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STUDY OF THE NATURE AND POSSIBLE CAUSE OF RING SHAKE IN DOUGLAS-FIR

by

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Lastly, I wish to express my appreciation to Mr. David Lowery, of the Missoula Research Center, U.S. Forest Service, for his able assistance in spiral angle determination.

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INTRODUCTION

Shakes, of which there are three kinds, are common defects in timber. A shake is a split or cleft in the wood; it may be a heart shake, star shake, or ring shake. Of these, the most frequently met with is heart shake. A heart shake is a split which passes across the center of the stem and is wider at the middle point than at its extremities.

Star shakes, as their name implies, are splits which radiate from the center of the tree outwards, so as to form a star. Sometimes they extend but a short distance from the center, again they may extend across the entire cross section of the tree.

Ring shake arises when the annual rings of the wood fail to adhere to one another, with the result that curved fissures, parallel to the annual rings, occur in the wood (figures 1 and 2). Forsaith (14) clearly demonstrated that the denser summerwood was stronger than the wood from the inner portion of an increment. He was able to prove this phenomenon with match-stick size yellow pine, in which, test specimens composed wholly of tissue from one growth increment were subject to tangential loading. A microscopical examination of the ring shake plane by Koehler (25) showed that the rupture frequently was in the springwood, rather than between two rings. Examinations of the cell structure of ring shake planes has led to another speculation - that ring shake represents the rupture of the cells in certain weak portions of the wood. Brown, Panshin, and Forsaith (5) stated that these cells

FIGURE 1. RING SHAKE IN A DOUGLAS-FIR SAWLOG. SHAKE NEAR THE LOG PERIPHERY.

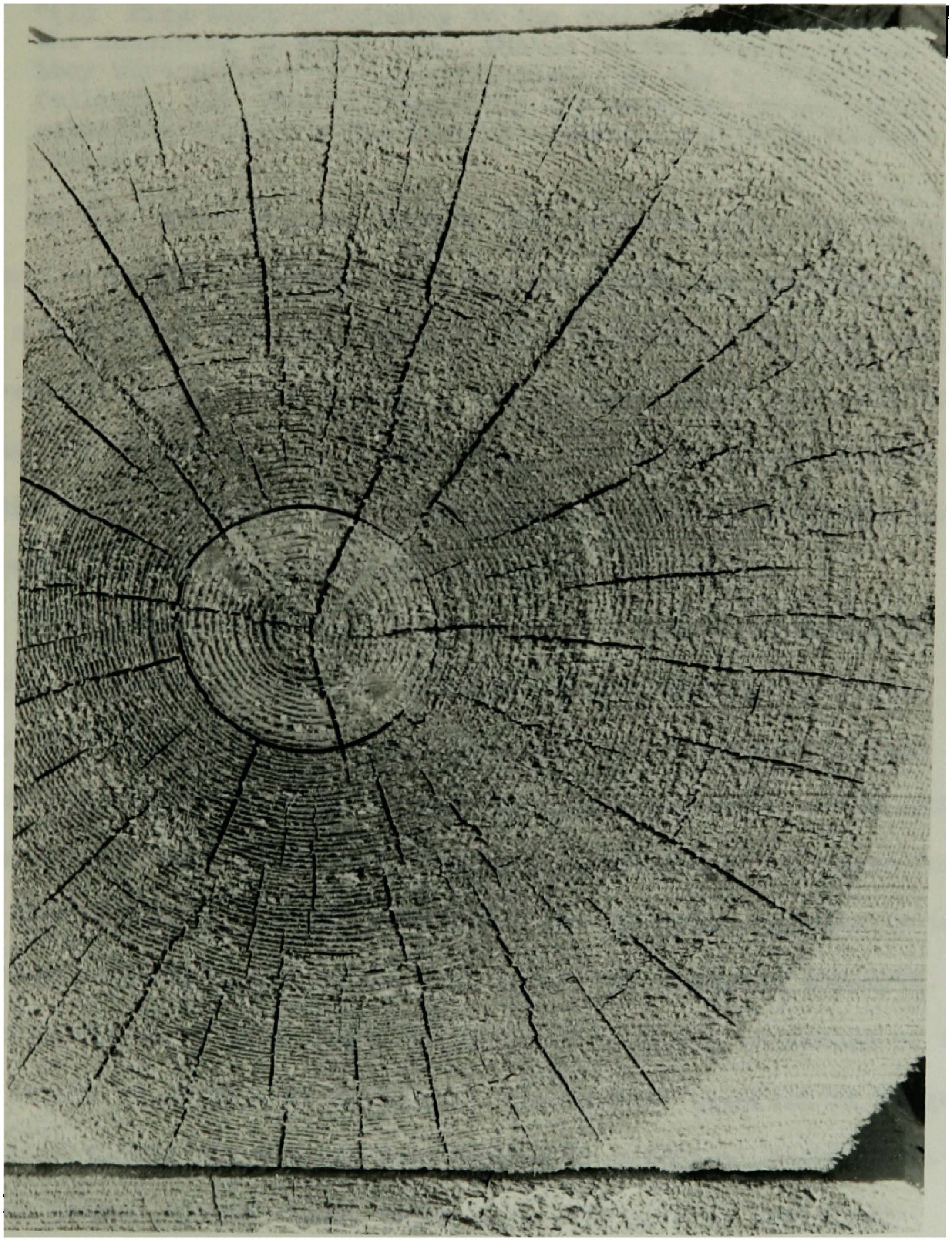


FIGURE 2. RING SHAKE IN A DOUGLAS-FIR SAWLOG. SHAKE NEAR THE PITH.

are pulled apart, but in most instances the cell walls themselves are ruptured. They conclude that ...

> "(1) Ring shake originates in the standing tree, not in the seasoning of wood; (2) Shakes seldom develop unless they were present to a certain degree in the tree before felling; (3) Shakes frequently are extended further with seasoning following the line of cleavage orginally established."

In the United States, Garratt (16) revealed that ring shake is common in hemlock, sycamore, and western larch, and speculated that it may occur in all species. Boulger (3) found that ring shake occurred in various species such as hazel, oak, poplar, pitch pine, and Lignum Vitae, and seemed to some extent local. He further stated that oaks of Sicily, a variety of the British species, and those of the Forest of Dean, England are peculiarly subject to this defect.

Ring shake is important because it is a prevalent defect in commercial timber tree species. A defect in wood defined by Brown, Panshin, and Forsaith (5), is "any abnormality or irregularity that lowers its commercial value by decreasing its strength, or by affecting adversely its working and finishing qualities or its appearance".

When shearing strength properties are critical, especially in structual material, ring shake will reduce the shearing strength. Weakening in shear from shakes consists of a direct reduction of the area acting in resistance to shear. It has been reported by Wangaard (49) that shakes are usually accompanied by a general weakness in bond between annual growth rings, which seriously affects the shear strength. This weakness usually extends far beyond the point of actual separation of the rings. He concluded that it is evident that the weakening effect of checks and shakes in beams and other members subjected to bending was largely dependent on shake proximity to the neutral plane, since it is here that the horizontal shearing stresses are at the maximum. In tension, Wangaard concluded that shakes have no effect on tensile properties when the load is applied in line with the grain, but any separation of the annual rings would destroy the tensile strength across the grain. The effect of shakes in compression is confined largely to causing an unequal distribution of stresses which result in a reduction of strength through the overstressing of some of the fibers before others. Therefore, failures occur at somewhat lower average loads than if the shake were not present.

In the lumber industry of the United States, Douglas-fir (Pseudotsuga menziesli (Mirb.) Franco)* occupies a prominent position, representing over 20 percent of the total lumber cut, as stated by Hanzlick (18). Douglas-fir is commonly used for lumber and structural materials, poles and piling, railroad ties, and veneer. Ring shake as a defect in lumber affects the appearance and strength properties. The location or position, form, number, and size of all defects determine the grade of every piece of lumber. In a study of lumber from old growth versus lumber from second growth in Pinus strobus, Davis (12) concluded that shake and decay, which are characteristic of overmature white pine, were often the determining defects in the old-growth low-common lumber, but almost negligible in the second growth. Similarly, Garratt (16) contends that old timber is more subject to shake than young trees. Shaky lumber cannot safely be sawn longitudi-

*Formerly recognized as Douglas-fir (Pseudotsuga taxifolia (Poir) Britt.)

nally down the middle, as the ring shake part may drop out, leaving in each half a deeply-grooved channel, equal to the arc of the shake.

In round timber, ring shake is tolerated as a limited defect since shakes have little effect on the compressive strength of a column. They are limited in sawn posts and timbers for the sake of appearance and, in exterior exposures, to reduce the opportunity for moisture to enter and decay to start. When ring shake logs are manufactured into veneer, a large percentage of the wood is wasted. If the shake is left in the veneer, the size and position of the shake will lower the appearance quality. Also, during the rotary veneer cutting procedure, difficulty might arise in turning. Finally, ring shake material is objectionable where material must be treated under pressure as it usually becomes worse during such treatment. Thus, it can readily be seen that ring shake is a major use-limiting defect and degrade factor in wood products.

SCOPE

Since we have learned to recognize ring shake and the considerable impact it has on the lumber industry, it was felt that more of the specific nature and origin of it should be known. Also, since scattered facts and theories have been written about ring shake and yet no unified source of information is available, it was desirable that this knowledge and theories be brought together in one paper. It is, therefore, the object of this paper to attempt to bring together the scattered facts and theories of ring shake, and to possibly add to this fund of information by some physical investigation.

The primary problem was to organize and evaluate these theories and their limitations because relatively little is commonly known about the cause and detailed nature of ring shake although a number of theories have been proposed.

This investigation is primarily restricted to Douglas-fir because the wider sapwood better tests some of the theories. Western larch (_Larix occidentalis_ Nutt.) was only investigated in detail concerning spirality, growth rate, and microscopical examinations. Increment cores of Engelmann spruce (_Picea Engelmanni_ Parry) and ponderosa pine (_Pinus ponderosa_ Law) were investigated as to spirality and growth rate.

The study was designed to make detailed observations of a large number of ring shake sawlogs to attempt to affirm or deny existing theories, and also to possibly find evidence for other theories.

Further, this study attempts some measure of demonstration of the validity or lack of validity of assumptions involved.

HISTORICAL REVIEW

So many different and varied shake theories have been advanced that it is difficult to credit one person with the initial contribution. The earliest reference to ring shake found was that of Laslett (27) in 1875. He revealed that...

> "... ring shake, which is most frequently met with near the roots of trees, consists of a cavity or separation of two of the concentric layers, and probably arises from sap failing to possess some of the elements necessary for uniting the new layer to that of the previous year's growth. This deficiency of the cohesive matter between the woody layers may result from sudden changes of temperature, from the roots passing through a peculiar vein of soil, and even from frosts or violent and sudden gusts of winds and storms may also help to produce it.
>
> It will sometimes happen that only a portion of a layer is detached, making the segment of a cup, at other times, a small part of several layers; and again, in some instances, it is found that the disjunction is not complete, owing to there being a few fibers remaining to connect the two layers. When it assumes its worse shape, that is, when the ring or cup is perfect, it will in all probability be found to prevail the greater part, if not the whole tree, evidence of it being frequently traceable in the remotest branches.
>
> The cup-defect occurs in perfectly sound and healthy looking trees, and there is nothing to indicate its presence to the surveyor while the tree is standing. It can only, therefore, be dealt with them when discovered in the log after being felled. This defect is, to some extent, local, and is especially so among the oaks, it being more frequently met with in the Sicilian oak than in perhaps, any other. It occurs in Virginian Pitch pine, and it is often found in Lignum Vitae."

Ring shake was also found in the British oak species, Quercus robur, by Boulger (3) in 1908.

> "Quercus robur is subject to ring shake which has been doubtfully ascribed either to the rocky character of the soil or to the swaying to and fro of the tall trees by strong winds.

> This action of wind bending the rings of wood alternately in opposite directions in a manner obviously calculated to tear the wood apart may explain the occurrence of this form of shake in poplar. Ring shake has been attributed to frost, the rings of sapwood and heartwood in a living tree containing varying proportions of water and the outer layers being most likely to freeze first."

In soft-wooded trees like the poplar and Spanish chestnut, Webster (50) concluded that ...

> "ring shake is brought about during stormy weather, as the stem, in bending backwards and forward to the blast, causes the concentric layers of wood by alternate compression and extension to separate. Moreover, ring shake is usually local, and on sandy soils on the Wobum estate, in Bedfordshire, the Spanish Chestnut over areas were badly affected, and the timber rendered quite useless for constructive purposes. The timber of the Scotch pine, particularly when attacked by fungus, is apt to suffer from star or ring shake. In some pines this defect is the result of the attacks of certain fungi (trametes) the spawn or mycelium of which spreads as a felted mass of colorless mould especially in the cambium."

Saxton (39) while working with timber sales upon the Flathead Indian Reservation, Montana, made an examination of ring shake in Douglas-fir. Most of the trees were found on deep soil of good fertility and in a mixture with yellow pine, on a slope having a northeasterly exposure. Timber from this area cut from five to seven logs a tree. About 42 percent of the trees examined indicated the presence of ring shake. Only 50 trees were examined, but from his brief study he drew the following conclusion with respect to this area.

> "1. The worst cases of wind shake were found in the more secluded pockets and protected areas. Indications point to the fact that such trees are tall and straight grained, and are therefore less able to resist the sudden gusts of wind that often visit these pockets.
>
> 2. Douglas-fir trees grown on ridges are less subject to wind shake than those grown in the pockets. He examined trees grown on ridges and found them free from shake, although these trees averaged five logs to the tree.

3. Shake is not always found in the butt. It may occur at any point in the tree. Examination of several specimens showed no evidence of butt shake, but ring shake was well developed in the second and third logs.

4. Shake occurs at the point of least resistance. As evidence of this, examples were found where an old scar, or cat face, had grown over, and shake had developed from that point on about 60 percent of the examples of shakiness. It was also found at the point where there was a marked change from wide to narrow annular rings, which was concluded as a point of weakness."

It has been reported by Noyes (32) that ...

"when there is a sudden fall in temperature, the outside layers of the tree which are full of sap, contract more rapidly than the inner portions. On the other hand when the temperature rapidly rises, the outside layer of the tree expands so much more rapidly than the inside, that they separate with a dull muffled chug, the check extending in a circular direction following the annual rings. These injuries are found in regions where sudden changes in temperature occur."

Rhoads (38) stated that various writers, Mayr (28), Sorauer (44) and (45) and Somerville (43), have concluded that ...

"an abnormal or pathological parenchyma tissue may occur as an interruption of the normal course of the wood elements in the growth rings of coniferous trees. This tissue may result from a variety of widely different causes, which may either directly or indirectly influence the growth of the cambium. Among these causes may be enumerated mechanical injuries of any kind, attacks by various cryptogamic and phanerogamic parasites which stimulate the woody tissue to an abnormal development, abnormal physiological conditions of growth and nutrition which produce an effect, premature defoliation, and injuries resulting from such meteorological causes as lightning frost, and drought."

Mayr (28) states that ...

"the stimulation action of a mild late frost on the annual ring already in a state of cambial activity exerts itself in such a way that in place of the elongated tracheids a short-called parenchyma arises. This abnormal wood may occur either on only one side of the stem or extend entirely around it depending upon the way in which the cold air strikes the plant."

A microscopic examination by Mix (29) showed that ...

> "the wood first formed in the spring following the injury was a comparatively narrow zone of parenchyma wood, that the normal xylem was soon laid down outside this zone, and that the remainder of the growth ring was normal."

Boyce (7) further concluded that ...

> "the injury to the cambium is a common form of frost damage. It may occur at any time during the growing season or even when the tree is dormant. With severe cold the cambium may be killed outright, or injured beyond recovery; or with a less severe temperature it may develop abnormal tissue. In conifers the abnormal tissue of a frost ring varies with the severity of the injury, being characterized by these symptoms: gummosis, crumpling of the wood cells that were but slightly lignified at the time of injury, development of parenchymatous tissue instead of tracheid, and marked broadening and strong lateral displacement of the medullary rays."

Rhoads (38) found no frost ring formation in coniferous stems larger than 2 inches in diameter.

> "Frost injury to the cambium is usually confined to young stems with thin bark. The cambium of stems with thick bark is sometimes killed or injured by excessively low temperatures in winter. Douglas-fir and Sitka spruce are susceptible to girdling of the main stem near the ground by frost. European larch is quite subject to this injury. Low temperature injury can occur when the temperature drops below 32° F. during the growing season although experimental evidence indicates that it must drop at least several degrees below freezing before forest trees are affected."

Tryon and True (48) in their investigation of blister shake in yellow poplar state ...

> "frost shake is a separation of wood in the bole of a tree generally parallel to the annual rings-temperature changes are responsible for the condition. This condition occurs when the outer layer of the wood suddenly are warmed but before any appreciable warming has occurred in the inner layer. As a result, the warmed outer layers expand and tend to pull away from the unexpanded central portion of the bole. Where such conditions prevail and a weakened zone is present within the bole, the outer portion may separate from the inner along this zone.
>
> Blister shake results when the cambium is sufficiently injured to cause it to produce abnormal wood tissue, but not damaged severely enough to be killed. Blister shake differs

> from frost shake in the location of the injury at the time of its occurrence. Frost shake occurs within the wood bole and forms a separation or shake between previously formed annual rings. In blister shake the separation occurs between cambium and wood. This results in a displacement of the succeeding annual rings, when growth continues within the growth ring, signifying the time at which the injury occurred."

Bruce (8) reported hearing a "dull muffled and confined chug" within trees when cold weather was suddenly followed by a warm spell. He cut trees in which the sound was heard and found shake.

A hypothesis concerning ring shake formation was also presented by Koehler (25). His hypothesis was that ...

> "... shakes in green lumber are due to transverse compression and tension stresses resulting from growth and are not due primarily to bending, although bending stresses may supplement the growth stresses. Contraction near the periphery indicates that the outer part of a green tree trunk is in compression tangentially. The compression must produce or be the result of a radial tensile stress, since the two necessarily go together. The radial tensile stress would tend to pull the wood apart along a plane or several planes running through the center or along the annual rings where the wood is weakest or the stresses are greatest. A failure resulting from such stresses would permit contraction and expansion of the portions that had been under tension and compression respectively (that tangential compression and radial tensions will produce radial cracks along the annual rings). Shake is more prevalent in some trees because greater stresses occur in them and this is due to:
>
> 1. Greater circumferential than radial growth.
> 2. Reduction in the turgidity of the older tissues.
> 3. Chemical shrinkage of the older wood."

The following conclusion was drawn by Perkity, Wajciechowki and Wnuk (35) working with beech logs.

> "Contrary to generally accepted opinion, the contraction of wood tissue owing to loss of water is, in general, not the cause of shake in beech logs. By means of rings 3 mm wide and 3 cm deep, cut out of the periphery of freshly felled logs, it was demonstrated through the existence of tensile strains and their connexion with shakes that theoretically tensile strains can appear in fibers near the circumference of living trees."

They recommended and discussed the following counter-shake measures:

> "(1) cutting the tree close to the ground and into the longest possible, preferably tree length, logs and cutting off the buttress and forked top immediately before sawing up; (2) storage in water, to prevent desorption type shakes; and (3) the possibilities of clams, hooks, and circular incisions."

It has been observed and concluded by Jacobs (22) in his study of the tension of wood stems in Eucalyptus that ...

> " ... the successive layers of growth differentiate in slight longitudinal tension, and are held stretched by the inside core. As a result, a radially cumulative tension is built up which imposes a compression on the heartwood. In trees the heartwood is finally compressed beyond its limits of elasticity, and its mechanical properties are seriously affected. This phenomenon called fiber tension causes or helps to cause brittle heart, compression failures, and shake in green lumber."

It was hypothesized by Winn (52) that ring shake is probably due to external causes.

> "The complete defoliation of the tree by insects may cause such a check in growth that ring shakes are induced. In the tropics the intense heat may be the cause."

Brown, Panshin and Forsaith (5) cite the work of earlier writers, in that ...

> " ... ring shake results from the swaying of the tree trunk in the wind and hence it is sometimes called wind shake. Other causes contributing to the formation of ring shakes were thought to be heavy frost resulting in a shrinkage followed by a swelling, of the outer layers of the wood, the tilting of a tree with the resulting disturbance to its root system, and possibly the shrinkage of the heartwood in the standing tree."

Both Wangaard (49) and Garratt (16) cite the earlier work of Saxton (39) in stating that ...

> " ... ring shake was most frequently found at the juncture of two growth rings of very unequal width. Consequently, it is likely to occur in trees that have grown slowly for a time,

> then show an abrupt increase in rate of diameter growth as a result of thinning or other treatments which improve the growing conditions. They conclude that the causes of ring shake are uncertain. The swaying action of the wind is frequently held responsible for the splitting or shearing apart of the growth rings, especially in trees growing in exposed places. The defect, however, often occurs in trees protected from the wind and is not necessarily confined to the portion of the tree where the greatest shear stresses are developed. Frost may in some instances be responsible for shake, or at least be a contributing factor, although trees growing in regions free from frost may also develop ring shake. Rapid changes in temperature which occur (spring especially) causes a contraction and expansion of the outer sapwood layers."

Paclt (33) from his work in poplars concluded that ...

> " ... in addition to *Trichothecium roseum*, preliminary studies have isolated a so far unidentified parasite *Deuteromyces (Sphaeropsidales)* as the cause of ring shake. This class of fungi more commonly known as *Fungi Imperfecti*, is not a natural one but comprises those fungi whose life histories are still in doubt in that no spore stage has been found which enables them to be allocated in the Phycomycetes, Ascomycetes, or Basidiomycetes classes.

Lachaussee (26) commented in his work on ring shake and frost crack of oak that ...

> "(1) Preduncculate oak in the Forest of Chaux, France was seriously affected with ring shake and frost crack and showed rusty stains following the medullary rays; (2) Pedunculate oak in the Forest of Amont-Avol, France was slightly affected with ring shake and frost crack but showed no staining, (3) while Pedunculate oak in the Forest of Saint-Aubin, France was perfectly sound. Analysis of samples from the butt logs and soils at base of three trees from these three sites showed that the prevalence of defects was closely related to the Ca/Fe ratio in (1) wood and (2) soil. The hypothesis put forward to explain these phenomena is that more Fe is taken up from the soil when Ca/Fe ratio is low and that the presence of larger quantities of Fe in the wood modifies its mechanical qualities and makes it more fissile."

METHOD AND PROCEDURE

The four phases of endeavor were: (1) to investigate grain spirality as a possible cause of ring shake; (2) to develop shearing stresses in Douglas-fir test specimens for the prime purpose of duplicating ring shake in normal wood; (3) microscopical examination of the ring shake plane; and (4) appraisal of existing ring shake theories.

Field data were designed to provide information concerning location with respect to directional orientation, as to heartwood against sapwood, included sapwood, proximity to outside circumference, association with resinous material, unequal growth ring width, shake plane to annual ring, position in the tree, log clearness and log shape. A field data collection sheet is inserted in the appendix.

I. Spiral Grain Aspect

On some selected samples, borings were taken to investigate the relationship of grain spirality to shake. Sawlogs that had ring shake were bored perpendicular to the rings at a distance of three or four inches from the log end with an eleven inch long, 8 mm diameter, core increment borer. One increment core was extracted from each sawlog. When the increment borer passed through more than one ring shake, each shake was assigned a number. Six of the 58 increment cores had two ring shakes, for a total of 64 ring shakes observed in 58 increment cores.

The following is a tabulation by species of the 58 increment cores taken.

TABLE I

SAMPLE INCREMENT CORES TAKEN TO INVESTIGATE SPIRAL GRAIN

Tree Species	No. of cores	Percent of total cores
Douglas-fir	28	48.3
Engelmann spruce	10	17.3
Ponderosa pine	8	13.7
Western larch	12	20.7
Total	58	100.0

The results were grouped together due to the limited number of samples. The method for measuring spiral direction was that proposed by the Missoula Research Center, U.S. Forest Service. The vertical axis of the wooden core was marked in reference to the central pith axis of the tree. The increment core was then divided and marked into 10 year intervals to determine the sawlog age. A sharp knife was used to par the marked increments of the wooden core. Each 10 year increment section was placed on graph paper with the disc axis corresponding to the graph paper axis. The grain direction from the vertical axis of the increment section was drawn on the graph paper. The angle between the lines developed was determined by trigonometric calculation. The measurements were recorded for each species for analysis. The spiral angle could have been determined much more rapidly with a protractor. In any future spiral angle determination, the author suggests the protractor.

II. Duplicating Ring Shake by Mechanical Means

It was also the plan of this study to attempt to duplicate shake by mechanical means in normal wood. The object of this portion of the study was to attempt to develop shearing stresses in the laboratory that: (1) occur in the standing tree; (2) might be the same as the stresses responsible for ring shake; and (3) duplicate ring shake in normal wood; and to observe if the rupture is between growth rings or, if otherwise, to observe the exact position of the break. The load was applied until failure occurred. The loads that were developed to duplicate the shearing stresses in the laboratory are summarized in Table VI.

An Olsen testing machine of 30,000 pounds capacity designed for testing wood, was used in this work. The speed of descent of the loading head was regulated by means of a gear box on the testing machine, being .015 inches per minute for tests in shear parallel to the grain. Douglas-fir, vertical grain, low and high density lumber was used in the testing. The total number of sample blocks was 384 pieces of which 192 were sapwood and 192 were heartwood pieces. The test specimens were further conditioned by air-dry or water soak treatments, and the following four temperatures were used to treat the test pieces: 0-10°; 40°; 70° and 100° Fahrenheit. The following figure is a diagrammatic resumé of the wooden block treatments.

The blocks were subjected to three shearing forces: (1) angle shear; (2) shear parallel to the grain; and (3) splitting shear.

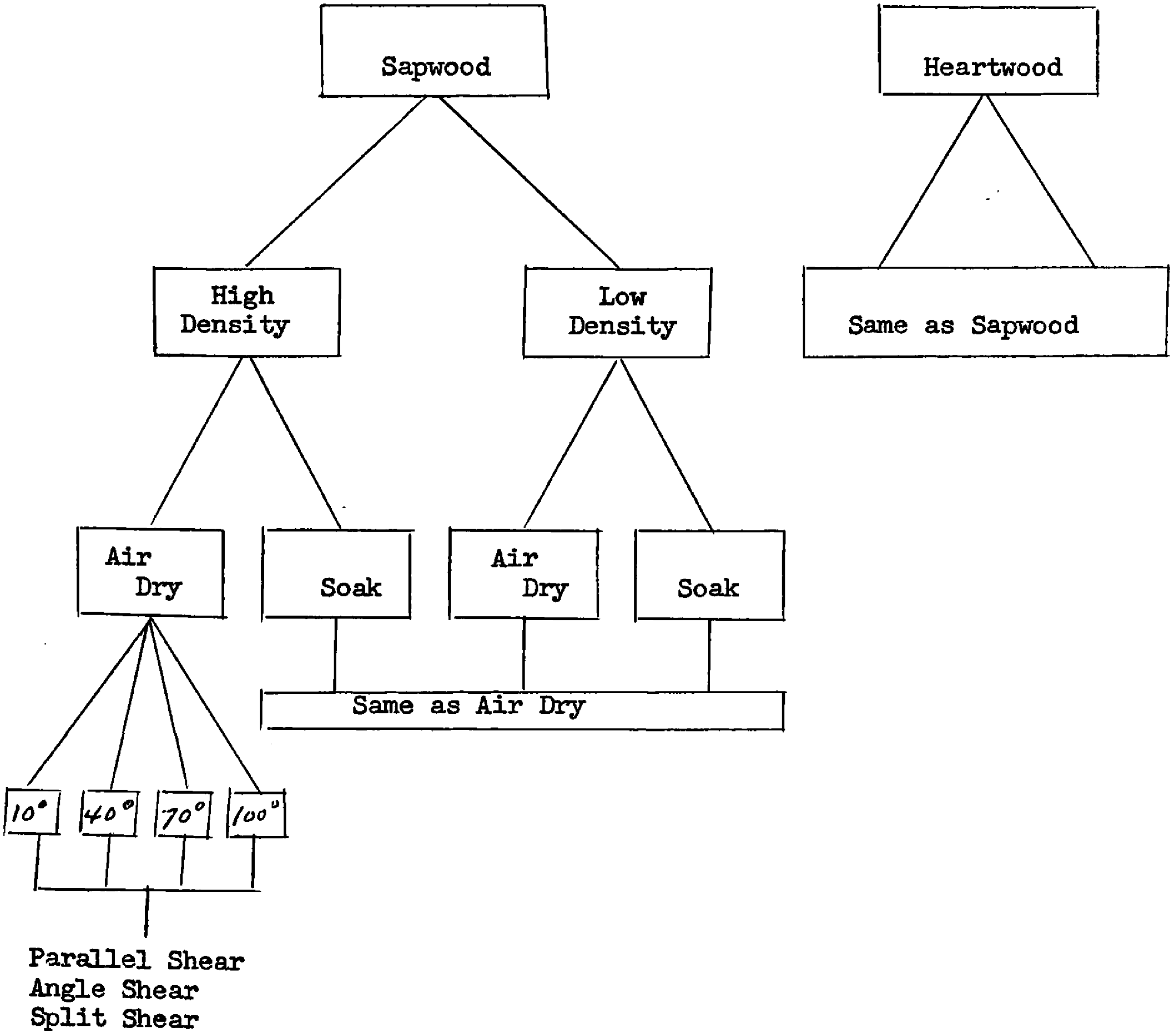


FIGURE 3. RESUME OF THE WOODEN BLOCK TREATMENTS.

TABLE II

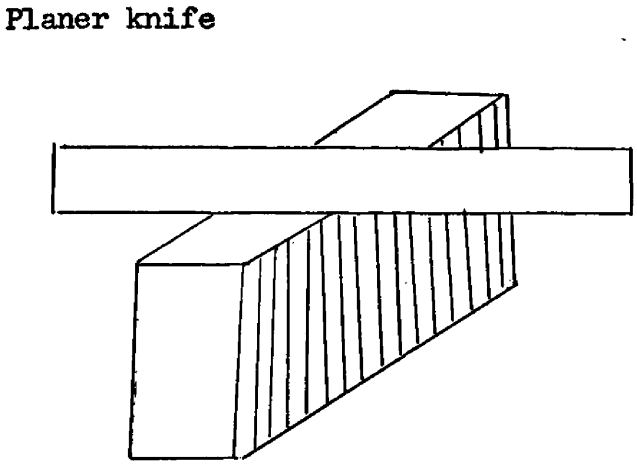
MOISTURE CONTENT PERCENT OF BLOCK SPECIMENS THAT WERE USED IN THE RING SHAKE MECHANICAL DUPLICATION TESTS, AND THE AVERAGE DIMENSION OF TEST SPECIMENS

Block type	Moisture content Percent
Soak	35.2%
Air Dry	9.0%
Test Type	**Dimensions (inches)**
<u>Shear parallel to grain</u>	
Length	1.5
Breadth	2.0
Thickness	.8
<u>Split and Angle shear</u>	
Length	2.0
Breadth	2.0
Thickness	.8
<u>Static Bending</u>	
Length	30
Breadth	2
Thickness	2

Observe figure 4 for a diagram of forces that were used and figures 5, 6, and 7 for the black samples subjected to the three different forces.

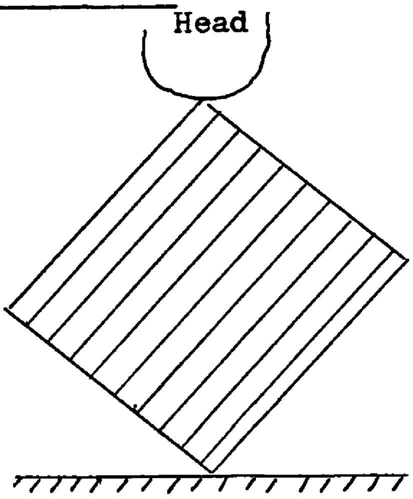
Splitting Method

This method may be defined as employing a force tending to divide lengthwise or in the direction of the ring with a sharp instrument



Angle Shearing Method

This method may be defined as a transverse load tending to cause the fibers to roll across one another in a longitudinal shear plane.



Shear Parallel to the Grain Method

This method may be defined as a stress resulting from applied forces which causes two contiguous parts of a body to slide relative to each other in opposite directions parallel to their plane of contact.

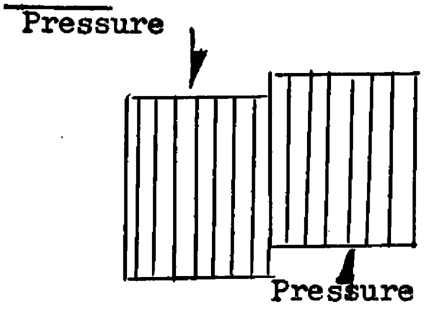


FIGURE 4. EXAMPLES OF FORCES USED TO MECHANICALLY DUPLICATE RING SHAKE IN NORMAL WOOD

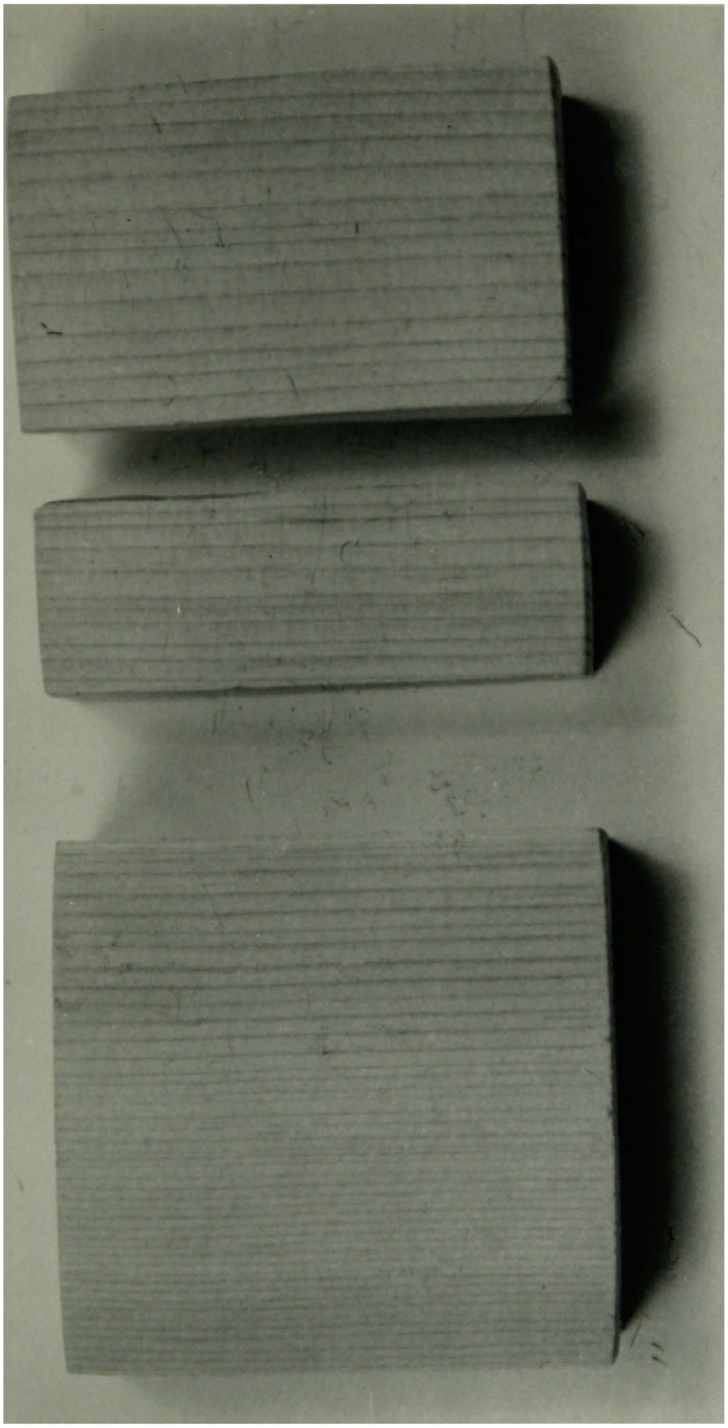


FIGURE 5. EXAMPLE OF BLOCK SAMPLES USED IN SPLITTING TESTS.

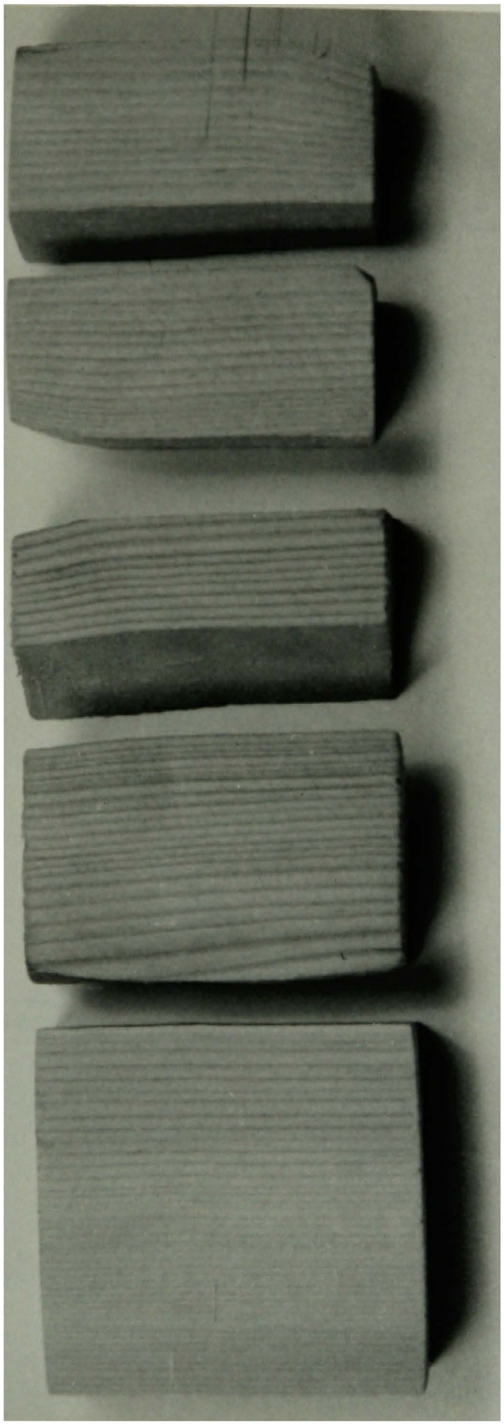


FIGURE 6. EXAMPLE OF BLOCK SAMPLES USED IN ANGLE SHEARING TESTS.

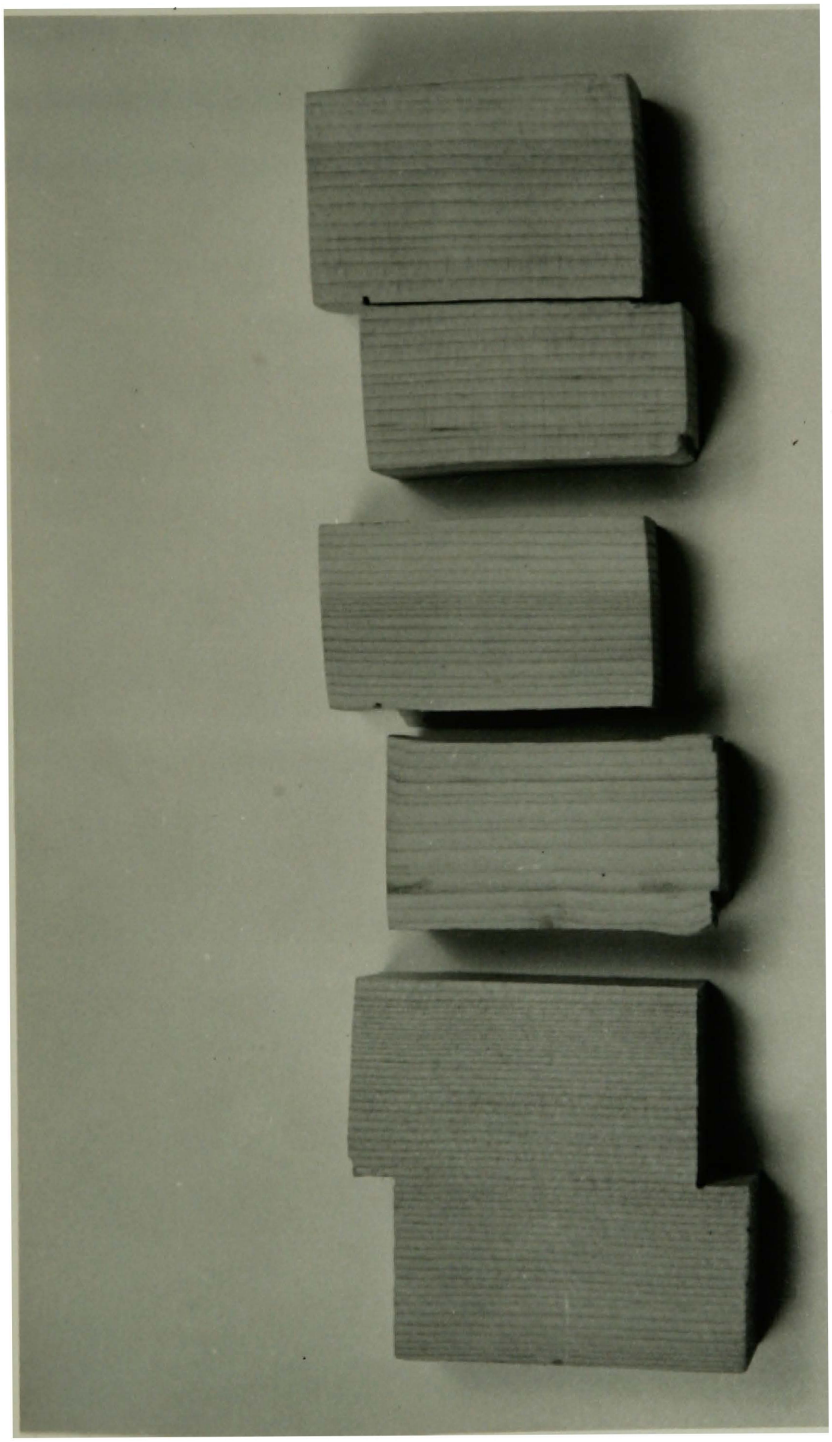


FIGURE 7. EXAMPLE OF BLOCK SAMPLES USED IN SHEARING PARALLEL TO THE GRAIN TESTS.

To evaluate the effect of static bending as the cause of ring shake, several test blocks were subjected to bending. Due to the lack of adequate test blocks, this part of the experiment was aimed at a generalization and not to any statistical conclusions. An example of a static bending test block is pictured on Figure 8.

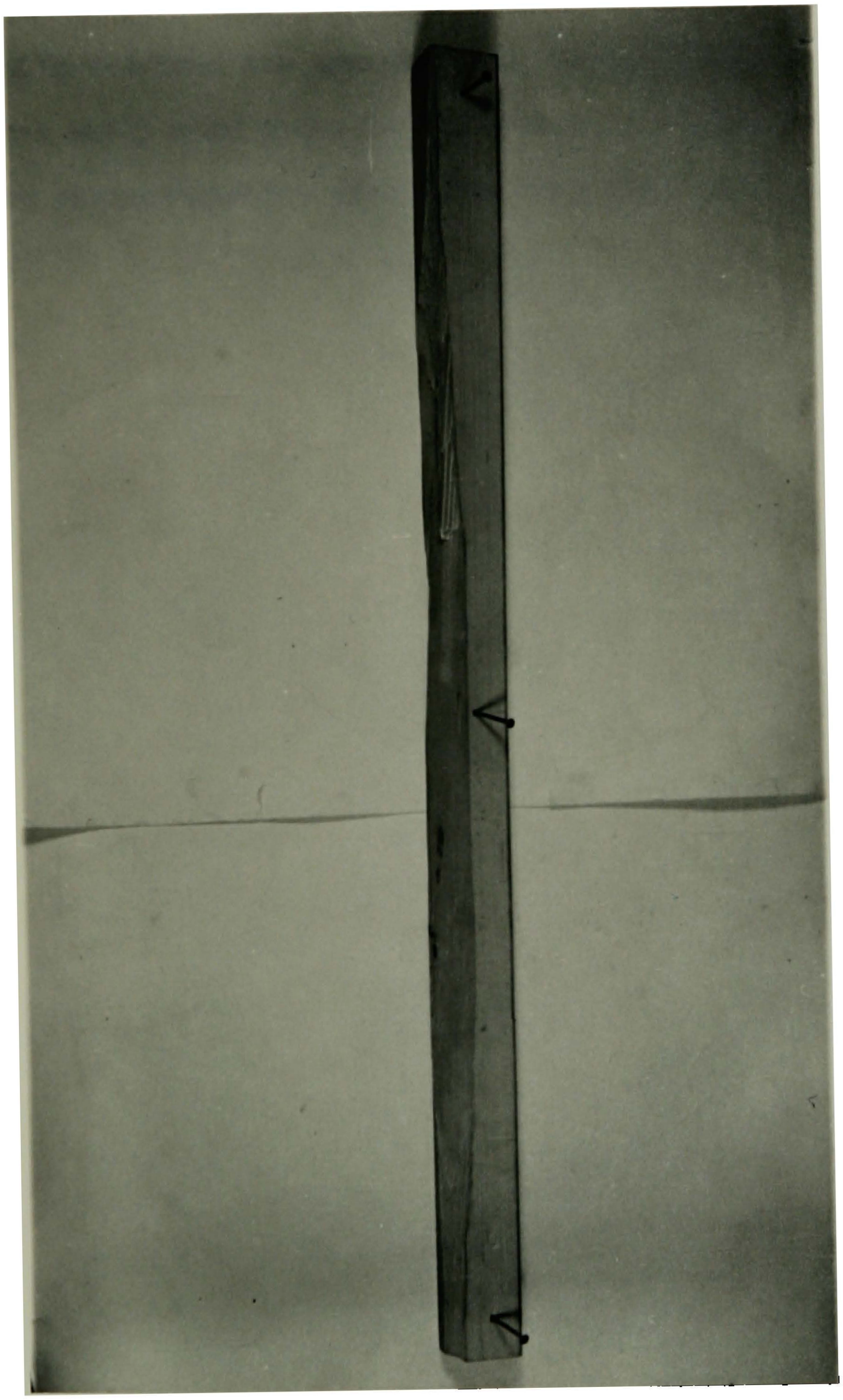


FIGURE 8. BROKEN PORTION OF SAMPLE BLOCK SUBJECTED TO STATIC BENDING - - NOTE SMOOTH TYPICAL RING SHAKE RUPTURE.

III. Examination of the Ring Shake Plane

Douglas-fir and western larch wood pieces containing ring shake were collected from the Anaconda Co., Lumber Division, Bonner, Montana. A typical shaky wood piece is reproduced in Figure 9 describing some of the wood characteristics with which this portion of the study was concerned.

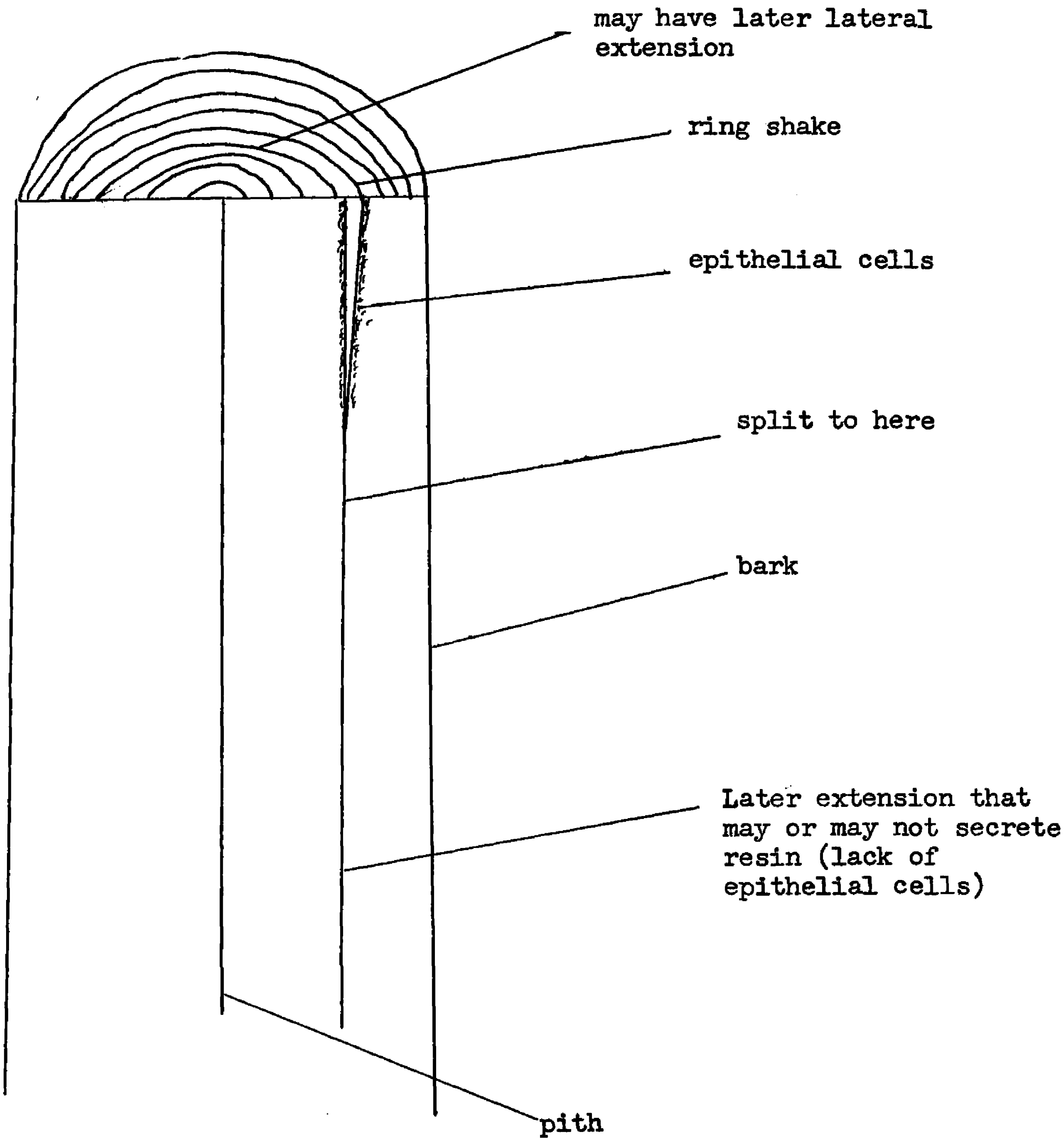


FIGURE 9. LONGITUDINAL VIEW OF THE INHERENT CHARACTERISTICS OF A TYPICAL RING SHAKE LOG SECTION.

Microscope slides were prepared using transverse and radial sections from ring shake wood pieces.

IV. Evaluation of the Existing Ring Shake Theories

Many theories have been advanced as the probable causes of ring shake. These theories and the methods of evaluating them will be discussed with the results.

RESULTS

I. SPIRALITY AS A CAUSE OF RING SHAKE

There were no theories found relating ring shake to grain spirality, but this theory appeared interesting. A hypothesis was generated in which it was postulated and visualized that since most trees have spiral grain and spiral angle differences throughout their life, Northcott (31), Paul (34), and Champion (9-10-11), changes in spiral angle or direction might create a stress plane which could possibly be the point of weakness that would be susceptible to ring shake. The author selected 58 increment log cores bored with an increment borer through opposite sides of the shake for the study. Results are shown in Table III.

TABLE III

SUMMARY OF CHANGING SPIRAL GRAIN DIRECTION IN RELATION TO RING SHAKE IN DOUGLAS-FIR, WESTERN LARCH, PONDEROSA PINE, AND ENGELMANN SPRUCE LOGS

Spiral Direction	Frequency
Gradual progression from left to right	22
Gradual progression from right to left	3
Passing the vertical plane	7
Reversing progression	29
Unidentified	3
Total	64

The general spiral pattern observed in the species investigated was an initial maximum left spiral which decreased in intensity with age, ultimately passing the vertical plane to a right spiral angle. In a few instances, a right to left spiral progression occurred, or the spiral angle decreased in magnitude never attaining a reversing direction. Variations in spiraling were observed between 10 year increments. The spiral direction is constantly changing so ring shake incidence relating to spiral changes was further classified into directional pattern changes. Fiber angles that progress gradually or reverse tend to be associated most closely with ring shake incidence. Spiral difference is here defined as the difference in degrees between successive 10 year increments. It was concluded from Table IV that a maximum spiral difference did not contribute markedly to any increase in ring shake incidence, nor did a slight spiral difference have any marked effect on ring shake incidence. Ring shake was most prevalent where the spiral difference was within 2-4 degrees and this may be concluded as the normal.

Table V treats ring shake incidence with the actual spiral angle (at the wood rupture) for the four softwood tree species observed. Generally, the actual spiral angle at the wood rupture was within the 0°-10° left or 0°-6° right spiral angle. The magnitude of the spiral angle did not have any appreciable effect on ring shake incidence.

TABLE IV

RING SHAKE VS. SPIRAL DIFFERENCE*

Degrees of Spiral Difference	Shake Occurrence				
	Douglas-fir	Englemann spruce	Ponderosa pine	Western larch	Total
0-1.9°	2	2	2	3	9
2-3.9°	11	4	5	3	23
4-5.9°	8	1	4	3	16
6-7.9°	5	1		3	9
8-9.9°	2				2
10-11.9°	2	1		1	4
12-13.9°					0
14-15.9					0
16-17.9		1		1	2
$18+^{\circ}$					0
	30	10	11	14	65/65

*Spiral difference measured at the 10 year interval on each side of shake plane

TABLE V

RING SHAKE VS. ACTUAL SPIRAL ANGLE*

Spiral Degree	Shake Frequency				
	Douglas-fir	Engelmann spruce	Ponderosa pine	Western larch	Total
20° plus left		1			1
19.59-15° "	3	1			4
14.59-15° "	5	2	1	2	10
9.59-0° "	5	2	5	3	15
4.59-0° "	9	2	2	5	18
0.4.59° Right	7		3	2	12
5-9.59° "	1	2			3
10-14.59° "					0
15-19.59° "					0

*Actual angle measured at the shake plane.

II. RING SHAKE DUPLICATION IN NORMAL WOOD

The object of this portion of the study was to attempt to develop shearing stresses in the laboratory that: (1) might occur in the standing tree; (2) might be the same as the stresses responsible for ring shake; (3) duplicate ring shake in normal wood; and (4) to observe if the rupture is between growth rings or to observe the exact position of the separation.

To produce ring shake by mechanical means in the wood samples previously described, the load was applied until failure occurred. For split and static bending applications, no loads were recorded. Loads that were applied to rupture test specimens for shear parallel to the grain, and angle shear are recorded in Table VI.

From Table VI it can be seen that the test specimens ruptured between a load of 900 and 2655 pounds per square inch.

The success in duplicating ring shake in normal wood by mechanical means was determined by the rupture developed. Figure 10 depicts an actual ring shake rupture. Breakage in normal wood usually occurred at the beginning of the springwood band.

TABLE VI

LOADS APPLIED TO RUPTURE TEST SPECIMENS FOR RING SHAKE DUPLICATION*

SHEAR PARALLEL TO THE GRAIN

Heartwood	0°F.		40°F.		70°F.		100°F.	
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Low Density	1515	2430	1835	1610	1580	1650	1325	1575
High Density	1700	2650	1270	2075	1425	1500	1160	2000
Sapwood								
Low Density	1405	2655	1450	1490	1500	1125	1137	1630
High Density	1905	2078	1800	1975	1365	1360	910	1500

ANGLE SHEAR

Heartwood	0°F.		40°F.		70°F.		100°F.	
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Low Density	1050	1050	1270	1300	1020	1172	1170	1230
High Density	1775	1075	1525	1845	1510	1877	900	1420
Sapwood								
Low Density	1115	1300	1085	1100	1317	1300	1075	1160
High Density	1170	1175	1150	1200	1215	1210	1022	1250

*Pressure in pounds per square inch.

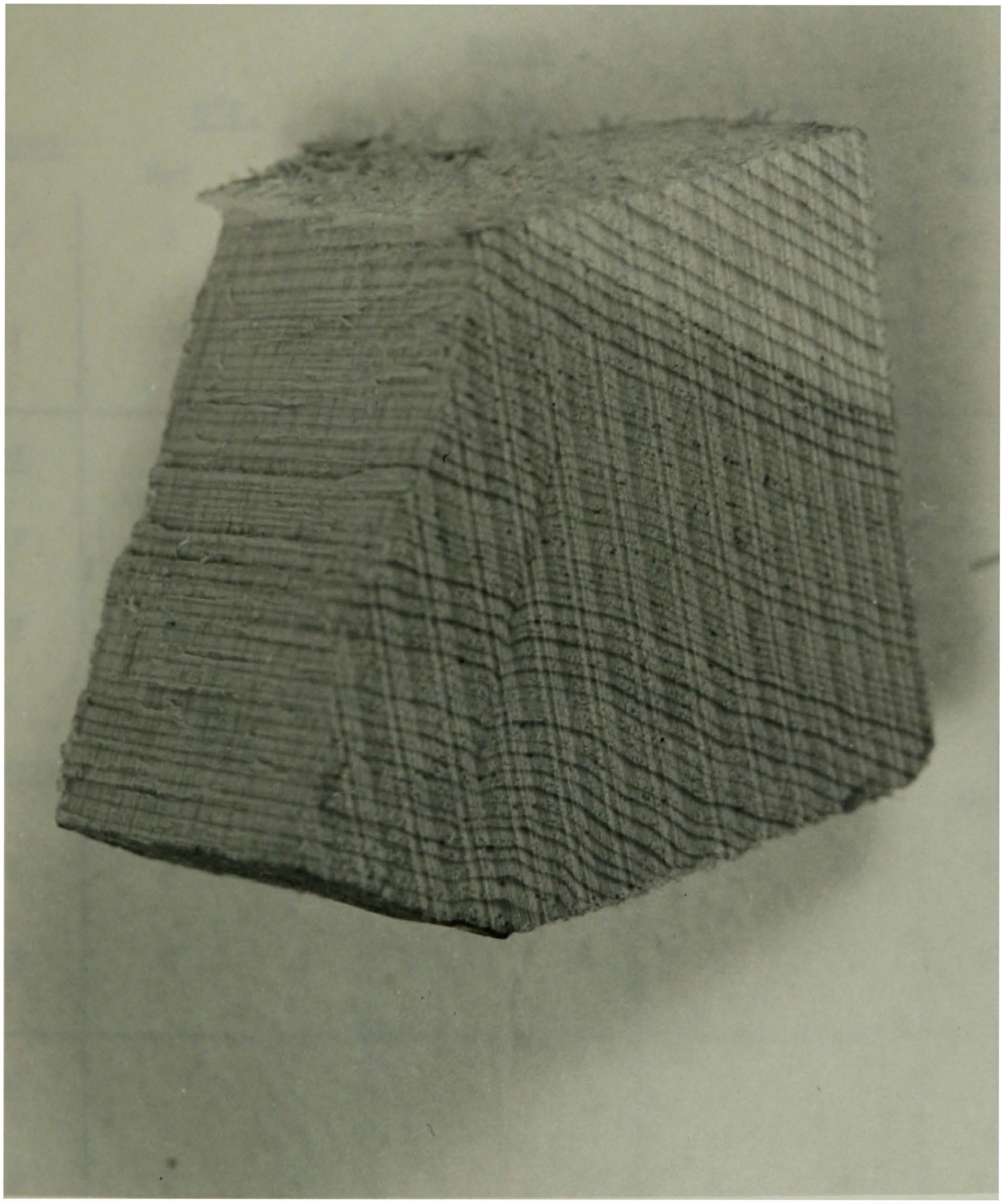


FIGURE 10. RESULT OF PRESSURE APPLIED TO NATURAL BLOCK - (NOTE SMOOTH SURFACE ON TANGENTIAL FACE).

The results of duplicating ring shake in the laboratory by mechanical means are shown in Table VII.

TABLE VII

SUCCESS IN DUPLICATING RING SHAKE IN THE LABORATORY BY MECHANICAL MEANS

Split

	0°F.		40°F.		70°F.		100°F.	
Heartwood	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Low Density	2	1	1	0	1	3	0	0
High Density	3	4	2	1	0	2	2	0
Sapwood								
Low Density	2	2	1	2	1	1	2	1
High Density	0	2	3	1	1	4	2	1

SHEAR PARALLEL TO GRAIN

	0°F.		40°F.		70°F.		100°F.	
Heartwood	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Low Density	4	2	4	4	4	4	2	2
High Density	0	1	4	2	4	3	2	1
Sapwood								
Low Density	2	0	1	0	2	2	1	2
High Density	1	2	1	0	1	0	2	2

TABLE VII (CONTINUED)

ANGLE SHEAR

	0°F.		40°F.		70°F.		100°F.	
Heartwood	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Low Density	3	4	2	3	4	3	3	3
High Density	4	4	4	4	4	3	4	3
Sapwood								
Low Density	3	2	1	2	2	1	2	4
High Density	2	3	3	3	0	3	1	1

TABLE VIII

RING SHAKE SEPARATIONS INDUCED IN NORMAL WOOD AS A PERCENT OF THE TOTAL NUMBER OF POSSIBLE SUCCESSES

Shear Type	Treatment	Percent - success
Split	Heartwood	34.4
	Sapwood	40.6
	0-10° F.	12.5
	40° F.	8.6
	70° F.	10.2
	100° F.	6.3
	Low Density	31.3
	High Density	43.8
Shear parallel to the grain	Heartwood	67.0
	Sapwood	29.7
	0-10° F.	9.4
	40° F.	12.5
	70° F.	15.6
	100° F.	10.9
	Low Density	56.3
	High Density	40.6
Angle Shear	Heartwood	85.9
	Sapwood	51.6
	0-10° F.	19.5
	40° F.	17.2
	70° F.	15.6
	100° F.	16.4
	Low Density	65.6
	High Density	71.9

From Table VIII the results indicate that ring shake type separations can be reproduced in normal wood. The best success came from those blocks that were subjected to angle shear. Varied results were produced with the different treatments.

The data on splitting were grouped in several ways and Chi-square tests were performed on each grouping. The groupings and the results of the tests are given below.

Splitting Method vs. Quality of Break

Method/ Quality	Split	Shear parallel to grain	Angle shear	Total
Good	48	62	88	198
Bad	112	98	72	282
Total	160	160	160	480

$X^2 = 20.9$ (2 degrees of freedom)

Hence, at a 95% level of significance we conclude that quality of split is not independent of splitting method.

Temperature vs. Quality in Split Blocks

Temperature/ Quality	0°F.	40°F.	70°F.	100°F.	Total
Good	16	11	13	8	48
Bad	24	29	27	32	112
Total	40	40	40	40	160

$X^2 = 4.04$ (3 degrees of freedom) Not significant at 95% level. Hence we conclude that quality of split is independent of temperature.

Density vs. Quality for Angle shear (Heartwood)*

Quality	Low Density	High Density	Total Blocks
Good	25	36	55
Bad	15	10	25
Total	40	40	80

$X^2 = 1.45$ (1 degree of freedom) not significant. Hence we conclude that for angle shear in heartwood, quality of split is independent of density.

Density vs. quality for Shear parallel to grain (Heartwood)*

Quality	Low Density	High Density	Total Blocks
Good	26	17	43
Bad	14	23	37
Total	40	40	80

$X^2 = 4.06$ (1 degree of freedom) significant at 95% level. Hence, at 95% level of significance, for shear parallel in grain in heartwood, quality of split is not independent of density.

---

*Sapwood calculations were not resolved because general visual observations did not show any correlation to ring shake formation from mechanical means.

Angle Shear

	Wet Good	Wet Poor	Dry Good	Dry Poor	Total
Heartwood	28	12	27	13	80
Sapwood	14	26	19	21	80
Total	42	38	46	34	160

$X^2 = 12.53$ (3 degrees of freedom) Thus the two classifications, heartwood and sapwood, do not tend to be independent of each other, but both classifications seem to be interrelated.

Angle Shear

	Heartwood Bad	Heartwood Good	Sapwood Bad	Sapwood Good	Total
Wet	28	12	26	14	80
Dry	27	13	21	19	80
Total	55	25	47	33	160

$X^2 = 1.22$ Thus wetness has no effect on the other classification. Wood test samples were not influenced by either wet or dry applications.

For angle shear, (heartwood) 55 of the 80 blocks split well. A 95% confidence interval for the proportion of heartwood blocks subjected to angle shear is $\frac{55}{80} \pm 1.96 \sqrt{\frac{55}{80} \cdot \frac{25}{80} \cdot \frac{1}{80}}$. Thus we can say with 95% confidence that probability lies between .59 and .79. (the correct interpretation of the 95% is the following: The true percentage lies between_____and_____unless something happened in the experiment which would happen in only 5% of all experiments of this type.)

More generally, if in a particular classification, n blocks were split and of these k split well, then a 95% confidence interval for the proportion splitting well in that category is

$$\frac{k}{n} + 1.96 \qquad \frac{k}{n} \quad \frac{n-k}{n} \quad \frac{1}{n}$$

Laboratory results indicated that ring shake could be duplicated in normal wood which led to the next portion of this study. Was ring shake associated with normal wood? The purpose of this portion of the study was to microscopically examine the ring shake plane. Douglas-fir ring shake logs and lumber were used except for several pieces of western larch. The shake plane was sectioned and observed. Two general groupings of the shake plane were made: those shake planes that were associated with resin and those without resin. Because resin canals are associated with resin, particular emphasis was placed on those shake specimens that lacked resin from visual observations.

III. MICROSCOPICAL EXAMINATION OF RING SHAKE

Because gross resinous secretions are associated with traumatic resin canals, particular emphasis was placed on those shake specimens that lacked resin from visual observation. Concisely, this phase of the study was to obtain information as to the histological nature of the shake separation. The microscopical study was undertaken to ascertain whether or not the shake separation occurred in normal woody tissue. Numerous samples were examined and the gross observation showed varying amounts of resin on the shake faces. (Table IX) Subsequent microscopical examination of samples that did not appear "pitchy" showed that even these contained a considerable accumulation of parenchyma cells on their surfaces. Due to the difficulty in sectioning, this examination was made by a light scraping of the faces. Subsequent further investigations led to the conclusion that these cells were epithelial parenchyma.

Microscope slides were prepared using transverse and radial sections from other shake materials. These slides all indicated the inevitable presence of parenchymatous tissue in the immediate area of separation.

Sections from large open shake areas did not exhibit identifiable structures, such as traumatic resin canals in these areas, so sections were cut from the lateral and from the longitudinal extremities of the shake. These sections clearly indicate the presence of a large number of tangentially arrayed traumatic resin canals.

Tables IX and X were made from visual observation of Douglas-fir and Western larch sawlogs respectively, for resin content at the section of ring shake plane.

TABLE IX

RING SHAKE DOUGLAS-FIR SAWLOGS INSPECTED FOR RESIN SECRETIONS

Shake characteristics		Frequency
Resin present at "X" section of shake plane		95
Resin absent at "X" section of shake plane		66
	Total	161

TABLE X

RING SHAKE IN WESTERN LARCH SAWLOGS INSPECTED FOR RESIN SECRETIONS

Shake characteristics		Frequency
Resin present at "X" section of shake plane		39
Resin absent at "X" section of shake plane		78
	Total	117

For an investigation of this kind, desirable test samples can be acquired from sawmill waste material. Waste material from the Anaconda Co., Lumber Division, Bonner, Montana, and the Intermountain Lumber Company, Missoula, Montana were used. Examples of the wood samples used are shown in Figures 11, 12, and 13.

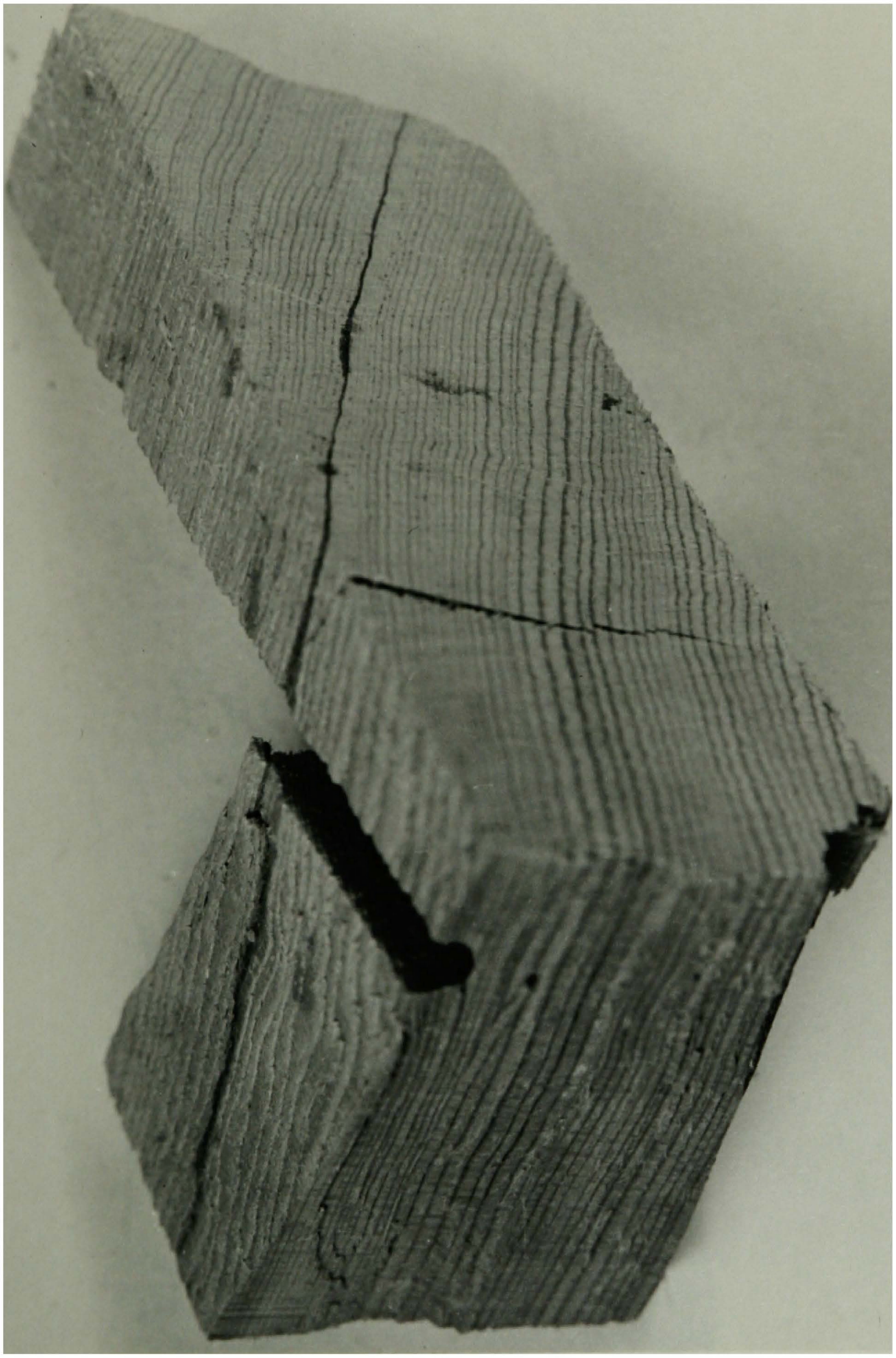


FIGURE 11. TYPICAL BLOCK SECTION FROM WHICH MICROSCOPICAL EXAMINATION WAS MADE.

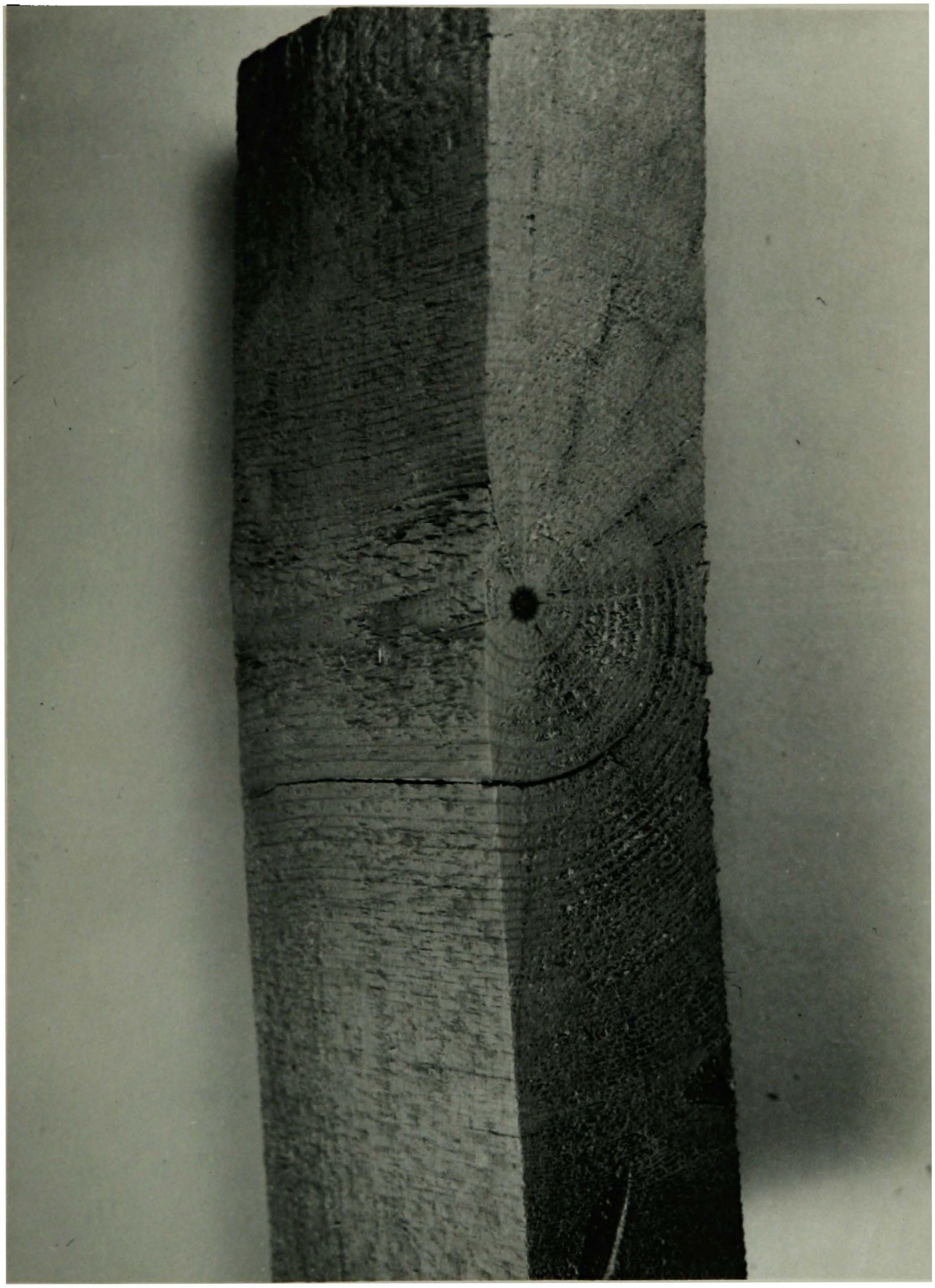


FIGURE 12. TYPICAL BLOCK SECTION FROM WHICH MICROSCOPICAL EXAMINATION WAS MADE.

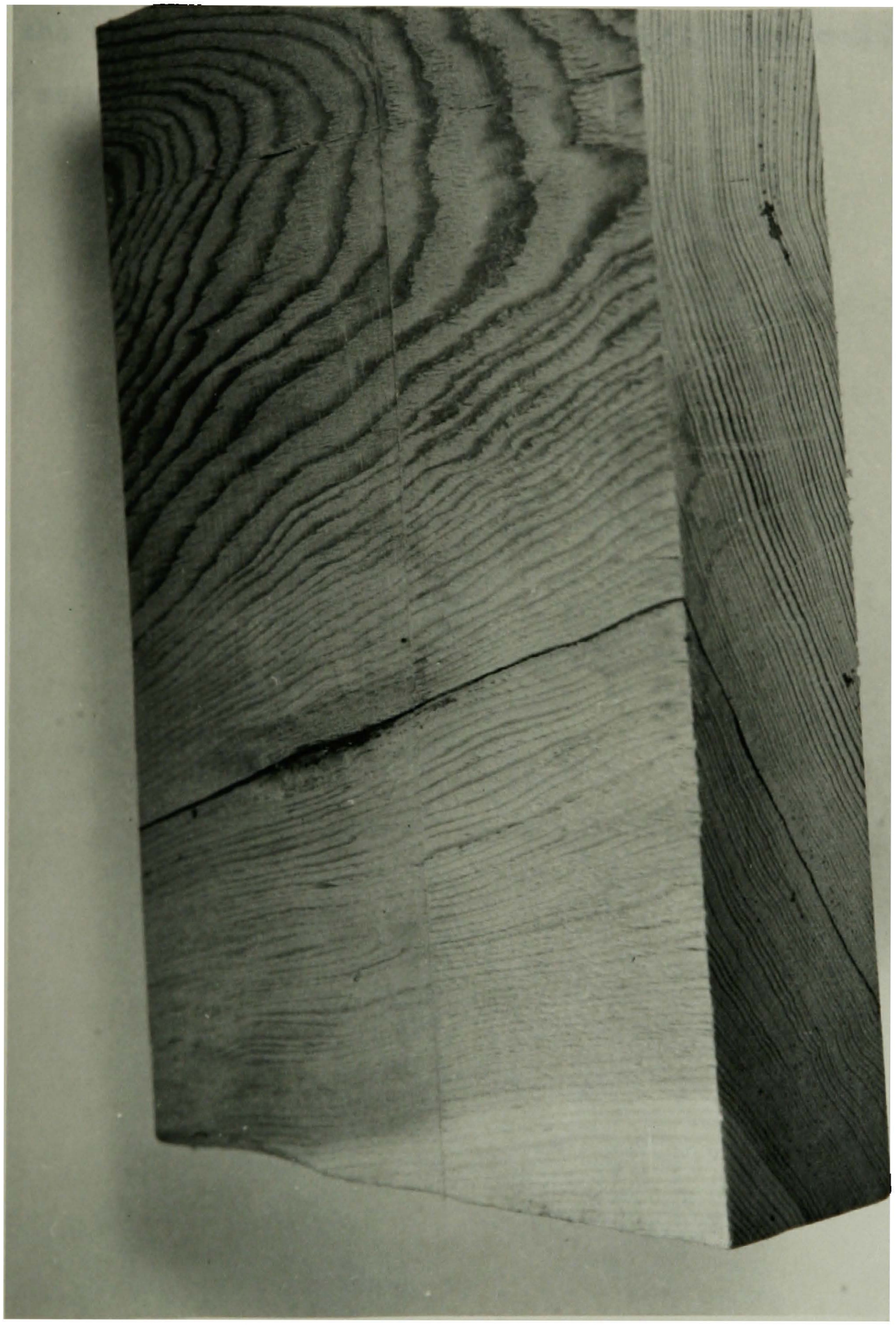


FIGURE 13. TYPICAL BLOCK SECTION FROM WHICH MICROSCOPICAL EXAMINATION WAS MADE.

Chronologically, Figures, 11, 12, and 13 show the location from which a typical section of this nature was taken and Figures 14 to 21 show the tangential alignment of the traumatic resin canals as seen under magnification of these sections

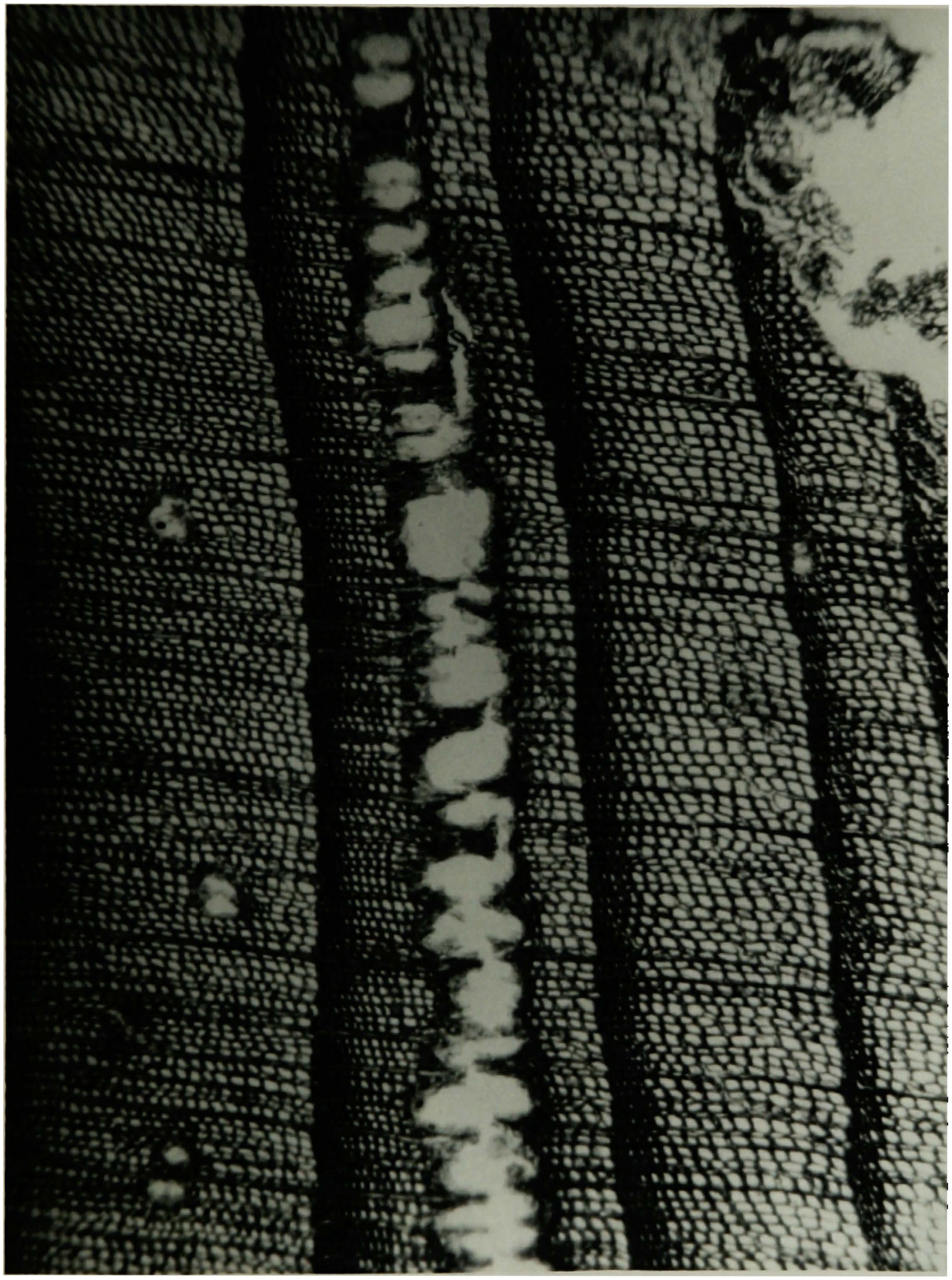


FIGURE 14. PHOTOMICROGRAPH OF RING SHAKE PLANE IN DOUGLAS-FIR (X-SECT.)

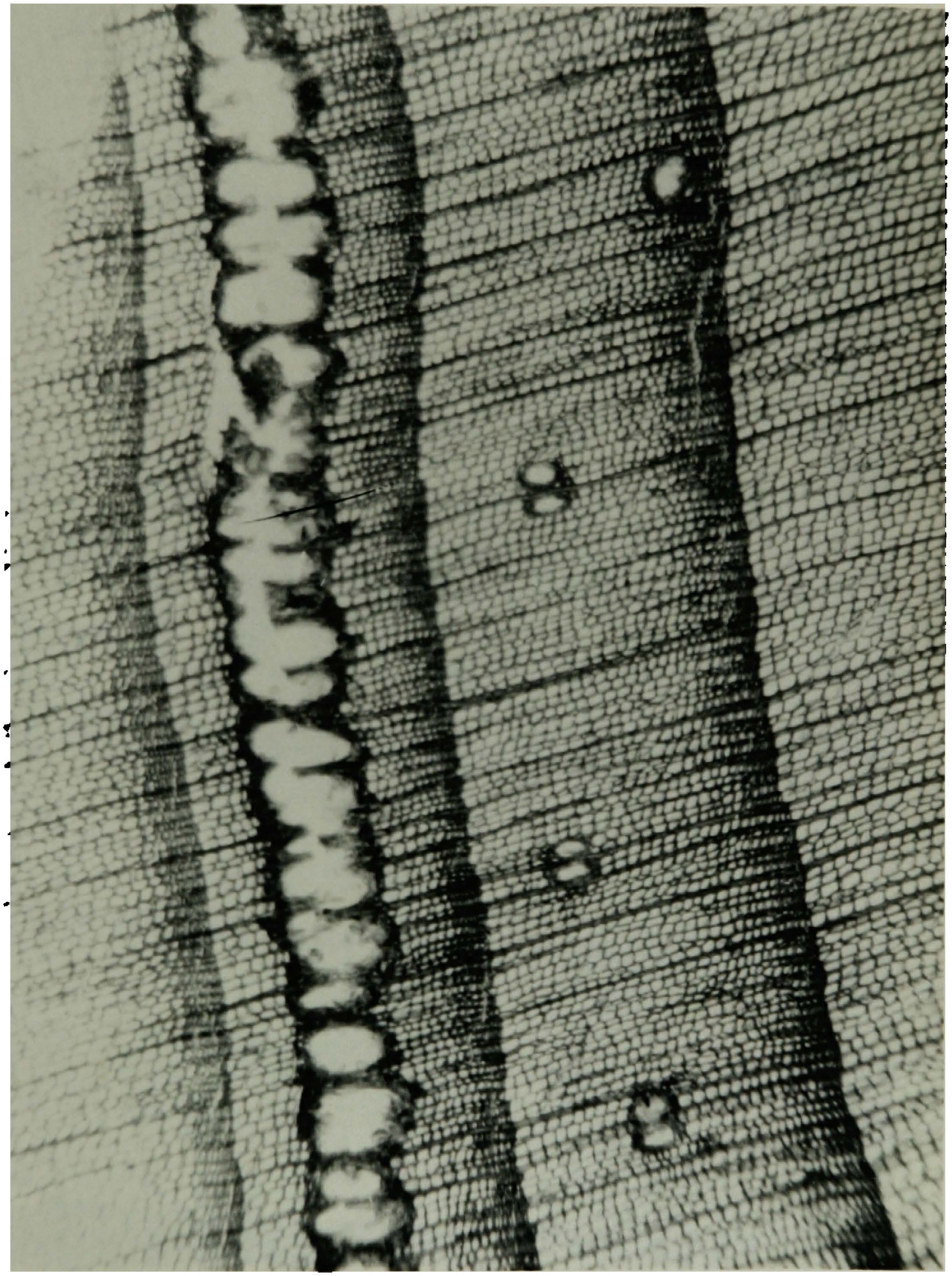


FIGURE 15. PHOTOMICROGRAPH OF RING SHAKE PLANE IN DOUGLAS-FIR (X-SECT.)

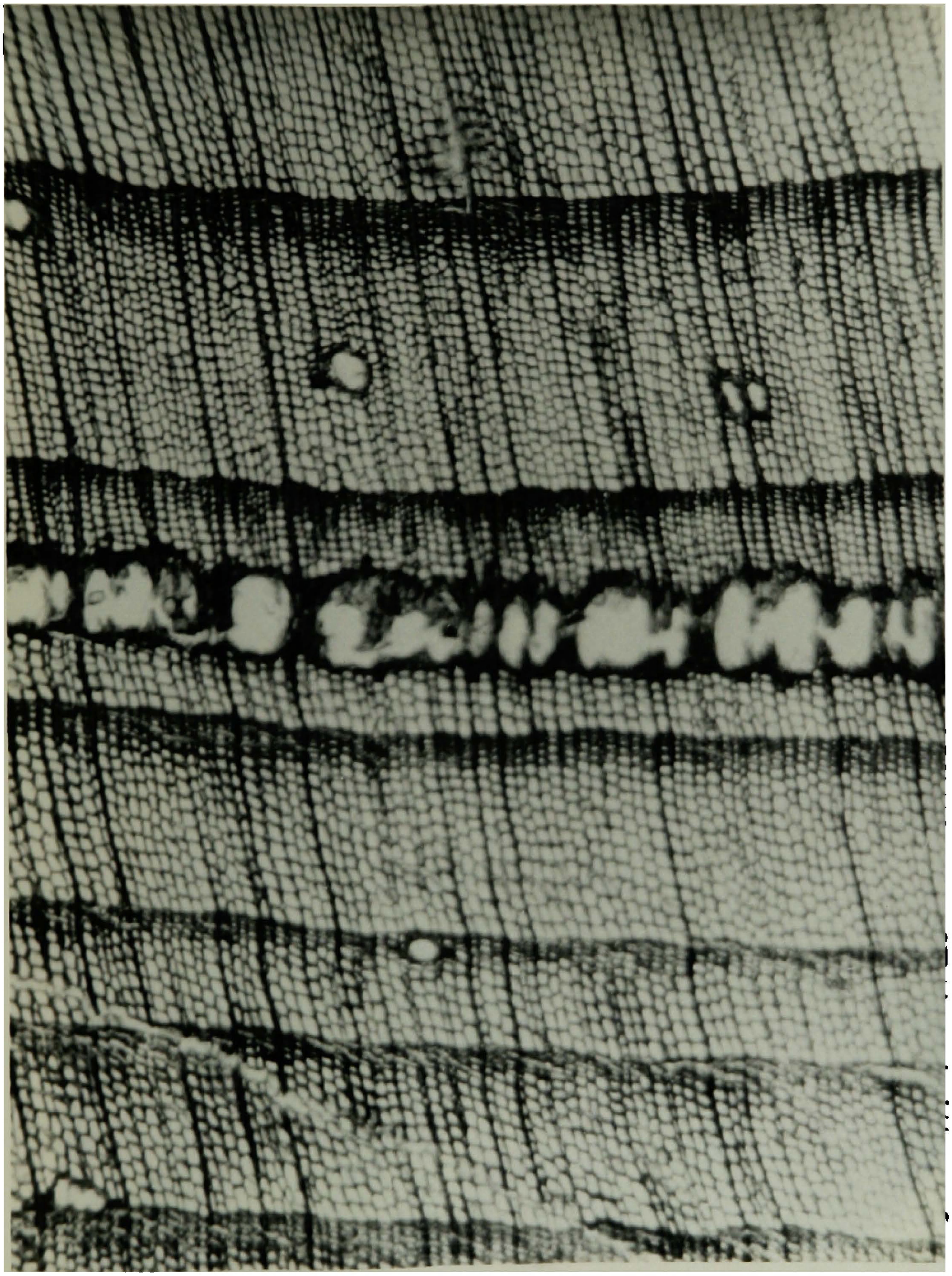


FIGURE 16. PHOTOMICROGRAPH OF RING SHAKE PLANE IN DOUGLAS-FIR (X-SECT.)

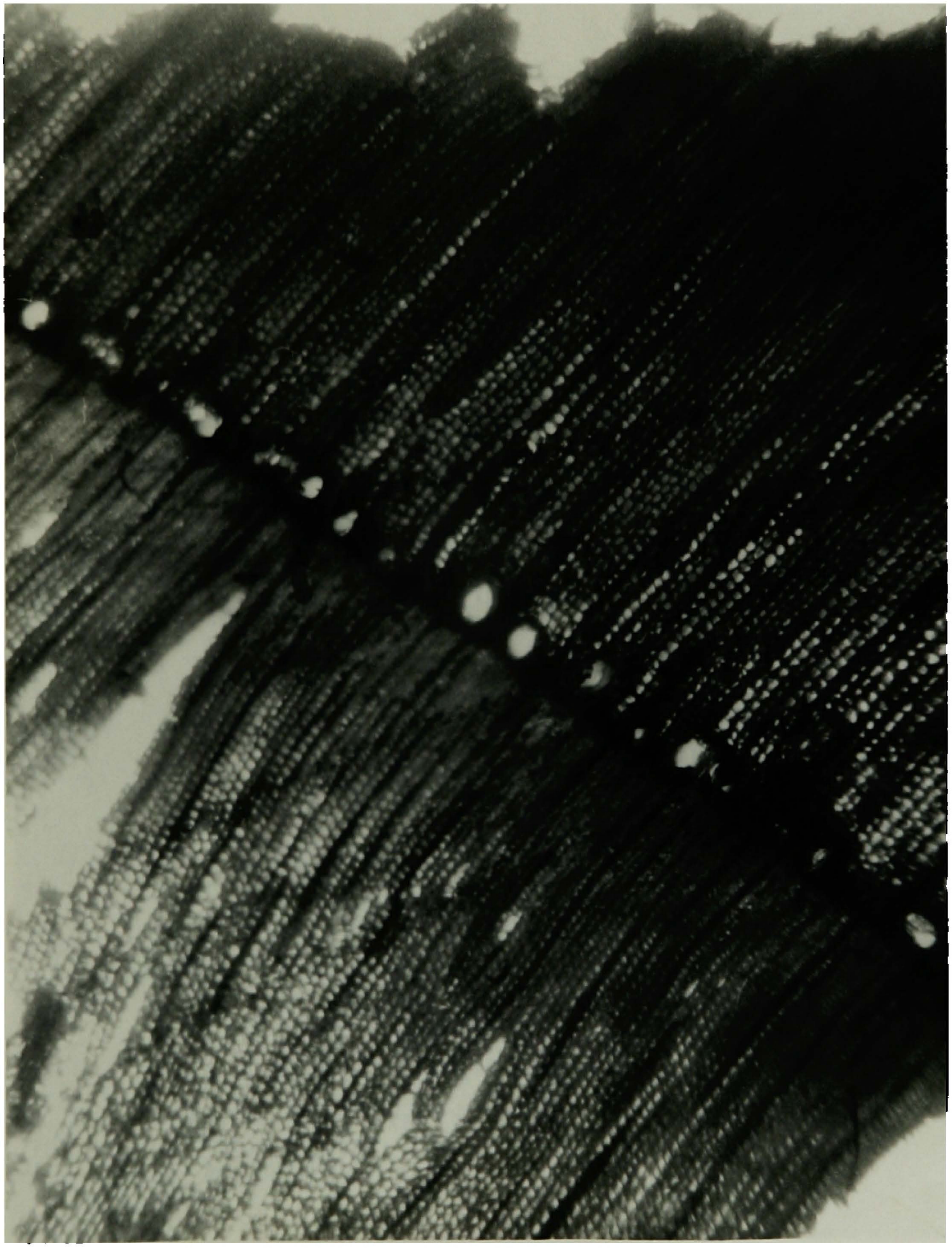


FIGURE 17. PHOTOMICROGRAPH OF RING SHAKE PLANE IN DOUGLAS-FIR (X-SECT.)

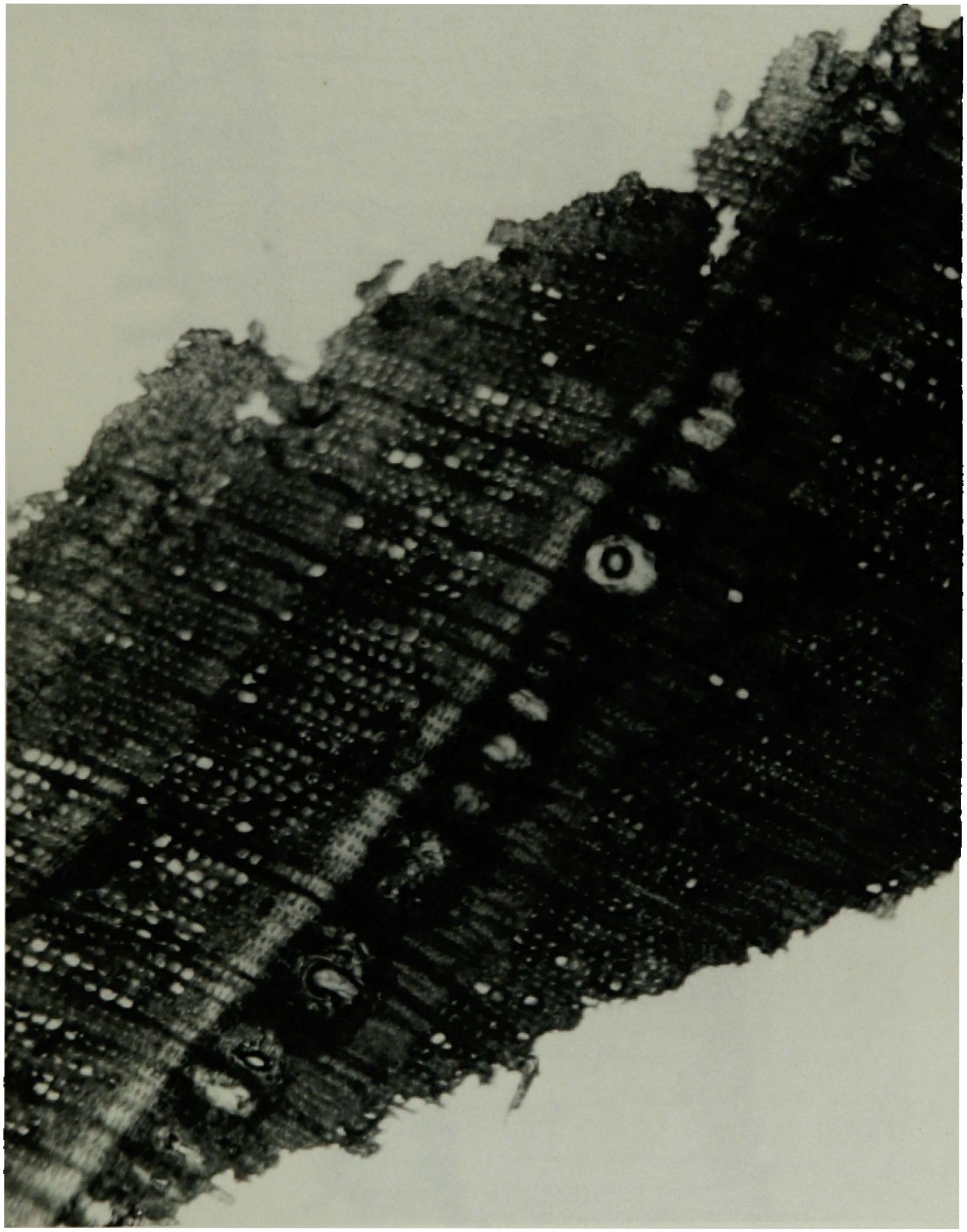


FIGURE 18. PHOTOMICROGRAPH OF RING SHAKE PLANE IN DOUGLAS-FIR (X-SECT.)

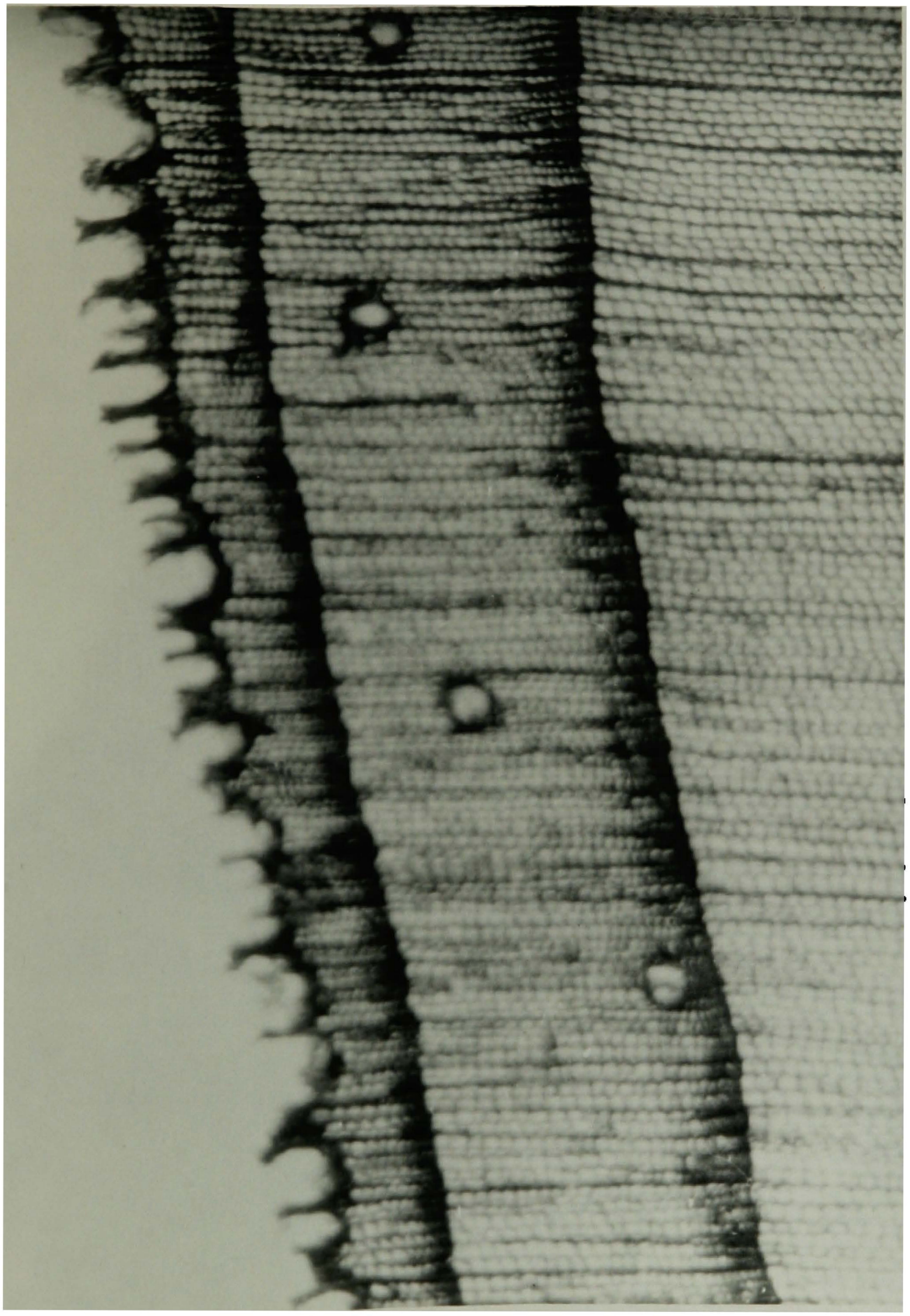


FIGURE 19. PHOTOMICROGRAPH OF RING SHAKE PLANE IN DOUGLAS-FIR (X-SECT.)

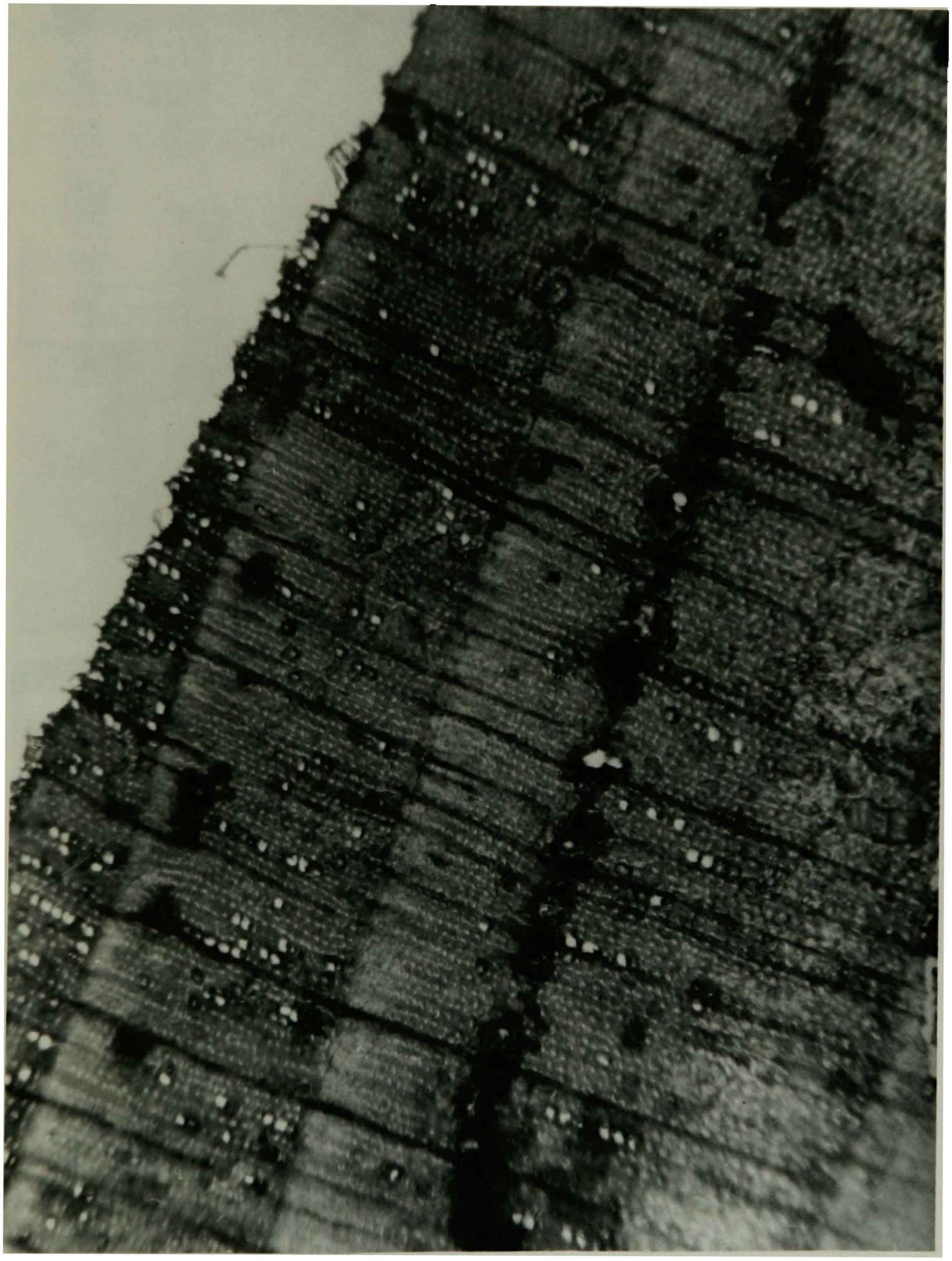


FIGURE 20. PHOTOMICROGRAPH OF RING SHAKE PLANE IN DOUGLAS-FIR (X-SECT.)

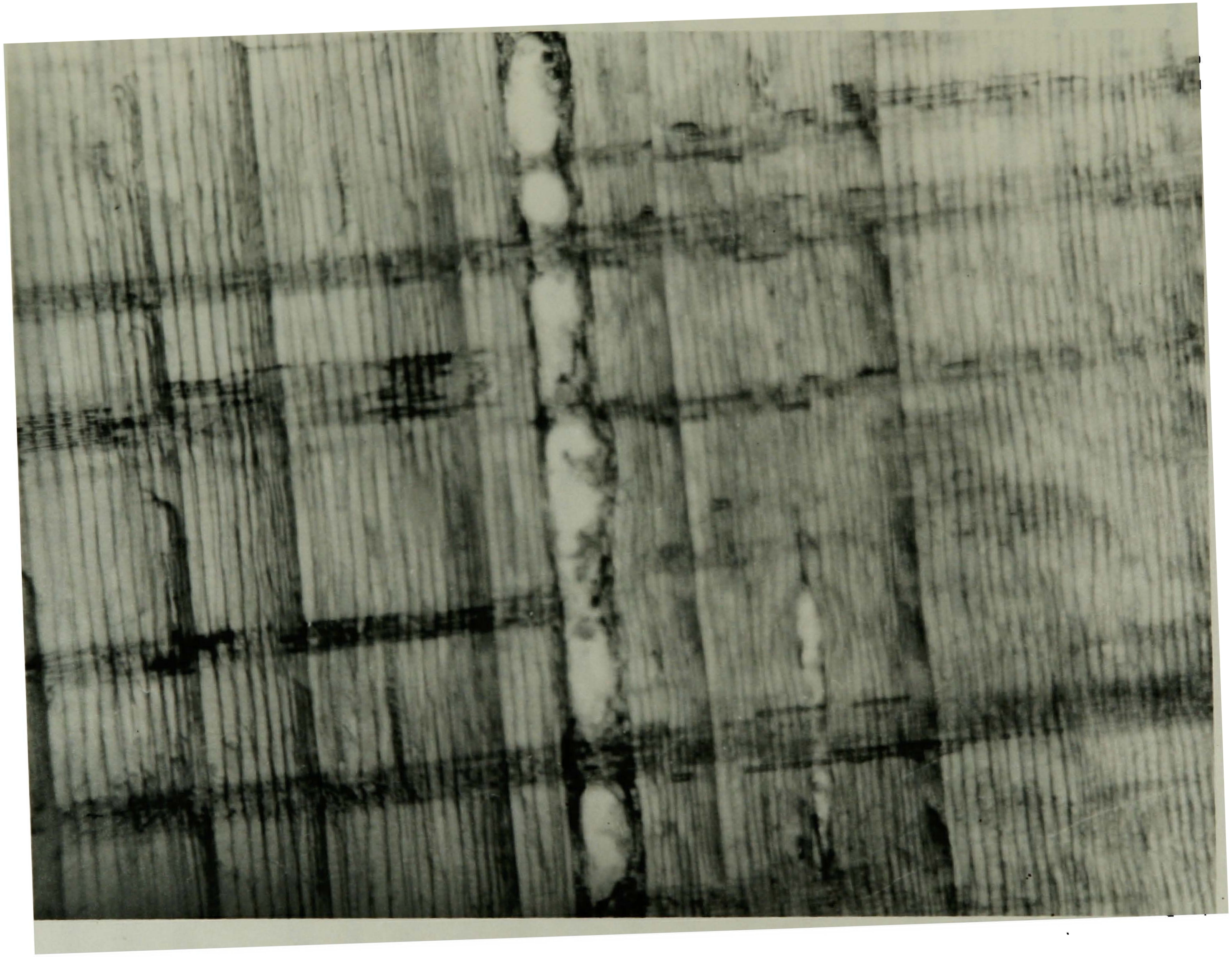


FIGURE 21. PHOTOMICROGRAPH OF RING SHAKE IN DOUGLAS-FIR (RADIAL SECT.)

These examinations have led to the hypothesis that the potential of ring shake begins at the immediate post cambial or cambial area, where a weakness develops. This weakness is probably caused by an excess of parenchyma cells that failed to differentiate into prosenchyma cells. This weakness may develop from an over-abundance of longitudinal parenchyma cells or in some conifers, from parenchymatous epithelial cell (traumatic resin canals) tissue formation. The above mentioned cell areas formed in wood are weak zones where separations may later develop.

Assuming this hypothesis to be correct, one may readily visualize this plane of weakness passing through the zone of maximum growth stresses, and/or into the heartwood before some mechanical stress causes it to open. It is also possible to visualize circumstances wherein no such opening stress occurs within the living tree, and the shake separation may appear only after logging or seasoning stresses provide the mechanical forces. Possibly the stress might not be encountered until the hammer action of the planer knives provide the force. This could account for the fact that shake is found in both the heartwood and sapwood, and it is occasionally detected only after the lumber has been seasoned and surfaced.

Whether traumatic resin canals are the cause or the result of the ring shake cannot conclusively be stated, however, logical deduction indicates that their occurrence must be associated with cell development in the immediate post-cambial area. This leads to the obvious conclusion that the plane of weakness from which the separation subsequently results and the stimulus which causes its formation must act at, or close to, the periphery of the xylem. Since it seems less logical that this cambial or post-cambial abnormality of growth was caused by internal stresses than by external injury to the cambium, the conclusion of the author is that the basic cause of ring shake is a plane of weakness generated through injury to the cambial area of the tree.

The author makes no attempt to explain the precise stimulus which brings about the initial injury to the cambial area because so many different agents could conceivably cause abnormal cell development. Abnormal parenchyma tissue may result from any of a variety of widely different causes which may either directly or indirectly influence the growth of the cambium. Among these causes may be enumerated mechanical injuries of any kind, attacks by various cryptogamic and phanerogamic parasites which stimulate the woody tissue to an abnormal development. Abnormal physiological condtions of growth and nutrition which produce an effect, premature defoliation, and injuries resulting from such meteorological causes as lightning, frost, and drought.

Since this study did not include hardwoods the author can only speculate on a similar mechanism, since wound parenchyma is known to be found in hardwoods and may create a similar plane of weakness.

IV. APPRAISAL OF EXISTING RING SHAKE THEORIES

The final phase of this study was to evaluate the existing theories on ring shake incidence. For a better understanding of ring shake incidence a survey was inaugurated in which abnormal characteristics contrary to our present theory or knowledge were stressed. The basic belief of ring shake is that it is found in the heartwood of large usually over-mature trees. In this examination phase, sapwood was most easily observed in younger tree growth. Because present known "facts" of ring shake incidence are so widely and vaguely accepted it appeared that more field investigation of ring shake incidence might clarify this subject. To facilitate field data collection, a data collection sheet was created to assist in obtaining definite information on the reported varied ring shake aspects (Appendix).

Ring shake aspects that have been proposed as possible causes of ring shake incidence may be summarized as:

1. Age
2. Bacteria or fungi
3. Plane of weakness
4. Difference in growth rate
5. Extreme cold or frost injury - sunscald
6. Iron/calcium content
7. Included sapwood
8. Sapwood-heartwood shrinkage
9. Tension and compression growth stresses (longitudinal and transverse)

10. Chemical seasoning
11. Severe wind storms
12. Environmental

Field data were collected from different sawmill's log and lumber stocks near Missoula, Montana. Table XI is a partial summarization of the field data in which shake was related to the sapwood, included sapwood, and the sapwood-heartwood junction of young trees.

TABLE XI

UNEXPECTED RESULTS OF RING SHAKE INCIDENCE AS SEEN FROM CROSS SECTION IN DOUGLAS-FIR SAWLOGS

Kind or location	Frequency
Sapwood*	33
Included sapwood	24
Sapwood-heartwood Junction	40
Total located in small logs with diameter of 12 inches or less**	107
Total located in sawlogs of 14-16 inches in diameter ***	388

* Shake in heartwood not denoted

** About 2,000 sawlogs observed

*** About 1,600 sawlogs observed

Due to the number of ring shake theories and their wide range of substance this report will present a discussion of each theory separately.

I. Age Aspect

Davis (12) stated that shake and decay are characteristics of overmature timber. Numerous authors have stated that ring shake is confined largely to the butt log, although, the defect is not necessarily confined to the portion of the tree where the greatest shear stresses are developed. Shake can and does occur in the smaller diameter trees. (Table XI.)

An age-frequency sample of ring shake incidence was taken, and from the results of this (Table XII ring shake was seen evident in all ages.

TABLE XII

AGE FROM PITH WHERE SHAKE WAS FOUND

Age class	Ring Shake Frequency
0-50	2
51-100	7
101-150	11
151-200	23
201-250	7
251-300	5
301-350	2
351-400	0
400-450	0
451-500	1

II. Bacteria or Fungi Aspect

It has been stated by Paclt (33) that parasites are associated with ring shake. In some instances the fungi have been classified. Boulger (3) believed that in some pines this defect was the result of the attack of certain fungus (Trametes) the mycelium of which spreads as a felted mass in the cambium. Although a ring shake fungus association is said to be common, it seems that this activity could result after the ring shake separation. On the other hand, it could be one of the real causes of cambial area injury and support the hypothesis of this paper.

Although this paper did not expound the bacteria-fungi theory, it does seem logical that the cambium tissue could be injured by bacteria and/or fungi, or even by insect attack and cause a plane of weakness in the tree.

III. Plane of Weakness Aspect

In the development of a tree, the weak bonding between annual increments has been ascribed by Wangaard (49) as a cause of ring shake development. Undoubtedly any band of weak cells will cause a plane of weakness that affects the shear strength. This weakness usually extends far beyond the point of actual separation of the rings. Although earlier writers did not elaborate on a bond weakness aspect, this author forwards the hypothesis that terminal parenchyma cells may be present at the juncture of annual rings which would cause a plane of weakness, for later ring shake development. The stimulation action of a mild late frost on the annual ring already in a state of cambial activity exerts itself in such a way that in place of the elongated tracheids a short-celled parenchyma arises Mayr (28). Mix (29) showed that the wood first formed in the spring following an injury was a comparatively narrow zone of parenchyma wood.

Observations were also made to attempt to find a consistency in where the actual rupture occurred. This investigation consisted of visual identification of the position of the ring shake plane within the annual ring in Douglas-fir sawlogs (Table XIV). In all cases the shake was within the limits of one annual ring which substantiates the results obtained in duplicating ring shake in normal wood.

IV. Difference in Growth Rate Aspect

Ring shake has been assoicated with abrupt changes of growth rates and generally would not be found with constant or uniform growth rates. Saxton (39) and Wangaard (49) reported that ring shake was most frequently found at the function of two growth rings of very unequal width. Consequently, it is likely to occur in trees that have grown slowly for a time, then shown an abrupt increase in rate of diameter growth, as a result of thinning or other treatments which improve the growing condition.

To determine the credibility of an abrupt growth rate as the cause of ring shake, observations were made near the proximity of the shake plane on Douglas-fir (Cross section) sawlogs. Only ring shake sawlogs were studied as to the annual increment width on each side of the rupture (Table XIII). Shake occurrence of greatest frequency was in the unchanged annual ring width areas, and tends to refute rather then substantiate the theory.

TABLE XIII

INCREMENT WIDTH CHANGE AN INFLUENCE IN RING SHAKE INCIDENCE IN DOUGLAS-FIR SAWLOGS*

Annual Growth Increment Width	Ring Shake Frequency
Unchanged width (growth rate)	99
1/3-2/3 increase width (growth rate)	24
2/3 + change width (growth rate)	6

*Annual ring nearest pith measured in width against previous annual ring.

It should be noted that subsequent annual growth rings were found to be associated with uniform growth widths.

TABLE XIV

POSITION OF THE RING SHAKE PLANE WITHIN THE ANNUAL RING IN 73 DOUGLAS-FIR SAWLOGS (VISUAL OBSERVATION)

Position		Frequency
Beginning of springwood band		55
Middle of springwood band		1
End of springwood band		3
Middle of summerwood band		7
Obscure		7
	Total	73

It can be noted from Table XIV that ring shake was identified with all positional categories, but was definitely most prevalent with ruptures at the beginning of the springwood band.

V. Extreme Cold or Frost Injury - Sunscald Aspect

Temperature fluctuations are often stated as the cause of ring shake incidence. Wangaard (49) states that ...

> "frost may in some instances be responsible for shake, or at least be a contributing factor, although, trees growing in regions free from frost may also develop the defect."

The theory is that the rings of sapwood and heartwood in a living tree contain varying proportions of water and the wetter outer layers are most likely to freeze first. Gougler (3), Rhoads (38), and Stone (46) report that microscopical examinations show that laterally displaced rays, distorted xylem elements, and short celled parenchyma characterize frost injury. Eastern and northern aspects and higher elevation should thus bear trees most seriously affected.

Wide temperature fluctuations within a relatively short period produce an injury known as cup-shakes. A sudden heating by sunshine of the outer tissues of the trunk, following low temperatures, will cause these tissues to expand more rapidly than the inner tissues, resulting in a cleavage or separation along an annual ring. It was reported by Noyes (32) that when there is a sudden fall in temperature, the outside layers of the tree, which are full of sap, contract more rapidly than the inner portions. On the other hand when the temperature rapidly rises, the outside layer of the tree expand so much more rapidly than the inside, that they separate with a "dull, muffled chug," the check extending in a circular direction following the annual rings. These injuries are found in regions where sudden changes of temperature occur.

To check the obvious aspects of this theory, four blocks were subjected to two treatments: (1) soak and freeze; and (2) soak and boil, as seen in the following table.

TABLE XV

MEASUREMENTS OF SHRINKAGE OR SWELLING OF WATER SOAKED BLOCKS THAT WERE SUBSEQUENTLY SUBJECT TO (1) 48 HOURS FREEZING TEMPERATURES, AND (2) 4 HOURS OF BOILING*

Block Number	After Soak	After Freeze	After Boil
1	.815	.815	.816
	.815	.815	.816
	.810	.810	.812
	.813	.813	.816
2	.804	.805	.810
	.807	.806	.807
	.800	.800	.800
	.800	.800	.800
3	.806	.806	.809
	.807	.807	.809
	.801	.801	.804
	.801	.801	.804
4	.817	.817	.820
	.817	.817	.821
	.821	.821	.825
	.823	.823	.828

*Block thickness measured in inches - four measurements of each block taken.

This experiment was designed to demonstrate temperature variations in the heartwood of a standing tree and to measure the contraction and expansion developed. From Table XV, it can be noted that the four blocks subjected to freezing did not shrink while those blocks that were subjected to boiling did expand slightly. It was concluded that wood dimensional changes are minor when related to any normal temperature changes. Thus, any expansion and contraction of the heartwood tree section would be secondary to the injury that would develop if the cambium was subjected to these same temperature variations.

VI. Iron/Calcium Content Aspect

A new hypothesis on ring shake incidence is that of the iron/calcium content. The hypothesis put forward by Lachaussee (26) to explain the phenomena is that more Fe is taken up from the soil when the Ca/Fe ratio is low and that the presence of larger quantities of Fe in the wood modifies the wood's mechanical qualities and makes it more fissile. Analysis of the butt logs and soils at the base of these trees showed that the prevalence of defect was closely related to the Ca/Fe ratio in wood and the soil. It seems that this hypothesis, at the best, is more appropriate to a localized situation than for a primary theory of ring shake incidence, therefore no research was inaugurated to evaluate this theory.

VII. Included Sapwood Aspect

Brown, Panshin, and Forsaith (5) define included sapwood as streaks of irregularly shaped wood (general appearance of normal sapwood) found embedded in the darker colored heartwood. If this sapwood is wetter than heartwood it would seem logical to assume that shrinkage and swelling stresses of different magnitude would exist. These stresses might be of sufficient magnitude to develop ring shake. From the table of unexpected results of ring shake (Table XI), it can be concluded that ring shake does occur in included sapwood. Although shake may be associated with included sapwood (Figure 22), this is the exception rather than the rule. Therefore, this theory does not support known facts.

VIII. Sapwood-heartwood Shrinkage Aspect

Sapwood-Heartwood theory. A sapwood-heartwood theory has been reported by Brown, Panshin, and Forsaith (5) in which they state that the possible shrinkage of the heartwood in the standing tree is the cause of ring shake. The sapwood of conifers is usually much wetter than the heartwood - often up to 200% of the dry weight - and in a given cross section, certain layers may be much dryer than others. Because of an assumed difference in shrinkage of the tissue in adjacent portions of the wood, occasioned by differing moisture contents, there is a presumed development of shrinkage stresses of different magnitudes. Figures 23 and 24 and Table XI show examples of ring shake found in the heartwood-sapwood junction. Although ring shake may be found at this point evidence points to ring shake being found more frequently elsewhere.

This theory is unlikely because the heartwood of trees is usually at or above its fiber saturation point. Little or no shrinkage occurs except below this point, so the core should not shrink. Further, in order to check this theory, ring shake occurrence in the physiologically active sapwood was sought. Table XVI definitely shows evidence of ring shake in the sapwood. Figure 25 also definitely shows evidence of ring shake in sapwood. Therefore, this theory does not explain ring shake incidence fully. Further, since the heartwood of Douglas-fir is generally above f.s.p., it is doubtful if it applies at all to this species.

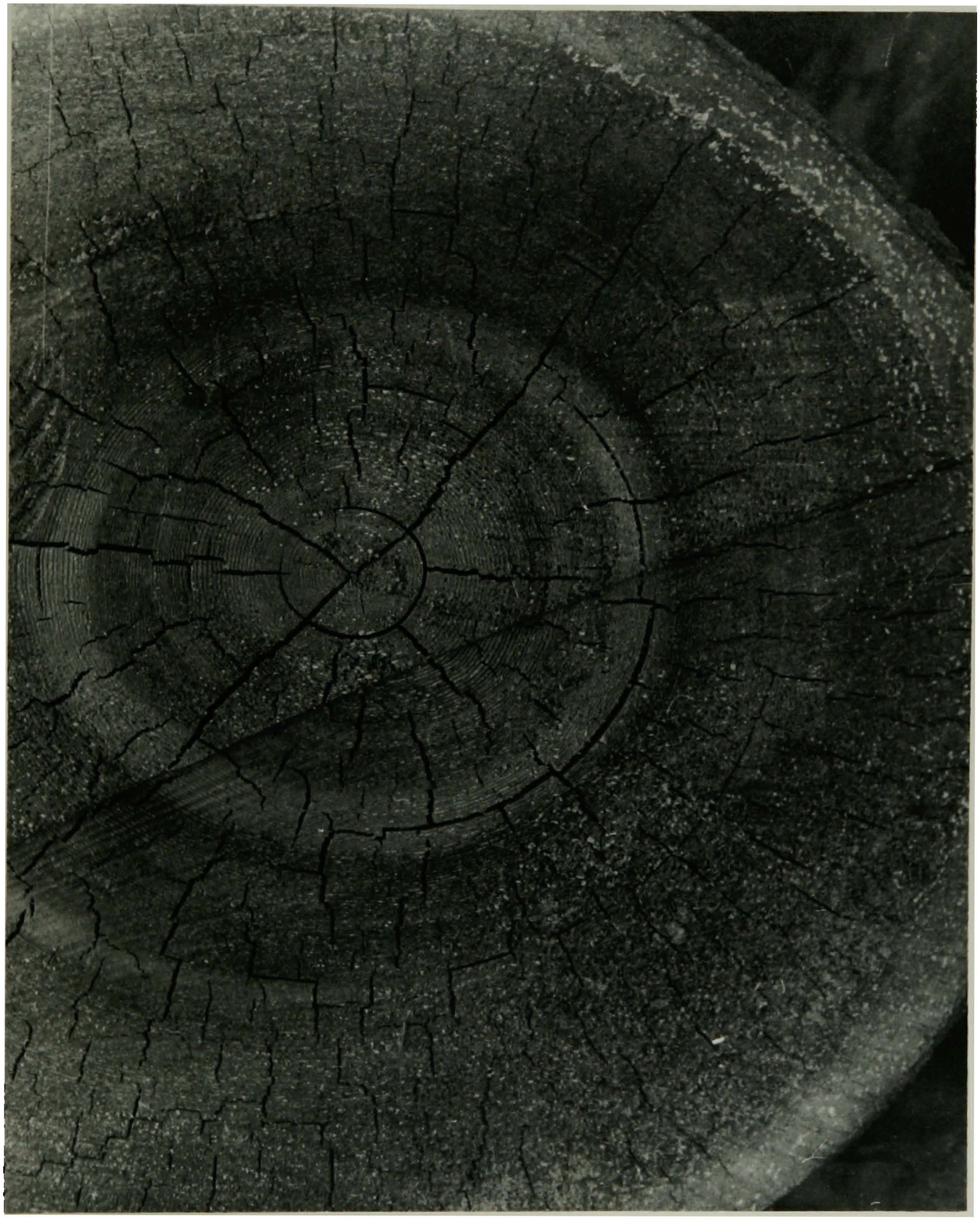


FIGURE 22. RING SHAKE IN INCLUDED SAPWOOD. (DOUGLAS-FIR)

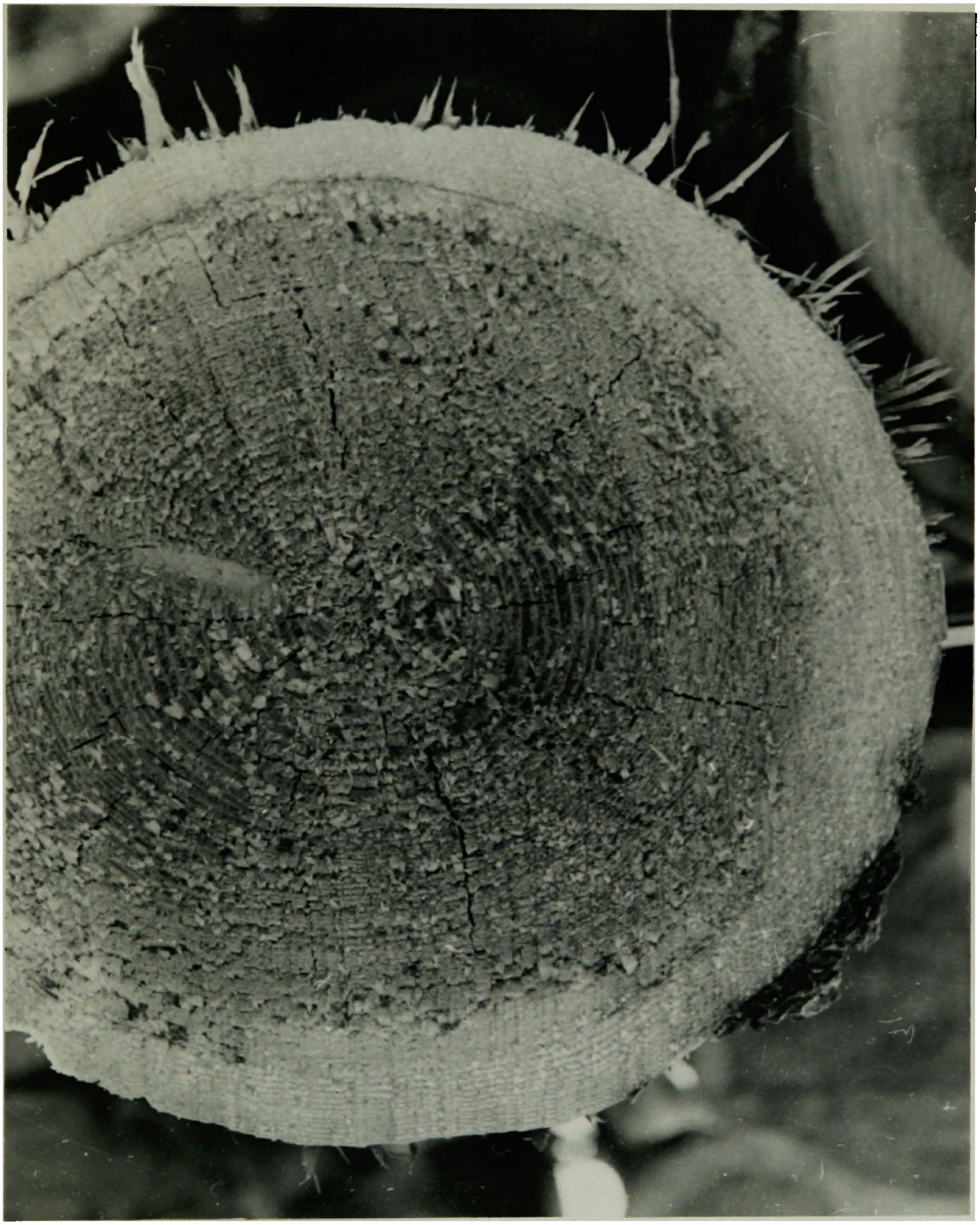


FIGURE 23. RING SHAKE AT THE SAPWOOD-HEARTWOOD JUNCTION OF A DOUGLAS-FIR SAWLOG.

FIGURE 24. RING SHAKE AT THE SAPWOOD-HEARTWOOD JUNCTION OF A DOUGLAS-FIR SAWLOG.

IX. Tension and Compression Growth Stress Aspect

Koehler (25), Jacobs (22) and later Perkity, Wajciechowki and Wnuk(35) concluded that growth stresses were the primary cause of ring shake incidence. It was concluded that the greatest shearing stresses are concentrated at the neutral plane. In sawlogs the neutral plane may be found by the following formula: Sawlog radius times .707 = neutral plane radius.

Reflection on the merits of this theory would be that if it were the basic cause of ring shake incidence, then ring shake would seldom if ever be found in the outer portions of the stem. Results from this investigation show that ring shake does occur near the circumference of sawlogs. Evidence of this is shown in Tables XVI and XVII and seen in Figure 25. In the course of so many shakes found near the sawlog periphery as close as 1/4 inches from the bark, it seems equitable to assume that questionable uncertainties do exist in advancing tension stresses as the sole cause of ring shake. This indicates that although growth stresses may have some effect on ring shake incidence it is not invariably the cause. It appears unlikely, with the number found and their close proximity to the bark, that growth stresses can be the prime cause. It is easy to visualize, however, how such stresses could possibly cause the separation of a plane of weakness already present.

TABLE XVI

RING SHAKE PRESENT IN MINING POSTS 14-16 INCHES IN DIAMETER

Distance from bark (inches)	Frequency
1/4	46
1/2	56
3/4	33
1	71
1 1/4	6
1 1/2	9
1 3/4	1
2	8
2 1/4	5
2 1/2	12
2 3/4	3
3	9
3 1/4	3
3 1/2	5
3 3/4	1
4	2
4 1/4	3
4 1/2	3
4 3/4	1
5	2

TABLE XVII

RING SHAKE TO BARK DISTANCE IN DOUGLAS-FIR SAWLOGS OF VARIOUS DIAMETER CLASSES

Diameter classes - Number of Sawlogs with Ring Shake

Shake to bark-Radial Distance	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42
1/4"			1	1	5								1					
1/2"	1	4	1	4	3	1		1		1	1							
3/4"		1	1	1		1						1						
1"		5	3	10	8	2	4	1			1							
1 1/4"			2		1	1		1		1			1					
1 1/2"			3	3	1	1		1	2			1		1				
1 3/4"				3	3	2	1	1	2	1	1	1		1	1			
2"										1								
2 1/4"				1			1	1		1								
2 1/2"																		
2 3/4"					2			2	1				1	1	1			
3"																		
3 1/4"					2		2	1					1	1	1			
3 1/2"							1			1	2	1	1					
3 3/4"																		
4"				1	1		2	2			1		1			1		
4 1/4"																		
4 1/2"				2	2		1		1		1			1				
4 3/4"																		
5"						1	1				1			1				
5 1/4"																		
5 1/2"							1											

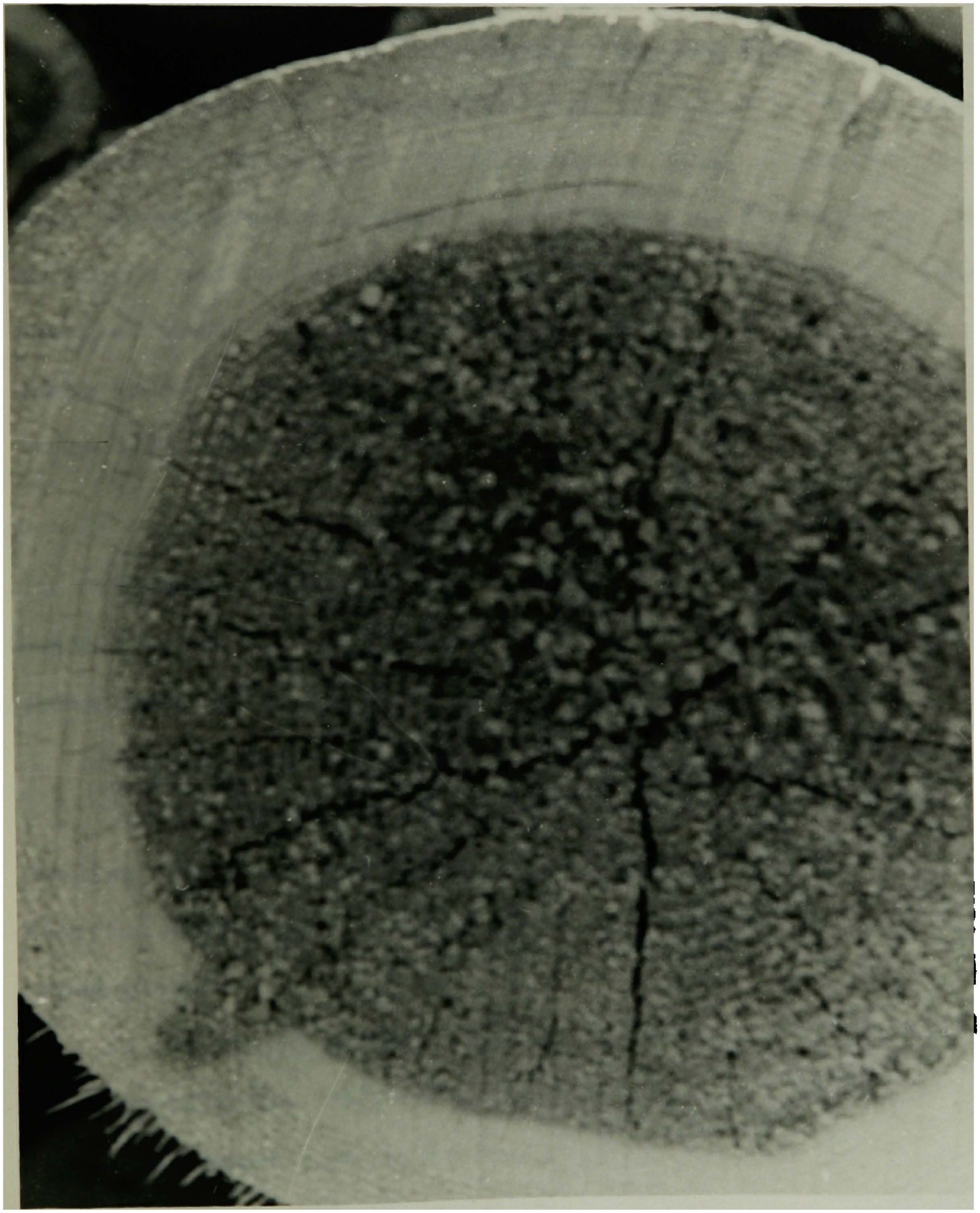


FIGURE 25. RING SHAKE IN THE SAPWOOD OF A DOUGLAS-FIR PILE.

X. Chemical Shrinkage

Chemical shrinkage has been listed as a secondary cause of tensions in the living tree. It is commonly presumed that chemical shrinkage is nil in the sapwood. The sapwood has little or no color change nor has chemical shrinkage been demonstrated. Thus, since ring shakes have been demonstrated to occur in areas where no differential chemical shrinkage can be presumed, it is difficult to visualize this theory as being of broad significance in this matter. Further, if it were true, shake would frequently occur at the sap/heart juncture; Table XI indicates that this is not usually so.

XI. Severe Winds - Storms Aspect

Numerous authors among them Saxton (39), Brown, Panshin, and Forsaith (5), Boulger (3), and Wangaard (49) have described wind as the prime cause of ring shake damage.

> "This action of the wind bending the rings of wood alternately in opposite directions in a manner obviously calculated to tear them apart will result in a longitudinal shear."

Swaying action of tree trunks is thought to cause the splitting or shearing apart of the growth rings, especially in trees growing in exposed places.

In the marshy areas, Prestridy (36) reported that where the trees can sway with the wind the fibers are not so easily broken down, whereas, in the areas with a dense subsoil the trees are more solidly rooted and cannot give with the wind which results in the breaking down of the fibers.

Although it has been shown herein that wood pieces can be broken into smooth ring shake type separations, it is doubtful that this is the primary cause. It is doubtful that this mechanical separation is the major cause in the Douglas-fir specimens examined primarily because ring shake was found to be associated with parenchyma cell tissue. It is conceivable, however, that such could be the cause under conditions of extreme stress, or where a plane of weakness already existed.

Ring shake was investigated as to the sawlog age where ring shake was found (Table XVIII). From these data, it was observed that ring shake was more prevalent in the wood of the young and vigorous tree growth portion than in the older tree portion. The weakness of juvenile wood in the sawlog may partially explain why ring shake incidence was more prevalent in the wood of the young and vigorous tree growth portion, as could the lack of rigidity of young trees, but many shakes were found in older wood areas and usually associated with parenchyma cell tissue.

TABLE XVIII

RING SHAKE VS. SAWLOG AGE WHEN RING SHAKE OCCURRED

Age at which ring shake was found	Douglas fir	Engelmann spruce	Ponderosa pine	Western larch	Total
0-50	10	8	4	2	24
51-100	7	2	5	6	20
101-150	11		2	2	15
151-200	3			1	4
201-250					
251-300					
301-350					
351-400					
401-450				1	1
				Total	64

Evidence revealed that shake can occur in "normal" wood although it generally occurred in abnormal wood. These circumstances exist and explain why everyone cannot accept one theory. The author believes the plane of weakness generated through injury to the cambium area is the best theory.

The general concept of a plane of weakness present in wood may also explain why heart and star shake develop in wood. The concept forwarded is that wood ruptures in close proximity to ray tissue provided sufficient stresses are envisioned.

XII. Environmental Aspect Such as Defoliation, Lightning, Drought, and Snow

Ring Shake has often been attributed to environmental conditions. Table XIX shows the results of a comparison of sawlog age in relation to shake. It can be noted from this table that ring shake occurrence cannot definitely be confined to any specific year. This may be because trees in general, may at different ages be more or less suscepitible to environmental forces or that the trees were not acted upon uniformly by exterior conditions.

TABLE XIX

SAWLOG AGE VS. NUMBER OF ANNUAL RINGS SINCE RING SHAKE OCCURRED

Sawlog age	Years since shake	Sawlog age	Years since shake
40	15	180	35
50	35		75
60	15		75
	45		85
	45		110
	45		140
80	55		170
90	75	190	140
	75		165
110	45	200	65
	45		70
	55		100
	85		160
	100		175
130	10	210	125
	85		145
	110	220	115
	115	230	190
140	45		200
	135		200
150	40	250	245
	30	260	80
	30		185
	45	290	225
	75		240
	85	300	160
170	45	310	210
	65	470	65
	80		
	90		
	105		
	125		
	125		
	145		
	155		

*Counted from the present to the ring shake.

SUMMARY

The following table summarizes the ring shake theories.

TABLE XX

SUMMARY OF EXISTING THEORIES

Best Basic Theory	1. Plane of weakness generated through injury to the cambial area
Theories with merit but limited in application	1. Severe winds
	2. Frost injury - sunscald
	3. Growth tension (longitudinal and tangential)
	4. Bacterial-fungi aspect except through injury to the cambial area
	5. Environment conditions such as defoliation, ligntning, drought, and snow load except through injury to the cambial area
Theories too limited in application or opposed to fact or logic	1. Age theory
	2. Sapwood-heartwood aspect
	3. Growth rate aspect
	4. Included sapwood aspect
	5. Spiral angle aspect
	6. Chemical seasoning aspect
	7. Freezing and/or warming of wood

RECOMMENDATIONS

Many new facets of investigation are needed to manifest a clearer explanation of the widely different causes which may either directly or indirectly influence the growth of the cambium and post-cambial differentiation. Environmental foreces are extremely influential in cambial and post-cambial activity and information is needed to disclose what effect they have on wood quality.

Future investigations should include studies of the formation of abnormal parenchyma in hardwoods as well as such tissue formation in conifers.

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APPENDIX

SAMPLE FIELD DATA COLLECTION SHEET

1. Species
2. Diameter
3. Shake location found
    - Sapwood
    - Included Sapwood
    - Heartwood
    - Heartwood-Sapwood Junction
4. Pitch in Shake Area
    - Present
    - Absent
5. Shake plane found at junction of two growth rings
    - Normal ring width
    - Slight ring width change
    - Abrupt ring width change
6. Ring shake to bark distance
7. Clearness of sawlogs*
    - Relatively free of knots
    - Knots clearly evident
8. Log shape**
    - Eccentric
    - Normal or circular
9. Postion of shake in tree***
    - Butt log
    - Middle log
    - Upper log
10. Postion of ring shake plane
    - Begin of springwood band
    - Middle of springwood band
    - End of springwood band
    - Middle of summerwood band

* No trend

** No trend

*** Not easily determined