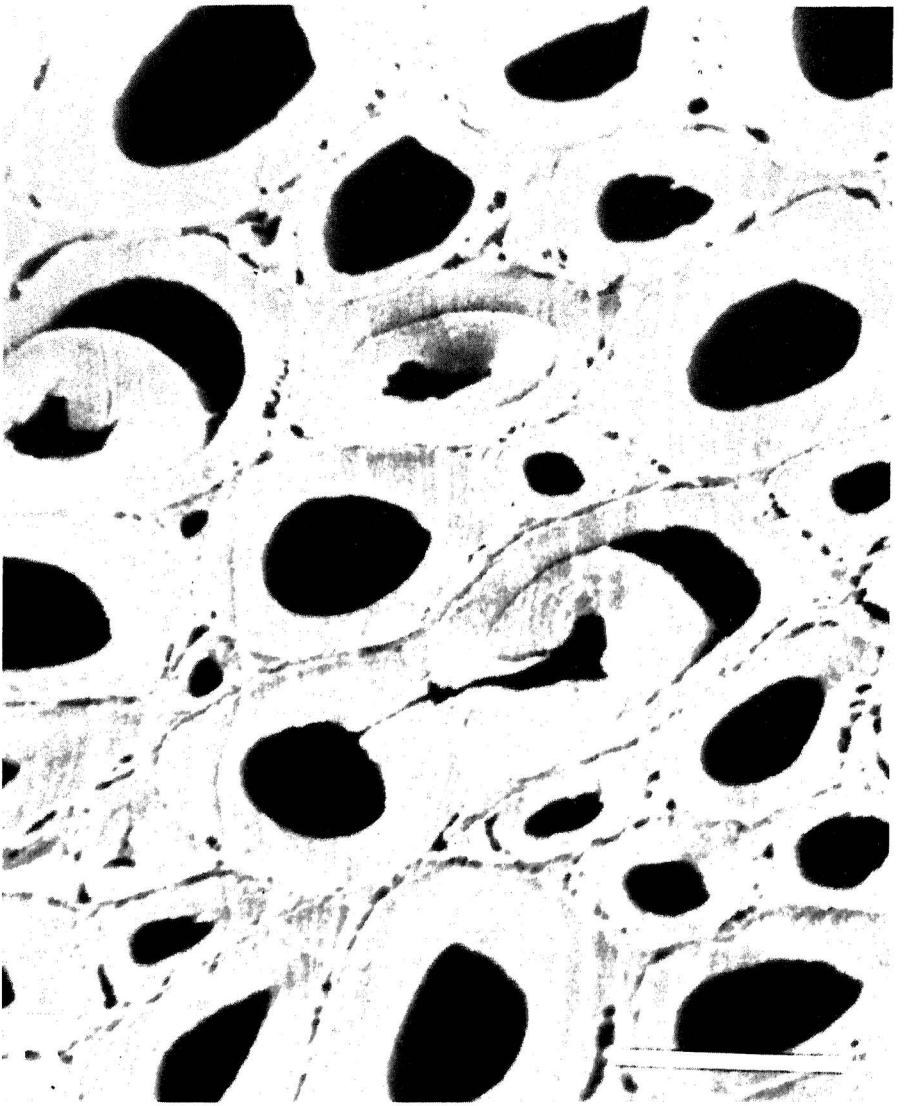


Figure 10. (continued)
B. Gelatinous fibers in latewood zone of increment. Magnification bar equals 10 micrometers.

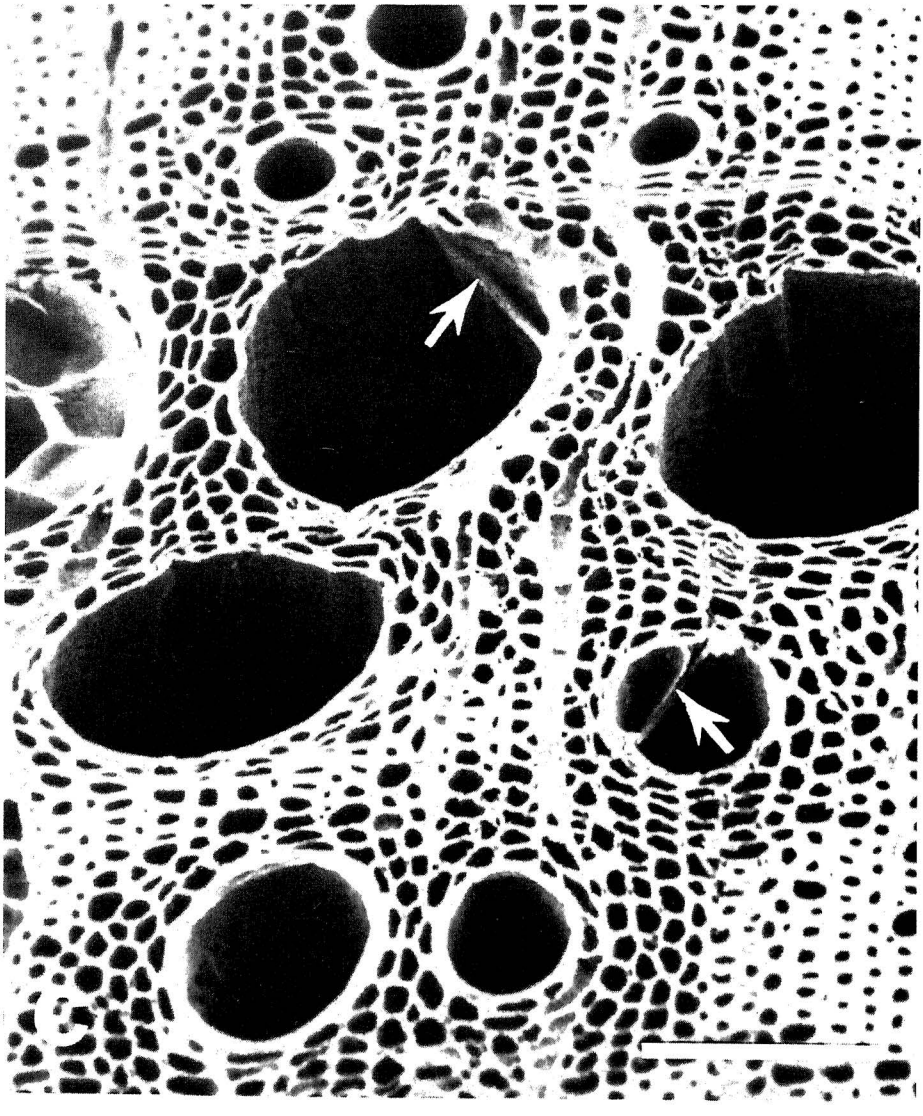


Figure 10. (continued)

C. Peripheral earlywood vessel wall infolding coupled with oblique perforation plates (arrows). Magnification bar equals 100 micrometers.

Figure 10. (continued)
D. Fungal hyphae shown on earlywood vessel wall; taken from zone "B" of Figure 8. Magnification bar equals 20 micrometers.

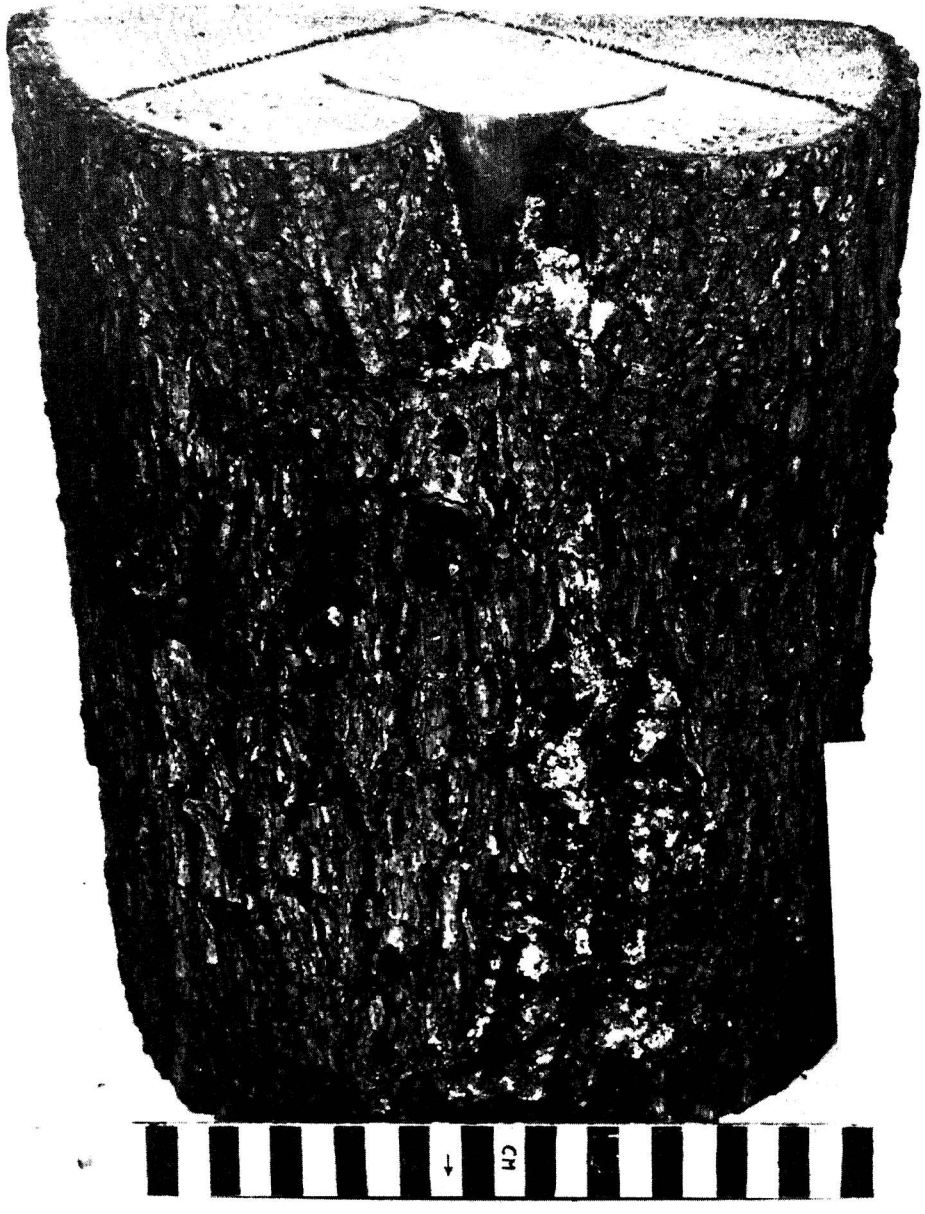


Figure 11. External view of bolt of white pine sectioned through the middle of injury. The injury occurred 29 years prior to felling. The wound closure is progressing without appearance of advanced decay in the central core of wood present prior to time of injury. Scale is in cm.

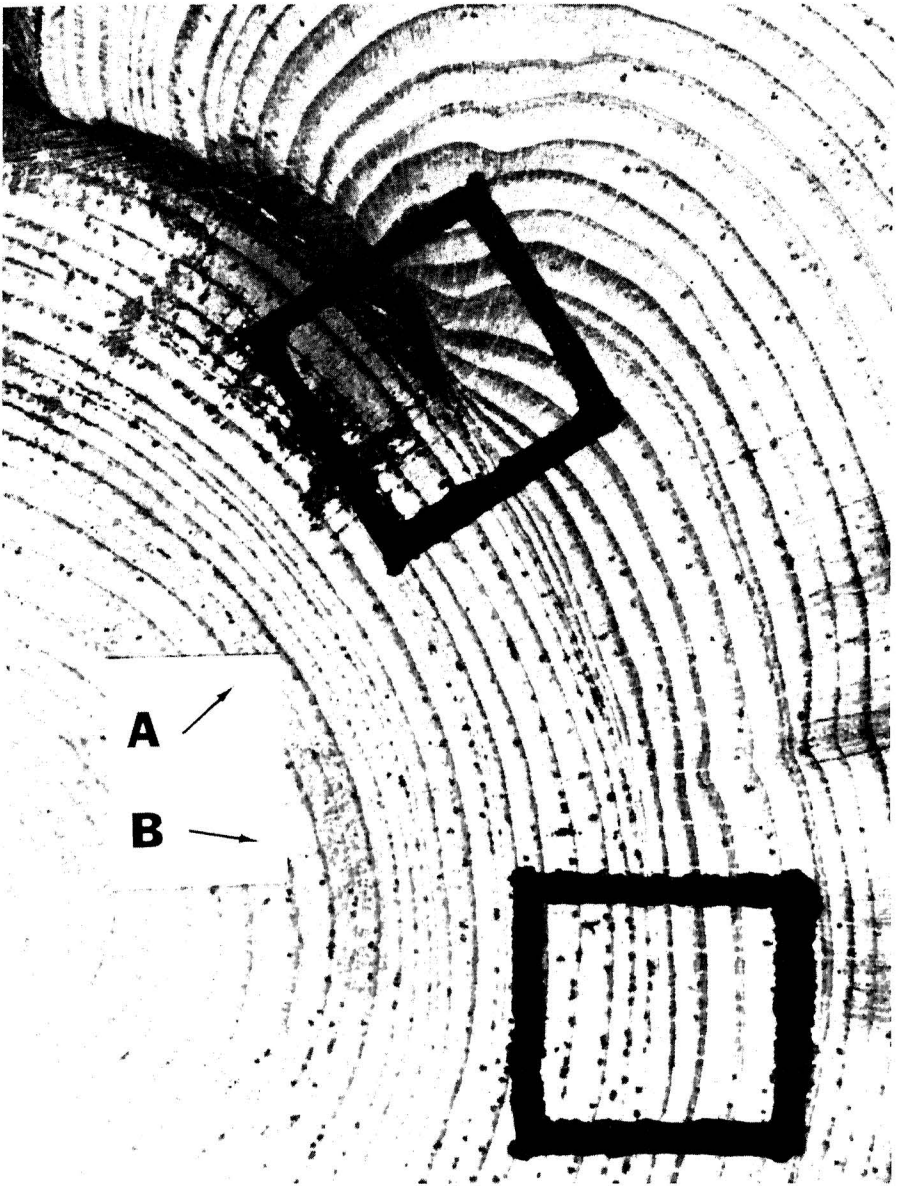
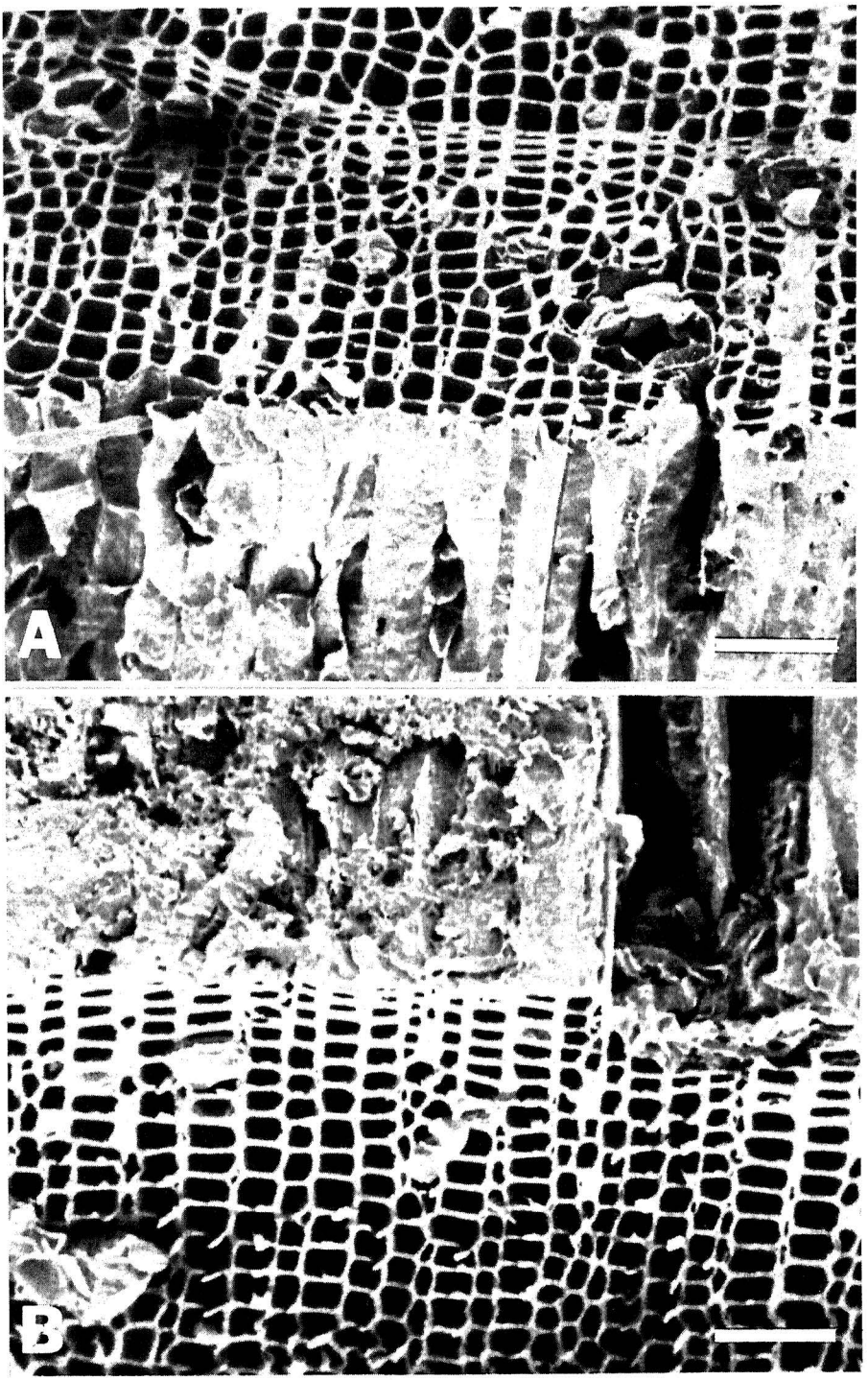


Figure 12. Cross-sectional view of white pine located at center of injury area (as for red oak in Figure 3). Note extremely slow growth for five-year period after injury. Wood present at time of injury shows little sign of discoloration or decay even though injury occurred 29 years prior to felling. Tangential coverage of original wound area is about 2/3 complete. Note that old wood-new wood interface is marked by a separation of these two zones as was case for red oak (Figure 4). Squares "A" and "B" are where samples were taken for microscopic analyses.

Figure 13. Zone "A" (Figure 12) where samples were removed for microscopic analyses. Xylem details were studied on the bark side ("A") of the injury as well as on the pith side ("B").

Right:

Figure 14. Bark side ("A") and pith side ("B") of white pine along old wood-new wood interface shown in Figure 13. Cell arrangement at this point is near "normal" in terms of cell types and arrangements although bark side ("A") did definitely produce a narrower increment in the immediate years following injury. The bark side of the injury ("A") displayed a greater frequency of longitudinal resin canals (per unit cross-sectional area) than the pith side. Magnification bars = 100 micrometers.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B

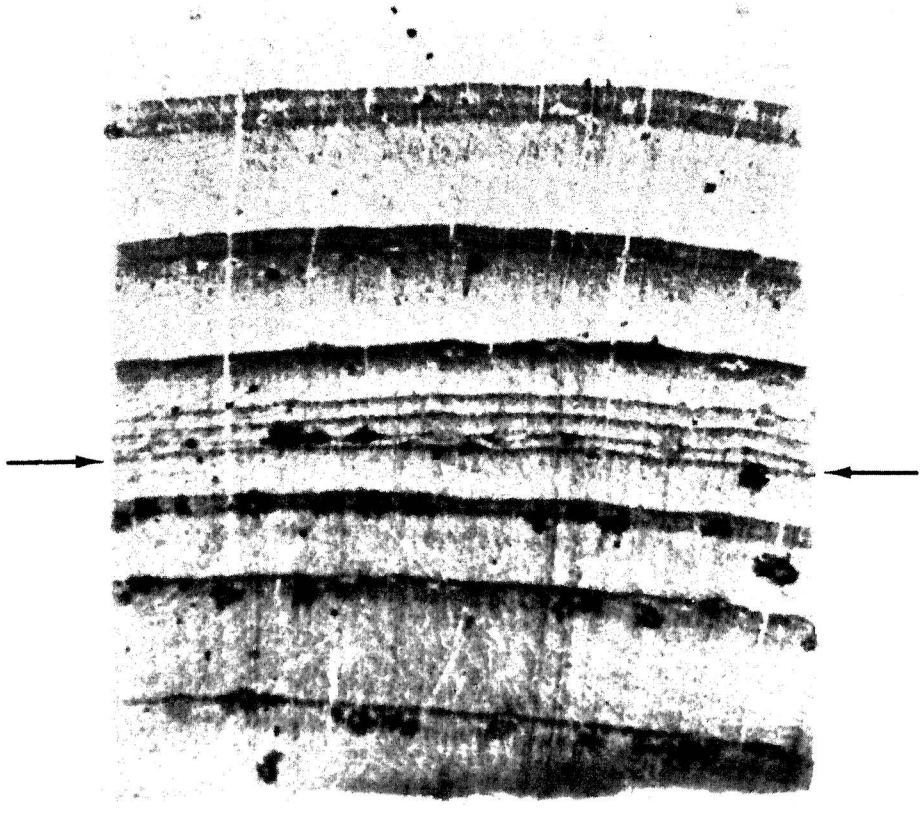
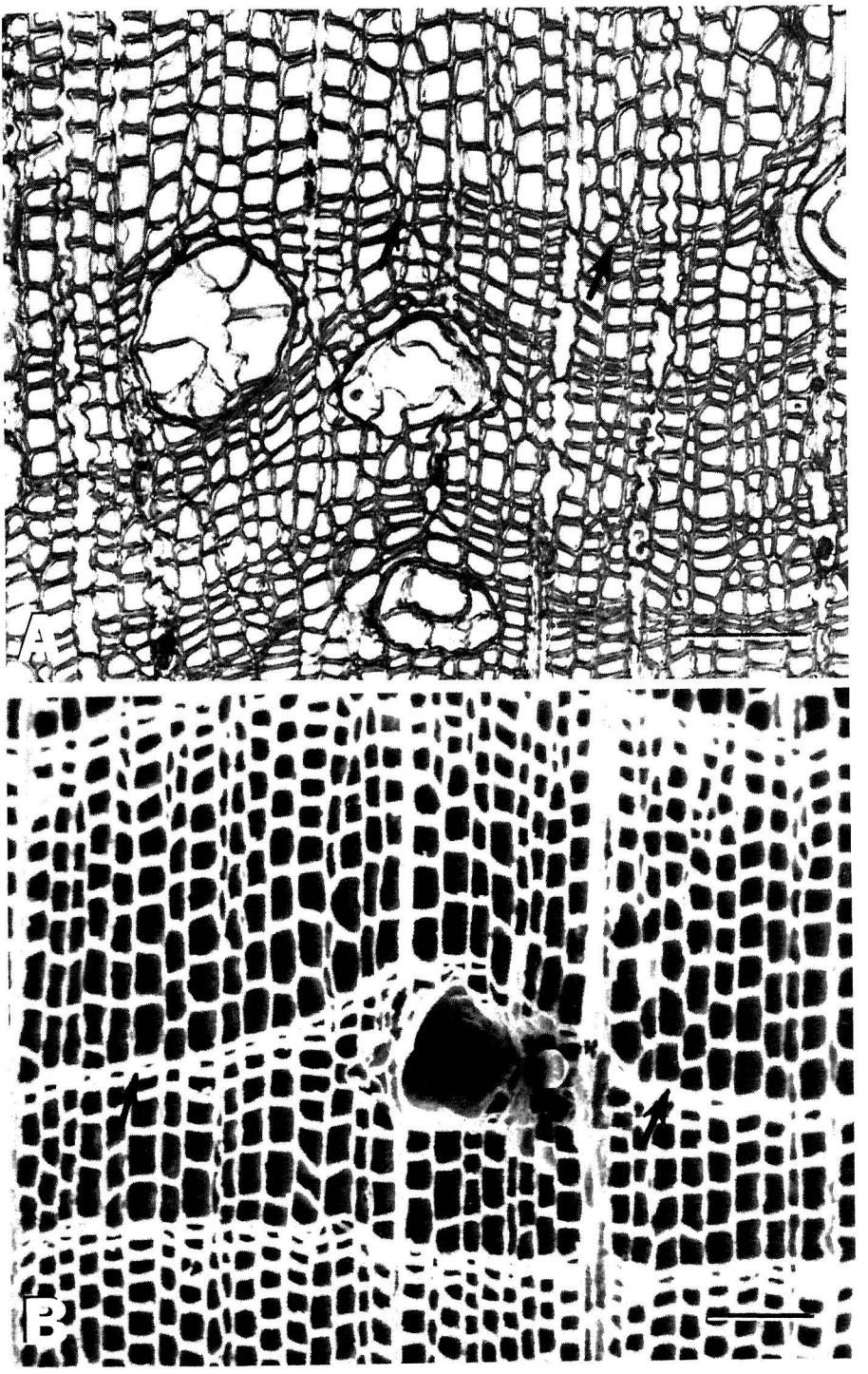


Figure 15. Area selected for microscopic analyses 90° (tangentially) from wound area in Eastern white pine (Zone "B" in Figure 12). Injury year is indicated by arrows. Note extremely slow growth in immediate years after injury; after this five-year period of growth, the tree layed down wood at a growth rate similar to that of years preceding injury.

Right:

Figure 16. The end of the first year (arrows) after injury in white pine (refer to Figure 12B) at a point 90° (tangentially) from the injury site. Top and bottom ("A" and "B") are light microscope and SEM views respectively. Note extremely slow radial growth (as few as five cells shown in both views). Longitudinal resin canal frequency (number per unit area) is greater in the four-five years after injury than in the years immediately preceding injury. Top view shows tylosoid resin ducts in cross-sectional aspect (also see Figure 18). Magnification bars equal 100 micrometers.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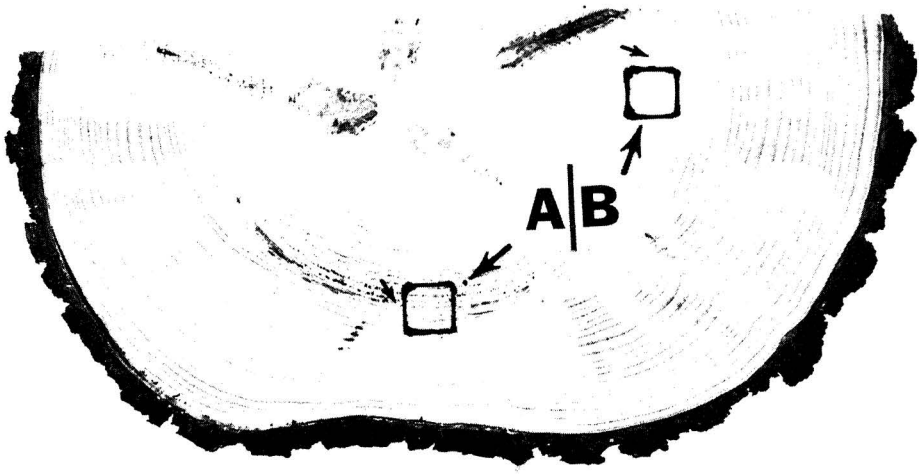


Figure 17. Cross-sectional disk removed 5 cm above wound ("A" area is directly above wound; "B" area is 90°, tangentially, from wound site). Sample taken at 15 cm above wound area showed similar patterns as sample at 5 cm except that growth rate for five years following injury was not as slow. "A" and "B" are areas where samples were taken for microscopic analyses.

Right:

Figure 18. Radial sectional views of white pine at point "A" (see Figure 17). Note tylosoid resin ducts ("A" above) and a separation, middle lamella zone between cells, occurring along the earlywood-latewood boundary of injury year in the lower figure ("B"). Magnification bar for "A" equals 100 micrometers, for "B", 200 micrometers.

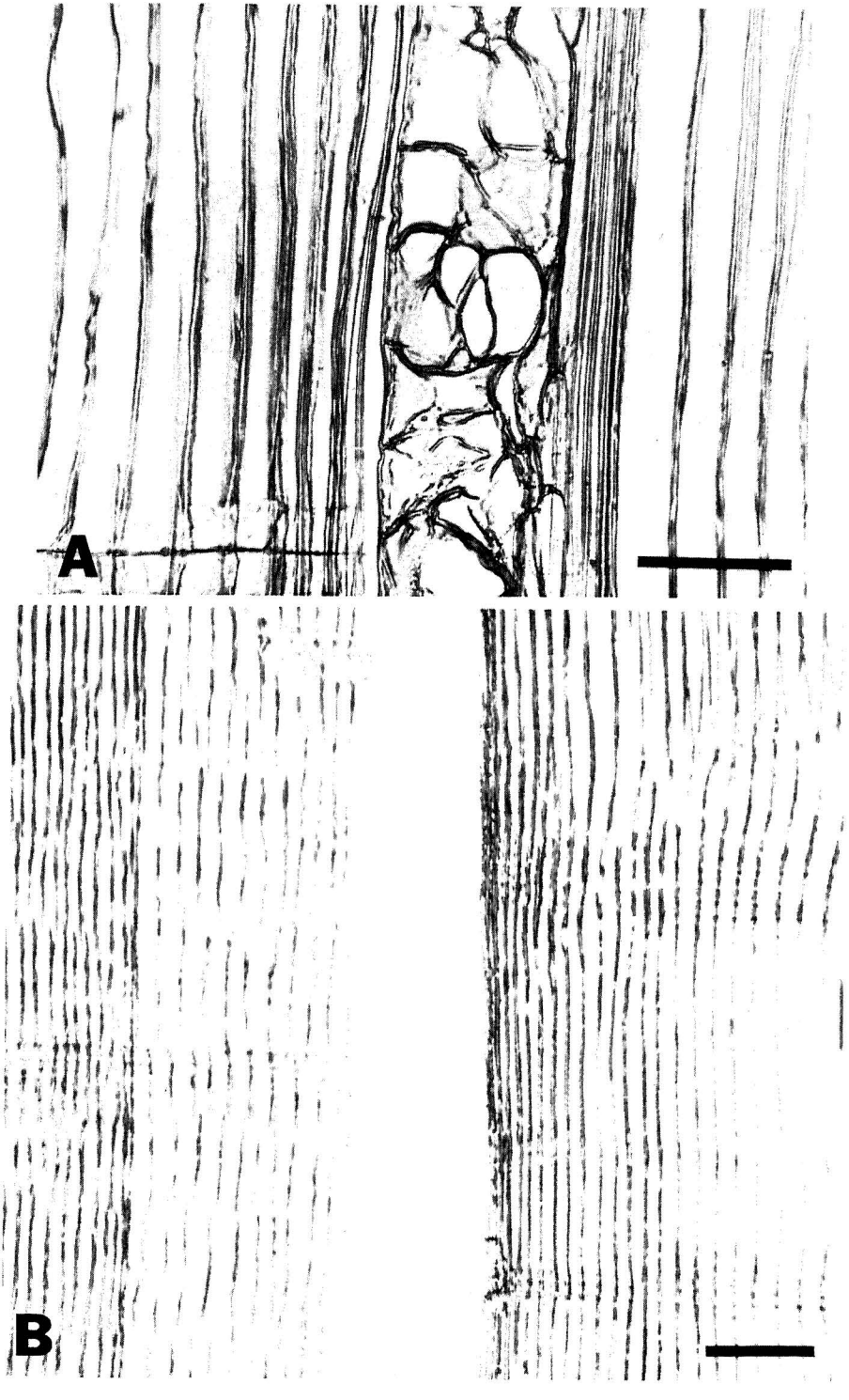

A
B

Figure 19. External view of red maple showing one of two wound areas that were four years old at time of felling. Another similar wound is on back side of bolt. Scale is in cm.

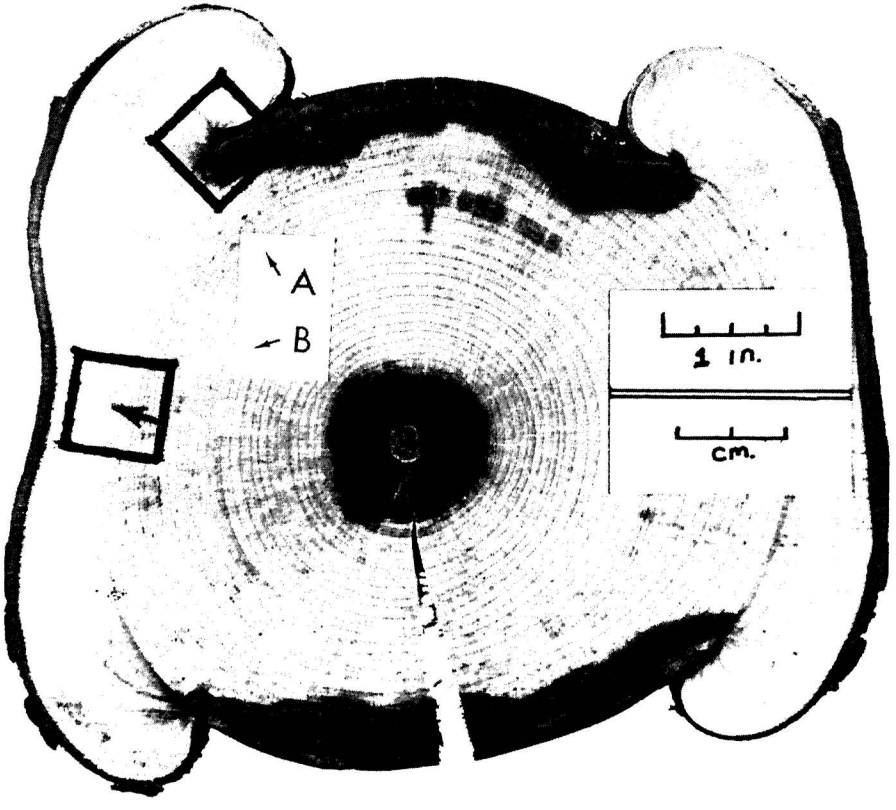


Figure 20. Cross-sectional view through center of injury area. Radial crack due to seasoning. Note intense discoloration on old wood zones exposed at time of injury. Central column of discoloration due to an injury that happened earlier in the life of the tree. Samples were taken from zones "A" and "B" for microscopic analyses. The red maple sample discolored much more on the exposed face than either the oak or the pine. Note dark ("Barrier Zone") line in section B (arrow).

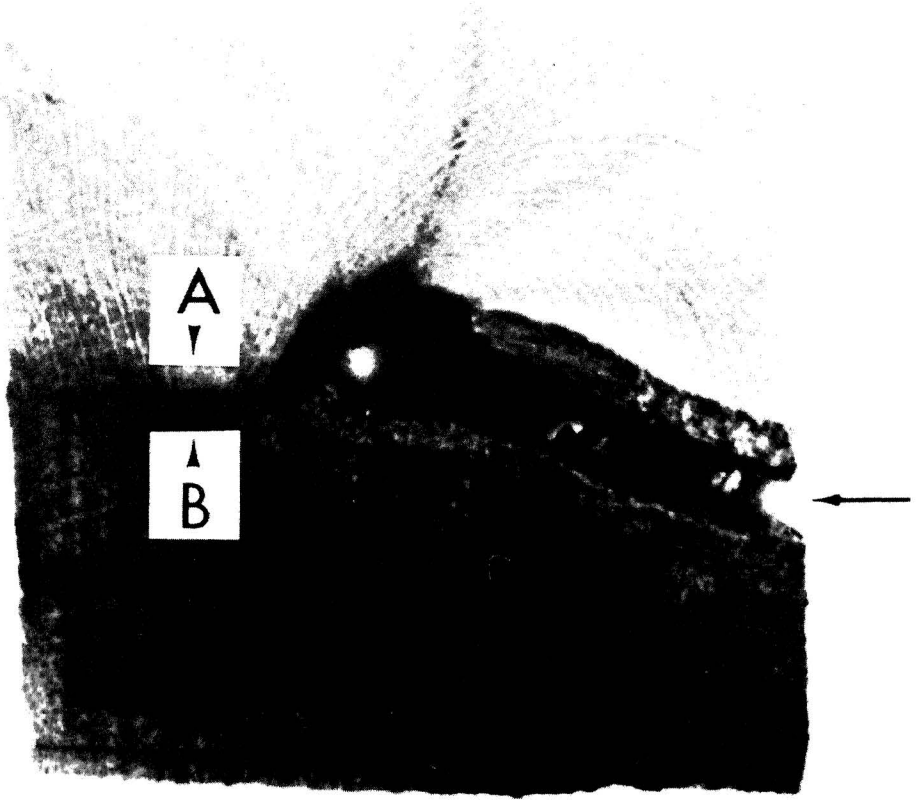
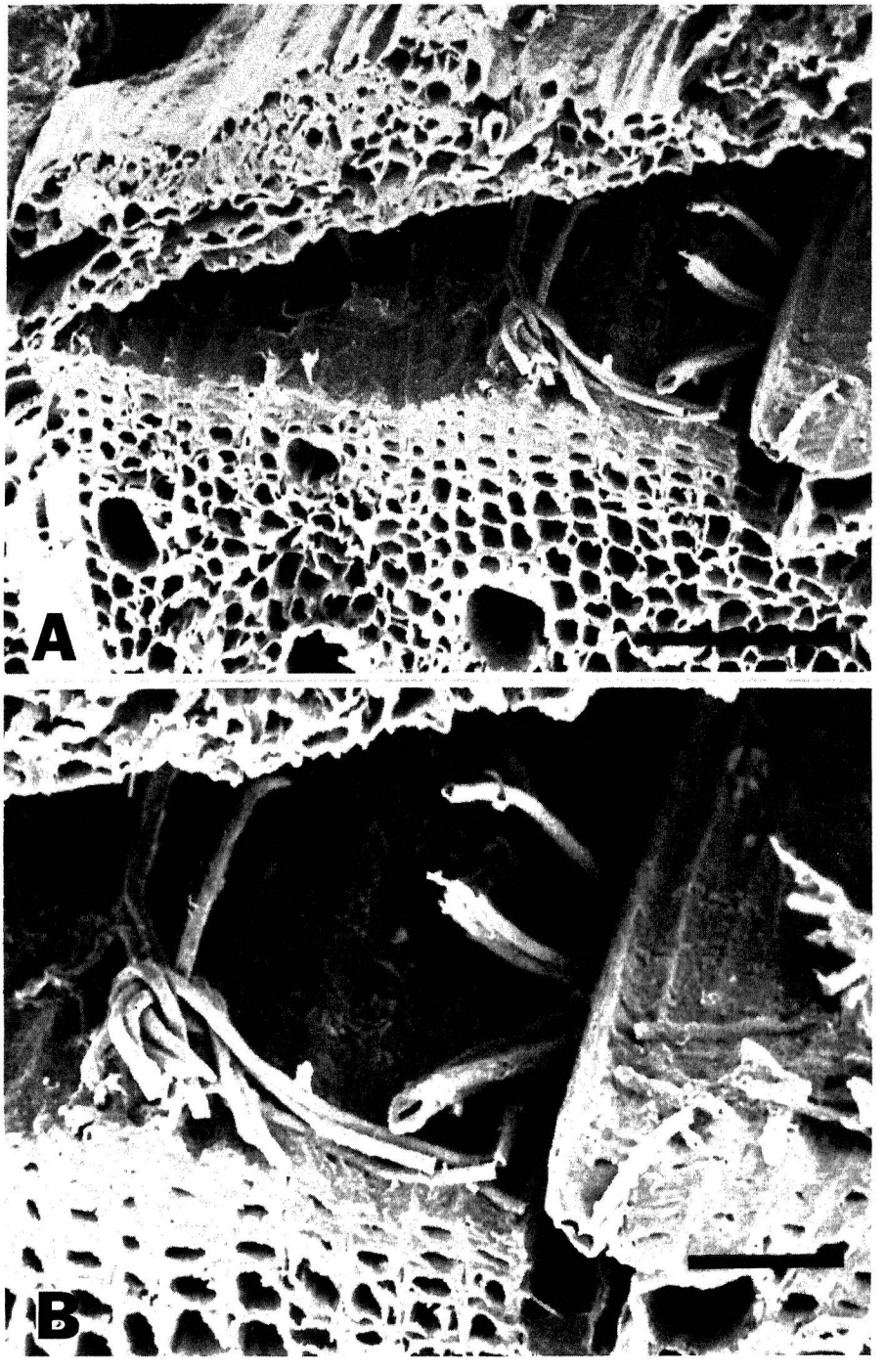


Figure 21. Sample block at junction of wounded and nonwounded area ("A", in Figure 20). Note discoloration and separation (arrow) along old wood-new wood interface (arrow). "A" and "B" are where samples were taken for microscopic study.

Right:

Figure 22. Microscopic (SEM) views incorporating zones "A" and "B" in Figure 21. Bark side is one on upper portion of separation area. Fungal hyphae are shown (particularly visible in lower Figure). The red maple did not retard development of discoloration and decay to the same degree as either the red oak or white pine. Magnification bar equals 100 micrometers in "A" and 50 micrometers in "B".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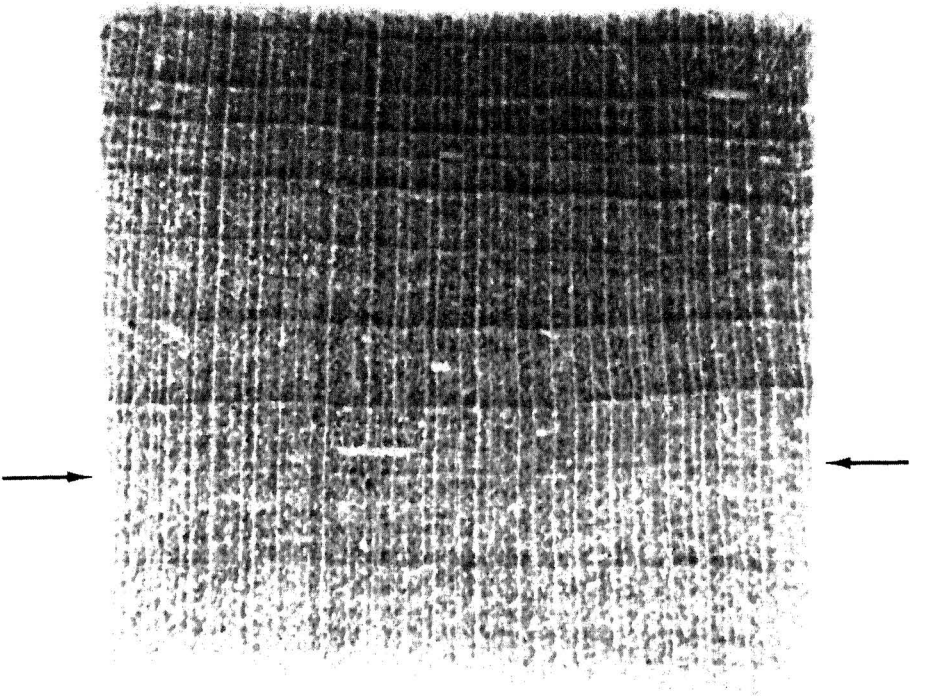

Figure 23. Sample block removed from zone "B" (Figure 20). Arrows indicate injury year. Cellular features observed were same as shown for sample taken 5 cm below injury site (see Figure 25). Growth rate after injury was similar to that before wounding.

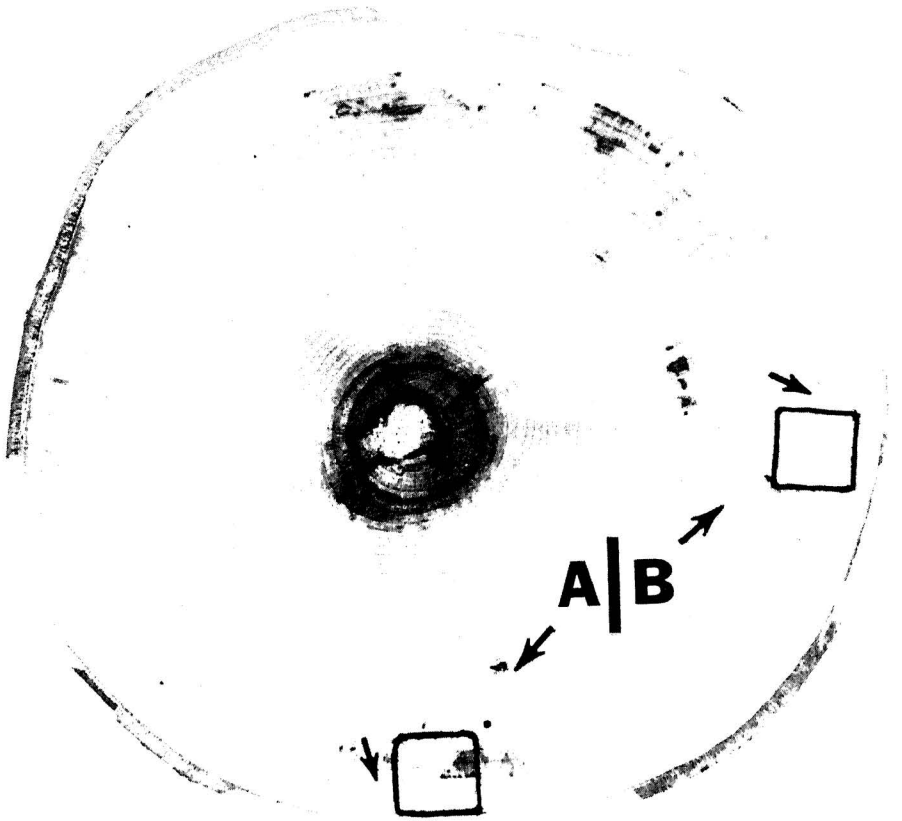

Figure 24. Sample disk removed 5 cm below injury site for red maple (see Figure 1). Smaller arrows point to injury year and barrier zone. Squares are where cubes were taken for microscopic study. Square designated "A" is located directly below wound while "B" is 90°, tangentially, removed from wound area. Central column of discoloration is due to earlier injury to tree.

Left:

Figure 25. Injury year ("A") directly below wound (see Figure 24) as seen in radial view. Earlywood of injury year is characterized by numerous axial parenchyma. More inclusions present in cells than in same increment examined 90° removed, tangentially, from injury area. Magnification bar equals 100 micrometers. Arrow points to bark side of wound.

Summary

A tree from each of the three general types of wood structure native to North America was studied to describe anatomical response to injury. The resultant "barrier zone" formed for each type is illustrated. Observations indicated that in both the longitudinal plane and the tangential plane, effects on anatomy were evident. These were less pronounced as distance from the wound site increased. The details were for the most part only discernable microscopically although macroscopic examination did indicate abnormalities usually as discoloration and/or growth rate pattern differences. The pictorial evidence presented supports the concept of "compartmentalization", by the tree, as a response to injury.

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